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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Yağ Gülü Tarımında Üretim Etkinliğinin Analizi: Isparta İli Örneği*

Analysis of Production Efficiencies in Oil-Bearing Rose Agriculture: The Case of Isparta Province

Orhan Orçun BITRAK[1*], Selim Adem HATIRLI[2]

Öz

Türkiye, dünya yağ gülü üretiminin %55'ini gerçekleştiren lider ülke konumundadır. Yağ gülü yetiştiriciliğinin yaygın olarak yapıldığı Isparta ili, üretimin yaklaşık %80'ini karşılamaktadır. Bu çalışmanın amacı, Isparta ilinde yağ gülü yetiştiriciliği yapan işletmelerin üretim etkinliğinin belirlenmesi ve işletmelerin etkinsizliklerine neden olan faktörlerin ortaya koyulmasıdır. Bu doğrultuda, işletmelerin 2021-2022 üretim dönemine ilişkin Isparta ilinde yağ gülü yetiştiriciliğinin yoğun olarak yapıldığı yedi ilçe ve bu ilçelerdeki köylerde bulunan 169 yağ gülü işletmesinden anket yöntemiyle elde edilen veriler kullanılmıştır. İşletmelerin etkinsizliğinin belirlenmesinde uygulanan stokastik üretim sınırı modeli, Cobb-Douglas fonksiyonu ile tahmin edilmiştir. Model tahmin sonuçlarına göre, işletmelerde ortalama üretim etkinsizliği 0.21 olarak hesaplanmış ve işletmelerin gözlenen üretimi ile ulaşabileceği maksimum üretim arasındaki farkın %50.3'ünün teknik ve dağılım etkinsizliklerinden kaynaklandığı, geriye kalan kısmın ise öngörülemeyen tesadüfi faktörlerden kaynaklandığı tespit edilmiştir. Bu sonuç, işletmelerdeki teknik ve dağılım etkinsizliklerinin önemini vurgulamaktadır. Üretim etkinsizliğinin sonucu olarak, yağ gülü yetiştiriciliği yapan işletmelerin dekara ortalama verim kayıplarının 95.10 kg olduğu belirlenmiştir. İşletmelerdeki üretim etkinsizliğinin nedenlerinin araştırıldığı model tahmin bulgularına göre, işletme yöneticisinin yaşı, yağ gülü bahçesindeki ortalama ağaç yaşı, yağ gülü arazisinin sulama durumu, yayım faaliyetlerine katılım durumu, işletmede yağ gülü dışında başka bir bitkisel ürüne yer verilip verilmediği, yağ gülü arazisinin rakım seviyesi ve kredi kullanımı değişkenleri istatistiksel olarak anlamlı bulunmuştur. Buna göre, işletme yöneticisinin yaşı, işletmenin sulu araziye sahip olması, yayım faaliyetlerine katılım ve kredi kullanımın etkinsizliği azalttığı, bahçedeki ağaçların ekonomik verim çağının dışında olması, işletmede yağ gülü dışında başka ürünlere yer verilmesi ve yağ gülü arazisinin rakım seviyesinin ise etkinsizliği artırdığı tespit edilmiştir.

Anahtar Kelimeler: Yağ gülü, Stokastik üretim sınırı, Cobb-Douglas, Üretim etkinliği

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Abstract

Turkey is the world's leading country realizing 55% of the world oil-bearing rose production. Isparta province, where widespread oil-bearing rose cultivation, meets more than 80% of country's production. This study aims to investigate the production efficiency of oil-bearing rose cultivation enterprises in Isparta province and to reveal the factors that cause the inefficiency of the enterprises. In this direction, the study, which covers the production period 2021-2022, used the data obtained through the survey method from 169 oil-bearing rose enterprises seven districts and villages in these districts where oil-bearing rose cultivation is intensively practiced in Isparta province. Stochastic Cobb-Douglas production frontier model was established to determine the production efficiency of the enterprises. According to the model estimation results, the average production inefficiency of the enterprises was calculated 0.21. It was found that 50.3% of the difference between the observed production of the enterprises and the maximum production they can achieve is the due to technical and allocation inefficiencies, while the remaining part is due to unexpected random factors. This result emphasizes the importance of technical and allocative inefficiencies in farms. As a result of production inefficiency, the average loss of yield per decare of oil-bearing rose farm was 95.10 kg. Among the variables included in the inefficiency model established to explain the production inefficiency in the enterprises, the age of the enterprise manager, the average age of the trees in the oil-bearing rose land, the irrigation status of the oil-bearing rose land, the participation in extension activities, whether the enterprise includes another crop other than oil-bearing rose, the altitude of the oil-bearing rose land, and use of credit were found to be statistically significant. Accordingly, it was found that the age of enterprise manager, having irrigated fields, participating in extension activities, and the use of credit decreased inefficiency. On the other side, the trees in the land were outside the economic yield age, cultivating crops other than oil-bearing rose on the farm, and the altitude level of the oil-bearing rose land increased inefficiency.

Keywords: Oil-bearing rose, Stochastic production frontier, Cobb-Douglas, Production efficiency

1. Giriş

Gül çiçeği, hem süs bitkisi sektöründe kesme çiçek ve açık hava bitkisi olarak kullanılan, hem de tıbbi ve aromatik bir bitki olarak gıda, parfümeri ve kozmetik endüstrilerinde büyük bir öneme sahiptir. Dünya genelinde 100'ün üzerinde gül çiçeği türü bulunmaktadır (Baydar ve ark., 2008). Bununla birlikte, endüstriyel amaçla kullanılan farklı gül çeşitleri arasından (*Rosa gallica* L., *Rosa alba* L., *Rosa centifolia* L., *Rosa moschata* Herrm ve *Rosa rugosa* L.) ekonomik değeri yüksek, en fazla uçucu yağ miktarına ve yüksek kaliteli koku bileşenlerine sahip olanı *Rosa damascena* Mill.'dir. Bu gül türü aynı zamanda "Isparta gülü," "Kazanlık gülü," "Şam gülü," "Pembe yağ gülü" veya sadece "Yağ Gülü" olarak da tanınmaktadır (Timor, 2011).

Dünya yağ gülü üretiminin yaklaşık %90'lık kısmı Türkiye ve Bulgaristan tarafından gerçekleştirilmektedir. 2022 yılı verilerine göre, yağ gülü ekili alanı Türkiye'de 4126 hektar, Bulgaristan'da ise 4373 hektardır. Ayrıca üretim miktarı, Türkiye'de yaklaşık 20 bin ton iken, Bulgaristan'da yaklaşık 13 bin ton olarak gerçekleşmiştir (TÜİK, 2023a; MZH, 2023).

Gül çiçeği doğrudan tüketilen bir ürün olmamakla birlikte, gülün işlenmesiyle elde edilen ürünlerin tüketimi söz konusudur (T.C. Ticaret Bakanlığı, 2020). Gül çiçeğinden gül yağı ve gül konkreti olmak üzere iki ana ürün, yan ürün olarak gül suyu elde edilmektedir (Bektaşoğlu, 2006; Örmeci Kart ve ark., 2012). Gülden elde edilen yağ, doğal karıştırıcı özelliği göstermekte olup diğer koku maddelerini birleştirme özelliği taşımaktadır (Öztürk ve ark., 2008). Gül ürünleri üretiminde, maliyetin %75'i kadar büyük bir bölümünü gül çiçeği girdisi oluşturmaktadır. Mevsimsel koşullara bağlı olarak değişmekle birlikte, 1 kg gül yağı elde edebilmek için genel olarak 3500 kg gül çiçeği kullanılmaktadır (Aslancan Ateş ve Toprak, 2018). Dünya gül ürünleri piyasasının neredeyse tümünü elinde bulunduran Türkiye ve Bulgaristan, yıllık ortalama 3 ton civarında gül yağı üretmektedir. Bu ülkelerde üretilen gülden elde edilen yağlar ve yan ürünlerinin sadece küçük bir bölümü ülke içinde tüketilmekte, büyük bir kısmı ise dünyanın önde gelen kozmetik ve sağlık ürünleri üreten ülkelerine ihraç edilmektedir (BAKA, 2020). Bu yönüyle sektör, ülkenin tarımsal ekonomisine sağladığı faydanın yanı sıra uçucu yağ ihracatında da oldukça önemli bir yere sahiptir (Örmeci Kart ve ark., 2012). 2022 yılında gülden elde edilen ürünlerden, Türkiye 19.15 milyon Euro, Bulgaristan ise 22.5 milyon Euro ihracat geliri elde etmiştir (TÜİK, 2023b; NSI, 2023).

Türkiye'de yağ gülü ve gül ürünleri üretimi, çoğunlukla Göller Bölgesi'nde (Isparta, Burdur, Afyonkarahisar ve Denizli), Bulgaristan'da Kazanlık Bölgesi'nde (Stara Zagora, Karlova, Plovdiv ve Pazarcık) yapılmaktadır (Baydar, 2015). Türkiye'deki yağ gülü ve güle dayalı ürün üretiminin %80'den fazlası Isparta ilinde gerçekleşmektedir. İlde yaklaşık 10 bin aile geçimini yağ gülü yetiştiriciliğiyle sağlamaktadır (T.C. Ticaret Bakanlığı, 2020). Dolayısıyla, Isparta hem bölgesinin hem de dünyanın önemli yağ gülü ve gül ürünleri üretim merkezi konumundadır (Atay ve ark., 2016; Özcan ve Dönmez, 2018).

Isparta'da yağ gülü yetiştiriciliğinde aile işletmeleri oldukça yaygın olup işletmelerin küçük ölçekli olmaları, üretim sürecinde kullanılan kaynakların etkin kullanımını daha da önemli kılmaktadır. Literatürde, yağ gülü sektörünü ekonomik açıdan ele alan birçok çalışma bulunmaktadır. Bu çalışmalarda, gül yetiştiriciliğinin ve işleyiciliğinin maliyet ve karlılığı (Singh ve Singh, 2001; Demircan, 2005; Giray ve Örmeci Kart, 2012; Aslancan Ateş ve Toprak, 2018), Türkiye'de yağ gülü yetiştiriciliğinin ekonomik yapısı (Öztürk ve ark., 2008; Gökdoğan ve Demir, 2011) ve Bulgaristan'da gül yağı sanayinin yapısı (Georgiev, 2016), Isparta gülünün Türkiye ekonomisindeki yeri (Gökdoğan, 2013), organik gül yetiştiriciliğini etkileyen sosyo-ekonomik faktörler (Chalova ve ark., 2017) ve Türkiye yağ gülü sektörünün sorunları (Dağlı, 2019) konuları ele alınmıştır. Bununla birlikte, literatürde yağ gülü sektöründeki işletmelerin üretim etkinliği üzerine yapılmış herhangi bir araştırmaya rastlanılamamıştır.

İşletmelerin performans ölçümünde etkinlik kavramı ön plana çıkmaktadır. Etkinlik, teknolojik koşullar sabitken mevcut girdi seviyesi ile maksimum çıktı miktarını elde etme becerisi veya mevcut çıktı seviyesini minimum girdi miktarı ile sağlama becerisi olarak tanımlanmaktadır (Farrel, 1957; Kopp, 1981; Coelli ve ark., 2003). Başka bir ifadeyle etkinlik, üretim birimlerinin amaçlarına ulaşmasında kullandığı mevcut ve potansiyel kaynaklar arasındaki farka yoğunlaşmakta ve doğru işleri yapmayı konu almaktadır (Yükçü ve Atağan, 2009). Etkinliğin belirlenmesi neticesinde, işletmeler sahip olduğu kaynakları ne derecede etkin olarak kullandıklarını belirleme fırsatına sahip olabilmektedirler. Böylece etkinliğin ölçümü, genel durum tespiti olarak

kullanılabilmekte ve genel refah seviyesi açısından mal ve hizmetler ile ilişkilendirerek ekonominin rekabet gücünün belirlenmesine de yardımcı olmaktadır (Çavmak ve Çavmak, 2017).

Bu çalışmanın temel amacı, dünya yağ gülü üretiminin önemli bir kısmını karşılayan Isparta ilindeki yağ gülü işletmelerinin üretim etkinlik seviyelerinin belirlenmesi ve belirlenen etkinlik seviyelerini etkileyen faktörlerin neler olduğunun tespit edilmesidir. Bu amaçla, Isparta ilinde yağ gülü tarımının yaygın olduğu Aksu, Atabey, Eğirdir, Gönen, Keçiborlu, Merkez ve Sütçüler ilçeleri ve bu ilçelere bağlı köylerde bulunan yağ gülü işletmeleri çalışma sahası olarak belirlenmiştir. İşletmelerin etkinsizliğinin belirlenmesinde ise literatürde yaygın olarak kullanılan stokastik üretim sınırı yaklaşımı ekonometrik olarak tahmin edilmiştir. Çalışmada, yağ gülü yetiştiren işletmelerin üretimdeki etkinliklerinin ve etkinsizliklerini azaltacak politika önerilerinin ortaya koyulması nedeniyle, literatürdeki önemli bir boşluğun doldurulması beklenmektedir. Diğer taraftan, işletmelerin doğru kaynak bileşimi kullanımı ve etkinlik düzeylerini artırmaya yönelik politikaların uygulanması sayesinde işletmelerin toplam gelirlerinde artış sağlanabileceği gibi maliyetlerin düşmesi sonucu Türkiye'nin uluslararası pazardaki rekabet gücü dolayısıyla gül ve gülden elde edilen ürünlerden sağlanan döviz girdisinin artırılması mümkün olabilecektir.

2. Materyal ve Metot

2.1. Materyal ve Örnekleme Yöntemi

Isparta ilinde ağırlıklı olarak yağ gülü yetiştiriciliğinin yapıldığı Aksu, Atabey, Eğirdir, Gönen, Keçiborlu, Sütçüler ve Merkez ilçeleri araştırma bölgesi olarak seçilmiş olup, anket uygulamasıyla elde edilen veriler araştırmanın ana materyalini oluşturmuştur. Araştırma bölgesine ilişkin üretici sayısı ve ekim alanı bilgilerine, T.C. Tarım ve Orman Bakanlığı Çiftçi Kayıt Sistemi'nden (ÇKS) ulaşılmış olup, veriler 2021 yılına aittir. Buna göre, araştırmanın evrenini, 16933 dekar alanda faaliyet gösteren toplam 2318 adet yağ gülü üreticisi oluşturmaktadır. Popülasyonu temsil edecek örneklem sayısının belirlenmesinde, ilk olarak Neyman yönteminin kullanılması planlanmış olsa da sahadaki gerçeklerden ve çerçeve listesinin oluşturulamamasından kaynaklı olarak basit tesadüfi örnekleme yöntemi kullanılmıştır (Yamane, 1967):

$$n = \frac{N\ x\ \sigma^2\ x\ t^2}{(N-1)d^2+(\sigma^2 x\ t^2)} \qquad \text{(Eş.1)}$$

Eşitlikte verilen n örnek sayısını, σ^2 popülasyonun varyansını, N popülasyonu oluşturan toplam üretici sayısını, t güven sınırını (%90 güven aralığına tekabül eden değeri) ve d (μ x 0.10) ise popülasyona ilişkin hata değerini ifade etmektedir.

Popülasyona ilişkin örneklem sayısı, %90 güven aralığında, %10 hata payı çerçevesinde belirlenmiştir. Yapılan hesaplamalar sonucu, araştırma bölgesini temsil edebilecek anket sayısı 166 olarak belirlenmiş olup, analizler 169 adet anket üzerinden gerçekleştirilmiştir. Anketler, Isparta ili merkez ve altı adet ilçesindeki toplam yağ gülü arazisi genişliklerine göre oransal olarak dağıtılarak uygulanmıştır. Veri toplama aşaması, 2022 yılı Ekim-Kasım aylarında, bizzat araştırmacı tarafından gerçekleştirilmiş olup veriler 2021-2022 üretim dönemine aittir. Saha anket çalışmasının yürütülmesi hususunda, Süleyman Demirel Üniversitesi, Üniversite Etik Kurulu tarafınca 30.03.2022 tarihli E-87432956-050.99-242734 sayılı etik kurulu kararıyla onay alınmıştır.

2.2. Araştırmada Kullanılan Yöntem

Literatürde etkinliğin ölçümünde, veri zarflama analizi (VZA) ve stokastik sınır analizi (SSA) yaklaşımları olmak üzere kullanımı oldukça yaygın olan iki yaklaşım öne çıkmıştır. Etkinliğin ölçümünde, Charnes, Cooper ve Rhodes tarafından 1978 yılında, benzer karar birimlerinin göreceli etkinliğinin değerlendirilmesi için matematiksel programlama formülasyonu tanımlanarak parametrik olmayan bir yaklaşım olan VZA geliştirilmiştir (Banker ve Morey, 1986). VZA yaklaşımında, Pareto-Koopmans'ın tam etklinlik yaklaşımı, üretim birimleri arasındaki göreli etkinliği hesaba katarak revize edilmiştir. Buna göre, herhangi bir karar verme birimi diğer karar verme birimleri ile karşılaştırıldığında, girdi veya çıktılarını iyileştiremeyeceği veya azaltamayacağı bir durumdaysa, bu karar verme birimi tam etkinlik seviyesinde olduğu kabul edilmektedir. (Cooper ve ark., 2011). Etkinliğin ölçümünde bir diğer yaygın yöntem olan SSA, Aigner ve ark. (1977) ile Meeusen ve van den Broeck (1977) gibi araştırmacılar tarafından parametrik bir ekonometrik yaklaşım olarak geliştirilmiştir. Bu yaklaşımda, her bir firmanın çıktısı rastgele biçimde değişebilen bir stokastik sınır tarafından belirlenmektedir. Bu teknikte, üretim sınırı üzerinde firmanın kontrolünde

olan ve olmayan sebeplerden kaynaklanan istatistiksel sapmalar açıkça gözlemlenebilmektedir (Schmidt ve Lovell, 1979).

Stokastik sınır analizi ve veri zarflama analizi yöntemlerini ayıran temel farklılıklar aşağıdaki gibi özetlenebilir (Hatırlı ve ark., 2008):

- Stokastik sınır analizinde fonksiyonel bir kalıp kullanılırken veri zarflama analizinde kullanılmamaktadır,
- Stokastik sınır analizinde etkinsizliği gösteren hata terimindeki dağılıma ilişkin varsayımlarda bulunulmaktadır,
- Stokastik sınır analizinde, sonuçların test edilebileceği istatistiki özellikler yer almaktadır.

Etkinliğin ölçümünde kullanılan her iki yöntemin de belirli avantaj ve dezavantajları bulunmaktadır. Bununla birlikte, SSA yöntemi, veri setinin kalitesine bağlı olarak izlenen tahmin prosedürü doğru uygulandığı takdirde etkili sonuçlar verebilmekte ve üretim sınırının üzerindeki bireysel açıklayıcı faktörlerin önemi hakkında istatistiksel çıkarımlar yapabilmektedir (Sarafidis, 2002). Böylece, çevresel değişkenlerle de kolayca başa çıkabilmektedir (Coelli ve ark., 2003). Bu sebeplerden dolayı SSA, çeşitli alanlarda yapılan politik analizlere uygundur (Bauer, 1990). Bunun yanı sıra, gelişmekte olan ülkelerdeki tarım ürünlerine yönelik etkinlik çalışmalarında, stokastik sınır analizi yönteminin daha uygun olduğu görüşü yaygındır. Bunun sebebi, tarım alanındaki faaliyetlerde, hava koşullarındaki değişkenlik ve hastalık ve zararlılardan kaynaklı ölçüm sapmalarının dikkate alınmasıdır (Gözener, 2013).

Bu çalışmada, yağ gülü yetiştiriciliği yapan işletmelerin etkinlik seviyelerinin belirlenmesi amacıyla stokastik üretim sınırı yaklaşımı kullanılmıştır. Stokastik üretim sınırı yaklaşımı genel olarak aşağıdaki şekilde ifade edilmektedir (Ali ve Flinn, 1989):

$$Y_i = f\left(P_{ij}, Z_{ik}, D_{ij}\right) exp(\, e_i) \qquad \text{(Eş.2)}$$

Eşitlikte, Y_i işletmenin çıktısını, P_{ij} girdi fiyatını, Z_{ik} sabit üretim faktörünün seviyesini, D_{ij} işletmeye özgü koşullara ilişkin dışsal değişkenler vektörünü ve e_i ise sınır yaklaşımına uygun olan hata terimini göstermektedir. Ayrıca eşitlikte bulunan hata teriminin $u_i - v_i$ olmak üzere iki bileşeni bulunmaktadır ve v_i ile u_i birbirlerinden bağımsız biçimde dağıldığı varsayılmaktadır. İstatistiksel gürültüyü ifade eden v_i bağımsız ve eşit, işletmenin etkinsizliğini gösteren u_i ise sıfıra eşit veya büyük tek yönlü olarak dağılmaktadır (Aigner ve ark., 1977).

Negatif olmayan tek yönlü bir yarı normal dağılım gösterdiği varsayımı altında, etkinsizlik teriminin (u_i) popülasyona ilişkin ortalama değer ve varyansı hesaplanabilmektedir. Hata terimine ilişkin marjinal sıklık fonksiyonu, asimetrik ortalama ve varyansla dağılmıştır. Bu durum aşağıdaki eşitliklerde ifade edilmiştir (Kumbhakar ve Lovell, 2003):

$$E(e) = -E(u) = -\,\sigma_u\sqrt{\frac{2}{\pi}} \qquad \text{(Eş.3)}$$

$$V(u) = \sigma_u^2\,\frac{(\pi-2)}{\pi} + \sigma_v^2 \qquad \text{(Eş.4)}$$

Popülasyonun beklenen (ortalama) etkinlik tahmincisi aşağıdaki eşitlikte gösterilmiştir;

$$E(\exp\{-u\}) = 2[1 - \emptyset(\sigma_u)] * \exp\left\{\frac{\sigma_u^2}{2}\right\} \qquad \text{(Eş.5)}$$

Her bir işletmenin koşullu etkinlik değerlerinin belirlenmesi için hata terimi (e_i) için etkinsizlik terimin (u_i) koşullu dağılımı aşağıdaki eşitlikte ifade edilir:

$$E(u_i \,/\, e_i) = \frac{f(u,e)}{f(e)} = \sigma_*\left[\frac{\varphi(e_i\lambda/\sigma)}{1-\emptyset(e_i\lambda/\sigma)} - \left(\frac{e_i\lambda}{\sigma}\right)\right] \qquad \text{(Eş.6)}$$

Yukarıdaki eşitliklerdeki φ (.) ve Ø (.) sembolleri sırasıyla, standart normal yoğunluk fonksiyonunu ve standart normal kümülatif dağılım fonksiyonunu (CDF) göstermektedir. Ayrıca, $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$ ve $\lambda = \sigma_u/\sigma_v$ şeklindedir.

Böylece her üreticiye ilişkin teknik etkinlik değerleri hesaplanabilmektedir;

$$TE_i = \exp\,(-\hat{u}_i) \qquad \text{(Eş.7)}$$

Eşitlikte (Eş.7) gösterilen $\hat{u}_i$, $E(u_i/e_i)$ olarak ifade edilmektedir ve her bir üreticiye özgü üretim etkinsizlik indeksi yukarıdaki eşitliğin sonuçlarının kullanılmasıyla aşağıdaki gibi gösterilmektedir:

$$UEI = (1 - exp[-\hat{u}_i\,]) \quad \text{(Eş.8)}$$

Etkinsizlikten kaynaklanan üretim kaybı, işletmenin teknoloji ve girdi seviyesi veri iken gözlemlenen çıktı ve potansiyel çıktı arasındaki farkı göstermektedir. İşletmenin üretim etkinsizliğini etkileyen faktörler, işletmeye özgü sosyo-ekonomik değişkenlerle modellenerek açıklanmaktadır. Yukarıdaki eşitlikten (Eş.8) elde edilen UEI vektörü ise bağımlı değişken olarak kullanılmaktadır (Battese ve Broca, 1997).

Bu çalışmada yağ gülü yetiştiriciliği yapan işletmelerde, stokastik üretim sınırı fonksiyonunda dışsal değişkenler olarak, işletmenin yağ gülü üretiminde kullandığı işgücü süresi, ekipman masraflarının toplamı, materyal masraflarının toplamı ve işletmenin yağ gülü alanı dikkate alınmıştır.

Stokastik üretim sınırı tahmininde, modelin deterministik kısmına ilişkin fonksiyon kalıbının belirlenmesi sonuçların güvenilirliği açısından büyük önem taşımaktadır (Li ve Rosenman, 2001; Hatırlı ve ark., 2008). Literatürde stokastik üretim sınırı tahmininde kullanılan farklı fonksiyon kalıpları bulunmasının yanı sıra Cobb-Douglas ve translog kalıpları sıklıkla tercih edilmektedir (Battese ve Broca, 1997; Ruggiero, 1999).

Translog fonksiyonu, Cobb-Douglas fonksiyonun daha esnek halidir. Bununla karşın, özellikle örneklem büyüklüğünün 100'ün altında olduğu durumlarda stokastik üretim sınırının performansının Cobb-Douglas fonksiyonuna göre daha zayıf ve hatalı sonuçlar verdiği, örneklem büyüklüğünün 100'ün üzerinde olduğu durumlarda ise sonuçların Cobb-Douglas formuna yaklaştığı belirlenmiştir (Ruggiero, 1999). Ayrıca, fonksiyon kalıbının esnek forma bürünmesi, daha fazla parametre tahmin edilmesine ve ekonometrik olarak zorlukların yaşanmasına neden olabilmektedir (Coelli ve ark., 2005). Analizde kullanılan veri setine hangi fonksiyon kalıbının uygulanması gerektiğinin test edilmesi, modelden elde edilen sonuçların istatistiksel güvenilirliği açısından önemlidir. Fonksiyon kalıbının seçimine ilişkin karar, literatürde sıklıkla kullanılan olabilirlik oranı testi (LR) yardımıyla yapılmaktadır (Coelli ve ark., 2003). Yaklaşık serbestlik derecesinin bağımsız kısıtlamaların sayısına eşit ki-kare dağılımına sahip olan LR testi aşağıdaki eşitlikte sunulmuştur (Wilson ve ark., 1998):

$$\lambda_{LR} = 2[L(H_1) - L(H_0)] \quad \text{(Eş.9)}$$

Eşitlikte, H_0, sıfır hipotezi (kısıtlı model) altında olabilirlik değerini; H_1 ise alternatif hipotez (kısıtsız model) altındaki ilgili değeri ifade etmektedir. Burada, üretim fonksiyonunda, Cobb-Douglas formunun uygunluğunu gösteren sıfır hipotezinin testi gerçekleştirilmektedir. Elde edilen LR istatistik değeri, tablo değerinden küçük ise Cobb-Douglas, tersi durumda ise translog formunun uygunluğunu göstermektedir.

Bu çalışmada, aşağıda ifade edilen Cobb-Douglas fonksiyon kalıbı kullanılmış ve fonksiyon kalıbının seçimine ilişkin uygulanan testin sonucu, araştırma bulguları bölümünde sunulmuştur. Buna göre, stokastik üretim sınırı modeli aşağıdaki eşitlikte ifade edilmiştir:

$$lnY_i = \alpha_0 + \alpha_1 lnP_{1i} + \alpha_2 lnP_{2i} + \alpha_3 lnP_{3i} + \beta_1 lnZ_{1i} + e_i \quad \text{(Eş.10)}$$

Eşitlikte, Y_i i'ninci işletmenin üretim verimini, P_1 işgücü kullanım süresini, P_2 işletmenin kullandığı toplam ekipman yakıt masrafını, P_3 işletmenin kullandığı toplam materyal masrafını ve Z_i işletmenin sahip olduğu yağ gülü alanını ifade etmektedir. Modelde bulunan e_i ise daha önce ifade edilmiş olan ($e_i = v_i - u_i$) bileşik hata terimini göstermektedir.

Stokastik üretim sınırı modelinde bağımlı değişken olarak ele alınan üretim verimi (Y_i), i'ninci işletmenin üretim miktarının yağ gülü arazisine bölünmesi ile elde edilmiştir. Modele açıklayıcı değişken olarak dahil edilen toplam işgücü kullanım süresi (P_{1i}), i'ninci işletmenin üretim döneminde, bakım ve hasat işlemleri için, kullandığı dekara işgücü süresinin toplamıdır. Modele açıklayıcı değişken olarak dahil edilen bir diğer değişken olan toplam ekipman masrafı (P_{2i}), i'ninci işletmenin yağ gülü üretiminde kullandığı traktör, budama motoru, motorlu çapa gibi ekipmanların dekara yakıt masraflarının toplanması ile elde edilmiştir. Toplam materyal masrafı değişkeni (P_{3i}) ise üretim döneminde kullanılan gübre, ilaç ve sulamayı da içeren dekara materyal masraflarının toplanması ile modele dahil edilmiştir. Modelde yer alan bir diğer dışsal değişken ise işletmenin toplam yağ gülü arazisi (Z_{1i})'dir. Stokastik Cobb-Douglas üretim sınırı modelinde kullanılan değişkenler ve bunlara ilişkin açıklamalar *Tablo 1*'de yer almaktadır.

Tablo 1. Stokastik Üretim Sınırı Modelinde Kullanılan Değişkenler ve Tanımlamaları

Table 1. Variables and Their Definitions Used in the Stochastic Production Frontier Model

Bağımlı Değişken	
Y_i	i'ninci işletmenin verimi (kg da^{-1})
Bağımsız Değişkenler	
P_1	İlgili üretim dönemindeki toplam işgücü kullanım süresi (sa da^{-1})
P_2	İlgili üretim dönemindeki toplam ekipman masrafı (TL da^{-1})
P_3	İlgili üretim dönemindeki toplam materyal masrafı (TL da^{-1})
Z_1	İlgili üretim dönemindeki yağ gülü yetiştiriciliği yapılan toplam alan (da)
e_i	Bileşik hata terimi

İlgili üretim dönemine ilişkin stokastik Cobb-Douglas fonksiyonu tahmin edildikten sonra, işletmelerin üretim etkinsizliğinin nedenlerini açıklayabilmek için, Eşitlik 8'de ifade edilen işletmeye özgü UEI değerlerinin bağımlı değişken olarak modellenmesi gerekmektedir. Literatürde, tarımsal ürünlerdeki etkinsizlik etkilerinin ölçümünde en küçük kareler (EKK) ve tobit regresyon yöntemlerinin sıklıkla kullanıldığı görülmektedir (Kalirajan ve Shand, 1988; Binici ve ark., 2006; Alemdar ve Işık, 2008; Kılıç ve ark., 2009; Tipi ve ark., 2009; Aktaş ve ark., 2011; Dlamini ve ark., 2012). Öte yandan, bağımlı değişken olarak hesaplanan üretim etkinsizlik değerleri 0 ile 1 sınırları arasında değişmektedir. Bağımlı değişkenin 0 ile 1 arasındaki sınırlar içerisinde modellendiği analizlerde, artıkların normal dağılımı ve değişen varyans gibi sorunlarla karşılaşılmaması ve daha tutarlı ve yansız sonuçlar elde edilebilmesi için kesirli tahmin modellerinden olan beta regresyon analizi yönteminin uygulanması önerilmektedir (Baum, 2008; Ferrari ve Cribari-Neto, 2004). Beta regresyon analizi, çeşitli disiplinlerde, sürekli ve oransal değer aralığında modellenen bağımlı değişkenlerin analizinde sıklıkla uygulanmaktadır (Hunger ve ark., 2011; Dünder ve ark., 2015; Koç, 2019). Bununla birlikte, Endalew ve ark. (2022) ve Endalew ve ark. (2023), çeşitli tarımsal ürünlerdeki etkinsizliği etkileyen faktörleri belirlemek amacıyla geliştirdikleri modellerde, bağımlı değişkenin 0 ile 1 değerlerinin içerisinde sınırlı olması nedeniyle ve tahmin edilen sonuçların tutarlılığı açısından beta regresyon analizi yöntemini tercih etmişlerdir.

Bu çalışmada, yağ gülü yetiştiriciliği yapan işletmelerin etkinsizliğini etkileyen faktörlerin belirlenmesinde beta regresyon modeli kullanılmış ve en yüksek olabilirlik (MLE) yöntemiyle tahmin edilmiştir. Analizdeki bağımlı değişken aşağıdaki eşitlikte bulunan beta dağılımına sahiptir (Ferrari ve Cribari-Neto, 2004):

$$f(y;p,q)=\frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)}y^{p-1}(1-y)^{q-1},\quad 0<y<1 \qquad \text{(Eş.11)}$$

Eşitlikte gösterilen $p>0, r>0$ ve $\Gamma(.)$ gamma fonksiyonunu ifade etmektedir. $\mu=\frac{p}{p+q}$ ve $\phi=p+q$ olmak üzere yukarıdaki eşitlik aşağıdaki gibi ifade edilir:

$$f(y;\ \mu,\phi)=\ \frac{\Gamma(\phi)}{\Gamma(\mu\phi)\Gamma(\phi(1-\mu))}y^{\mu\phi-1}(1-y)^{(1-\mu)\phi-1} \qquad \text{(Eş.12)}$$

$0<y<1$, $0<\mu<1$ ve $\phi>0$ iken $y\sim B(\mu,\phi)$ ve $E(y)=\mu$, $Var(y)=\mu(1-\mu)/(1+\phi)$ olmaktadır. Burada, μ bağımlı değişkenin ortalaması olarak gösterilmiştir. ϕ, μ sabit olduğunda dağılımın ne kadar yayıldığını gösteren bir yayılım parametresi olarak yorumlanmakta ve bu değerin yüksek olması, bağımlı değişkenin varyansının düşük olduğunu göstermektedir (Endalew ve ark., 2023).

$y_1 \dots\dots\dots y_n$ bağımsız rastgele değişkenlerdir. Her bir y_t, $t=1,\dots..n$ için beta dağılımına sahiptir ve dağılımın ortalaması μ_t ve hassasiyeti ϕ_t ile tanımlanmaktadır (Ferrari ve Cribari-Neto, 2004):

$$g(\mu_t)=\ \sum_{i=1}^{k}x_{ti}\beta_i \qquad \text{(Eş.13)}$$

Burada, $\beta=(\beta_1,\beta_2\dots\dots.\beta_k)^T$ bilinmeyen regresyon parametrelerini temsil etmektedir. $x=(x_{t1}x_{t2}\dots\dots.x_{tk})$ sabit kovaryatları belirtmektedir. $g(.)$ ise sıkı bir biçimde monoton ve iki kez türevlenebilir olan bağlantı fonksiyonunu göstermektedir. Beta regresyonda, logit, probit, cloglog ve loglog olmak üzere çeşitli bağlantı fonksiyonları kullanılabilmektedir. Uygun bir bağlantı fonksiyonunun seçilmesi modeli önemli ölçüde iyileştirebilmektedir. Bu nedenle, en iyi bağlantı fonksiyonunu belirlemek için AIC ve BIC kriterleri kullanılmaktadır (Dünder ve ark., 2015). Bununla birlikte, bağımlı değişkenin 0 ile 1 değerleri arasında olduğu

ancak sınır değerlerini içermediği durumlarda logit bağlantı fonksiyonunun tercih edilmesi önerilmektedir (Endalew ve ark., 2022; Endalew ve ark., 2023).

Yağ gülü yetiştiriciliği yapan işletmelerin etkinlik seviyesini etkileyen faktörlerin araştırılmasında, potansiyel bağımsız değişkenler, önceki literatür gözden geçirilerek belirlenmiştir Literatürde etkinsizliğin belirleyicileri olarak, genellikle, üreticinin yaşı ve eğitim durumu ile işletmelerin arazi kullanım biçimi, arazi özellikleri, bölgesel farklılıklar, işletmenin finansman imkanları ve işletmenin faaliyetlerindeki yönetsel farklılıklarına ilişkin değişkenlere yer verilmiştir (Kalirajan ve Shand, 1988; Ali ve Flinn, 1989; Wilson ve ark., 1998; Battese ve Coelli, 1995; Abdulai ve Huffman, 1998; Ahmad ve ark., 2002; Binam ve ark., 2005; Bozoğlu ve Ceyhan, 2007; Kılıç ve ark., 2009; Rahman ve ark., 2012; Mukete ve ark., 2016; Ali ve ark., 2019; Endalew ve ark., 2022). Bu çalışmada, yağ gülü yetiştiriciliğinin yapıldığı işletmelerdeki üretim etkinsizliğini açıklamak için dışsal değişkenler olarak üreticinin yaşı, eğitim durumu, gül alanı için parsel sayısı, işletmedeki gül ağaçlarının ortalama yaşı, gül arazisinin sulama durumu, yayım faaliyetlerine katılım durumu, işletmenin tarımsal kooperatif üyeliği, gül arazisinin rakım seviyesi ve kredi kullanım durumu dikkate alınmıştır. Buna göre, üretim etkinsizlik modeli, logit bağlantı fonksiyonu kullanılarak beta regresyon yöntemi ile aşağıdaki eşitlikte ifade edilmiştir:

$$g(UEI_i) = log\left(\frac{UEI_i}{1-UEI_i}\right)$$

$$g(UEI_i) = \delta_0 + \delta_1 Y_i + \delta_2 ED_{2i} + \delta_3 ED_{3i} + \delta_4 PS_i + \delta_5 BY_{2i} + \delta_6 BY_{3i} + \delta_7 SV_i + \delta_8 YF_i + \delta_9 GDU_i + \delta_{10} UYE_i + \delta_{11} RAK_i + \delta_{12} KK_i \quad \text{(Eş.14)}$$

Yukarıdaki eşitlikte, bağımlı değişken olarak ele alınan üretim etkinsizlik indeksi (UEI_i), i'ninci işletmenin teknik etkinlik değerinin birden çıkarılması ile hesaplanmıştır. Diğer taraftan, i'ninci işletmeye ilişkin, üreticinin yaşı (Y_i), eğitim durumu (ED_{2i} ve ED_{3i}), gül bahçesinin parsel sayısı (PS_i), gül bahçesinde bulunan ağaçların ortalama yaşı (BY_{2i} ve BY_{3i}), gül arazisinin sulama durumu (SV_i), işletmenin yayım faaliyetlerine katılım durumu (YF_i), işletmede yağ gülü dışında başka bir bitkisel ürüne yer verme durumu (GDU_i), işletmenin tarımsal kooperatife üyeliği (UYE_i), yağ gülü arazisinin rakım seviyesi (RAK_i), kredi kullanım durumu (KK_i), açıklayıcı değişkenlerinin tümü çeşitli kıstaslar göz önünde bulundurularak modele kukla değişkenler olarak dahil edilmiştir. İşletmecinin yaşı ve gül bahçelerinin parsel sayısını gösteren kukla değişkenlerin değeri, ilgili değişkenlere ilişkin örneklemin ortalama değerleri dikkate alınarak hesaplanmıştır. Üreticinin eğitim durumu kukla değişkeni, işletmecinin eğitim seviyesinin yüksekokul ve üzeri öğrenime sahip olup olmama durumuna göre (referans) modele dahil edilmiştir. İşletmede yer alan yağ gülü ağaçlarının ortalama yaşını gösteren kukla değişkenler ise yağ gülü ağaçlarının ekonomik çağı olan 5 ve 10 yaş aralığında olup olmama durumlarına göre (referans) belirlenmiştir. İşletmelerin üretim etkinsizliğini açıklayan dışsal değişkenler ve bunlara ilişkin açıklamalar *Tablo 2*'de verilmiştir.

Tablo 2. Üretim Etkinsizlik Modelinde Kullanılan Değişkenler ve Tanımlamaları

Table 2. Variables and Their Definitions Used in the Production Inefficiency Model

Bağımlı Değişken	
UEI_i	i'ninci işletmenin üretim etkinsizlik indeksi
Bağımsız Değişkenler	
Y	Üreticinin yaşı
ED_1	Üreticinin eğitim durumu yüksekokul ve üzeri ise=1, değilse=0 (Referans)
ED_2	Üreticinin eğitim durumu ilkokul ve altı ise=1, değilse=0
ED_3	Üreticinin eğitim durumu ortaokul ve lise ise=1, değilse=0
PS	İşletmedeki gül bahçelerinin parsel sayısı
BY_1	Yağ gülü bahçesinin ortalama yaşı ekonomik verim çağında ise=1, değilse=0 (Referans)
BY_2	Yağ gülü bahçesinin ortalama yaşı ekonomik verim çağının altında ise=1, değilse=0
BY_3	Yağ gülü bahçesinin ortalama yaşı ekonomik verim çağının üzerinde ise=1, değilse=0
SV	Yağ gülü arazisinde sulu tarım uygulanıyorsa=1, değilse=0
YF	İşletme yayım faaliyetlerine katılıyorsa=1, değilse=0
GDU	İşletmede yağ gülü dışında bitkisel ürün üretimi yapılıyorsa=1, değilse=0
UYE	İşletme tarımsal kooperatife üye ise=1, değilse=0
RAK	Rakım seviyesi 1200 m ve üzeri ise=1, değilse=0
KK	İşletme tarım kredisi kullanıyorsa=1, değilse=0

3. Araştırma Sonuçları ve Tartışma

Isparta ilinde yağ gülü tarımı yapan işletmelerin arazi dağılımı incelendiğinde, görüşülen işletmelerdeki işletme başına düşen toplam arazi genişliğinin 15.70 dekar olduğu tespit edilmiştir. Toplam işletme arazisi içerisindeki yağ gülü arazisinin payı ise ortalama %39.89'luk oranla 7.14 dekar olarak hesaplanmıştır. Üreticilere uygulanan anketler, işletmelerin yağ gülü alanı dağılımına göre üç gruba ayrılmıştır. Buna göre 2.99 dekar ve altında yağ gülü alanına sahip işletmeler (37 işletme) I. grup, 3-8.99 dekar arasındaki yağ gülü alanına sahip işletmeler (89 işletme) II. grup, 9 ve üzeri dekar yağ gülü alanına sahip işletmeler (43 işletme) III. grup olarak tanımlanmıştır. Yağ gülü arazisi genişlik grupları itibariyle, toplam işletme arazisi içerisindeki yağ gülü arazisinin payı I. grupta %18.91, II. grupta %39.35 ve III. grupta %59.06 olarak hesaplanmıştır. Ayrıca görüşülen işletmelerde, yağ gülü arazilerinin ortalama yaşının 7.86 yıl olduğu, ortalama parsel sayısının ise 1.66 olduğu belirlenmiştir. İncelenen işletmelerde, ortalama hane genişliğinin 3.08 kişi olduğu, ortalama işletme yöneticisi yaşının yaklaşık 54 olduğu ve işletme yöneticilerinin %33.73'ünün ilkokul ve altı, %49.70'inin ortaokul-lise ve %16.57'sinin ise yüksekokul ve üzeri eğitim seviyesine sahip olduğu tespit edilmiştir.

Isparta ilinde yağ gülü yetiştiriciliği yapan işletmelerin üretim etkinsizliği ve etkinsizlik nedenlerinin belirlenmesi için öncelikle stokastik üretim sınırı deterministik kısmının (fonksiyon kalıbı) belirlenmesi ve bu aşamayı takiben model tahmini yapılması gerekmektedir. Modeldeki fonksiyon kalıbının, veri setine göre değişim göstermesi nedeniyle mevcut kullanılan veri seti için hangi fonksiyon kalıbının uygulanması gerektiği test edilmelidir. Bu amaç doğrultusunda, olabilirlik oran testi (LR) kullanılmıştır. Test sonucuna göre, LR değerinin 12.18 olduğu ve ki-kare dağılımına göre %1 önem seviyesindeki ki-kare değerinden düşük olduğu belirlenmiştir. Buna göre, Cobb-Douglas fonksiyon kalıbının uygunluğunu belirten H_0 hipotezi kabul edilmiştir.

Eşitlik 10'da ifade edilen çift yönlü logaritmik Cobb-Douglas üretim sınırı modeli en yüksek olabilirlik tekniği (MLE) ile LIMDEP programı kullanılarak tahmin edilmiş olup model tahmin sonuçları *Tablo 3*'te sunulmuştur. Analizden elde edilen sonuçlara göre, modele dahil edilen değişkenlerin önemli bir bölümünün istatistiksel olarak anlamlı olduğu ve tüm değişkenlerin beklenen işarete sahip olduğu görülmektedir. Toplam işgücü kullanım süresi, toplam ekipman masrafı ve toplam materyal masrafları değişkenlerinin katsayıları pozitif ve toplam işgücü süresi ve toplam materyal masrafı değişkenlerinin katsayıları sırasıyla istatistiksel olarak %1 ve %10 önem seviyesinde anlamlı bulunmuştur. Buna göre, yağ gülü işletmelerinin faaliyetlerinde toplam işgücü süresi, toplam ekipman masrafları ve toplam materyal masraflarında meydana gelecek artışların verim üzerinde olumlu bir etkide bulunacağı öngörülmektedir. Bu sonuç, beklentiyle uyumludur. Nitekim gül tarımında özellikle hasat zamanında işgücü kullanımı, rekolte miktarına olumlu bir etki göstermektedir. Ayrıca arazi bakım işlemlerinde, ekipman masrafı ve gübre, ilaç ve sulamaya ilişkin yapılan materyal masrafları üretim verimini artırmaktadır. Buna karşın, toplam ekipman masrafı değişkeninin katsayısı istatistiksel olarak anlamsız sonuç vermiştir. Bunun nedeni olarak, Isparta ilindeki gül bahçelerinin, genel olarak, düşük dekara sahip olması ve sıra aralarının sık olması gösterilebilir. Gül bahçelerinde sıra aralarının sık olması, bakım işlemlerinde traktör kullanımını önlemektedir. Bunlara ek olarak gül tarımında, bakım ve hasat işlemlerinin daha çok emek yoğun olarak gerçekleştirildiği ve tarımda mekanizasyon tekniklerinin ilgili üründe uygulanmasının oldukça zor olduğu da bir gerçektir (Chalova ve ark., 2017). Stokastik sınır analizinde, girdi unsurlarının yanı sıra toplam yağ gülü alanı da modele dahil edilmiştir. Analizden elde edilen sonuçlara göre, toplam yağ gülü alanı değişkeni, pozitif katsayısı ile istatistiksel olarak %1 önem seviyesinde anlamlı bulunmuştur. Bu sonuç, yağ gülü alanı büyük olan işletmelerde verimin küçük alana sahip olanlara göre daha yüksek olduğunu göstermektedir.

Model tahmin sonuçlarına göre hesaplanan lamda (λ) değeri (1.005), u'nun standart sapmasının v'nin standart sapmasına oranlanması ile hesaplanmış olup her önem seviyesinde istatistiksel olarak anlamlı sonuç vermiştir. Buna göre, etkinsizliği ifade eden tek yönlü hata teriminin (u), simetrik hata terimine (v) göre baskın olduğu belirlenmiştir. Bu sonuca göre, işletmelerin mümkün olan maksimum üretim veriminden sapmalarının ve daha düşük düzeyde üretim verimi elde etmelerinin nedeni, işletme tarafından kontrol edilmeyen tesadüfi şoklardan değil, işletmeler arasındaki uygulama farklılıklarından kaynaklandığı belirlenmiştir. Diğer taraftan, işletmelerin etkinsizliğinin ifade edilmesinde kullanılan bir diğer gösterge de hata terimlerinin varyansları ile hesaplanan $\tau = (\frac{\sigma_u^2}{\sigma_v^2+\sigma_u^2})$, τ parametresi yardımıyla belirlenmektedir (Battese ve Corra, 1977). Hesaplanan τ parametresi, sıfır ile bir arasında bir değer almaktadır. Parametre değerinin sıfıra yakın olması etkinsizliğin düşük seviyede olduğunu,

bire yakın olması ise yüksek seviyede etkinsizliğin varlığını göstermektedir. Model tahmin sonuçlarından elde edilen τ değeri 0.503 olarak hesaplanmıştır. Buna göre, işletmelerin gözlenen üretim verimi ile ulaşabilecekleri maksimum üretim verimi arasındaki farkın %50.3'ünün teknik ve dağılım etkinsizliğinden kaynaklandığı ve kalan kısmının ise işletmenin kontrolünde olmayan tesadüfi faktörlerden kaynaklandığı belirlenmiştir (*Tablo 3*).

Tablo 3. Stokastik Üretim Sınırı Modelinin Tahmin Sonuçları

Table 3. Estimation Results of the Stochastic Production Frontier Model

Değişken	Parametre	Katsayı	Standart	z-İstatistiği	Anlamlılık
Sabit	α_0	1.901	0.510	3.722	0.000*
$\boldsymbol{lnP_1}$	α_1	0.559	0.698	8.007	0.000*
$\boldsymbol{lnP_2}$	α_2	0.070	0.046	1.536	0.124
$\boldsymbol{lnP_3}$	α_3	0.088	0.050	1.768	0.077**
$\boldsymbol{lnZ_1}$	β_1	0.121	0.044	2.734	0.006*
Lamda	λ	1.005	0.215	4.671	0.000*
Sigma	σ	0.419	0.001	225.988	0.000*
	σ_u	0.297			
	σ_v	0.295			
Log-likelihood		-60.046			

* ve ** sırasıyla %1 ve %10 önem seviyesinde istatistiksel olarak anlamlıdır.

Üretim etkinsizliğinin işletme yüzdelerine göre dağılımı incelendiğinde, işletmelerde, üretim etkinsizlik değerinin 0.09 ile 0.45 arasında değiştiği belirlenmiş ve işletmelerin ortalama etkinsizlik değeri ise 0.21 olarak hesaplanmıştır (*Şekil 1*). Hesaplanan ortalama etkinsizlik değeri, işletmelerin ulaşabileceği üretim verimi sınırının %21 altında faaliyet gösterdiklerini ifade etmektedir. Ayrıca, işletmelerin yaklaşık %59'unun ortalama etkinsizlik değerinin altında faaliyette bulunduğu belirlenmiştir. Bu sonuca göre, teknik ve dağılım etkinliğinin sağlanması halinde işletmeler, ortalamada mevcut üretim verimlerini %21 oranında artırabileceklerdir. Model tahmin sonuçları doğrultusunda, işletmelerin etkinsizlikten dolayı dekara ortalama üretim verimi kaybının 95.10 kg olduğu belirlenmiştir. Diğer bir ifadeyle, işletmelerin faaliyetlerinde etkinliği sağladıkları takdirde dekara üretim verimini ortalama 95.10 kg artırabileceklerdir.

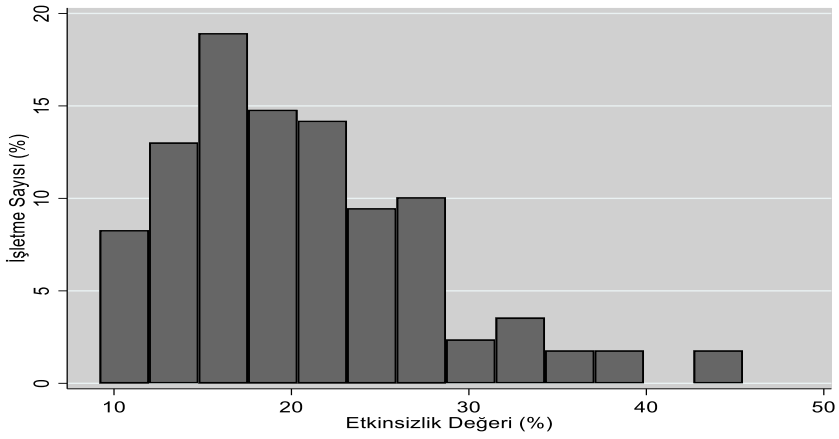

Figure 1. The Distribution of Production Inefficiency in Enterprises

Şekil 1. İşletmelerin Üretim Etkinsizliğinin Dağılımı

Isparta ilinde yağ gülü yetiştiriciliği yapan işletmelerin üretim etkinsizliğinin nedenlerini belirlemek amacıyla, daha önce Eşitlik 14'te ifade edilen ekonometrik model, STATA programı kullanılarak beta regresyon analizi ve maksimum olabilirlik (MLE) yöntemi ile tahmin edilmiştir. Modelin tahmini, işletmelere ilişkin etkinsizlik değerlerinin 0.09 ve 0.45 arasında olması ve 0 ile 1 sınır değerlerine ulaşmaması nedeniyle logit bağlantı fonksiyonu kullanılarak yapılmıştır. Araştırma kapsamındaki işletmelerin üretim etkinsizliğine ilişkin modelden elde edilen tahmin sonuçları *Tablo 4*'te sunulmuştur.

Tablo 4. Üretim Etkinsizlik Modelinin Tahmin Sonuçları

Table 4. Estimation Results of the Production Inefficiency Model

Değişken	Parametre	Katsayı	Standart Hata	z-İstatistiği	Anlamlılık Seviyesi
Sabit	δ_0	-1.28	0.11	-11.60	0.00*
$\boldsymbol{Y}$	δ_1	-0.14	0.06	-2.25	0.02**
$\boldsymbol{ED_2}$	δ_2	-0.03	0.08	-0.36	0.72
$\boldsymbol{ED_3}$	δ_3	-0.13	0.08	-1.63	0.10
$\boldsymbol{PS}$	δ_4	0.03	0.05	0.66	0.50
$\boldsymbol{BY_2}$	δ_5	0.20	0.06	3.07	0.00*
$\boldsymbol{BY_3}$	δ_6	0.14	0.07	1.98	0.04**
$\boldsymbol{SV}$	δ_7	-0.10	0.05	-1.83	0.06***
$\boldsymbol{YF}$	δ_8	-0.16	0.06	-2.68	0.00*
$\boldsymbol{GDU}$	δ_9	0.14	0.06	2.40	0.01**
$\boldsymbol{UYE}$	δ_{10}	0.04	0.06	0.64	0.51
$\boldsymbol{RAK}$	δ_{11}	0.12	0.06	2.14	0.03**
$\boldsymbol{KK}$	δ_{12}	-0.15	0.08	-1.88	0.06***
∅		3.78	0.11	34.99	0.00*
Log-likelihood= 238.1874		Ki-kare= 46.09 (0.000)			

*, ** ve *** sırasıyla %1, %5 ve %10 önem seviyesinde istatistiksel olarak anlamlıdır.

Yağ gülü işletmelerinin etkinsizliğinin belirleyicilerinin incelendiği beta regresyon analizi sonuçları değerlendirildiğinde, ki-kare ve ϕ yayılım parametresinin %1 önem seviyesinde anlamlı olduğu tespit edilmiştir. Ki-kare değeri modelin uyumunun iyi olduğunu gösterirken, 3.78 olarak hesaplanan yayılım parametresinin istatistiksel olarak anlamlı olması, modelin varyansının iyi bir şekilde açıklandığını, yani modelin bağımlı değişken üzerindeki değişimi yakalamada başarılı olduğunu ve tahmin edilen değerlerin gözlemlenen değerlerle uyumlu olduğunu ifade etmektedir. Etkinsizlik modeli katsayıları ise eğitim durumu, parsel sayısı ve kooperatif üyeliği dışındaki tüm değişkenlerin istatistiksel olarak anlamlı olduğunu göstermektedir.

Araştırma kapsamındaki işletmelerde, işletme yöneticisinin yaşı yaklaşık ortalama 54 olarak hesaplanmıştır. Analiz sonuçları, işletme yöneticisi yaşının ortalama üzerinde olmasının işletmenin üretim etkinsizliğini azalttığını göstermektedir. İşletme yöneticisinin yaşındaki artışın deneyimin artması olarak kabul edilebileceğinden dolayı elde edilen sonuç beklentiye uyumludur. Nitekim literatürde, üreticinin deneyiminin etkinsizliği azaltıcı bir etkisi olduğunu destekleyen çeşitli araştırmalar mevcuttur (Wilson ve ark., 1998; Kebede, 2001; Bozoğlu ve Ceyhan, 2007; Alemdar ve Işık, 2008; Dlamini ve ark., 2012; Gbigbi, 2021). Araştırma kapsamındaki işletmelerdeki dekara üretim verimi, 54 yaşının üzerindeki yöneticilere sahip işletmelerde 463.21 kg, 54 yaşının altındaki yöneticiye sahip işletmelerde ise 439.88 kg olarak hesaplanmıştır. Dolayısıyla, ilgili değişkenin işareti araştırma bulgularıyla desteklenmektedir. Bu doğrultuda, yayım faaliyetleri uygulamalarındaki hedef kitlenin genç üreticiler olması, işletmelerin üretim etkinsizliğinin azaltılmasında etkili olabilecektir.

Analize dahil edilen bir diğer değişken işletmecinin eğitim durumu kukla değişkenidir. Model sonuçları, işletme yöneticisinin eğitim durumunun ilkokul ve altı ve ortaokul-lise seviyesinde olmasının işletmelerde üretim etkinsizliğini azalttığını göstermektedir. Diğer bir ifadeyle, yüksekokul ve üzerinde eğitim seviyesine sahip üreticilerin ilkokul ve altı ve ortaokul-lise seviyesindeki üreticilere nazaran daha etkinsiz olduğu sonucuna ulaşılmıştır. Ancak ilgili değişkenler istatistiksel olarak anlamlı bulunmamıştır. İlgili sonucun beklentiyle uyumlu olmadığı görülmekle birlikte, işletme yöneticisinin yüksek eğitim seviyesine sahip olması, tarım dışı gelir ile ilişkilendirilebilir. Literatürde tarım dışı çalışma ve tarım dışı gelir durumunun etkinsizliğe sebep olduğunu destekleyen çeşitli araştırmalar bulunmaktadır (Ali ve Flinn, 1989; Abdulai ve Huffman, 1998; Aktaş ve ark., 2011; Tipi ve ark., 2009). Araştırma kapsamında yer alan ve yüksekokul ve üzeri eğitim seviyesine sahip, tarım dışı çalışma ve tarım dışı gelire sahip olan işletme yöneticilerinin sayısı azımsanmayacak ölçüdedir. Nitekim incelenen işletmelerde, yüksekokul ve üzeri eğitime sahip, tarım dışı çalışan üreticilerin oranı yaklaşık %28.57 olarak hesaplanmıştır. Diğer taraftan yüksekokul ve üzeri eğitim seviyesinde olan tüm üreticilerin tarım dışı gelire sahip oldukları belirlenmiştir. Bu doğrultuda ortaya çıkan bu sonucun başlıca nedenleri olarak, işletme yöneticilerinin

gül tarımından elde edecekleri gelire önemli derecede bağımlı olmamaları, gül tarımına yeterli zamanı ayıramamaları ve çalışma durumuna bağlı olarak gül bahçelerine uzak bir konumda ikamet etmeleri gösterilebilmektedir.

Üretim etkinsizliğinin açıklanmasında, işletmelerin sahip olduğu gül bahçesine ilişkin bazı özellikler modele dahil edilmiştir. İncelenen işletmelerin yağ gülü arazilerinin ortalama olarak 1.66 parçadan oluştuğu belirlenmiş olup ortalama üzerinde parsele sahip olan işletmelerin üretim etkinsizliğinin ortalamanın altında parsel sayısına sahip olan işletmelere göre daha fazla olduğu belirlenmiştir. Ancak ilgili değişken istatistiksel olarak anlamlı bir katsayıya sahip değildir. Diğer taraftan, incelenen işletmelerin üretim verimi, ortalama ve üzerinde parsele sahip olan işletmelerde 415.30 kg, ortalamanın altında olan işletmelerde ise 481.41 kg olarak hesaplanmıştır. Bu yönüyle elde edilen sonuç, işletmelerin parsel sayısı arttıkça üretim etkinsizliğinin artacağı yönündeki ilgili değişkenin işareti ile tutarlılık göstermektedir.

Gül bitkisi, ekonomik çağına 4-6 yaşlarında ulaşmakta ve on yaşından sonra ise yaşlanarak verimden düşmektedir (Baydar, 2015). Model tahmin sonucuna göre, incelenen işletmelerdeki ortalama beş yaşının altında ve on yaşının üzerindeki yağ gülü ağaçlarının, ortalama beş ve on yaşları arasındaki ağaçlara nazaran daha fazla üretim etkinsizliğine neden olduğu tespit edilmiştir. Diğer bir ifadeyle, gül bahçelerinde, ağaç yaşının ekonomik verim çağının altında ve üzerinde olması, üretim etkinsizliğini artırmaktadır. Elde edilen sonuç beklentiyle uyumludur.

Gül tarımında sulama imkanı, verimi önemli ölçüde olumlu etkilemektedir (BAKA, 2020). Modele kukla değişken olarak dahil edilen, gül bahçelerinde sulu tarım yapma durumu ise negatif katsayısı ile beklentiyle uyumlu olarak üretim etkinsizliğini azalttığı belirlenmiştir. Başka bir deyişle, gül tarımında sulama yapılan arazilerin sulama yapılmayan arazilere göre daha etkin olduğu sonucuna ulaşılmıştır.

İşletmelerde yayım faaliyetlerine katılım durumunun, işletmelerin üretim etkinsizliği üzerindeki etkisi modelde araştırılmıştır. Model tahmin sonuçlarına göre, yayım faaliyeti kukla değişkeni ile üretim etkinsizliği arasında negatif bir ilişkinin bulunduğu tespit edilmiştir. Bu sonuca göre, beklentiyle uyumlu olarak, yayım faaliyetlerine katılım sağlayan işletmelerin katılım sağlamayanlara nazaran üretim etkinliğinin daha fazla olduğu tespit edilmiştir. Başka bir ifadeyle, yayım faaliyetlerine katılımın üretim etkinsizliğini azaltıcı etkisi bulunmakla birlikte literatürdeki çeşitli araştırmalarda benzer sonuçlara ulaşılmıştır (Ahmad ve ark., 2002; Ali ve ark., 2019; Bozoğlu ve Ceyhan, 2007; Mukete ve ark., 2016; Hayran, 2019; Ngango ve Kim, 2019).

İşletmelerin üretim deseninin etkinsizlik üzerindeki etkisinin belirlenmesi amacıyla, modele işletmede yağ gülü dışında ürün üretilip üretilmediğine ilişkin kukla değişken dahil edilmiştir. Elde edilen sonuçlara göre, yağ gülü dışında başka bitkisel ürün üreten işletmelerin sadece yağ gülü üreten işletmelere nazaran daha etkinsiz oldukları saptanmıştır. Literatürdeki çeşitli araştırmalarda, birden fazla bitkisel ürün üreten işletmelerin tek ürüne odaklanan işletmelere göre daha etkinsiz olduğuna ilişkin benzer sonuçlar elde edilmiştir (Abdulai ve Huffman, 1998; Lachaal ve ark., 2005).

Görüşülen işletmelerde, Türkiye'deki yağ gülü ihracatında öncü ve önemli bir konuma sahip olan GÜLBİRLİK'e üyelik durumunun üretim etkinliği üzerine etkisi de modele dahil edilmiştir. Analiz sonuçlarına göre, GÜLBİRLİK'e üye olan işletmelerin üye olmayanlara nazaran daha etkinsiz oldukları ve değişkene ait katsayının istatistiksel olarak anlamsız olduğu tespit edilmiştir. Beklentiyle uyumlu olmayan bu sonucun ortaya çıkmasındaki başlıca nedenler olarak, kooperatifin araştırma kapsamındaki bazı bölgelerde herhangi bir faaliyet göstermemesi, kota uygulamaları ve faaliyetlerini büyük ölçüde ürün pazarlaması ile sınırlandırması belirtilebilir. Diğer taraftan incelenen işletmelerde, kooperatife üye olanların dekara üretim verimi 430.97 kg iken, üye olmayanların ise 463.70 kg olarak hesaplanmıştır. Bu sonuçlar model bulgusu ile desteklense de daha önce belirtildiği üzere bu durumun ortaya çıkmasında, işletmelerin kooperatife üyeliği dışındaki uygulamaları ve işletmelerin yönetsel ve yapısal durumlarından da kaynaklanabilir. Nitekim yapılan saha çalışmasında, kooperatife üye olan üreticilerin büyük bir bölümünün aileden kalan üyeliklerinin devam ettiği ve üyelik durumuna bakılmaksızın üreticiler, ortalama olarak, toplam rekoltesinin yalnızca %9.12'lik bir bölümünü kooperatifçe pazarladığı anlaşılmıştır. Tüm bu bulgular değerlendirildiğinde, işletmelerin GÜLBİRLİK'e olan üyeliklerinin etkinlik üzerine etkisinin ürünün kalitesi, fiyatları, gül bahçelerinin yaşı gibi faktörlerin de dikkate alınarak daha kapsamlı araştırılması önem arz etmektedir.

İşletmelerdeki etkinsizlik nedenlerinin belirlenmesinde yağ gülü bahçelerinin bulunduğu coğrafi konum da araştırılmıştır. Bu amaçla, yağ gülü bahçelerinin rakım seviyesini açıklayan kukla değişken modele dahil edilmiştir. Isparta ilinde yağ gülü arazilerinin rakımı 800 ve 1600 metre arasında değişmektedir (BAKA, 2020). Araştırma bulgularına göre, incelenen işletmelerin %31.26'sı faaliyetlerini 1200 metre ve üzeri rakımda gerçekleştirmektedir. Modelde, rakım seviyesi, 1200 metre ve üzerinde bir konumda olan yağ gülü bahçelerinin diğer konumdaki bahçelere nazaran daha etkinsiz olduğu sonucuna ulaşılmıştır. Bu durum, yüksek rakım seviyesindeki bahçelerdeki olumsuz iklim koşulları ile açıklanabilmektedir. Nitekim 1200 metre ve üzerindeki rakım seviyesinde konumlanmış işletmelerin dekara üretim verimi 383.86 kg olarak hesaplanırken 1200 metrenin altındaki işletmelerde 484.37 kg olarak hesaplanmıştır.

Etkinsizlik modelinde, işletmelerin finansman olanaklarını irdelemek amacıyla ilgili dönemde kredi kullanımının yapılıp yapılmadığına ilişkin kukla değişken analize dahil edilmiştir. Analizden elde edilen sonuçlara göre, kredi kullanımının üretim etkinsizliği azalttığı tespit edilmiştir. Diğer bir ifadeyle, kredi kullanan işletmelerin diğerlerine nazaran daha etkin olduğu sonucuna ulaşılmıştır. Elde edilen sonucun literatürde tarımsal kredi kullanımının üretim etkinliği üzerine etkisinin araştırıldığı birçok çalışma ile tutarlılık gösterdiği belirlenmiştir (Abdulai ve Huffman, 1998; Kebede, 2001; Ahmad ve ark., 2002; Bozoğlu ve Ceyhan, 2007; Mukete ve ark., 2016; Hayran, 2019; Endalew ve ark. 2022).

4. Sonuç

Dünya kozmetik, parfümeri ve ilaç sanayi için temel bir girdi niteliğinde olan yağ gülünün bu sanayi dalları arasındaki kritik konumuna rağmen, dünyada yetiştiriciliğinin yapıldığı alanlar oldukça sınırlıdır. Keza dünyada, yağ gülü üretiminin yaklaşık %90'ı Türkiye ve Bulgaristan tarafından gerçekleştirilmektedir. Dünya yağ gülü arazilerinin yaklaşık %45'ine ve yıllık ortalama 20 bin tonluk üretime sahip olan Türkiye, dünya yağ gülü üretiminin %55'ini gerçekleştiren lider ülke konumundadır. Türkiye'nin dünya yağ gülü üretimi ile ihracatındaki avantajlı konumunu devam ettirmesi ve etkinsizliğini artırması uygulayacağı politikalara bağlıdır. Türkiye'deki yağ gülü üretiminin %80'inden fazlasının gerçekleştirildiği Isparta ilinde, yağ gülü yetiştiriciliğinin yapıldığı işletmelerin üretim etkinliğinin ve üretim etkinsizliğini etkileyen faktörlerin araştırılması amacıyla yapılan bu çalışmada, işletmelerdeki etkinsizlik kaynaklarının belirlenmesi ile sektöre ilişkin izlenecek politikaların saptanması amaçlanmıştır.

İşletmelerin etkinsizlik seviyelerinin belirlenmesi amacıyla oluşturulan Cobb-Douglas üretim sınırı modeli sonuçlarına göre, yağ gülü işletmelerinin üretim etkinsizliğine bağlı nedenlerden üretim sınırından sapmalar yaşadıkları belirlenmiştir. Ayrıca işgücü kullanım süresi, toplam materyal masrafı ve işletmenin sahip olduğu yağ gülü arazisinin işletmenin dekara üretim verimini olumlu etkilediği belirlenmiştir. Yağ gülü işletmelerinin üretim etkinsizliğinin nedenlerinin incelendiği etkinsizlik modeli sonuçlarına göre, işletme yöneticisinin yaşı, sulama, yayım faaliyetine katılım ve kredi kullanımının üretim etkinsizliğini azaltıcı, gül bahçesinin ekonomik verim çağı dışında olması, işletmede yağ gülü dışında başka bitkisel ürüne yer verilmesi ve yağ gülü arazisinin rakım seviyesinin etkinsizliği artırıcı faktörlerden olduğu belirlenmiştir.

Stokastik Cobb-Douglas üretim sınırı ve etkinsizliği modelinden elde edilen sonuçlar doğrultusunda, faaliyetlerin daha çok emek yoğun olarak gerçekleştirildiği gül tarımında gerek bakım gerekse hasat işlemlerinde yeterli ve nitelikli sayıda işçinin bulunması üretim verimini artırabileceği belirlenmiştir. Bunun yanı sıra, bakım işlemlerinde gerek çiçek veriminin artırılması gerekse hastalık ve zararlılara bağlı olarak yaşanacak üretim kayıplarının önüne geçilmesi açısından gübre, ilaç ve sulama masraflarında kaydedilecek artışlar üretim verimine olumlu katkılar sağlayabilecektir. Bu bağlamda, sektörü düzenleyen kurum ve kuruluşların ilaç ve gübre gibi materyallere ilişkin vereceği destek ve eğitimler önem arz etmektedir. Diğer taraftan, yoğun tarım tekniklerinin kullanılabilmesini mümkün kılan büyük ölçekli bahçelerin tesisine yönelik destekleyici politikaların uygulanması verim üzerine olumlu etkiler sağlayabilecektir. Bunların yanında, yayım faaliyetlerinin sayısı ve özellikle hedef kitlenin genç üreticilere yönelik olarak çeşitliliğinin artırılması, işletmelerin parçalanmasını azaltıcı önlemler, bahçelerin yenilenmesini teşvik edici gençleştirme budaması desteği, tarım kredisine ulaşımın kolaylaştırılması ve bahçe tesisinde üretim deseninin iklim özelliklerinin göz önünde bulundurulmasına yönelik politikaların yağ gülü işletmelerinde üretim etkinliğinin artırılmasında etkili olabilecektir.

Araştırmadan elde edilen sonuçların işletmelerin etkinsizliğinin nedenleriyle ortaya koyması sebebiyle ve işletmelerin ekonomik etkinliğini artıracak politikaların belirlenmesi sayesinde, sektörde bulunan ilgili kişi ve

kuruluşlara önemli katkılarda bulunması beklenmektedir. İşletmelerin etkinsizliğini azaltacak politikaların uygulanması, işletmelerin maliyet ve kaynak kullanımına olumlu etki sağlayacak, sektörde bulunan işletmelerin gelir ve karlılığında artış sağlanabilecektir. Ayrıca bu sayede, Türkiye yağ gülü sektörünün uluslararası pazardaki rekabet gücü ve dolayısıyla gülden elde edilen ürünlerden sağlanan ihracat geliri ve döviz girdisinin artması da mümkün olabilecektir.

Teşekkür

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Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

Yazarlık Katkı Beyanı

Planlama: Bıtrak, O.O., Hatırlı, S.A.; Materyal ve Metot: Bıtrak, O.O., Hatırlı, S.A.; Veri toplama ve İşleme: Bıtrak, O.O.; İstatistiki Analiz: Bıtrak, O.O., Hatırlı, S.A.; Literatür Tarama: Bıtrak, O.O.; Makale Yazımı, İnceleme ve Düzenleme: Bıtrak, O.O., Hatırlı, S.A.

Kaynakça

Abdulai, A. and Huffman, W. E. (1998). An Examination of Profit Inefficiency of Rice Farmers in Northern Ghana. Staff Paper 296, Department of Economics, Iowa State University, U.S.A.

Ahmad, M., Chaudhry, G. M. and Iqbal, M. (2002). Wheat productivity, efficiency, and sustainability: A stochastic production frontier analysis. *The Pakistan Development Review,* 41(4): 643-663.

Aigner, D. J., Lovell, C. A. K. and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics,* 6: 21-37.

Aktaş, A. R., Öztürk, E. ve Hatırlı, S. A. (2011). Türkiye fındık tarımında kar etkinsizliğinin analizi. *Tarım Bilimleri Dergisi,* 17: 230-240.

Alemdar, T. and Işık, H. (2008). Technical efficiency of peanut growing farms in Turkey. *Acta Scientiarum Polonorum, Oeconomia,* 7(4): 5-15.

Ali, I., Xue-xi, H., Khan, I., Ali, H., Baz, K. and Khan, S. U. (2019). Technical efficiency of hybrid maize growers: A stochastic frontier model approach. *Journal of Integrative Agriculture,* 18(10): 2408-2421.

Ali, M. and Flinn, J. C. (1989). Profit efficiency among basmati rice producers in Pakistan Punjab. *American Journal of Agricultural Economics,* 71(2): 303-310.

Aslancan Ateş, B ve Toprak, A. (2018). Gül ürünleri üreten işletmelerde birleşik mamul maliyetlerinin belirlenmesi. *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi,* 23(1): 319-331.

Atay, O. A., Ekinci, K. ve Umurcu, Y. (2016). Yağ Gülü damıtma atıkları, kızılçam kabuğu ve linyit kömür tozundan elde edilen peletlerin baca gazı emisyonlarının belirlenmesi. *Tekirdağ Ziraat Fakültesi Dergisi,* 13(2): 1-9.

BAKA (2020). Yağ Gülü Tarımı ve Endüstrisi Fizibilite Raporu. T.C. Sanayi ve Teknoloji Bakanlığı, Batı Akdeniz Kalkınma Ajansı.

Banker, R. D. and Morey, R. C. (1986). Efficiency analysis for exogenously fixed inputs and outputs. *Operations Research,* 34(4): 513-521.

Battese, G. E. and Broca, S. S. (1997). Functional forms of stochastic frontier production functions and models for technical inefficiency effects: A comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis,* 8: 395-414.

Battese, G. E. and Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics,* 20: 325-332.

Battese, G. E. and Corra, G. S. (1977). Estimation of a production frontier model: With application to the Pastoral Zone of Eastern Australia. *Australian Journal of Agricultural Economics,* 21(3): 169-179.

Bauer, P. W. (1990). Recent developments in the econometric estimation of frontiers. *Journal of Econometrics,* 46(1-2): 39-56.

Baum, C. F. (2008). Stata tip 63: Modeling proportions. *The Stata Journal,* 8(2), 299-303.

Baydar H. (2015). Yağ gülü tarımı ve endüstrisi. *Harmantime,* 29: 1-11.

Baydar, H., Kazaz, S., Erbaş, S. ve Örücü, Ö. K. (2008). Soğukta muhafaza ve kurutmanın yağ gülü çiçeklerinin uçucu yağ içeriği ve bileşimine etkileri. *Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi,* 3(1): 42-48.

Bektaşoğlu, S. (2006). Uçucu Yağlar. T.C. Başbakanlık Dış Ticaret Müsteşarlığı İhracatı Geliştirme Etüd Merkezi (İGEME), Ankara.

Binam, J. N., Tonye, J. and Wandji, N. (2005). Source of technical efficiency among small holder maize and peanut farmers in the Slash and burn agriculture zone of Cameroon. *Journal of Economic Cooperation,* 26: 193-210.

Binici, T., Zulauf, C. R., Kaçıra, O. O. ve Karlı, B. (2006). Assessing the efficiency of cotton production on the Harran Plain, Turkey. *Outlook on Agriculture,* 35(3), 227-232.

Bozoğlu, M. and Ceyhan, V. (2007). Measuring the technical efficiency and exploring the inefficiency determinants of vegetable farms in Samsun province, Turkey. *Agricultural Systems,* 94(3): 649-656.

Chalova, I. C., Manolov, I. G. and Manolova, V. S. (2017). Challenges for commercial organic production of oil-bearing rose in Bulgaria, *Biological Agriculture & Horticulture,* 33(3): 183-194.

Coelli, T. J., Estache, A., Perelman, S. and Trujillo, L. (2003). A Primer on Efficiency Measurement for Utilities and Transport Regulators. World Bank Publications, Vol. 953, Washington D.C., U.S.A.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. and Battese, G. E. (2005). An Introduction to Efficiency and Productivity Analysis. Second Edition, Springer Science & Business Media, New York, U.S.A.

Cooper, W. W., Seiford, L. M. and Zhu, J. (2011). Handbook on Data Envelopment Analysis. International Series in Operations Research and Management Sciences, New York: Springer-Verlag, U.S.A.

Çavmak, Ş. ve Çavmak, D. (2017). Sağlık hizmetlerinde etkinlik kavramı. *Sağlık Yönetimi Dergisi,* 1(1): 21-34.

T.C. Tarım ve Orman Bakanlığı (2021). Isparta İlinde Yağ Gülü Tarımı Yapılan Arazilerin Dağılımı. Çiftçi Kayıt Sistemi (ÇKS).

Dağlı, İ. (2019). Türkiye'de yağ gülünün son on yıldaki ekonomik gelişimi ve sektöre ilişkin mevcut sorunların analizi. *Isparta Uygulamalı Bilimler Üniversitesi Uygulamalı Bilimler ve Güzel Sanatlar Dergisi (SOSGÜZ),* 1(1): 10-20.

Demircan, V. (2005). Isparta ilinde gülün üretim girdileri, maliyeti ve karlılığının belirlenmesi. *Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi,* 9(3): 64-71.

Dlamini, S. I., Masuku, M. B. ve Rugambisa, J. I. (2012). Technical efficiency of maize production in Swaziland: A stochastic frontier approach. *African Journal of Agricultural Research,* 7(42): 5628-5636.

Dünder, E., Gümüştekin, S. and Cengiz, M. A. (2015). Evaluation of determinants of employment efficiency using stochastic frontier analysis and beta regression. *Journal Mathematics Computer Science,* 5(6): 848-856.

Endalew, B., Anteneh, A. and Tasie, K. (2022). Technical efficiency of teff production among smallholder farmers: Beta regression approach. *The European Journal of Development Research,* 34(2): 1076-1096.

Endalew, B., Aynalem, M., Anteneh, A. and Mossie, H. (2023). Sources of wheat production technical inefficiency among smallholder farmers in Northwestern Ethiopia: Beta regression approach. *Cogent Economics & Finance,* 11(1): 2208895.

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society, Series A (General),* 120(3): 253-290.

Ferrari, S. and Cribari-Neto, F. (2004). Beta regression for modelling rates and proportions. *Journal of Applied Statistics,* 31(7): 799-815.

Gbigbi, T. M. (2021). Technical efficiency and profitability of cassava production in Delta State: A stochastic frontier production function analysis. *Journal of Tekirdag Agricultural Faculty,* 18(1): 21-31.

Georgiev, P. V. (2016). *What can be learned about the development of the Bulgarian rose oil industry by employing the cluster approach?.* (MSc. Thesis) Lund University School of Economics and Management, Lund, Sweden.

Giray, F. H. and Örmerci Kart, M. C. (2012). Economics of *Rosa damascena* in Isparta, Turkey. *Bulgarian Journal of Agricultural Science,* 18(5): 658-667.

Gökdoğan, O. ve Demir, F. (2011). Isparta yöresindeki gül işletmelerinin tarımsal yapısı. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi,* 8(2): 29-34.

Gökdoğan, O. (2013). Isparta yöresinde yağ gülü yetiştiriciliğinin Türkiye ekonomisindeki yeri. *Süleyman Demirel Üniversitesi Sosyal Bilimler Enstitüsü Dergisi,* Gül Özel Sayısı: 51-58.

Gözener, B. (2013). *TR 83 Bölgesinde sığır besiciliğine yer veren işletmelerin ekonomik analizi ve teknik etkinlik.* (Doktora Tezi) Gaziosmanpaşa Üniversitesi Fen Bilimleri Enstitüsü Tarım Ekonomisi Anabilim Dalı, Tokat, Türkiye.

Hatırlı, S. A., Öztürk, E. ve Aktaş, A. R. (2008). *Türkiye fındık tarımında kar etkinliğinin ve dünya piyasalarında pazar gücünün araştırılması.* Tübitak-Tovag, Proje (104O542), Proje Sonuç Raporu (Erişim Linki: https://search.trdizin.gov.tr/tr/yayin/detay/608766/turkiye-findik-tariminda-kar-etkinliginin-ve-dunya-piyasalarinda-pazar-gucunun-arastirilmasi).

Hayran, S. (2019). *Plastik serada sivri biber üretiminde etkinlik analizi: Mersin ili örneği.* (Doktora Tezi) Çukurova Üniversitesi Fen Bilimleri Enstitüsü Tarım Ekonomisi Anabilim Dalı, Adana, Türkiye.

Hunger, M., Baumert, J. and Holle, R. (2011). Analysis of SF-6D index data: is beta regression appropriate?. *Value in Health,* 14(5): 759-767.

Kalirajan, K. P. and Shand, R. T. (1988). Firm and product-specific technical efficiencies in a multiproduct cycle system. *The Journal of Development Studies,* 25(1): 83-96.

Kebede, T. A. (2001). *Farm household technical efficiency: A stochastic frontier analysis A study of rice producers in Mardi Watershed in the Western Development Region of Nepal.* (MSc. Thesis) Department of Economics and Social Sciences Agricultural University of Norway.

Kılıç, O., Binici, T., and Zulauf, C. R. (2009). Assessing the efficiency of hazelnut production. *African Journal of Agricultural Research*, 4(8): 695-700.

Koç, T. (2019). Türkiye'de boşanma oranlarını etkileyen faktörlerin beta regresyon modeli ile belirlenmesi. *Avrasya Uluslararası Araştırmalar Dergisi,* 7(16): 1111-1117.

Kopp, R. J. (1981). The measurement of productive efficiency: A reconsideration. *The Quarterly Journal of Economics,* 96(3): 477-503.

Kumbhakar, S. C. and Lovell, C. A. K. (2003). Stochastic Frontier Analysis. Cambridge University Press, Cambridge, England.

Lachaal, L., Karray, B., Dhehibi, B. and Chebil, A. (2005). Technical efficiency measures and its determinants for olive producing farms in Tunisia: A stochastic frontier analysis. *African Development Review,* 17(3): 580-591.

Li, T. and Rosenman, R. (2001). Cost inefficiency in Washington hospitals: A stochastic frontier approach using panel data. *Health Care Management Science,* 4: 73-81.

Meeusen, W. and van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review,* 18(2): 435-444.

Mukete, N., Zhu, J., Beckline, M., Gilbert, T., Jude, K. and Dominic, A. (2016). Analysis of the technical efficiency of smallholder cocoa farmers in South West Cameroon. *American Journal of Rural Development,* 4(6): 129-133.

MZH (2023). Operational Analysis of Basic Agricultural Crops. Ministry of Agriculture, Food and Forestry (MZH), Sofia, Bulgaria. (In Bulgarian)

Ngango, J. and Kim, S. G. (2019). Assessment of technical efficiency and its potential determinants among small-scale coffee farmers in Rwanda. *Agriculture,* 9(7): 161.

NSI (2023). Foreign Trade of Essential Oils by Harmonized System National Statistical Institute of Bulgaria.

Örmeci Kart, M. Ç., İkiz, M. ve Demircan, V. (2012). Türkiye'de yağ gülü (*Rosa damascena*) üretimi ve ticaretinin gelişimi. *Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi,* 7(1): 124-134.

Özcan, K. ve Dönmez, İ. E. (2018). Isparta Güneykent Bölgesinde yetişen gül odununun (*Rosa damascena* Mill.) kimyasal bileşimi ve lif özellikleri. *Türkiye Ormancılık Dergisi,* 19(4): 442-446.

Öztürk, P., Karamürsel, D., Emre, M. ve Kaçal, E. (2008). Türkiye'de Yağ Gülü (*Rosa damascena* Mill.) Yetiştiriciliği ve Yakın Gelecekte Beklenen Gelişmeler. *VIII. Ulusal Tarım Ekonomisi Kongresi Gıda İşletmeciliği,* 25-27 Haziran*,* Bursa, Türkiye.

Rahman, K. M. M., Mia, M. I. A. and Bhuiyan, M. K. J. (2012). A Stochastic frontier approach to model technical efficiency of rice farmers in Bangladesh: An empirical analysis. *The Agriculturists,* 10(2): 9-19.

Ruggiero, J. (1999). Efficiency estimation and error decomposition in the stochastic frontier model: A Monte Carlo analysis. *European Journal of Operational Research,* 115(3): 555-563.

Sarafidis, V. (2002). An assessment of comparative efficiency measurement techniques. *Europe Economics,* 16: 1-21.

Schmidt, P. and Lovell, C. A. K. (1979). Estimating technical and allocative inefficiency relative to stochastic production and cost. *Journal of Econometrics,* 9: 343-366.

Singh, K. and Singh, V. (2001). Economics of cultivation and distillation of damask rose: A case study in Palampur (Himachal Pradesh). *Indian Journal of Agricultural Economics,* 56(4): 696-707.

T.C. Ticaret Bakanlığı (2020). 2019 Yılı Gül Çiçeği Raporu. Esnaf, Sanatkarlar ve Kooperatifçilik Genel Müdürlüğü, Nisan 2020.

Timor, A. N. (2011). World production oil rose and rose oil. *e-Journal of New World Sciences Academy Nature Sciences,* 6(2): 93-110.

Tipi, T., Yıldız, N., Nargeleçekenler, M. and Çetin, B. (2009). Measuring the technical efficiency and determinants of efficiency of rice (Oryza Sativa) farms in Marmara Region, Turkey. *New Zealand Journal of Crop and Horticultural Science,* 37(2): 121-129.

TÜİK (2023a). Türkiye İstatistik Kurumu Bitkisel Üretim İstatistikleri. https://data.tuik.gov.tr/Kategori/GetKategori?p=Tarim-111 (Erişim Tarihi: 15.11.2023).

TÜİK (2023b). Türkiye İstatistik Kurumu Dış Ticaret İstatistikleri HS12(GTIP) Sınıflamasına Göre Dış Ticaret (HS12(GTIP)-Ülke). https://biruni.tuik.gov.tr/disticaretapp/disticaret.zul?param1=25&param2=4&sitcrev=0&isicrev=0&sayac=5802 (Erişim Tarihi: 26.12.2023).

Wilson, P., Hadley, D., Ramsden, S. and Kaltsas, I. (1998). Measuring and explaining technical efficiency in UK potato production. *Journal of Agricultural Economics,* 49(3): 294-305.

Yamane, T. (1967). Elementary Sampling Theory. Prentice-Hall, Inc, New Jersey, Englewood Cliffs, U.S.A.

Yükçü, S. ve Atağan, G. (2009). Etkinlik, etkililik ve verimlilik kavramlarının yarattığı karışıklık. *Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi,* 23(4): 44-59.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Investigation of the Effects of Rooting Medium and IBA Concentration on Rooting and Shoot Development of Bougainvillea (*Bougainvillea* spp.) Cuttings

Begonvil (*Bougainvillea* spp.) Çeliklerinin Köklenme ve Sürgün Gelişimi Üzerine, Köklendirme Ortamı ve IBA Konsantrasyonunun Etkilerinin Araştırılması

Ary Taher RASUL[1], Bekir Erol AK[2], Yousif Ali ABDULRAHMAN[3], İbrahim Halil HATİPOĞLU[4]

Abstract

In this study, the effect of different rooting mediums (peat moss, peat + sand, peat + loam) and IBA (indole-3-butyric acid) concentration was investigated on hardwood cuttings taken from *Bougainvillea glabra*, *Bougainvillea spectabilis*, and *Bougainvillea* x *buttiana* species. The cuttings were treated with 0, 1000, 2000 and 3000 mg/l IBA. Statistical evaluation was performed according to a randomized block experimental design with three factors and three repetitions. The results showed that *Bougainvillea* x *buttiana* cuttings had the highest number of roots, root fresh weight, longest shoot length, and shoot fresh weight. Cuttings grown in 100% peat medium had the highest rooting percentage, root number, root dry weight, leaf number, and shoot fresh weight. Regarding IBA concentrations, the cuttings treated with 3000 ppm IBA had the highest number of roots, root length, and root fresh weight. Furthermore, in all of the *Bougainvillea* species, the highest rooting percentage and leaf number were observed in cuttings treated with 2000 ppm IBA. Notably, *Bougainvillea* x *buttiana* cuttings treated with 1000 ppm IBA dose and planted in peat medium provided the longest shoot length, highest shoot fresh weight, and shoot dry weight. In conclusion, the findings show that the growing medium has a statistically significant effect on the rooting and root quality of cuttings and that it would be useful to investigate various rooting hormones, dasages and rooting media to increase rooting and shoot development. Considering growing medium plays a crucial role in plant growth, it can be stated that further improvements in rooting and growth can be realized via utilizing the enhanced physical and chemical properties of peat-based mixtures.

Keywords: *Bougainvillea*, IBA, Ornamental plants, Plant propagation, Rooting medium

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Öz

Bu çalışmada, *Bougainvillea glabra*, *Bougainvillea spectabilis* ve *Bougainvillea* x *buttiana* türlerine ait sert odun çelikleri için farklı köklendirme ortamlarının (turba yosunu, turba yosunu + tın (1:1), turba + kum (1:1)) ve IBA (indol-3-bütirik asit) konsantrasyonunun etkisi araştırılmıştır. Çeliklere 0 (Kontrol), 1000, 2000 ve 3000 mg/l seviyelerinde IBA uygulanmıştır. İstatistiksel değerlendirme, tesadüf bloklarında üç faktörlü ve üç tekrarlı, deney olarak tasarlanmıştır. Sonuçlar, *Bougainvillea* x *buttiana* çeliklerinin en fazla kök sayısına, kök taze ağırlığına, en uzun sürgün uzunluğuna ve sürgün taze ağırlığına sahip olduğunu göstermiştir. Yalnızca turba yosunu ortamında yetiştirilen çeliklerde en yüksek köklenme yüzdesine, kök sayısına, kök kuru ağırlığına, yaprak sayısına ve sürgün taze ağırlığına ulaşıldığı belirlenmiştir. IBA konsantrasyonlarının etkisine bakıldığında, 3000 ppm IBA uygulanan çeliklerin en yüksek kök sayısına, kök uzunluğuna ve kök taze ağırlığına sahip olduğu görülmüştür. Ayrıca Begonvil türlerinin tamamında en yüksek köklenme yüzdesi ve yaprak sayısının 2000 ppm IBA uygulanan çeliklerden sağlandığı görülmüştür. Özellikle, 1000 ppm IBA dozu ile muamele edilen ve yalnızca turba yosunu bulunan ortamına dikilen *Bougainvillea* x *buttiana* çeliklerinden en uzun sürgün uzunluğu, en yüksek sürgün taze ağırlığı ve sürgün kuru ağırlığı sağladığı belirlenmiştir. Sonuç olarak, bulguların genel değerlendirmesi, yetiştirme ortamının çeliklerde köklenme yeteneği ve kök kalitesi üzerinde istatistiksel olarak önemli bir etkiye sahip olduğunu ve köklenme ve sürgün gelişimini arttırmak için çeşitli köklendirme hormonlarının, dozlarının ve köklendirme ortamlarının araştırılmasının faydalı olacağını göstermektedir. Yetiştirme ortamının bitki büyümesinde çok önemli bir rol oynadığı göz önüne alındığında, turba yosunu bazlı karışımların gelişmiş fiziksel ve kimyasal özelliklerden yararlanılarak köklenme ve büyümede daha fazla olumlu sonuç alınabileceği söylenebilir.

Anahtar Kelimeler: Begonvil, IBA, Süs bitkileri, Bitki yetiştiriciliği, Köklendirme ortamı

1. Introduction

Nyctaginaceae family comprises 300-400 species of trees, shrubs, and herbaceous plants grouped into approximately 30 genera (Mabberley, 1997). Among them, the *Bougainvillea* genus includes 14 species. *Bougainvillea* is a popular tropical and subtropical ornamental plant commonly grown in containers in cooler climates during summer, and it can be overwintered or replanted annually (Gilman, 1999). The name "*Bougainvillea*" is derived from Louis Antoine de Bougainville, a French sailor and military leader who first observed the Brazilian plant in 1768 (Kobayashi et al., 2007). This climbing plant with thorns grows chaotically and can reach heights of up to nine meters. It is frequently used as a hedge, barrier, or slope cover, effectively covering large and challenging-to-maintain areas, preventing weed growth (Eed et al., 2015).

Bougainvillea is a versatile ornamental plant, suitable for hanging baskets, containers, and bonsai (Kobayashi et al., 2007; Rasul et al., 2021). Its popularity has grown due to urbanization, landscape horticulture, pollution and drought resistance, easy maintenance compared to other plants, and numerous applications (Singh, 2017). Additionally, it has gained attention for planting in heavy industrial areas and traffic islands to mitigate pollutants and greenhouse gases (Chauhan et al., 2016).

The *Bougainvillea* plant is utilized as a traditional treatment for digestive disorders in Mandsaur, India. *Bougainvillea glabra* has shown antidiarrheal activity linked to its antimicrobial properties. The genus *Bougainvillea* is known for its presence of anti-diabetic compounds. For optimal growth, *Bougainvillea* plants require full sun, high light density, and well-drained, acidic soil with specific temperature ranges. Reproduction is mainly achieved through stem cuttings.

The onset of urbanization, the emergence of environmental problems, and the longing of people who are away from nature for green areas have increased the importance of ornamental plants and forest trees (Gencer Gokce et al., 2022). There are some problems in plant propagation methods in the ornamental plant breeding sector, and it becomes extremely important to determine the appropriate propagation techniques of plants (Ak et al., 2022). The choice of a suitable propagation medium is crucial for successful rooting of cuttings. It provides an ideal environment for root development and nutrient uptake (Laubscher and Ndakidemi, 2008; Ak et al., 2021). A proper growing medium allows plants to extract water and nutrients effectively from the soil, contributing to healthy root systems (Landis et al., 1990). The quality of the rooting medium significantly influences rooting percentage and root quality (Kumar et al., 2015). It's essential to ensure adequate moisture and aeration in the medium for successful cutting establishment. While various propagation media exist, not all are suitable for all plant varieties and environmental conditions. Factors like plant type, season, use of growth-promoting compounds, and interactions between these elements affect the effectiveness of the propagation process (Dirr and Heuser, 1987; Ak et al., 2021). The most effective propagation method varies based on the plant type, cutting type, season, and the propagation facility used. Techniques such as misting fog and polyethylene tunnels are sometimes employed to control environmental conditions like air, temperature, relative humidity, and light during propagation (Beyl and Trigiano, 2016).

IBA (Indole-3-butyric acid) is a type of auxin that plays a crucial role in promoting the growth of adventitious roots in plants. Auxin is essential for plant propagation as it regulates various developmental processes, including stem elongation, early root formation, callus production, enzyme induction, and flowering, fruit, and leaf senescence. The rooting potential of certain plant species varies significantly based on the season when stem cuttings are taken, rather than a specific calendar date (Hartmann et al., 1997). Additionally, factors like the age of the mother tree and the use of plant growth regulators influence the rooting process of cuttings (Altoé et al., 2011; De Oliveira et al., 2015). It was determined that only the use of IBA during the rooting stages increased the number of roots (Öcalan et al., 2023).

Bougainvilleas are generally propagated by cuttings, but rooting failure is observed when propagated by hardwood cuttings. Auxin must be used to promote rooting (Akyiğit and Baktır, 1989; Ibironke, 2019). Rooting percentages of cuttings in Bougainvillea plants are low. This may cause economic losses (De Klerk et al., 1999). In this context, the hormones IBA, IAA and NAA are recommended, but due to the availability, accessibility and cost of supply of auxins, the study focused on determining the appropriate concentration of a single hormone.

The main objectives of this study are to compare the rooting ability of hardwood cuttings of three different *Bougainvillea* species (*Bougainvillea glabra*, *Bougainvillea spectabilis*, and *Bougainvillea* x *buttiana*). It was

aimed to determine the suitable environment and appropriate IBA concentration for hardwood cuttings of three different Bougainvillea plant species.

2. Materials and Methods

2.1. Material

The study was carried out in the plastic house of the Horticulture Department at the Directorate General of Agriculture in Duhok Governorate, located at 36° 51′42" N, 42° 56′13" E, and at an altitude of 522 m. The research was conducted from 15th February to 30th May 2021.

In the study, 3 different *Bougainvillea* species were used as plant material. The characteristics of these plants are explained in the following paragraphs.

Bougainvillea glabra is an evergreen climber with elliptical leaves that are green or variegated and have a glossy shine. The plant produces bracts in various sizes and shapes, usually triangular and mauve or purple, sometimes white. The bracts grow along the branches and at the branch tips, with blooms ranging in color from white to cream. The plant has short thorns with a curled point, and green-leaf types exhibit rapid growth with a spreading habit.

Bougainvillea spectabilis is distinguished by its sticky stems and leaves. The large, ovate leaves have hairs on the underside and rippled edges. The small flowers are cream-colored, while the bracts come in dark pink, red, or purple shades. The species exhibits an intense growth habit with vibrant bracts appearing both above and below the branches. Thorns on this plant can be large and curved.

Bougainvillea hybrids, specifically *B.* x *buttiana*, display dark pink or red bracts and short, straight thorns. The plant's open growth habit requires regular trimming to maintain a bushy appearance. These hybrids are known for blooming multiple times a year on average (Kobayashi et al., 2007).

The brand of peatmoss used is Greenterra®. The sand size used in this study is 0.2 - 0.5 mm (*Figure 1*).

Figure 1. Growing media used in the research

Table 1. Some physical and chemical properties of the propagation media.

Media	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	pH	EC (dS/m)	OM(%)	WHC(%)
Peat moss	-	-	-	6.47	0.74	74.70	70.00
Peat + Sand (1:1)	711.70	141.10	147.20	7.10	0.19	7.86	65.00
Peat + Loam (1:1)	500.50	303.30	191.70	7.15	0.265	11.35	52.00

OM: Organic matter,
WHC: Water Holding Capacity
The g/kg ratios in the table are determined according to dry weight.

In *Table 1*, various chemical and physical characteristics of samples were collected from three different growth mediums were presented. Texture analysis of media, including sand, silt, and clay content, was conducted using the

hydrometer method proposed by Bouyoucos (1962). pH and EC measurements were performed following the procedures outlined by Page et al. (1982). Organic matter content in the soil was assessed using soil analysis methods provided by Black et al. (1965).

2.2. Methods

In this study, the rooting response of three *Bougainvillea* species to different propagation media and varying IBA concentrations were investigated. Cuttings of the species were obtained in January from plants grown in the gardens of floriculture nurseries in the Department of Horticulture in Duhok province.

All cuttings that were cut were 20 cm and had 10 to 12 buds. These cuttings were taken from branches that were 2 years old. The cuttings were kept in a damp cloth in cold storage until February. The fresh weight is taken, then placed in a nylon bag inside a paper bag and dried in the oven for 48 hours at a temperature of 70 degrees Celsius the dry weight is taken. This process is carried out in the laboratories of the College of Agriculture at the University of Duhok. Irrigation is done according to soil dryness and use elecronic soil tester.

The cuttings from these species were treated with four different IBA concentrations (0, 1000, 2000, and 3000 mg l^{-1}). The cuttings were kept in the hormone for 10 seconds. All cuttings were at length 20 cm, and cut out a slant shape and put in 2/3 of the cuttings in the rooting media after it has been treated with rooting hormone. Subsequently, they were planted in black plastic pots of 28cm height×24cm dimensions, filled with three different media, that is, a peat moss and two peat moss-based mixtures. The peat moss-based mixtures were prepared using peat moss and sand in a ratio of 1:1 by volume and peat moss and loam in a ratio of 1:1 by volume.

Both the cuttings and the planting media were sterilized using Beltanol L 50% at a concentration of 1 ml l^{-1}.

In this experiment, a factorial Randomized Complete Block Design (RCBD) with three factors was employed, resulting in a total of (3 × 3 × 4) = 36 different treatments. Each treatment was replicated three times, and in each replication, there were eight cuttings per pot, resulting in a total of (3 × 3 × 4 × 3 × 8) = 864 cuttings for all species combined and 288 cuttings for each individual species.

At the end of the experimental period, the number of cuttings that had successfully developed roots was recorded, and these numbers were then converted into percentages for all the experiments.

After each experiment, the researchers recorded the number of visible roots formed on each cutting and measured the longest root length in centimeters from the base to the tip of the longest root using a ruler. The roots produced on the cuttings were then separated, placed in paper bags, and dried in an oven at 70°C for 48 hours. Once dried, the roots were weighed precisely using a balance. Moreover, the researchers counted the number of shoots that sprouted from the cuttings for each treatment and replication. The length of the shoots on the rooted cuttings was measured with a ruler and centimeter. Additionally, the number of leaves that developed on the cuttings was recorded for each treatment and replication.

The data from the experiments were analyzed using the SAS program (Anonymous, 2001), with means compared through Duncan's Multiple Range Test at a confidence level of less than 5%.

3. Results and Discussion

3.1. Rooting percentage (%)

The interaction between species and growing media affects significantly the rooting percentage of the cuttings. The highest rooting percentage (90.42%) was observed in the interaction of cuttings planted in peat moss medium, while the lowest percentage (66.67%) was found in peat moss + loam medium. Regarding IBA treatment, *B. glabra* cuttings treated with 1000 and 2000 mg L^{-1} IBA exhibited the highest rooting percentages of 85.00% and 84.72%, respectively. *B. spectabilis* cuttings with 0 mg L^{-1} IBA showed the lowest percentage of 61.11%. The interaction between growth media and IBA also played a significant role in rooting. The highest percentage (94.44%) observed in cuttings treated with 2000 mg L^{-1} IBA and planted in peat moss, while the lowest value (56.94%) was recorded in peat moss + loam medium.

Regarding the tree factor interactions between media, species and IBA dosages, the highest rooting percentage (100%) was observed in *B. glabra* cuttings planted in peat moss and treated with 2000 mg L^{-1} of IBA, indicating a successful rooting response. On the other hand, the lowest rooting percentage (50%) was recorded for untreated

cuttings of *B. spectabilis* planted in peat moss + loam medium, indicating a less favorable rooting outcome in this specific combination.

Table 2. Propagation media and IBA concentrations' effect on the rooting percentage of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				
		0ppm	1000ppm	2000ppm	3000ppm	Species x Media
B. glabra	Peat	87.50cd	92.50bc	100.00a	81.67d-f	90.42a
	Peat+Sand	79.17ef	87.50cd	58.33i	83.33de	77.08bc
	Peat+Loam	50.00j	75.00fg	95.83ab	75.00fg	73.96c
B. spectabilis	Peat	79.17ef	79.17ef	95.83ab	95.83ab	87.50a
	Peat+Sand	54.17ij	75.00ef	87.50cd	79.17ef	73.96c
	Peat+Loam	50.00j	87.50cd	66.67h	75.00fg	69.79d
B. x *buttiana*	Peat	79.07ef	66.67h	87.50cd	75.00fg	77.06bc
	Peat+Sand	83.33de	75.00fg	79.17ef	79.17ef	79.17b
	Peat+Loam	70.83gh	70.83gh	58.33i	66.67h	66.67e
	Peat+Sand	72.22f	79.17cd	75.00ef	80.56cd	
	Peat+Loam	56.94g	77.78de	73.61f	72.22f	
						Species means
Species × IBA Conc.	*B. glabra*	72.22 ef	85.00a	84.72a	80.00bc	80.49a
	B. spectabilis	61.11g	80.56bc	83.33ab	83.33ab	77.08b
	B. x buttiana	77.74cd	7083f	75.00de	73.61ef	74.30c
						Media means
Media × IBA Conc.	Peat	81.91bc	79.44cd	94.44a	84.17b	84.99a
	Peat+Sand	72.22f	79.17cd	75.00ef	80.56cd	76.74b
	Peat+Loam	56.94g	77.78de	73.61f	72.22f	70.14c
IBA conc. means		69.69c	78.80b	81.02a	78.98b	-

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

Table 3. Propagation media and IBA concentrations' effect on roots number of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	9.99r	16.38i-l	13.54m-q	13.12n-q	13.26de	
	Peat+Sand	11.46qr	12.61o-q	14.00l-p	11.47qr	12.38e	12.03c
	Peat+Loam	5.78s	11.92p-r	14.17l-p	9.88r	10.44f	
B. spectabilis	Peat	16.19j-l	21.01d-f	21.93c-e	28.69a	21.96a	
	Peat+Sand	15.25j-n	16.17j-l	19.23f-h	20.22e-g	17.72c	17.15b
	Peat+Loam	6.27s	16.93h-k	15.28j-n	15.88j-m	13.59d	
B. x *buttiana*	Peat	20.15e-g	23.28b-d	22.37c-e	23.66bc	22.37a	
	Peat+Sand	17.65h-j	17.29h-j	21.38c-f	23.29b-d	19.90b	20.10a
	Peat+Loam	18.64g-i	14.55k-o	13.94l-p	24.97b	18.03c	
Species × IBA Conc.	*B. glabra*	9.08g	13.64de	13.90d	11.49f		
	B. spectabilis	12.57ef	18.03c	18.81c	21.60b	Media means	
	B. x buttiana	18.81c	18.37c	19.23c	23.97a		
Media × IBA Conc.	Peat	15.44e	20.22b	19.28bc	21.82a	19.19a	
	Peat+Sand	14.79e	79.17cd	18.20c	18.33c	16.67b	
	Peat+Loam	10.23f	77.78de	14.46e	16.91d	14.02c	
IBA conc. means		13.00c	16.68b	17.32b	19.02a	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

3.2. Root number per cutting

The results presented in *Table 3* demonstrate that the species, growth media, and IBA concentrations all have significant effects on the number of roots formed on the cuttings. According to species main effect, *B.* x *buttiana* had the highest number of roots per cutting (20.10), while *B. glabra* had the lowest (12.03). The peat moss medium resulted in the maximum number of roots per cutting (19.19), while the medium containing peat moss + loam (1:1) had the lowest number (14.02). Treatment with 3000 mg L^{-1} IBA led to a significant increase in the number of roots per cutting (19.02) compared to the untreated cuttings (13 roots) (*Figure 2*). The interactions between species and propagation media, species and IBA concentrations, and propagation media and IBA concentrations also showed significant differences in the number of roots formed on the cuttings. The highest root number was observed in *B*. x *buttiana* cuttings planted in peat moss medium with 3000 ppm IBA treatment (22.37 roots), while the lowest number was in *B. glabra* cuttings planted in peat moss + loam medium (10.44 roots). Triple interaction effects also revealed significant differences, with *B. spectabilis* cuttings planted in peat moss medium with 3000 mg L^{-1} IBA showing the highest root number (28.69 roots), and *B. glabra* cuttings planted in peat moss + loam medium and untreated (0 ppm) having the lowest root number.

Figure 2. Effects of IBA concentrations on root number

3.3. Length of longest root per cutting

The data in the *Table 4* indicated that main effect of *Bougainvillea* species were significant on the longest roots length, the cuttings of *B. glabra* and B. x *buttiana* had the longest root length (26.54 and 26.00 cm) respectively when compared with cuttings of *B. spectabilis* which gave a shorter root length (24.41 cm). The roots produced on cuttings planted in peat moss medium provided the longest root length (26.18cm) in comparison with the shorter root length (24.99 cm) for Peatmoss + Loam (1:1) medium. IBA concentration (3000) mg L-1 showed the highest root length (26.30 cm) which was significant with control (24.78 cm). It was concluded from the results of the dual interaction between species and propagation media the excellence of cuttings of *B. glabra* planted in alone peat moss medium which gave the longest roots (27.33 cm) in comparison to minimum roots length (23.53 cm) were found on cuttings of *B. spectabilis* planted in medium contained peatmoss + loam (1:1). From the interaction between species and IBA concentrations, the significantly highest length root was found from Cuttings *B. glabra* treated with 3000 mg L^{-1} IBA (28.12 cm) in comparison with the least root length (24.11 cm) from 2000 mg L^{-1} of *B. spectabilis* cuttings. The results for a dual-action of propagation medium and concentrations of IBA cleared that the cuttings planted in peat moss medium and treated with 3000 mg L^{-1} of IBA provided the significantly highest root length (26.98 cm) while the minimum root length (24.03 cm) were shown in the control treatment 0 mg L^{-1} in peatmoss + loam media (1:1). For triple interaction among all three studied factors, the significant highest length of roots (29.56 cm) was noticed for *B. glabra* cuttings that were planted in peatmoss medium and treated

with 3000 mg L^{-1} of IBA which was different importantly with all interactions while the minimum length of roots (22.66 cm) was for same species cuttings that planted in peatmoss + loam (1:1) and treated with 0 mg L^{-1} of IBA.

The data presented in *Table 4* shows that the length of roots on *Bougainvillea* cuttings is influenced by the species, propagation media, and IBA concentrations. *B. glabra* and B. x *buttiana* cuttings had the longest roots (26.54 cm and 26.00 cm, respectively) compared to *B. spectabilis* (24.41 cm). Peat moss medium resulted in longer roots (26.18 cm) compared to peatmoss + loam (1:1) medium (24.99 cm). The highest IBA concentration (3000 mg L^{-1}) showed the longest root length (26.30 cm), significantly different from the control (24.78 cm). The dual interaction between species and propagation media revealed that *B. glabra* cuttings in peat moss had the longest roots (27.33 cm) while *B. spectabilis* cuttings in peatmoss + loam (1:1) had the shortest (23.53 cm). In the dual interaction between species and IBA concentrations, *B. glabra* cuttings treated with 3000 mg L^{-1} IBA had the longest roots (28.12 cm), whereas *B. spectabilis* cuttings treated with 2000 mg L^{-1} had the shortest (24.11 cm). The interaction between propagation media and IBA concentrations showed that cuttings in peat moss treated with 3000 mg L^{-1} IBA had the longest roots (26.98 cm), while the control treatment in peatmoss + loam media (1:1) had the shortest (24.03 cm). For the triple interaction among all factors, the longest roots (29.56 cm) were observed in *B. glabra* cuttings planted in peatmoss medium and treated with 3000 mg L^{-1} of IBA, significantly different from all other interactions, while the shortest roots (22.66 cm) were found in *B. glabra* cuttings in peatmoss + loam (1:1) medium and treated with 0 mg L^{-1} of IBA.

Table 4. Propagation media and IBA concentrations' effect on the longest root length (cm) of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	27.07a-f	28.26a-d	24.41d-h	29.56a	27.33a	
	Peat+Sand	23.65e-h	25.97a-h	29.33ab	28.99a-d	26.81ab	26.54a
	Peat+Loam	22.66h	26.67a-h	26.07a-h	26.51a-h	25.48a-c	
B. spectabilis	Peat	24.71d-h	26.80a-g	24.20d-h	24.11e-h	24.95b-d	
	Peat+Sand	24.90d-h	23.92e-h	25.23c-h	24.95d-h	24.75cd	24.41b
	Peat+Loam	24.07e-h	23.61e-h	22.91gh	23.54e-h	23.53d	
B. x *buttiana*	Peat	27.04a-g	26.71a-h	24.00e-h	27.26a-e	26.25a-c	
	Peat+Sand	24.10e-h	27.40a-e	25.51a-h	26.22a-h	25.81a-c	26.00a
	Peat+Loam	25.36b-h	23.00f-h	29.22a-c	26.23a-h	25.95a-c	
Species × IBA Conc.	*B. glabra*	24.46cd	26.97ab	26.61a-c	28.12a		
	B. spectabilis	24.56cd	24.78b-d	24.11d	24.20d	Media means	
	B. x buttiana	25.50b-d	25.70b-d	26.24a-d	26.57a-c		
Media × IBA Conc.	Peat	26.27a-c	27.26a	24.20cd	26.98a	26.18a	
	Peat+Sand	24.22cd	25.76a-d	26.69a	26.49ab	25.79ab	
	Peat+Loam	24.03d	24.43b-d	26.07a-d	25.43a-d	24.99b	
IBA conc. means		24.78b	25.82ab	25.65ab	26.30a	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

3.4. Fresh weight of roots

The data in *Table 5* reveals that the species, propagation media, and IBA concentrations were significant for the fresh weight of roots per cutting in *Bougainvillea*. B. x *buttiana* had the highest root fresh weight (3.39 g) while *B. glabra* had the lowest (1.89 g). Peatmoss + loam medium resulted in the highest root fresh weight (2.71 g) while peatmoss + sand (1:1) had the lowest (2.35 g). IBA concentration at 3000 mg L-1 showed the highest fresh weight of roots (2.76 g) compared to the control (1.95 g). In the dual interaction, B. x *buttiana* cuttings in peat moss medium had the maximum fresh weight (3.61 g) while *B. glabra* cuttings in peatmoss and peatmoss + sand (1:1) had the least (1.63 g). For the interaction between species and IBA concentrations, B. x *buttiana* cuttings treated with 3000 mg L-1 had the highest fresh weight (4.17 g) compared to *B. glabra* cuttings treated with the same concentration (1.59 g). In the dual interaction between media and IBA concentrations, cuttings in peatmoss + loam (1:1) treated with 2000 and 3000 ppm had the highest fresh weight of roots (3.04 g and 3.17 g) respectively, while the control in peatmoss medium had the lowest (1.86 g). The triple interaction showed that B. x *buttiana* cuttings treated with 3000 ppm of IBA and planted in peatmoss and peatmoss + loam (1:1) had significantly the

highest fresh weight of roots (4.45 g and 4.52 g) respectively, while *B. glabra* cuttings treated with the same concentration in peatmoss + sand (1:1) had the lowest (1.07 g).

Table 4. Propagation media and IBA concentrations' effect on root frest weight (g) of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	1.69k-m	1.53lm	1.60k-m	1.71k-m	1.63f	
	Peat+Sand	1.87j-m	1.61k-m	1.99i-l	1.07n	1.63f	1.89c
	Peat+Loam	1.46mn	3.41d-f	2.75gh	1.99i-l	2.40d	
B. spectabilis	Peat	1.68k-m	2.37hi	1.99i-l	1.74k-m	1.95e	
	Peat+Sand	1.43mn	2,03i-k	1.82j-m	2.82g	2.02e	2.17b
	Peat+Loam	1.48mn	2.66gh	3.09fg	2.99fg	2.55d	
B. x *buttiana*	Peat	2.22ij	3.74cd	4.03bc	4.45a	3.61a	
	Peat+Sand	3.09fg	4.22ab	2.68gh	3.55de	3.39b	3.39a
	Peat+Loam	3.32d-f	1.61k-m	3.28ef	4.52a	3.18c	
Species × IBA Conc.	*B. glabra*	1.67f	2.18e	2.11e	1.59f		
	B. spectabilis	1.53f	2.35de	2.30de	2.52d	Media means	
	B. x buttiana	2.88c	3.19b	3.33b	4.17a		
Media × IBA Conc.	Peat	1.86d	2.55b	2.54b	2.63b	2.39b	
	Peat+Sand	2.13c	2.62b	2.16c	2.48b	2.35b	
	Peat+Loam	2.09cd	2.56b	3.04a	3.17a	2.71a	
IBA conc. means		1.95c	2.57b	2.58b	2.76a	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

Table 5. Propagation media and IBA concentrations' effect on root dry weight (g) of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	0.397no	0.487k-n	0.357no	0.610h-l	0.463ef	
	Peat+Sand	0.363no	0.413m-o	0.530i-n	0.413m-o	0.430f	0.467c
	Peat+Loam	0.293o	0.593h-m	0.500j-n	0.643g-l	0.508d-f	
B. spectabilis	Peat	0.640g-l	0.763c-h	0.473k-o	0.647g-l	0.631c	
	Peat+Sand	0.353no	0.730d-h	0.4633-o	0.593h-m	0.535de	0.584b
	Peat+Loam	0.350no	0.660g-k	0.677f-j	0.660g-k	0.587cd	
B. x *buttiana*	Peat	0.367no	0.927bc	1.850a	0.847c-f	0.998a	
	Peat+Sand	0.620h-l	0.903b-d	0.710e-i	0.813c-g	0.787b	0.849a
	Peat+Loam	0.823c-g	0.387no	0.873c-e	1.063b	0.787b	
Species × IBA Conc.	*B. glabra*	0.351h	0.498fg	0.462fg	0.556ef		
	B. spectabilis	0.448g	0.718cd	0.538e-g	0.633de	Media means	
	B. x buttiana	0.603e	0.739c	1.144a	0.908b		
Media × IBA Conc.	Peat	0.468gh	0.726bc	0.893a	0.701b-d	0.697a	
	Peat+Sand	0.446h	0.682cd	0.568ef	0.607de	0.576c	
	Peat+Loam	0.489f-h	0.547e-g	0.683cd	0.789b	0.627b	
IBA conc. means		0.455c	0.651b	0.715a	0.699ab	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

3.5. Dry weight of roots

The dry weight of roots per cutting in different *Bougainvillea* species was significantly differed, with B. x *buttiana* cuttings showing the highest dry weight (0.849 g) and *B. glabra* cuttings having the least dry weight (0.467 g). Planting cuttings in peat moss medium resulted in the highest dry weight of roots (0.697 g), while peat moss + sand (1:1) medium had the lowest weight (0.576 g). Treatment with 2000 mg L^{-1} IBA significantly increased the dry weight of roots (0.715 g) compared to untreated cuttings (0 mg L^{-1} IBA, 0.455 g). Dual interactions revealed that *B.* x *buttiana* cuttings in peat moss medium had the highest dry weight (0.998 g), and *B. glabra* cuttings in peat moss + sand (1:1) had the least dry weight (0.430 g). Additionally, *B.* x *buttiana* cuttings treated with 2000 mg L^{-1} IBA showed the highest dry weight (1.144 g) in interaction, while *B. glabra* cuttings with 0 mg L-1 IBA exhibited the lowest dry weight (0.351 g). The triple interaction indicated that *B.* x *buttiana* cuttings planted in peat moss and treated with 2000 mg L^{-1} IBA had the highest dry weight (1.850 g), while *B. glabra* cuttings in peat moss + loam (1:1) with 0 mg L^{-1} IBA showed the lowest weight (0.293 g).

3.6. Shoot number per cutting

The results presented in *Table 6* show that the number of shoots per cutting was affected by the factors studied. *B. spectabilis* species had the highest number of shoots (2.81) per cutting, while *B.* x *buttiana* had the lowest (2.24). Cuttings planted in peatmoss and peatmoss + loam (1:1) media produced the highest number of shoots (2.54 and 2.57, respectively) compared to the lowest number (2.34) in peatmoss + sand (1:1) medium. Untreated cuttings with 0 mg L^{-1} IBA had the maximum number of shoots (2.64), significantly higher than cuttings treated with 1000 and 3000 mg L^{-1} IBA (2.42 and 2.41, respectively). Regarding dual interactions, *B. spectabilis* cuttings in peatmoss + loam (1:1) medium had the highest number of shoots (2.92), while *B.* x *buttiana* cuttings in peatmoss + sand (1:1) had the lowest (2.18). The highest number of shoots from dual interactions between species and IBA doses was found in *B. spectabilis* cuttings treated with 3000 ppm of IBA (2.92), while B. x *buttiana* cuttings treated with 1000 mg L^{-1} IBA had the lowest (1.98). The interaction of peatmoss + loam (1:1) medium and 0 mg L^{-1} IBA resulted in the highest number of shoots (2.75), while peatmoss + sand (1:1) medium and 1000 mg L^{-1} IBA showed the lowest (2.15). In the triple interaction, the highest number of shoots (3.24) was observed in *B. spectabilis* cuttings planted in peatmoss + loam (1:1) medium and treated with 3000 mg L^{-1} IBA, while the lowest number (1.72) was found in *B. glabra* cuttings treated with the same IBA treatment and planted in peatmoss + sand (1:1) medium.

Table 6. Propagation media and IBA concentrations' effect on shoot number per cutting of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	2.74b-f	2.56c-I	2.33e-l	2.53c-j	2.54bc	
	Peat+Sand	2.54c-i	2.29f-m	2.39d-l	1.72o	2.23de	2.41b
	Peat+Loam	2.67b-h	2.66b-h	2.44d-l	2.02k-o	2.45b-d	
B. spectabilis	Peat	3.00a-c	3.08ab	2.69b-g	2.83a-e	2.90a	
	Peat+Sand	2.75b-f	2.41d-l	2.61b-i	2.69b-g	2.62b	2.81a
	Peat+Loam	2.89a-d	2.81a-f	2.72b-g	3.24a	2.92a	
B. x *buttiana*	Peat	2.22g-n	2.38d-l	1.97l-o	2.17h-o	2.19e	
	Peat+Sand	2.03j-o	1.75no	2.81a-f	2.13i-o	2.18e	2.24c
	Peat+Loam	2.69b-g	1.80m-o	2.50c-k	2.37e-l	2.34c-e	
Species × IBA Conc.	*B. glabra*	2.65b-d	2.50c-e	2.39d-f	2.09gh		
	B. spectabilis	2.88ab	2.77ab	2.67a-c	2.22a	Media means	
	B. x buttiana	2.31e-g	1.98h	2.43c-f	2.51a-c		
Media × IBA Conc.	Peat	2.65ab	2.67ab	2.33c-e	2.51a-c	2.54a	
	Peat+Sand	2.44b-d	2.15e	2.60a-c	2.18de	2.34b	
	Peat+Loam	2.75a	2.42b-d	2.56a-c	2.54a-c	2.57a	
IBA conc. means		2.64a	2.42b	2.50ab	2.41b	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

3.7. Leaves number per cutting

The results presented in *Table 7* indicate that the effects of factors were significant with regard to number of leaves per cutting. Cuttings of *B. spectabilis* had the highest number of leaves (59.76) when treated with 2000 mg L^{-1} IBA, while the lowest number (47.85) was observed with 3000 mg L^{-1} IBA treatment. In terms of dual interactions, *B. spectabilis* cuttings planted in peatmoss medium showed the highest number of leaves (74.76) compared to other interactions, especially when *B. glabra* cuttings were planted in peatmoss + loam (1:1) medium, resulting in the lowest number of leaves (31.27). The number of leaves per cutting for *B. glabra* cuttings varied with different IBA concentrations, with the highest number (70.00) observed with 2000 mg L^{-1} IBA treatment and the lowest number (35.34) with 3000 mg L^{-1} IBA treatment. Additionally, when cuttings were planted in peatmoss medium and treated with 1000 mg L^{-1} IBA, the highest number of leaves per cutting (75.64) was obtained, while the lowest number (34.10) was observed for cuttings planted in peatmoss + loam (1:1) and treated with 2000 mg L^{-1} IBA. The largest number of leaves (97.33) was noticed in the triple interaction of *B. glabra* cuttings treated with 2000 mg L^{-1} IBA and planted in peatmoss + sand (1:1) medium, whereas the lowest number (31.63) was seen with *B. spectabilis* cuttings treated with the same concentration of IBA and planted in peatmoss + loam (1:1) medium.

Table 7. Propagation media and IBA concentrations' effect on leaves number per cutting of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	68.73ef	73.68de	77.46cd	49.07k-m	67.23b	
	Peat+Sand	49.92j-l	61.94gh	97.33a	35.19pq	61.10c	53.20b
	Peat+Loam	32.89q	35.22pq	35.21pq	21.77r	31.27g	
B. spectabilis	Peat	73.13de	90.00b	71.06e	6486fg	74.76a	
	Peat+Sand	57.37hi	50.93jk	81.82c	62.47gh	6315c	59.62a
	Peat+Loam	52.49i-k	35.91pq	31.63q	43.77m-o	40.95f	
B. x *buttiana*	Peat	38.85op	63.25g	55.29ij	52.66i-k	52.51d	
	Peat+Sand	47.45k-m	40.84n-p	52.61i-k	49.21k-m	47.53e	47.09c
	Peat+Loam	45.00l-n	32.80q	35.47pq	51.63jk	41.23f	
Species × IBA Conc.	*B. glabra*	50.51de	56.95c	70.00a	35.34h		
	B. spectabilis	60.99b	58.95bc	61.50b	57.03c	Media means	
	B. x buttiana	43.77g	45.63fg	47.79ef	51.17d		
Media × IBA Conc.	Peat	60.24c	75.64a	67.93b	55.53d	64.84a	
	Peat+Sand	51.58e	51.24e	77.25a	48.96e	57.26b	
	Peat+Loam	43.46f	34.64h	34.10h	39.06g	37.82c	
IBA conc. means		52.48c	53.84b	59.76a	47.85d	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

3.8 Shoots fresh weight

The results from *Table 8* show significant variations in fresh shoot weight among *Bougainvillea* species. *B.* x *buttiana* cuttings had the highest fresh shoot weight (22.07 g) compared to *B. glabra* cuttings (10.62 g). Planting cuttings in peatmoss medium resulted in the highest fresh shoot weight (16.94 g), while peatmoss + loam (1:1) medium had the lowest weight (12.71 g). IBA concentrations of 2000 and 3000 mg L^{-1} produced the maximum fresh shoot weight (16.33 g and 16.01 g) respectively, significantly higher than the control (12.47 g). In terms of dual interactions, B. x *buttiana* cuttings planted in peatmoss medium showed the highest fresh shoot weight (24.40 g), while *B. glabra* cuttings in peatmoss + loam (1:1) had the lowest weight (7.98 g). Similarly, *B.* x *buttiana* cuttings treated with 3000 mg L^{-1} IBA had the highest fresh shoot weight (25.69 g), whereas *B. glabra* cuttings treated with the same concentration of IBA had the lowest weight (8.76 g). Cuttings planted in peatmoss and treated with 1000 mg L^{-1} IBA showed the highest fresh shoot weight (20.32 g), while peatmoss + loam (1:1) medium without IBA treatment had the lowest weight (11.36 g). In the triple interaction, *B.* x *buttiana* cuttings in

peatmoss and treated with 1000 mg L^{-1} IBA exhibited the highest fresh shoot weight (30.59 g), while *B. glabra* cuttings in peatmoss + loam (1:1) and treated with 3000 mg L^{-1} IBA had the lowest weight (6.37 g).

Table 8. Propagation media and IBA concentrations' effect on shoot fresh weight of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	11.23l-n	12.75i-l	12.39j-l	9.98no	11.59d	
	Peat+Sand	10.35m-o	11.21l-n	17.72g	9.93no	12.30d	10.62c
	Peat+Loam	7.06qr	9.94no	8.54o-q	6.37r	7.98f	
B. spectabilis	Peat	13.71h-k	17.63g	14.17h-j	13.80h-k	14.83c	
	Peat+Sand	12.08k-m	12.68i-l	18.04fg	15.59h	14.60c	12.97b
	Peat+Loam	9.39n-p	9.66no	7.50p-r	11.35l-n	9.47e	
B. x *buttiana*	Peat	14.73hi	30.59a	25.99c	26.28c	24.40a	
	Peat+Sand	19.70ef	21.75d	20.97de	22.15d	21.14b	22.07a
	Peat+Loam	17.62g	14.79h	21.69d	28.63b	20.68b	
Species × IBA Conc.	*B. glabra*	9.55f	11.30e	12.88d	8.76f		
	B. spectabilis	11.73e	13.32d	13.23d	13.58d	Media means	
	B. x buttiana	17.35c	22.38b	22.88b	25.69cd		
Media × IBA Conc.	Peat	13.23fg	20.32a	17.51c	16.69cd	16.94a	
	Peat+Sand	14.04f	15.21e	18.91b	15.89de	16.01b	
	Peat+Loam	11.36h	11.46h	12.57g	15.45e	12.71c	
IBA conc. means		12.47c	15.66ab	16.33a	16.01a	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

Table 9. Propagation media and IBA concentrations' effect on shoot dry weight of hardwood cuttings of three Bougainvillea species

Species	Media	IBA Concentrations				Species x Media	Species means
		0ppm	1000ppm	2000ppm	3000ppm		
B. glabra	Peat	3.42h-l	3.41h-l	3.15i-m	2.82k-n	3.20d	
	Peat+Sand	2.56l-n	3.11j-m	4.42e-g	2.20mn	3.07d	2.87c
	Peat+Loam	1.88n	3.07j-m	2.38mn	2.04n	3.07d	
B. spectabilis	Peat	4.10e-I	4.98e	3.91f-j	3.98f-j	4.24c	
	Peat+Sand	3.13j-m	3.80g-j	4.80ef	4.51e-g	4.06c	3.79b
	Peat+Loam	3.62g-k	2.82k-n	2.25mn	3.60g-k	3.08d	
B. x *buttiana*	Peat	4.32e-h	9.58a	7.62b	6.87bc	7.10a	
	Peat+Sand	5.99cd	6.65cd	5.90d	6.43cd	6.24b	6.57a
	Peat+Loam	5.84d	4.39e-g	6.31cd	8.97a	6.38b	
Species × IBA Conc.	*B. glabra*	2.62f	3.20e	3.31e	2.35f		
	B. spectabilis	3.62de	3.87d	3.65de	4.03d	Media means	
	B. x buttiana	5.38c	6.87b	6.61b	7.42a		
Media × IBA Conc.	Peat	3.95de	5.99a	4.89bc	4.56bc	4.85a	
	Peat+Sand	3.89de	4.52bc	5.04b	4.38cd	4.46b	
	Peat+Loam	3.78e	3.43e	3.65e	4.87bc	3.93c	
IBA conc. means		3.74b	4.65a	4.53a	4.60a	-	

According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at the 5% level.

The available results from *Tables 2* to *9* consistently show that the use of alone peat moss as a propagation medium provides better outcomes compared to other media for various characteristics. It leads to significantly higher rooting percentage (84.99%), more roots per cutting (19.19 roots), longer root length per cutting (26.18 cm), greater root dry

weight (0.697 g), longer shoots length per cutting (34.55 cm), more leaves per cutting (64.84), higher fresh weight of shoots (16.94 g), and higher dry weight of shoots (4.85 g).

The findings from various studies (Bosila et al., 2010; Abdulrahman, 2012; Hasan and Hammo, 2021; Mehmood et al., 2013) consistently confirm that peat moss is an excellent medium for promoting high rooting rates and improving root characteristics in various plant cuttings. Peat moss has been shown to enhance root length, dry weight of roots, and number of shoots, shoot length, and overall plant growth. Its physical and chemical properties, such as high-water retention, low bulk density, and high porosity, contribute to its effectiveness as a growth medium. Additionally, when combined with other media, peat moss can further enhance its physical qualities, resulting in improved plant rooting and growth. The fertility of the medium also plays a crucial role in nutrient absorption and plant growth, especially regarding nitrogen and other essential elements. Overall, the choice of growth medium is a vital component of the propagation system, significantly influencing rooting ability and root quality in cuttings.

The results presented in *Tables 2*, *6*, and *7* demonstrate that treating the cuttings with 2000 mg L-1 IBA led to a significant increase in rooting percentage, number of leaves per cutting, and dry weight of roots. These findings are in line with previous studies conducted by Hammo et al. (2013), Kuldeep et al. (2013), Wagh et al. (2013), and Çorbacı et al. (2023) on various plant species, which also showed positive effects of IBA on rooting and plant growth. Similarly, *Tables 2* and *4* show that the application of 3000 mg L-1 IBA resulted in the highest number of roots per cutting, longest root length. These observations are supported by the research of Ashok and Ravivarman (2020) and Youssef (2020) on different plant cuttings, including *Bougainvillea* and *Ficus benjamin*. Additionally, *Table 9* indicates that the highest length of the longest shoot per cutting was achieved with 1000 mg L-1 IBA, consistent with the findings of Yeshiwas et al. (2015) and Mehraj et al. (2013) on rose and *Bougainvillea* cuttings, respectively. Overall, plant hormones, particularly auxins like IBA, play a crucial role in the cutting propagation process, influencing root development, cell division, elongation, and differentiation, as well as other growth and developmental processes in plants.

On the other hand, *B. glabra* species resulted in the highest rooting percentage per cutting (80.49%) according to *Table 2*. The greatest length of the longest root was found in *B. glabra* (26.54 cm) and B. x *buttiana* (26.00 cm) species, as indicated in *Table 4*. Moreover, *B. spectabilis* showed the maximum number of shoots per cutting (2.81 shoots) and leaves number per cutting (59.62 leaves) as shown in *Tables 6* and *7*, respectively. In summary, B. x *buttiana* cuttings generally outperformed the other species in terms of rooting ability, root and shoot characteristics, while *B. glabra* exhibited the highest rooting percentage. *B. spectabilis*, on the other hand, showed superior performance in terms of shoot and leaf development.

The ability of stem cuttings to produce adventitious roots can vary significantly among different plant species (Beyl and Trigiano, 2016). The success of woody species in cutting reproduction is often associated with the availability of reserve components, especially carbohydrates, in the stem, providing the necessary energy for root development (Stuepp et al., 2017).

Regarding the longest root length per cutting, *B. glabra* and *B.* x *buttiana* species performed noticeably better than *B. spectabilis*, similar to the differences observed in stem cuttings of *Actinidia deliciosa* and *Actinidia arguta* (Peticila et al., 2016). The improvement in root length can be attributed to genetic factors and the number of leaves. Genetic factors play a crucial role in establishing a robust root system, while the number of leaves contributes to food production and translocation of nutrients to support root growth (Osterbye, 1970). The influence of plant species is evident in the highest number of shoots and leaves produced by *B. spectabilis* cuttings, consistent with the results of Banjara (2017) on Terminalia species. A well-developed root system supports the growth of new shoots by ensuring efficient transport of water and nutrients from the propagation media to the developing plant (Mewar and Naithani, 2016). The plant hormone cytokinin also plays a role in regulating cell division and differentiation during leaf and shoot growth (Efroni et al., 2013).

Noiton et al. (1992) suggested that the plant hormone ABA (abscisic acid) could be one of the factors hindering root production in difficult-to-root plants. Swamy et al. (2002) studied the relationship between the amount of natural auxins and their function in cuttings, as well as the presence of accessible forms of carbohydrates and nitrogenous elements at the cutting's base, which can influence the rooting process and other properties. Additionally, the formation of shoots on cuttings before root development, due to favorable environmental factors, may lead to the release of cytokinins from these shoots, encouraging the development of buds on cuttings, as mentioned by Abdlqader (1999).

When roots develop on cuttings, they provide the necessary water and nutrients for shoot development and growth.

4. Conclusions

According to the obtained data, *Bougainvillea* x *buttiana* cuttings showed significant superiority in terms of rooting characteristics. The highest number of roots, fresh and dry root weight, longest shoots, and shoot weight were recorded for *Bougainvillea* x *buttiana*. On the other hand, *Bougainvillea glabra* had the highest rooting percentage, while *Bougainvillea spectabilis* had the highest number of shoots and leaves. Peat moss medium generally demonstrated the best rooting performance. It resulted in the highest number of roots, dry root weight, leaves number, fresh shoot weight, and dry shoot weight. Peat moss + loam (1:1) provided the highest fresh root weight, and alone peat moss and peat moss + sand (1:1) produced the longest roots and shoots, respectively. Different IBA concentrations significantly affected rooting. Treatment with 3000 mg L-1 IBA resulted in the highest number of roots and fresh root weight. 2000 mg L-1 IBA treatment led to the highest rooting percentage and leaves number, while 1000 mg L-1 IBA treatment produced the longest shoots. Root dry weight was highest at 2000 and 3000 mg L-1 IBA treatments, whereas fresh and dry shoot weights were highest at 2000, 3000, and 1000 mg L-1 IBA treatments, respectively. Overall, the best results were obtained with *Bougainvillea* x *buttiana* cuttings planted in peat moss medium and treated with 1000 mg L-1 IBA. *Bougainvillea glabra* cuttings planted in peat moss medium and treated with 2000 and 3000 mg L-1 IBA showed the highest rooting percentage and longest roots, respectively. *Bougainvillea spectabilis* cuttings treated with 3000 mg L-1 IBA in peat moss medium and peat moss + loam (1:1) medium produced the highest number of roots and shoots, respectively.

The conducted experiment provides valuable recommendations for the propagation of *Bougainvillea* species:

- *Bougainvillea* x *buttiana* is the preferred species for propagation over *Bougainvillea glabra* and *Bougainvillea spectabilis* due to its superior rooting capability and higher success rate.
- The use of auxin (IBA) treatment is recommended for enhancing the rate of rooting in cuttings, especially at higher concentrations. IBA promotes physiological processes within the cuttings, leading to improved rooting and shoot development.
- Planting the cuttings in alone peat moss medium yields favorable results. Ensuring proper environmental conditions, such as temperature and relative humidity, is crucial for successful rooting.
- Future research should focus on the individual effects of various factors on the rooting process and shoot development. Analyzing all cutting components, including hormones, can provide valuable insights.
- Investigating the impact of the wounding process on cuttings' success is essential to understand its beneficial and harmful effects.
- Exploring the use of other types of auxins, such as IAA and NAA, and combining them with IBA, may lead to even better results in rooting cuttings of *Bougainvillea* species.
- Experimenting with various media types and mixtures for propagating cuttings of *Bougainvillea* can help optimize the rooting process and overall plant development. By considering these recommendations, horticulturists and researchers can improve the propagation success of *Bougainvillea* species and potentially enhance their cultivation and commercial applications.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authorship Contribution Statement

Concept: Rasul, A. T., Ak, B. E.; Design: Rasul, A. T., Ak, B. E, Abdulrahman Y. A., Hatipoğlu İ. H.; Data Collection or Processing: Rasul, A. T., Abdulrahman Y. A.; Statistical Analyses: Rasul, A. T., Hatipoğlu İ. H.; Literature Search: Rasul, A. T., Hatipoğlu İ. H.; Writing, Review and Editing: Rasul, A. T., Ak, B. E, Abdulrahman Y. A., Hatipoğlu İ. H.

References

Abdlqader, H. A. (1999). *Effect of pinching and use of benzyl adenine on shooting and rooting of Dracaena fragrance shoots*. (MSc. Thesis), Agriculture and Forestry College, Mosul University, Iraq.

Abdulrahman, Y. A. (2012). Effect of propagation media and different concentrations of IBA on rooting of *Bougainvillea glabra* cuttings. *Mesopotamia Journal of Agriculture*, 40(1): 64–74.

Ak, B. E., Fidancı, A. and Hatipoglu, I. H. (2022). The effect of different growing media, auxins and concentrations on the propagation of the *Schefflera arbicola* (Hayata) Merr. by cuttings. *Journal of Agriculture and Nature*, 25(5): 1023-1027. https://doi.org/10.18016/ksutarimdoga.vi.951082 (In Turkish)

Ak, B. E., Hatipoğlu, İ. H. and Dikmetaş, B. (2021). Propagation of Fruit Trees. (Chapter 3), Receny Headways in Pomology, p. 55-92, Iksad Publications, Ankara, Türkiye.

Akyiğit, İ. and Baktır, İ. (1989). A research on propagating three different Bougainvillea species from year- roond taken hardwood cuttings. *Akdeniz University Journal of the Faculty of Agriculture*, 2(2): 23-31. (In Turkish)

Altoé, J. A., Marinho, C. S., Terra, M. I. D. C. and Carvalho, A. J. C. D. (2011). Multiplying guava cultivars by minicutting technique. *Bragantia*, 70(4): 801-809.

Anonymous (2001). Statistical Analysis System. User's Guide: Statistics, Version 8.2. SAS Institute, NC, USA.

Ashok, A. D., Ravivarman, J. (2020). Stimulating capability of IBA on rooting in stem cuttings of *Pseuderanthemum carruthersii* var. Atropurpureum. *International Journal of Conservation Science,* 8(4):2503–2505.

Banjara, K. (2017). *Effect of auxin concentrations and species on rooting of stem cuttings of Terminalia genus.* (MSc. Thesis) Department of Forestry, College of Agriculture, Faculty of Agriculture, Indira Gandhi Agricultural University, Raipur, India.

Beyl, C. A. and Trigiano, R. N. (2016). Plant Propagation Concepts and Laboratory Exercises. CRC Press. https://doi.org/10.1201/b17340

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., Clark, F. E. and Dinauer, R. C. (1965). Methods of Soil Analysis. Pt. 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. Pt. 2. Chemical and Microbiological Properties (No. 631.42 B627). American Society of Agronomy, Madison, WI (EUA).

Bosila, H. A., Zewil, M. A., Hamza, M. A. and Amin, M. M. (2010). Infelunce of planting date and media on rooting of stem cutting of *Bougainvillea glabra*. *Journal of Plant Production*, 1(7): 1033-1040.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal*, 54(5): 464-465.

Chauhan, P., Mahajan, S., Kulshrestha, A., Shrivastava, S., Sharma, B., Goswamy, H. M. and Prasad, G. B. K. S. (2016). *Bougainvillea spectabilis* exhibits antihyperglycemic and antioxidant activities in experimental diabetes. *Journal of Evidence-based Complementary and Alternative Medicine*, 21(3): 177-185.

Çorbacı, Ö. L., Ekren, E. and Bayram, F. (2023). Determination of the effects of different IBA (Indole-3-Butyric Acid) doses on the growth and development of *Argyranthemum frutescens* (L.) Sch.Bip. (Marguerite Daisy) cuttings. *Artvin Coruh University Journal of Forestry Faculty,* 24 (2): 108-116. https://doi.org10.17474/artvinofd.1324619 (In Turkish)

De Klerk, G. J, Van Der Krieken, W. M. and De Jong, J. C. (1999). The formation of adventitious roots; new concepts, new possibilities. *In Vitro Cellular & Developmental Biology-Plant*, 35: 189–199.

De Oliveira F. R., Witt, N. G. D. P. M., Obrzut, V. V., Valério, S., Zuffellato-Ribas, K. C. and Stuepp, C. A. (2015). Maintenance of leaves and indolebutyric acid in rooting of juvenile Japanese Flowering Cherry cuttings. *Revista Brasileira de Ciências Agrárias*, 10 (1): 97-101.

Dirr, M. A. and Heuser C. W. (1987). The Reference Manual of Woody Plant Propagation: From Seed to Tissue Culture. (No. 634.96702 D5.)

Eed, A. M., Albana'a, B. and Almaqtari, S. (2015). The effect of growing media and stem cutting type on rooting and growth of Bougainvillea Spectabilis Plants. *University of Aden Journal of Natural and Applied Sciences,* 19(1): 141-147.

Efroni, I., Han, S. K., Kim, H. J., Wu, M. F., Steiner, E., Birnbaum, K. D. and Wagner, D. (2013). Regulation of leaf maturation by chromatin-mediated modulation of cytokinin responses. *Developmental Cell*, 24(4): 438-445.

Gencer Gokce, P., Kılıç, N. and Çobanoğlu, S. (2022). The determination of Mite (Acari) species and their hosts on park and ornamental plants in Tekirdag Province (Turkiye). *Journal of Tekirdag Agricultural Faculty*, 19 (3): 697-711. https://doi.org10.33462/jotaf.1124376 (In Turkish)

Gilman, E. F. (1999). *Bougainvillea* spp. Cooperative Extension Service, University of Florida, Fact Sheet, FPS-70.

Hammo, Y. H., Kareem, B. Z. A. and Salih, M. I. (2013). Effect of planting media and IBA concentration on rotting ability of stem cutting of *Ligustrum ovalifolium*. *Journal of Agriculture and Veterinary Science,* 6: 47-51.

Hartmann, H. T., Kester, D. E., Davies, F. T. and Geneve, R. L. (1997). Propagation by Specialized Stems and Roots. Plant Propagation. Principles and Practices. Sixth edition. Prentice Hall, Inc. New Jersey US.

Hasan, N. S. and Hammo, Y. H. (2021). Influence of IBA and media on rooting percentage and growth of semi-hardwood cuttings of red-tip photinia plant (*Photinia* cx *fraseri*). *Journal of Duhok University*, 24(1): 114-119.

Ibironke, O. A. (2019). Root initiation of *Bougainvillea* from cuttings using different rooting hormones. *Advances in Plants & Agriculture Research*, 9(1): 121–125.

Kobayashi, K. D., McConnell, J. and Griffis J. (2007). Bougainvillea. Ornamentals and Flowers, Oct. 2007, OF-38, Cooperative Extension Service, University of Hawai'I at Manoa.

Kuldeep, S., Singh, J. N. and Abhishek, S. (2013). Studies on the effect of IBA on rooting of *Bougainvillea* (var. Thimma) cuttings in open field and polyhouse conditions. *Asian Journal of Horticulture*, 8(1): 140-142.

Kumar, V., Singh, M. K., Kumar, M., Prakash, S., Kumar, A., Rao, S. and Malik, S. (2015). Effect of different doses of IBA and rooting media on rooting of stem cutting of lemon (*Citrus limon* Burm) cv. Pant lemon-1. *Journal of Plant Development Sciences*, 7(7): 587-591.

Landis, T. D., Jacobs, D. F., Wilkinson, K. M. and Luna, T. (1990). Growing Media. The Container Tree Nursery Manual, 2: 41-85.

Laubscher, C. P. and Ndakidemi, P. A. (2008). Rooting success using IBA auxin on endangered Leucadendron laxum (PROTEACEAE) in different rooting mediums. *African Journal of Biotechnology*, 7(19): 3437-3442.

Mabberley, D. J. (1997). The Plant-Book: A Portable Dictionary of the Vascular Plants. Cambridge University Press.

Mehmood, T., Ahmad, W., Ahmad, K. S., Shafi, J., Shehzad, M. A. and Sarwar, M. A. (2013). Comparative effect of different potting media on vegetative and reproductive growth of floral shower (*Antirrhinum majus* L.). *Universal Journal of Plant Science*, 1(3): 104-111.

Mehraj, H., Shiam, I. H., Taufique, T., Shahrin, S. and Jamaluddin, A. F. M. (2013). Influence of Indole-3-Butyric Acid (IBA) on sprouting and rooting potential of Bougainvillea spectabilis cuttings. *Bangladesh Research Publications Journal*, 9(1): 44-49.

Mewar, D. and Naithani, D. C. (2016). Effect of different IBA concentrations and planting time on stem cuttings of wild fig (*Ficus palmata* forsk.). *Plant Archives*, 16 (2): 959-962.

Noiton, D., Vine, J. H. and Mullins, M. G. (1992). Endogenous indole-3-acetic acid and abscisic acid in apple microcuttings in relation to adventitious root formation. *Plant Growth Regulation*, 11(1): 63-67.

Öcalan, O. N., Saraçoğlu, O., Yıldız, K., Çezik, F. and Al-Salıhı, A. A. M. (2023). Effect of IBA and Caffeic Acid on rooting of Black Mulberry (*Morus nigra* L.) hardwood cuttings in different dark conditions. *Journal of Tekirdag Agricultural Faculty*, 20(2): 270-277. https://doi.org/10.33462/jotaf.1034584 (In Turkish)

Osterbye, U. (1970). Rooting of rose cuttings. *Nordisk Jordbrugsforsknin*, 52: 136-137.

Page, A. L., Miller, R. H. and Keeney, D. R. (1982). Methods of Analysis. Part Two, Chemical and Microbiological Properties. American Society of Agronomy. In Soil Science Society of America, Vol. 1159.

Peticilă, A. G., Madjar, R. M., Scăeţeanu, G. V. and Asănică, A. (2016). Effect of rooting hormone treatments on propagation of *Actinidia* sp. by hardwood cuttings. *AgroLife Scientific Journal*, 5(2): 112-118.

Rasul, A. T., Ak, B. E. and Hatipoğlu, İ. H., 2021. Some *Bougainvillea* Species and Characteristics and Reproduction Techniques. *Anatolian Congresses 7th International Applied Sciences Congress*, September 11- 12, 2021, p: 23-31, Diyarbakır, Türkiye.

Singh, K. S. (2017). Multiplication of phalsa (*Grewia asetica* L.) Cv. Dwarf type through hardwood stem cutting under Srinagar Garhwal Himalayas. *International Journal of Current Microbiology and Applied Sciences*, 6(2): 1173-1178.

Stuepp, C. A., Bitencourt, J. D., Wendling, I., Koehler, H. S. and Zuffellato-Ribas, K. C. (2017). Age of stock plants, seasons and IBA effect on vegetative propagation of *Ilex paraguariensis*. *Revista Árvore*, 41(2): e410204. http://dx.doi.org/10.1590/1806-90882017000200004

Swamy, S. L., Puri, S. and Kanwar, K. (2002). Propagation of *Robinia pseudoacacia* Linn. and *Grewiaoptiva* Drummond from rooted stem cuttings. *Agroforestry Systems*, 55(3): 231-237.

Wagh, S. T., Golliwar, V. J., Raut, P. D. and Thakre, S. A. (2013). Response of IBA to different types of stem cuttings in *Bougainvillea* (var. Torch Glow). *Journal of Agriculture Research and Technology*, 38(1): 25-28.

Yeshiwas, T., Alemayehu, M. and Alemayehu, G. (2015). Effects of indole butyric acid (IBA) and stem cuttings on growth of stenting-propagated rose in Bahir Dar, Ethiopia. *World Journal of Agricultural Sciences*, 11(4): 191-197.

Youssef, A. S. M. (2020). Effect of some rooting media and IBA treatments on rooting, growth and chemical composition of stem cuttings of *Ficus benjamina* cv. Vivian. *Annals of Agricultural Science, Moshtohor*, 58(4): 999-1010.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

From Practice to Science: Assessment Soil Nutrient Status Using "Minus One Element Technique (MOET)" for Early Growth of Maize

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Abstract

Soil nutrient deficiency will influence maize growth, so it is necessary to add nutrients based on the fertility status of the soil. One way to find out the nutrient soil status using a simple method is using the minus one element technique (MOET). The minus one element technique (MOET) determines which element is the limiting factor. This study was carried out to confirm the nutrient soil status using the minus one element technique (MOET) with the early growth of maize as the indicator. The research was conducted in greenhouse, Polytechnic of Lamandau, Central Borneo, Indonesia, at an altitude of 50 m above sea level. The research used a non-factorial design arranged in a completely randomized block design and five fertilizer treatments based on the minus one element technique consisting of control (without fertilization), PK, NP, NK, and NPK with three replications. The results showed that the deficiency of nitrogen, potassium, and phosphorus reduced the growth of maize, leaf greenness, photosynthetic rate, and especially the total dry weight of the plant. The dry weight of maize roots decreased by 18.85% - 75.47% when N, P, and K fertilizer were not applied. Then the decrease in photosynthesis rate ranged from 18.23% to 46.21% when N, P, and K fertilizer were not applied. The low of photosynthesis rates resulted in the accumulation of plant dry weight was hampered, and there was a decrease of 8.00% -74.43%. The results of the evaluation of fertility status are based on the results of the relative dry weight of the plant, which was <80% in the PK and NP fertilization treatments, meaning that nitrogen and potassium were deficient in the soil.

Keywords: Nutrient deficiency, Nitrogen, Phosphorus, Potassium, Soil

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1. Introduction

Maize is one of the most important food commodities after rice because it has a strategic role in agricultural and economic development in the world, especially in developed countries. Maize is included in multipurpose commodities (4F) for food, feed, fuel, and fiber (Shiferaw et al., 2011; Law-Ogbomo and Ekunwe, 2011; Mardhiana et al., 2021). Maize production in Indonesia has had an increasing trend since 2010-2018 with total national production in 2018 reaching 30.25 million tones. However, maize production decreased in 2019 by 25% to 22.59 million tons and production decreased again by 0.38% in 2020 (FAO, 2022). One of the factors influencing the decline in national maize production is the level of soil fertility (Dawar et al., 2022).

Soil fertility in optimizing maize productivity is related to the availability of nutrients in the soil. By the right balance of nutrients soil, that is support the healthy growth and development of maize, leading to higher productivity and maximizing yield (Yessoufou et al., 2023). Insufficient soil nutrient can have detrimental effects on plant (Öner and Demirkıran, 2023). Without an adequate of nutrients, maize may experience stunted growth, resulting in lower yields (Aliyu et al., 2021; Putra and Ismoyojati, 2021). In previous studies found that insufficient soil nutrients such as N, P, K can reduce the physiological conditions and growth of maize (Studer et al., 2017; Basal and Szabo, 2020). These deficiencies manifest through symptoms such as yellowing or discoloration of leaves, stunted growth, decreased photosynthesis rate, decreased biomass and yield (Ding et al., 2005; Jezek et al., 2015; Attia et al., 2022). To deal with the latter issue, soil nutrient testing can be carried out before the maize cultivation is carried out on the field. Determining the level of nutrient availability in the soil requires soil analysis in the laboratory. However, soil analysis requires high costs, and farmers do not have access to soil analysis, so practical techniques are needed to be adopted by farmers in the analysis of soil nutrients status (O'Connell and Osmond, 2022). A method that can be used to analyze soil nutrients status developed by the Philippine Rice Research Institute, namely the minus one element technique (MOET) (Magahud et al., 2019).

MOET is easy to perform, providing a user-friendly method for assessing soil nutrients status. MOET can be conducted in areas where soil testing laboratories are not available. Its effectiveness is comparable to soil lab analysis. In the previous study, Cagasan et al. (2020) found that rice fields in Central Luzon State University were deficient in nitrogen and sulfur after conducting MOET. Azhiri-Sigari et al. (2003) also used MOET to evaluate 118 rice fields in the Philippines and found 60% were deficient in nutrients, especially nitrogen, phosphorus, and potassium in Ifugao rice field. Because these advantages make MOET a practical and reliable option for farmers seeking cost-effective and accessible soil diagnostic solutions. However, so far, no scientific researchers have conducted soil tests using MOET on maize fields. Maize is generally planted in dry land while rice is in wet land. Dry land and wet land have different physical, chemical and biological characteristics (Mujiyo et al., 2022). Then the nutritional needs of maize and rice plants are also different (Yin et al., 2019; Berge et al., 2021; Nasseri, 2021). It is estimated that these differences will affect the effectiveness of soil nutrient status analysis using MOET on maize fields. Therefore, a study is needed to try to test soil nutrients using MOET. Overall, this study was carried out to confirm the nutrient soil status using the minus one element technique (MOET) with the early growth of maize as the indicator.

2. Materials and Methods

2.1. Experimental Site

The research was conducted in greenhouse at Polytechnic of Lamandau, Central Borneo, Indonesia at an altitude of 50 m above sea level. The average minimum and maximum temperatures in greenhouse were 21 °C and 35.8 °C respectively, and the average relative humidity in greenhouse was 73% during the experimental period of March to April 2021.

2.2. Experimental Design

The study used a non-factorial design arranged in a completely randomized block design. The study used five fertilization treatments with three replications based on the minus one element technique using maize cultivar (cv. Bisi-2) as a plant indicator. The soil used is soil on former oil palm plantations taken at a depth of 20 cm (top soil). Then the soil was put into pots with a size of 15 cm x 30 cm, each experimental plot consisted of 5 pots so that the total pots used were 75 pots. The fertilizers used in this study were urea as a source of nitrogen, SP36 as a source of phosphorus, and KCl as a source of potassium (*Table 1*).

Table 1. Treatment fertilizer with minus one element test (MOET) method

Treatment	Fertilizer Dosage (kg. ha^{-1})*		
	Urea	SP-36	KCl
Without Fertilizer (Control)	0	0	0
PK	0	150	100
NK	350	0	100
NP	350	150	0
NPK	350	150	100

Note: Determination of dosage is based on site-specific fertilizer recommendations in Lamandau, Central Borneo, Indonesia.

2.3. Determination of Leaf Greenness Index and Photosynthesis Rate

A quick and non-destructive method of determining the nutritional status of plants concerning nitrogen is frequently used in agricultural practice (Argenta et al., 2004; Shah et al., 2017). It involves employing an N-Tester or a SPAD-502 optical instrument (Soil and Plant Analysis Development) to measure the intensity of leaf greenness (Uddling et al., 2007). The top four fully formed leaves have a SPAD value. There were three locations where SPAD readings were taken: (a) 1/3, (b), 1/2, and (c) 2/3 of the distance from the leaf base. The average of the SPAD data across all leaves was then calculated (Yuan et al., 2016). In addition, Li-Cor 6400 (USA) machine measured the photosynthesis rate at maximum vegetative stage conditions in all treatments.

2.4. Determination of Biomass

Maize biomass was harvested at silking. At the time of biomass harvesting, leaf area measurements (dm^2) were carried out using the Cl 202 portable leaf area meter. The shoot was divided into two parts: leaf and stalk of maize. It was determined that 80 to 90% of root dry weight is distributed in the top 0 to 20 cm of soil (Osaki et al., 1995; Dwyer et al., 1996), thus determining the sampling depth. The limiting nutrients of soil determined using the method of percent dry weight total relative is used as follows:

$$\%TDW = \frac{\text{TDW on minus one element treatment}}{\text{TDW on completed fertilizer}} \text{x } 100\% \quad \text{(Eq. 1)}$$

Where TDW is total dry weight of plant. If %TDW value was < 80% is classified as deficient for the corresponding nutrient element (Descalsota et al., 2000).

2.5. Data analysis

An analysis of variance (ANOVA) based on a complete randomized design based on ms was used to analyze the observational data obtained. An error rate of 5% was applied to the Excel macro add-ins (DSAASTAT version 1.101), which were further tested with the Tukey HSD test if a significant difference was found after the variance analysis (Onofri and Pannacci, 2014).

3. Results and Discussion

3.1. Root surface area of maize

Based on the evaluating method of the nutrient status using the minus one element technique on the root surface area of maize, it was found that nitrogen was slightly available in the soil, followed by potassium and phosphorus. The results showed that the fertilization of the minus one element technique significantly affected the surface area of maize roots (*Table 2*). *Table 2* showed that the without fertilizer appeared to have the lowest root surface area of maize compared to other treatments, namely 82.06 dm^2. In the NPK, maize's highest root surface area was 334.49 dm^2. NP showed a significant decrease in root surface area of 50.82% compared to NPK.

The maize without potassium will experience a decrease in root surface area between 13.33%-31.17% (Du et al., 2017). NK showed an insignificant decrease in the root surface area of maize, which was only 18.85%. Then when PK was carried out or without nitrogen, it showed a significant decrease in root surface area, namely 59.43%. The crops that are not given nitrogen resulted in a 15%-40% reduction in root surface area (Guo et al., 2022; Chen et al., 2020). This demonstrates how nitrogen can encourage the development of roots. However, too much nitrogen fertilizer treatment prevents the growth of the root surface area. Plant roots are directly affected by the nitrogen in urea (Wang et al., 2019; Yang et al., 2019). Urea in this study contains nitrate, which involves several root

development processes, such as proliferation in the root system (formation of new roots). A study by Saito et al. (2014) shows that nitrogen plays a crucial role in crop development.

Table 2. Root Surface Area (dm^2)

Treatment	Root Surface Area (dm^2)	% Decreased of RSA
Control	82.06 ± 39.47 b	75.47
PK	135.71 ± 6.50 b	59.43
NK	271.43 ± 20.33 a	18.85
NP	164.49 ± 10.32 b	50.82
NPK	334.49 ± 48.03 a	-
C.V. (%)	14.92	
LSD ($P < 0.01$)	80.79	

Note: Based on the Tukey HSD test 0.05, there is no discernible difference between the values in the same column followed by the same letter.

The deficiency of nitrogen and potassium can have detrimental effects on the root surface area of crops, impacting root growth. Research has shown that potassium deficiency inhibits root growth in maize (Guo, 2023). For instance, under potassium deficiency, root length, surface area, and diameter were found to decrease in maize (Du et al., 2017). Similarly, in peanut, nitrogen and potassium deficiencies were shown to affect root growth and development (Li et al., 2021). Additionally, potassium-deficient stress can lead to reductions in root growth and alterations in ion balance, nitrogen metabolism, and photosynthesis in maize (Qu et al., 2011). Furthermore, studies have indicated that changes in nitrogen availability can affect the concentration of amino acids in maize root exudates, potentially influencing transcriptional profiles and root development (Carvalhais et al., 2013).

3.2. Plant height and leaf area of maize

The MOET significantly affected plant height growth (*Figure 1*) and leaf area of maize (*Figure 2*). The application of NPK showed the highest growth of plant height, 164.70 cm (*Figure 1*). When applied with NP without potassium, there was a significant decrease in plant height, 9.64%, compared to NPK. The decrease in plant height due to the absence of potassium in the soil occurred in the study of Amanullah et al. (2016) and Kandil et al. (2020), which is 4.67%-6.21%. The deficiency of potassium in plants significantly impacts their growth, particularly in terms of height. Potassium is a crucial macronutrient that plays a vital role in various physiological processes, including photosynthesis, enzyme activation, and water regulation within plant cells (Thornburg et al., 2020). A deficiency in potassium may result in stunted growth, reduced leaf size, and, ultimately, a decrease in overall plant height (Hasanuzzaman et al., 2018). Research has shown that potassium deficiency leads to a reduction in plant height due to its essential role in cell elongation and division. For instance, noted that the application of potassium, particularly in conjunction with low-use elements, significantly enhances plant height, suggesting that potassium is critical for optimal growth conditions (Aghdam, 2023). Similarly, found that increasing potassium levels positively correlated with the height of kenaf plants, indicating that adequate potassium supply is essential for achieving maximum growth potential (Salih et al., 2014).

The application of NK showed an insignificant decrease in plant height, namely 1.82%, compared to the application of NPK. At the time of application of PK, there was a significant decrease in plant height, namely 23.19%, compared to NPK. Then when not given fertilizer, there was a significant decrease in plant height compared to NPK which was 35.90%. This follows the opinion of Law-Ogbomo and Law-Ogbomo (2009) and Ahmadu et al. (2020) that the plant provides better plant height growth when given NPK. The deficiency of nitrogen and phosphorus in plants significantly reduces plant height, impacting overall growth and development. Both nutrients play critical roles in various physiological processes essential for plant health. A study by demonstrated that nitrogen deficiency leads to decreased crop height, leaf area, and overall biomass in wheat plants, indicating that insufficient nitrogen directly hampers vegetative growth (Liu et al., 2020). Furthermore, highlighted that early-season nitrogen deficiencies can slow down plant maturity and growth rates, leading to shorter plants (Zhang et al., 2010). Additionally, research on maize indicated that phosphorus deficiency resulted in shorter plant heights and reduced leaf area index, as phosphorus enhances root development and nutrient absorption (Khaleeq, 2023).

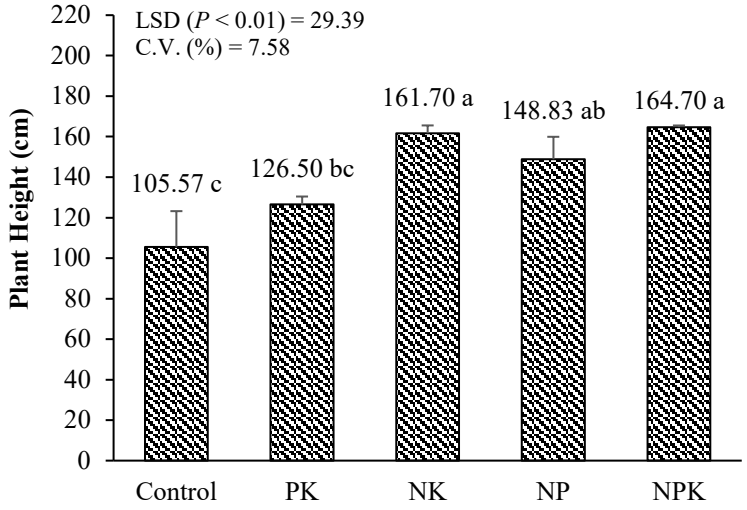

Figure 1. Plant height of maize

The variable leaf area of maize showed that NPK was able to form the highest leaf area of maize compared to other fertilization, namely 1,234.77 dm^2 (Figure 2). However, when NP was given, the plant leaf area decreased significantly compared to the NPK of 33.08%. The application of NK without phosphorus experienced a significant decrease in the leaf area of maize compared to NPK of 14.67%. Then when given PK and control (without fertilizer), the leaf area of maize experienced a very significant decrease compared to NPK which was 48.54% and 75.28%, respectively. The growth of the leaf area of maize is very sensitive to nutrient deficiency. The deficiency of nitrogen, potassium, and phosphorus in plants leads to a significant reduction in leaf area, which adversely affects overall plant health and productivity. Each of these nutrients plays a distinct yet interconnected role in leaf development and expansion. Research has shown that nitrogen deficiency results in a marked decrease in leaf area. nitrogen deficiency often leads to the redistribution of nitrogen from older leaves to younger parts, which can reduce the photosynthetic capacity of lower leaves, further contributing to decrease leaf area (Živčák et al., 2014). Then, potassium deficiency has been linked to reduced leaf area and chlorosis, as it impairs the plant's ability to maintain turgor pressure and conduct photosynthesis effectively (Song, 2023). And research has shown that potassium and phosphorus deficient plants exhibit dwarfing and a decrease in leaf area, which ultimately inhibits growth and yield (Kavanová et al., 2008; Song, 2023). The decrease in leaf area of crop reached 97.08% when NPK was not given (Law-Ogbomo and Law-Ogbomo, 2009).

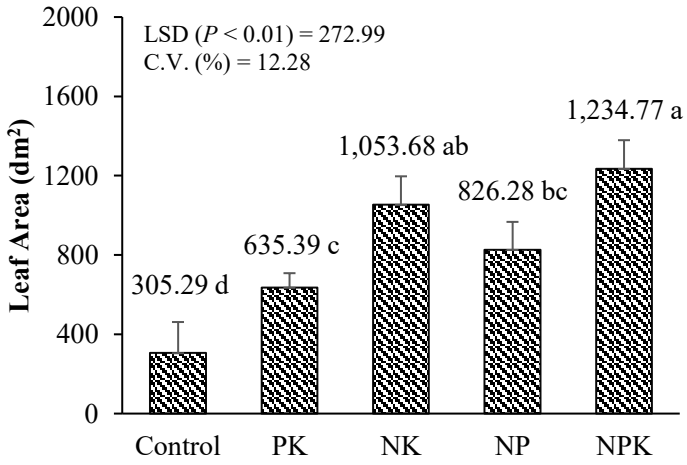

Figure 2. Leaf area of maize

3.3. Leaf greenness index and photosynthetic rate

The leaf greenness index in maize under all treatments MOET significantly decreased when compared to the NPK (*Figure 3*). About 18.18% - 62.01% leaf greenness index decreased due to missing nutrients like N, P, and K than NPK. The highest decrease in the leaf greenness index was found in maize leaves with PK, namely 62.01%. For maize, leaf chlorophyll content, biomass yield, and yield observations are linearly correlated with the leaf greenness index (SPAD) (Rostami et al., 2008; Kandel, 2020). Chlorophyll content has a connection to plant nitrate nutrition and can be used as a timely and accurate indication of crop nitrate nutrient status (Cendrero-Mateo et al., 2015). According to Wu et al. (2019), N stress may have harmed internal chloroplast structure and reduced chlorophyll concentration, leaving plants more susceptible to light damage. In our experiments, PK significantly decreased the chlorophyll contents.

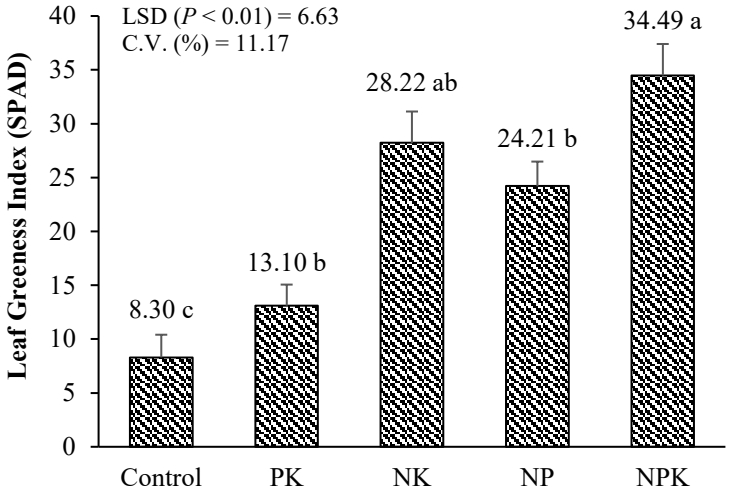

Figure 3. Leaf greenness Index of maize

In NK and NP, the leaf greenness Index decreased by 18.18% and 29.81%. A by product of photosynthesis, ATP, is produced through phosphate metabolism, catalyzed by potassium (Wang and Wu, 2013). A drop in leaf greenness Index was anticipated in the absence of N and K. Due to low chlorophyll content, crop leaves capacity to receive and transmit light was compromised under low N and K levels, inhibiting photosynthesis (Rey-Caramés et al., 2016).

Maize photosynthetic rate was higher when it received NPK than when just one nutrient element was absent (*Figure 4*). When nutrients like N, P, and K are lacking, the photosynthetic rate decreases by about 18.23% to 46.21% compared to NPK. With the PK, maize showed the greatest reduction in photosynthetic rate (42.61%). The deficiency of nitrogen in plants leads to a significant decrease in the photosynthetic rate, which can be attributed to several physiological and biochemical mechanisms. Nitrogen is a fundamental component of chlorophyll, the pigment responsible for capturing light energy during photosynthesis, and it is also a critical element in the structure of various proteins, including those involved in the photosynthetic process (Han, 2011). Low N stress impacted leaf N concentration, reducing the photosynthetic rate (Hiratsuka et al., 2015). This observation aligns with the findings of, who reported that higher nitrogen fertilization levels corresponded with increased net photosynthetic rates in wheat, indicating that nitrogen availability is crucial for maintaining optimal photosynthetic activity (Olszewski et al., 2014; Mu et al., 2017). Similarly, demonstrated that N deficiency in sweetpotato resulted in decreased chlorophyll content, which was linked to reduced photosynthesis (Meng et al., 2015). The decrease in pigment contents, particularly chlorophyll, is a critical factor contributing to the decline in photosynthetic activity following nitrogen deficiency (Zhao et al., 2017).

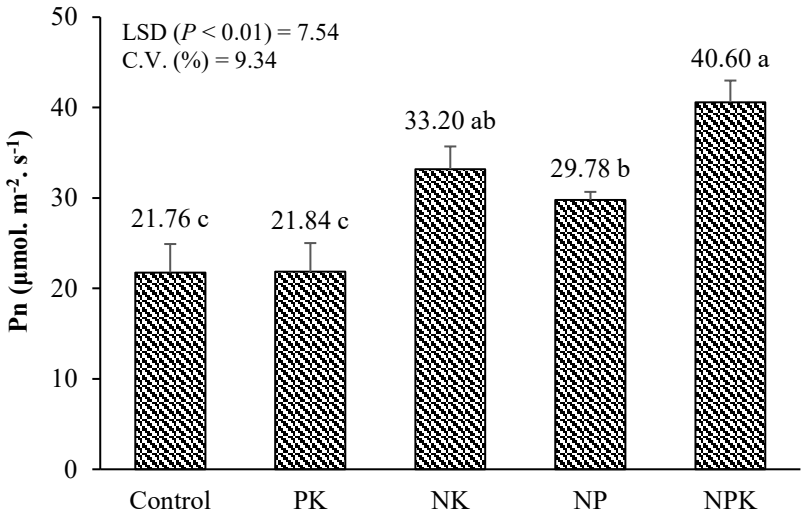

Figure 4. Photosynthetic rate of maize

In the NK and NP, the photosynthesis rate decreased by 18.23% and 26.65%. Haque et al. (2019) explained that there was a decrease in the rate of photosynthesis of 10-28% when plants experienced a shortage of macronutrients. The soil's nutrient ratios are altered when a certain nutrient is missing, causing plants to experience either excess or deficiency and diminished physiological activity (Veazie et al., 2020; Wu et al., 2019). So, depending on the absent elements, we have discovered varying photosynthetic rates. The photosynthetic rate was also boosted by adding the missing nutritional element (Haque et al., 2019).

3.4. Biomass dry weight of maize

The results showed that the MOET significantly affected root dry weight, stem dry weight, leaf dry weight, and total dry weight of maize (*Table 3*). The NPK showed the highest root dry weight, stem dry weight, leaf dry weight, and total dry weight of maize. This is after the reduction of one nutrient in the fertilization process, the dry weight of maize decreases. A significant decrease in total dry weight occurred in the PK, which was 58.55% of the total dry weight of the NPK. Cagasan et al. (2020) showed that in the deficiency nitrogen, the dry weight of the plant declined up to 70% from the NPK. This is related to soils lacking nitrogen which will directly affect the form of dry matter in plants during the vegetative phase. The deficiency of N, P, K significantly decreases the biomass dry weight of plants, which is a critical indicator of overall plant health and productivity. Each of these macronutrients plays a vital role in various physiological processes that contribute to biomass accumulation (Khan et al., 2023; El-Sheekh et al., 2024). The combined deficiency of N, P, K creates a compounded effect that severely limits biomass accumulation. It finds that the interaction of these nutrients are critical for maximizing growth and biomass efficiency, as deficiencies in any of these macronutrients can lead to significant reductions in plant dry weight (Akgül and Akgül, 2022). Furthermore, indicated that nutrient deficiencies impact crop yield and quality, emphasizing the necessity of balanced fertilization for optimal biomass production (Sobhana et al., 2022).

Table 3. The dry weight of maize biomass (g)

Treatment	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Total Dry Weight (g)
Control	2.17 ± 1.05 c	5.86 ± 3.73 b	3.62 ± 1.76 c	11.62 ± 6.51 b
PK	3.52 ± 0.64 bc	9.07 ± 1.07 b	6.24 ± 1.53 bc	18.84 ± 3.03 b
NK	9.01 ± 1.41 ab	20.58 ± 1.65 a	12.16 ± 1.10 a	41.81 ± 3.63 a
NP	6.01 ± 2.73 abc	13.94 ± 4.99 ab	9.24 ± 2.94 ab	29.18 ± 10.48 ab
NPK	10.66 ± 3.76 a	20.92 ± 5.46 a	13.87 ± 0.81 a	45.45 ± 9.35 a
C.V. (%)	31.47	27.21	18.88	23.19
LSD ($P < 0.01$)	5.41	10.49	4.67	18.67

Note: Based on the Tukey HSD test 0.05, there is no discernible difference between the values in the same column followed by the same letter.

3.5. Evaluation of soil nutrient status with biological yield

Based on the estimation of soil fertility in *Table 4*, it is clear that the control and PK was only able to form a total dry weight of 25.56% and 41.45% compared to the NPK. Then the NP and NK formed a total dry weight of 64.20% and 91.99%, respectively. The MOET method results show that the soil in Lamandau is deficient in nitrogen and potassium. Because the total plant dry weight relative value of maize without nitrogen (PK) and potassium (NP) is less than 80%. In contrast, maize without phosphorus (NK) has a total plant dry weight relative value is more than 80%. Descalsota et al. (2000) believe that if the total dry weight relative value is less than 80%, the soil is deficient in a nutrient element.

Table 4. Biological soil nutrient status based on maize biomass

Treatment	Total Dry Weight (g)	%TDW	Criteria*
Control	11.62	25.56	Deficient
PK	18.84	41.45	Deficient
NK	41.81	91.99	Undeficient
NP	29.18	64.20	Deficient
NPK	45.45	100.00	-

4. Conclusions

In conclusion, nutrient deficiency causes decreased plant growth, such as root growth area, plant height, leaf area, and dry weight of maize plant biomass. PK and NP fertilizers resulted in a total plant dry weight of 41.45% and 64.20%, respectively. Then NK fertilizer resulted in a total plant dry weight relative to 91.99%. Based on this, the fertility status of soil in Lamandau Regency is a deficiency of nitrogen (N) and potassium (K) because the total dry weight of the relative plants that are not given nitrogen (N) and potassium (K) fertilizers is <80%. Future research by confirming the soil test method with MOET in maize fields is compared with the results of laboratory analysis and observing N, P, and K uptake in maize so that the MOET method becomes more valid for the development of maize yield.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Putra, F.P.; Design: Putra, F.P., Sas, M.G.A.; Data Collection or Processing: Putra, F.P., Sas, M.G.A., Rosyida, R.; Statistical Analyses: Putra, F.P., Subrata, B.A.G.; Literature Search: Putra, F.P., Subrata, B.A.G., Rosyida, R.; Writing, Review and Editing: Putra, F.P., Subrata, B.A.G., Sas, M.G.A.

References

Aghdam, M. (2023). The effect of stopping irrigation, potassium and low consumption elements on growth indicators of fodder corn. *Nutrition and Food Processing*, 6(3): 01-07. https://doi.org/10.31579/2637-8914/126

Ahmadu, R., Law-Ogbomo, K. E. and Ogedegbe, S. A. (2020). Comparative effects of some soil amendments on the agronomic performance of maize varieties in a low fertile soil. *Notulae Scientia Biologicae*, 12(1): 189-195. https://doi.org/10.15835/nsb12110529

Akgül, F. and Akgül, R. (2022). Combined effect of nitrogen and phosphorus on growth and biochemical composition of *Tetradesmus obliquus* (turpin) m.j. wynne. *International Journal of Secondary Metabolite*, 9(4): 525-537. https://doi.org/10.21448/ijsm.1102592

Aliyu, K. T., Huising, J., Kamara, A. Y., Jibrin J. M., Mohammed, I. B., Nziguheba, G., Adam, A. M. and Vanlauwe, B. (2021). Understanding nutrient imbalances in maize (*Zea mays* L.) using the diagnosis and recommendation integrated system (DRIS) approach in the Maize belt of Nigeria. *Scientifc Reports*, 11: 16018. https://doi.org/10.1038/s41598-021-95172-7

Amanullah, Iqbal, A., Irfanullah and Hidayat, Z. (2016). Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. *Scientific Reports*, 6(34627): 1-12. https://doi.org/10.1038/srep34627.

Argenta, G., Regis Ferreira da Silva, P. and Sangoi, L. (2004). Leaf relative chlorophyll content as an indicator to predict nitrogen fertilization in maize. *Ciencia Rural*, 34: 1379–1387.

Attia, H., Rebah, F., Ouhibi, C., Saleh, M. A., Althobaiti, A. T., Alamer, K. H., Ben Nasri, M. and Lachaâl, M. (2022). Effect of potassium deficiency on physiological responses and anatomical structure of basil *Ocimum basilicum L. Biology*, 11: 1557. https://doi.org/10.3390/biology11111557

Azhiri-Sigari, T., Gines, H. C., Casimero, M. C. and Sebastian, L. S. (2003). Soil fertility status of Philrice Ces Ricefields in Maligaya, Nueva Ecija by soil analysis & minus-one-element technique (MOET). *Philippine Journal of Crop Science*, 28(3): 31-47.

Basal, O. and Szabo, A. (2020). Yield and quality of two soybean cultivars in response to drought and N fertilization. *Journal of Tekirdag Agricultural Faculty*, 17(2): 203-210.

Berge, H. F. M., Hijbeekb, R., van Loonb, M. P., Rurindac, J., Tesfayed, K., Zingorec, S., Craufurde, P., van Heerwaardenb, J., Brentrupf, F., Schrödera, J. J., Boogaardg, H. L., de Grootg, H. L. E. and van Ittersum, M. K. (2019). Maize crop nutrient input requirements for food security in sub-Saharan Africa. *Global Food Security,* 23: 9-21. https://doi.org/10.1016/j.gfs.2019.02.001

Cagasan, U. A., Libre, M. J. P., Santiago, D. A., Cantoneros, J. A., Tumaca, C. M., Pablo, A. and Hamora, G. A. (2020) Assessment on the nutrient status of lowland rice soil using minus one element technique (MOET). *Eurasian Journal of Agricultural Research*, 4(1): 56-63.

Carvalhais, L., Dennis, P., Fan, B., Fedoseyenko, D., Kierul, K., Becker, A. and Borriss, R. (2013). Linking plant nutritional status to plant-microbe interactions. *Plos One,* 8(7): e68555. https://doi.org/10.1371/journal.pone.0068555

Cendrero-Mateo, M. P., Moran, M. S., Papuga, S. A., Thorp, K. R., Alonso, L., Moreno, J., Ponce-Campos, G., Rascher, U. and Wang, G. (2015). Plant chlorophyll fluorescence: Active and passive measurements at canopy and leaf scales with different nitrogen treatments. *Journal of Experimental Botany*, 67: 275–286.

Chen, J., Liu, L., Wang, Z., Zhang, Y., Sun, H., Song, S., Bai, Z., Lu, Z. and Li, C. (2020). Nitrogen fertilization increases root growth and coordinates the root–shoot relationship in cotton. *Frontiers in Plant Science,* 11(880): 1-13. https://doi.org/10.3389/fpls.2020.00880.

Dawar, K., Khan, A., Mian, I. A., Khan, B., Ali, S. and Ahmad, S. (2022). Maize productivity and soil nutrients variations by the application of vermicompost and biochar. *PLoS ONE*, 17(5): e0267483. https://doi.org/10.1371/journal.pone.0267483

Ding, L., Wang, K. J., Jiang, J. M., Biswas, D. K., Xu, H., LI, L. F. and LI, Y. H. (2005). Effects of nitrogen deficiency on photosynthetic traits of maize hybrids released in different years. *Annals of Botany*, 96(5): 925–930. https://doi.org/10.1093/aob/mci244

Du, Q., Zhao, X., Jiang, C., Wang, X., Han, Y., Wang, J. and Yu, H. (2017). Effect of potassium deficiency on root growth and nutrient uptake in maize (*Zea mays* L.). *Agricultural Sciences*, 08(11): 1263-1277. https://doi.org/10.4236/as.2017.811091

Descalsota, J. P., Mamaril, C. P., San Valentin, G. O., Corton, T. M. and Obien, S. R. (2000). Biological Method for Diagnosis of Nutrient Limitations and Balancing Fertilizer Application to Lowland Rice Soils. *Bureau of Agricultural Research 12th National Research Symposium*, Oct 4-5.

Dwyer, L. M., Ma, B. L., Stewart, D. W., Hayhoe, H. N. and Balchin, D. (1996). Root mass distribution under conventional and conservation tillage. *Canadian Journal of Soil Science*, 76: 23–28.

El-Sheekh, M. M., Galal, H. R. and Mousa, A. S. H. (2024). Impact of macronutrients and salinity stress on biomass and biochemical constituents in *Monoraphidium braunii* to enhance biodiesel production. *Scientific Reports,* 14: 2725. https://doi.org/10.1038/s41598-024-53216-8.

FAO (2022). FAOSTAT: Production: Crops and livestock products. In: FAO. Rome. Cited December 2022. https://www.fao.org/faostat/en/#data/QCL

Guo, S., Liu, Z., Zhou, Z., Lu, T., Chen, S., He, M., Zeng, X., Chen, K., Yu, H. and Shangguan, Y. (2022). Root system architecture differences of maize cultivars affect yield and nitrogen accumulation in southwest china. *Agriculture*, 12 (209): 1-14. https://doi.org/10.3390/agriculture12020209

Guo, S. (2023). Dynamic transcriptome analysis unravels key regulatory genes of maize root growth and development in response to potassium deficiency. *Planta*, 258: 99 https://doi.org/10.1007/s00425-023-04260-7.

Han, Q. M. (2011). Height-related decreases in mesophyll conductance, leaf photosynthesis and compensating adjustments associated with leaf nitrogen concentrations in *Pinus densiflora*. *Tree Physiology*, 31: 976–984.

Haque, M. M., Sha, A. L., Biswas, J. C., Islam, M. R., Islam, A. and Naher, U. A. (2019). Effect of missing nutrient elements on grain yield of wet season rice in Bangladesh. *American Journal of Plant Sciences*, 10: 631-639. https://doi.org/10.4236/ajps.2019.104046

Hasanuzzaman, M., Bhuyan, M. H. M. B., Nahar, K., Hossain, M. S., Mahmud, J. A., Hossen, M. S., Masud, A. A. C. and Moumita, Fujita, M. (2018). Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy*, 8: 31. https://doi.org/10.3390/agronomy8030031

Hiratsuka, S., Suzuki, M., Nishimura, H. and Nada, K. (2015). Fruit photosynthesis in Satsuma mandarin. *Plant Science*, 241: 65–69.

Jezek, M., Geilfus, C. M., Bayer, A. and Mühling, K. H. (2015). Photosynthetic capacity, nutrient status, and growth of maize (*Zea mays* L.) upon MgSO4 leaf-application. *Frontiers in Plant Science,* 5: 781. https://doi.org/10.3389/fpls.2014.00781

Kavanová, M., Lattanzi, F. and Schnyder, H. (2008). Nitrogen deficiency inhibits leaf blade growth in *Lolium perenne* by increasing cell cycle duration and decreasing mitotic and post-mitotic growth rates. *Plant Cell & Environment*, 31(6): 727-737. https://doi.org/10.1111/j.1365-3040.2008.01787.x

Kandel, B. P. (2020). SPAD value varies with age and leaf of maize plant and its relationship with grain yield. *BMC Research Notes*, 13: 475. https://doi.org/10.1186/s13104-020-05324-7

Kandil, E. E., Abdelsalam, N. R., Mansour, M. A., Ali, H. M. and Siddiqui, M. H. (2020). Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth and production. *Scientific Reports*, 10(8752): 1-11. https://doi.org/10.1038/s41598-020-65749-9

Khaleeq, K. (2023). Response of maize (*Zea mays* L.) to the soil application of phosphorus fertilizer. *Journal of Agriculture and Ecology*, 17: 90-93. https://doi.org/10.58628/jae-2317-316

Khan, F., Siddique, A. B., Shabala, S., Zhou, M. and Zhao, C. (2023). Phosphorus plays key roles in regulating plants' physiological responses to abiotic stresses. *Plants*, 12: 2861. https://doi.org/10.3390/plants12152861

Law-Ogbomo, K. E. and Law-Ogbomo, J. E. (2009). The performance of *Zea mays* as influenced by NPK fertilizer application. *Notulae Scientia Biologicae,* 1(1): 59-62. https://doi.org/10.15835/nsb113459.

Law-Ogbomo, K. E. and Ekunwe, P. A. (2011). Economic yield and profitability of maize/melon intercrop as influenced by inorganic fertilizer application in humid forest ultisol. *Notulae Scientia Biologicae*, 3(4): 66–70. https://doi.org/10.15835/nsb346309

Li, L., Li, Q., Davis, K., Patterson, C., Oo, S., Liu, W. and Zhang, B. (2021). Response of root growth and development to nitrogen and potassium deficiency as well as microrna-mediated mechanism in peanut (*Arachis hypogaea* L.). *Frontiers in Plant Science*, 12: 695234. https://doi.org/10.3389/fpls.2021.695234

Liu, X., Yin, C., Li, X., Jiang, W. and Xu, S. (2020). Transcription strategies related to photosynthesis and nitrogen metabolism of wheat in response to nitrogen deficiency. *BMC Plant Biology*, 20: 448. https://doi.org/10.1186/s12870-020-02662-3

Magahud, J. C., Dalumpines, S. L. P., Lincuna, A. E. and Estoy, G. F. (2019). Growth of rice, PSB Rc 82, and status of nutrients in lowland Agusan soil under alternate wetting and drying and minus-one-element conditions. *Philippine Science Letters,* 12(2): 107-121.

Mardhiana, M., Apriyani, D., Adiwena, M. and Pradana, A. P. (2021). Growth and yield performance of maize at red-yellow podzolic acid soil after oil palm empty fruit bunches compost and rice husk charcoal application. *Journal of Degraded Mining Lands Management,* 8(2): 2653-2660. https://doi.org/10.15243/jdmlm.2021.082.2653

Meng, W., Zhang, A., Li, H., Tang, Z. and Chen, X. (2015). Growth and physiological response to nitrogen deficiency and re-supply in leaf-vegetable sweetpotato (*Ipomoea batatas* Lam). *Hortscience*, 50(5): 754-758. https://doi.org/10.21273/hortsci.50.5.754

Mu, X., Chen, Q., Chen, F., Yuan, L. and Mi, G. (2017). A rna-seq analysis of the response of photosynthetic system to low nitrogen supply in maize leaf. *International Journal of Molecular Sciences*, 18(12): 2624. https://doi.org/10.3390/ijms18122624

Mujiyo, M., Puspito, G. J., Suntoro, S., Rahayu, R. and Purwanto, P. (2022). The effect of change in function from paddy field to dry land on soil fertility index. *Environment and Natural Resources Journal,* 20(1): 42-50. https://doi.org/10.32526/ennrj/20/202100127

Nasseri, A. (2021). Long-term water productivity of maize (*Zea mays* L.) from limited irrigation conditions under moderate semi-arid environment. *Journal of Tekirdag Agricultural Faculty*, 18(3): 400-410.

O'Connell, C. and Osmond, D. L. (2022). Why soil testing is not enough: A mixed methods study of farmer nutrient management decision-making among U.S. producers. *Journal of Environmental Management,* 314: 115017. https://doi.org/10.1016/j.jenvman.2022.115027

Olszewski, J., Makowska, M., Pszczółkowska, A., Okorski, A. and Bieniaszewski, T. (2014). The effect of nitrogen fertilization on flag leaf and ear photosynthesis and grain yield of spring wheat. *Plant Soil and Environment*, 60(12): 531-536. https://doi.org/10.17221/880/2013-pse

Öner, N. and Demirkıran, A. R. (2023). The effect of decreasing or increasing of the fertilizer amount on sunflower yield, nutrient contents and fertilizer costs. *Journal of Agriculture*, 6(2): 155-164. https://doi.org/10.46876/ja.1400564

Onofri, A. and Pannacci, E. (2014). Spreadsheet tools for biometry classes in crop science programmes. *Communications in Biometry and Crop Science*, 9(2): 3–13.

Osaki, M., Shinano, T., Matsumoto, M., Ushiki, J. and Shinano, M. M. (1995). Productivity of high-yielding crops. V. Root growth and specific absorption rate of nitrogen. *Soil Science and Plant Nutrition*, 41: 635–647.

Putra, F. P. and Ismoyojati, R. (2021). Monitoring of maize root growth on N, P, and K fertiliztion using rhizotron. *Jurnal Ilmiah Pertanian*, 17(2): 74-79. https://doi.org/10.31849/jip.v17i2.5748

Qu, C., Liu, C., Ze, Y., Gong, X., Hong, M., Wang, L. and Hong, F. (2011). Inhibition of nitrogen and photosynthetic carbon assimilation of maize seedlings by exposure to a combination of salt stress and potassium-deficient stress. *Biological Trace Element Research*, 144(1-3): 1159-1174. https://doi.org/10.1007/s12011-011-9037-6

Rey-Caramés, C., Tardaguila, J., Sanz-Garcia, A., Chica-Olmo, M. and Diago, M. P. (2016). Quantifying spatio-temporal variation of leaf chlorophyll and nitrogen contents in vineyards. *Biosystems Engineering*, 150: 201–213.

Rostami, M., Koocheki, A. R., Mahallati, M. N. and Kafi, M. (2008). Evaluation of chlorophyll mater (SPAD) data for prediction of nitrogen status in corn (*Zea mays L.*). *American Eurasian Journal of Agricultural and Environmental Sciences*, 3: 79–85.

Saito, A., Tanabata, S., Tanabata, T., Tajima, S., Ueno, M., Ishikawa, S., Ohtake, N., Sueyoshi, K. and Ohyama, T. (2014). Effect of nitrate on nodule and root growth of soybean (*Glycine max (L.) merr.*). *International Journal of Molecular Sciences,* 15(3): 4464-4480. https://doi.org/10.3390/ijms15034464

Salih, R., Abdan, K. and Wayayok, A. (2014). Growth responses of two kenaf varieties (*Hibiscus cannabinus* L.) applied by different levels of potassium, boron and zinc. *Journal of Agricultural Science*, 6(9): 37-45. https://doi.org/10.5539/jas.v6n9p37

Shah, S. H., Houborg, R. and McCabe, M. F. (2017). Response of chlorophyll, carotenoid and SPAD-502 measurement to salinity and nutrient stress in wheat (*Triticum aestivum* L.). *Agronomy*, 7: 61.

Shiferaw, B., Prasanna, B.M., Hellin, J. and Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security,* 3: 307–327. https://doi.org/10.1007/s12571-011-0140-5

Sobhana, M., Vallabhaneni, R., Vasireddy, T. and Polavarpu, D. (2022). Deep ensemble mobile application for recommendation of fertilizer based on nutrient deficiency in rice plants using transfer learning models. *International Journal of Interactive Mobile Technologies*, 16(16): 100-112. https://doi.org/10.3991/ijim.v16i16.31497

Song, J. (2023). How to diagnose potassium abundance and deficiency in tomato leaves at the early cultivation stage. *Horticulturae,* 9(11): 1225. https://doi.org/10.3390/horticulturae9111225

Studer, C., Hu, Y. and Schmidhalter, U. (2017). Interactive effects of N-, P- and K-nutrition and drought stress on the development of maize seedlings. *Agriculture,* 7: 90. https://doi.org/10.3390/agriculture7110090

Thornburg, T. E., Liu, J., Li, Q., Xue, H., Wang, G., Li, L., Fontana, J. E., Davis, K. E., Liu, W., Zhang, B., Zhang, Z., Liu, M. and Pan, X. (2020). Potassium deficiency significantly affected plant growth and development as well as microRNA-Mediated mechanism in wheat (*Triticum aestivum* L.). *Frontiers in Plant Science,* 11:1219. https://doi.org/10.3389/fpls.2020.01219

Uddling, J., Gelang-Alfredsson, J., Piikki, K. and Pleijel, H. (2007). Evaluation of the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynthesis Research*, 91: 37–46.

Veazie, P., Cockson, P., Henry, J., Perkins-Veazie, P. and Whipker, B. (2020). Characterization of nutrient disorders and impacts on chlorophyll and anthocyanin concentration of *Brassica rapa* var. *Chinensis. Agriculture*, 10: 461. https://doi.org/10.3390/agriculture10100461

Wang, Y., Zhang, X., Chen, J., Chen, A., Wang, L., Guo, X., Niu, Y., Liu, S., Mi, G. and Gao, Q. (2019). Reducing basal nitrogen rate to improve maize seedling growth, water and nitrogen use efficiencies under drought stress by optimizing root morphology and distribution. *Agricultural Water Management,* 212: 328-337. https://doi.org/10.1016/j.agwat.2018.09.010

Wang, Y. and Wu, W.H. (2013). Potassium transport and signaling in higher plants. *Annual Review of Plant Biology,* 64: 451–476.

Wu, Y., Qiang, L., Rong, J., Wei, C., Xiao-lin, L., Fan-lei, K., Yong-pei, K., Haichun, S. and Ji-chao, Y. (2019). Effect of low-nitrogen stress on photosynthesis and chlorophyll fluorescence characteristics of maize cultivars with different low nitrogen tolerance. *Journal of Integrative Agriculture*, 18(6): 1246–1256. https://doi.org/10.1016/S2095-3119(18)62030-1

Yang, J. T., Schneider, H. M., Brown, K. M. and Lynch, J. P. (2019). Genotypic variation and nitrogen stress effects on root anatomy in maize are node specific. *Journal of Experimental Botany*, 70(19): 5311-5325. https://doi.org/10.1093/jxb/erz293

Yessoufou, M. W. I. A., Tovihoudji, P. G., Zakari, S., Adjogboto, A., Djenontin, A. J. and Irenikatche Akponikpe, P. B. I. (2023). Hill-placement of manure and fertilizer for improving maize nutrient- and water-use efficiencies in the northern Benin. *Heliyon,* 9:e17823. https://doi.org/10.1016/j.heliyon.2023.e17823.

Yin, Y., Ying, H., Zheng, H., Zhang, Q., Xue, Y. and Cui, Z. (2019). Estimation of NPK requirements for rice production in diverse Chinese environments under optimal fertilization rates. *Agricultural and Forest Meteorology* 279: 107756. https://doi.org/10.1016/j.agrformet.2019.107756.

Yuan, Z., Cao, Q., Zhang, K., Ata-Ul-Karim, S.T., Tian, Y., Zhu, Y., Cao, W. and Liu, X. (2016). Optimal Leaf Positions for SPAD Meter Measurement in Rice. *Frontiers in Plant Science,* 7:719. https://doi.org/10.3389/fpls.2016.00719

Zhang, J., Blackmer, A., Blackmer, T. and Kyveryga, P. (2010). Fertilizer bands affect early growth of corn. *Communications in Soil Science and Plant Analysis,* 41(11): 1306-1314. https://doi.org/10.1080/00103621003759312

Zhao, L., Li, K., Wang, Q., Song, X., Su, H., Xie, B. and Zhang, Y. (2017). Nitrogen starvation impacts the photosynthetic performance of *Porphyridium cruentum* as revealed by chlorophyll a fluorescence. *Scientific Reports*, 7(1): 8542. https://doi.org/10.1038/s41598-017-08428-6

Živčák, M., Olsaovska, K., Slamka, P., Galambošová, J., Rataj, V., Shao, H., Brestič, M. (2014). Measurements of chlorophyll fluorescence in different leaf positions may detect nitrogen deficiency in wheat. *Zemdirbyste-Agriculture*, 101(4): 437-444. https://doi.org/10.13080/z-a.2014.101.056.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Biological Control Agent Bacteria Against Crown Gall*

Kök Kanserine Karşı Biyolojik Mücadele Ajanı Bakterilerin Belirlenmesi

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Abstract

This study was carried out to determine new bioagent bacteria for *in vitro* and semi-*in vivo* biological control of crown gall disease [*Rhizobium radiobacter* (*Agrobacterium tumefaciens*)]. A total of 2012 potential bioagent bacterial strains belonging to different genera were tested *in vitro* against the pathogen. Microbial identification systems (MIS) diagnoses of bioagent bacterial strains found to be effective as a result of *in vitro* tests were supported by some conventional tests. Then, the strains' semi-*in vivo* biocontrol activities found to be effective were tested in carrot slices and squash fruits. Statistical analysis of the data was made according to the percentage of surface coverage in carrot slices and the number and size of tumors in squash fruits. Then, the most effective bioagent and pathogenic bacterial strain diagnoses were determined molecularly. According to the results; 106 bioagent bacterial strains (66 antibiosis; 40 hyperparasitic effects) were found to be effective against *R. radiobacter in vitro* conditions. It was determined that conventional test results of bioagent bacteria and MIS results supported each other. As a result of semi-*in vivo* biocontrol activity, it was determined that 8 bioagent bacterial strains out of 106 bioagent bacterial strains did not produce pectolytic activity, and 8 bioagent bacterial strains could be evaluated as a result of semi-*in vivo* test. The most effective strain suppressing the development of the pathogen in carrot slices and squash fruits was RK 1986 (carrot slices 1.78±0.47; squash fruits 0.26±0.04), followed by RK 570A (carrot slices 2.89±0.82; squash fruits 0.35+0.03) and RK 1074 (carrot slices 3.44±0.99; squash fruits 0.46±0.05) strains were followed. According to the results of molecular identification, the most effective bioagent bacterial strain (RK 1986) was *Bacillus mojavensis*, and the pathogenic bacteria strain (1B) was *R. radiobacter*.

Keywords: *Agrobacterium tumefaciens*, *Bacillus mojavensis,* Biological control, Crown gall, *Rhizobium radiobacter*

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*This study was summarized from the Nasibe Tekiner Aydın PhD thesis.

Öz

Bu çalışma kök kanseri hastalığının [*Rhizobium radiobacter* (*Agrobacterium tumefaciens*)] *in vitro* ve yarı *in vivo* testlerle biyolojik mücadelesine yönelik yeni biyoajan bakterilerinin belirlenmesi amacıyla yapılmıştır. Farklı cinslere ait toplam 2012 adet potansiyel biyoajan bakteri straini patojene karşı *in vitro* koşullarda test edilmiştir. *In vitro* test sonucu etkili bulunan biyoajan bakteri strainlerinin mikrobiyal identifikasyon sistem tanıları (MIS) bazı konvansiyonel testler ile desteklenmiştir. Daha sonra etkili bulunan izolatların yarı *in vivo* biyokontrol aktiviteleri havuç dilimi ve kabak meyvesinde test edilmiştir. Havuç dilimlerinde yüzey kaplama yüzdesi kullanılırken, kabak meyvesinde ise ur sayı ve büyüklüğüne göre veriler elde edilmiş ve istatistiki analizi yapılmıştır. Daha sonra en etkili bulunan biyoajan ve patojen bakteri strainlerinin tanıları moleküler olarak belirlenmiştir. Elde edilen bulgulara göre; *R. radiobacter*'e karşı *in vitro* koşullarda 106 adet biyoajan bakteri straini (66 adedi antibiyozis etki; 40 adedi hiperparazitik etki) etkili bulunmuştur. Biyoajan bakterilerin konvansiyonel tanı test sonuçları ile mikrobiyal identifikasyon tanı sonuçlarının birbirini destekler nitelikte olduğu belirlenmiştir. Yarı *in vivo* biyokontrol aktivite test sonucu 106 adet biyoajan bakteri strainden 8 adetinin pektolitik aktivite oluşturmadığı belirlenmiş ve yarı *in vivo* test sonucu 8 adet biyoajan bakteri straini değerlendirilebilmiştir. Havuç dilimi ve kabak meyvesinde patojenin gelişimini baskılayan en etkili strainin RK 1986 (havuç dilimi 1.78±0.47; kabak meyvesi 0.26±0.04) olduğu, onu RK 570A (havuç dilimi 2.89±0.82; kabak meyvesi 0.35±0.03) ve RK 1074 (havuç dilimi 3.44±0.99; kabak meyvesi 0.46±0.05) strainlerinin takip ettiği tespit edilmiştir. Moleküler tanı sonuçlarına göre en etkili olan biyoajan bakteri straini (RK 1986) *Bacillus mojavensis*, patojen bakteri strainin ise (1B) *Rhizobium radiobacter* olduğu kaydedilmiştir.

Anahtar Kelimeler: *Agrobacterium tumefaciens*, *Bacillus mojavensis,* Biyolojik mücadele, Kök kanseri, *Rhizobium radiobacter*

1. Introduction

Rhizobium radiobacter (*Agrobacterium tumefaciens*) is a soil-borne plant pathogen that is common worldwide, is among the top ten bacteria in plant bacterial diseases, and causes crown gall (EPPO, 2019). All virulent agent species have Tumor Inducing Plasmid (Ti), an extrachromosomal structure, except for DNA. Transferring the T-DNA region in the pathogen Ti plasmid to the plant genome, causes the formation of galls in the root and root collar of the plants (140 genera in more than 100 different plant families) (Agrios, 1997; Gupta et al., 2010), causing significant economic losses in seedling cultivation (Frikha-Gargouri et al., 2017).

In the control of crown gall disease, such as using production material without disease (Peluso et al., 2003), choosing tolerant rootstock (Goodman et al., 1993), avoiding injuring the plant (Vrain and Copeman, 1987), paying attention to the disinfection of pruning tools (Cazelles et al., 1991), not planting in heavy and moist soils (Gloyer, 1934), soil solarization and using chemical pesticides (Moore and Canfield, 1996; Gupta and Kamal, 2006). However, disadvantages such as intensive labor, low effect, high cost, and high phytotoxicity have made biological control, an alternative more environmentally friendly method, important (Kotan et al., 2009; Kotan and Tozlu, 2021). Although *R. radiobacter* K-84 and K-1026 are widely used in the biological control against the agent (Moore, 1988), the failure of K-84 and K-1026 in some economically important plants and the limited number of studies makes it necessary to determine different bacterial strains that can be alternative biological control agents showed (Khmel et al., 1998; Tolba and Soliman, 2013). In recent years, extensive research has been carried out to determine different bacterial strains that can be used against crown gall. Accordingly, it has been reported that bacterial genera such as *Pseudomonas*, *Bacillus*, *Brevibacillus*, *Lactobacillus*, *Curtobacterium*, and *Azospirillium* have strains that can control crown gall disease (Zhang et al., 1991; Farrand and Wang, 1992; Moore and Canfield, 1996; Khmel et al., 1998; Rhouma et al., 2004; Gupta and Kamal, 2006; Gupta et al., 2007; Hammami et al., 2008; Dandurishvili et al., 2010; Tolba and Soliman, 2013; Limanska et al., 2015; Abdallah et al., 2018; Bozkurt and Soylu, 2019).

In this study, it was aimed to detect new bioagents for the biological control of crown gall disease *in vitro* and to determine the ability of effective bioagents to suppress tumor formation in semi-*in vivo* conditions.

2. Materials and Methods

2.1. Preparation of microorganisms and cultures

R. radiobacter (1B) strain strain from a peach plant and tested for virulence was used as a pathogen strain (Tekiner Aydın and Kotan, 2022). As a potential bioagent bacterial strain, 2012 strains belonging to 99 bacterial species kept in the Recep Kotan Culture Collection of Atatürk University, Faculty of Agriculture, Department of Plant Protection were tested. Many of these strains have been tested against different plant diseases and pests before or are composed of strains to be used for the first time in this study. Diagnosis of potential bioagent strains has been done by different researchers in microbial identification systems (MIS) (MIDI, Sherlock Microbial Identification System version 4.5 inc., Newark, DE).

Bacterial inoculum was prepared according to Eastwell et al. (2006). Briefly, pure bacterial cultures were grown for 24 hours (h) by transferring them to 250 ml Nutrient Broth (NB). Bacterial cultures were cooled on ice for 30 minutes (min), then centrifuged at 6000 rpm for 15 min and washed 2 times with 0.85% NaCl (saline). Then, their density was adjusted to $1x10^8$ colony forming bacteria milliliter (cfu ml^{-1}) on a spectrophotometer (600 nm) with sterile distilled water (sdH_2O).

2.2. In vitro assay

1B pathogen strain was sown on the entire surface of the Petri dish (90 mm) containing Nutrient Agar (NA) with the help of a swab. Then, potential candidate bioagents were drawn as a single line in the middle of these plates with the help of a loop and the plates were incubated at 27 °C for 2-4 days. Antibiosis strains formed an inhibition zone (mm) and the width of this zone was measured. In those with hyperparasitism, the area covered by the bioagent strain (mm) was measured in the area where the pathogen strain developed. Measurements were taken from 3 different points in each petri dish for both interactions and 3 replications were made for each bioagent strain.

2.3. Identification of bioagent bacteria by conventional tests

Some conventional tests have been performed to support MIS diagnosis of bioagent strains found to be effective against 1B pathogen strain *in vitro*. These tests are; Potassium hydroxide (KOH) test (Moore et al., 2001), catalase test (Klement et al., 1990), oxidase test (Kovacs, 1956), starch hydrolysis (Klement et al., 1990), determination of nitrogen fixation of strains (Guerinot and Colwell, 1985), detection of phosphate solvent bacteria (Nautiyal, 1999), levan test, pectolytic activity test and hemolytic activity test (Lelliot and Stead, 1987).

2.4. Semi-in vivo biocontrol activity

The ability of bioagent strains to suppress tumor formation was tested in carrot slices and squash fruit since *in vitro* experiments have certain limitations that the efficacy of biocontrol activity may not be fully expressed *in vivo*. Briefly, carrot and squash fruits were subjected to surface sterilization. Sterilized carrots were cut into 0.5-0.8 cm thicknesses and placed in 90 mm diameter Petri dishes with moist blotting papers; sterile squash fruits were placed in transparent rectangular boxes (7 L) covered with moist blotting papers. Eastwell et al. (2006) pathogen/bioagent bacteria inoculum (1:1, v:v) prepared according to ($1x10^8$ cfu ml^{-1}) were inoculated on the surface of carrot slices and 100 µL in pits opened with toothpicks on squash fruits. Only pathogen bacteria were used as positive control and only bioagent bacteria as negative control. The study was performed in 3 replications for each bioagent. The evaluation was made 30 days after inoculation. Evaluation of carrot slices Limanska et al. (2015) + + + + cambial ring is completely covered with tumor; + + + covers 75% of the cambial ring; + + covers 50% of the cambial ring; + covers less than 25% of the cambial ring; - Evaluation was made, and evaluation was made in squash fruits by measuring the number and size of tumor according to Tolba and Soliman (2013).

2.5.Molecular identification of pathogen and bioagent bacteria

The comparative DNA sequencing method is one of the best genotypic methods in microbial diagnosis. Most commonly, strains are identified using the 16S rDNA gene region. DNA extraction was performed according to Lazo et al. (1987) for the molecular diagnosis of the bioagent and pathogen strain with the most effective semi-*in vivo* biocontrol activity test result. Then, universal primer pair (27F and 1492R) recognizing pathogen and bioagent bacterial strains was used and polymerase chain reactions (PCR) were performed. The reaction mix of PCR consisted of dH_2O 37.2 µl, 10X PCR buffer 5 µl, $MgCl_2$ 3 µl, dNTP mix 0.7 µl, forward primer 0.8 µl, reverse primer 0.8 µl, DNA 2 µl and Taq polymerase (250 U) 0.5 µl. PCR's cycle is 95 °C for 2 min (1 cycle); 94 °C 60 s, 53 °C 60 s, and 72 °C 90 s (35 cycles); Consisting of 10 min (1 cycle) at 72 °C. In order to perform sequence analysis of the PCR results, PCR products were purified with a commercially available PCR purification kit (Invitrogen), and the purified PCR samples were sequenced by obtaining sequence service from Refgen Biotechnology Company (Ankara, Türkiye).

3. Results

3.1. In vitro assay results

The antibiosis effect (mean inhibition zone) of the bioagent bacterial strains that were effective in the study and the hyperparasitic effect (mean spreading area) are given in *Table 1*. Out of 2012 potential bioagent bacterial strains belonging to 99 bacterial strains tested, 106 bioagent bacterial strains belonging to 27 bacterial strains were found to be effective. Of these 106 bioagent bacterial strains, 66 showed an antibiosis effect, while 40 showed a hyperparasitic effect. It was determined that the strain with the highest antibiosis effect in Petri trials was RK 1977 (37.5 mm), followed by RK 1978 (30 mm) and RK 1250 (24 mm). RK 1095 (3.5 mm) was determined to be the strain that formed the lowest mean inhibition zone. In Petri trials, the strain with the highest hyperparasitic effect was RK 593 (78.5 mm), followed by FDG 105 (70 mm), and FDG 137 (70 mm) strains. RK 1223 (12.5 mm) bioagent bacterial strain was also determined to be the strain with the lowest hyperparasitic effect.

3.2. Identification of bioagent bacteria by conventional tests results

The biochemical and cultural test results of 106 potential bioagent bacterial strains that were effective in Petri trials are given in *Table 1*. Thirty eight strains showed positive results, while sixty-eight strains gave negative results in the KOH test. According to the catalase test, all strains gave positive results. According to the starch hydrolysis test result; except for ten strains, all strains were able to hydrolyze starch. Thirty four strains of bacteria

planted in a nitrogen-free medium made strong nitrogen fixation, fifty- eight strains weak nitrogen fixation, while fourteen strains could not make nitrogen fixation at all. According to the scale used for the detection of phosphate solvent bacteria; Thirty two strains could not dissolve any phosphate (6:-), thirty one strains were the lowest (5:+), five strains (4:+ +), thirty strains (3:+ + +) and six strains (2:+ + + +) resolved phosphate. According to the Levan test result, nineteen strains gave a positive reaction, while eighty seven strains gave negative results. As a result of the oxidase test, twenty one strains gave positive results in the oxidase test, and eighty five bacterial strains gave negative results. According to the pectolytic activity test, except for eight strains, other bacterial strains caused pectolytic activity in potato slices. According to the hemolytic activity test, all strains showed hemolytic activity except three.

Table 1. Bioagent bacterial strains' antibiosis and hyperparasitic effects against 1B pathogen, and conventional test results

Strain	MIS	Antibiosis Effect		Conventional Tests								
		AIZ [1] (mm)		KOH[2]	K[3]	NH[4]	N[5]	P[6]	L[7]	O[8]	PA[9]	HA[10]
RK 1250	*Bacillus atrophaeus*	24±0.49	C	-	+	+	Z+	6	-	-	+	+
RK 1986	Not determined	21±0.08	D	-	+	+	Z+	2	-	+	-	+
FDG 48	*Bacillus sphaericus*	19±0.08	DE	-	+	+	Z+	5	-	+	+	+
RK 546	*Bacillus subtilis*	16.5±0.12	EF	-	+	+	K+	3	-	-	+	+
RK 1062	*Brevibacillus choshinensis*	16±0.34	GL	-	+	+	Z+	6	-	+	+	+
RK 554	*Bacillus atrophaeus*	15±0.0	FG	-	+	+	K+	3	-	-	+	+
RK 578B	*Brevibacillus choshinensis*	15±0.24	FG	+	+	+	-	4	+	+	+	-
RK 1077	*Achromobacter xylosoxidans*	15±0.41	FG	+	+	+	K+	6	-	+	+	+
RK 547	*Bacillus megaterium*	14.5±0.12	F-H	-	+	+	Z+	5	-	-	+	+
RK 576B	*Serretia fonticola*	14.5±0.29	FH	+	+	+	K+	3	+	-	-	-
RK 834	*Bacillus cereus*	14±0.08	F-I	-	+	+	Z+	3	-	-	+	+
RK 594	*Salmonella typhimurium*	14±0.33	F-I	+	+	+	K+	3	+	-	+	+
RK 1763	*Paenibacillus macerans*	13.5±0.12	G-J	-	+	+	Z+	2	-	-	+	+
RK 1224	*Pantoea agglomerans*	13±0.24	G-K	+	+	+	K+	2	+	-	-	+
R2/2	*Paenibacillus polymyxa*	12.5±0.20	G-L	-	+	+	Z+	3	-	-	+	+
FDG 98	*Yersinia pseudotuberculosis*	12.5±0.20	G-L	+	+	+	-	5	-	-	+	+
RK 578A	*Bacillus megaterium*	12.5±0.12	G-L	-	+	+	K+	5	-	-	+	+
RK 957	*Chryseobacterium meningosepticum*	12±0.33	H-M	+	+	+	-	4	+	+	-	+
RK 1071	*Stenotrophpmonas maltophilia*	12±0.24	H-M	-	+	+	Z+	3	-	-	+	+
RK 1088	*Vibrio hollisae*	12±0.24	H-M	+	+	+	Z+	6	-	+	+	+
RK 600	*Hafnia alvei*	11.5±0.12	I-N	+	+	-	Z+	3	+	-	+	+
RK 1064	*Pseudomonas stutzeri*	11.5±0.12	I-N	-	+	+	Z+	5	-	+	+	+
RK 1080	*Bacillus megaterium*	11.5±0.29	I-N	-	+	+	Z+	4	-	-	+	+
RK 844	*Bacillus megaterium*	11±0.08	J-O	-	+	+	Z+	3	-	-	+	+
RK 562	*Vibrio hollisae*	11±0.08	J-O	+	+	+	K+	3	+	+	+	+
RK 572B	*Stenotrophpmonas maltophilia*	11±0.08	J-O	-	+	+	Z+	5	-	-	+	+
RK 588	*Salmonella typhimurium*	11±0.08	J-O	+	+	+	K+	3	+	-	+	+
RK 1255	*Bacillus atrophaeus*	10.5±0.04	K-P	-	+	+	K+	3	-	-	-	+
FDG 27	*Brevibacillus brevis*	10±0.0	L-Q	-	+	+	Z+	3	-	+	+	+
RK 574A	*Bacillus cereus*	10±0.0	L-Q	-	+	+	Z+	3	-	-	+	+
RK 1031	*Alcaligenes faecalis*	10±0.0	L-Q	+	+	-	-	5	-	+	+	+
RK 1074	*Achromobacter xylosoxi*	10±0.0	L-Q	+	+	+	K+	6	-	+	-	+
RK 932	*Bacillus megaterium*	9.5±0.37	M-R	-	+	+	K+	4	-	-	+	+
RK 1257	*Bacillus atrophaeus*	9.5±0.12	M-R	-	+	+	K+	5	-	-	+	+
RK 561	*Bacillus subtilis*	9±0.08	N-S	-	+	+	Z+	3	-	-	+	+
RK 1061	*Pseudoalteromonas terraodonis*	9±0.08	N-S	-	+	+	K+	6	-	+	+	+

Table 1. Bioagent bacterial strains' antibiosis and hyperparasitic effects against 1B pathogen, and conventional test results (continued)

Strain	MIS	Antibiosis Effect		Conventional Tests								
		AIZ[1] (mm)		KOH[2]	K[3]	NH[4]	N[5]	P[6]	L[7]	O[8]	PA[9]	HA[10]
RK 581	*Salmonella typhimurium*	8.5±0.12	O-T	+	+	+	K+	2	+	-	+	+
RK 590	*Salmonella typhimurium*	8.5±0.12	O-T	+	+	+	K+	2	+	-	+	+
RK 602	*Salmonella typhimurium*	8.5±0.12	O-T	+	+	+	Z+	3	+	-	+	+
RK 1253	*Bacillus atrophaeus*	8±0.16	P-T	-	+	+	Z+	5	-	-	+	+
RK 1273	*Peanibacillus macerans*	8±0.16	P-T	-	+	+	Z+	3	-	-	+	+
RK 37	*Curtobacterium flaccumfaciens*	7.5±0.20	Q-U	-	+	+	K+	3	-	-	+	+
RK 1050	*Bacillus megaterium*	7.5±0.12	Q-U	-	+	+	Z+	5	-	-	+	+
RK 1078	*Bacillus subtilis*	7.5±0.20	Q-U	-	+	-	Z+	5	-	-	+	+
RK 605	*Brevibacillus choshinensis*	7±0.16	R-V	+	+	+	K+	2	+	+	+	+
RK 985	*Stenotrophpmonas maltophilia*	7±0.16	R-V	+	+	+	Z+	3	-	-	+	+
RK 1086	*Aeromonas salmonicida*	7±0.24	R-V	+	+	+	-	6	-	+	-	+
RK 1252	*Bacillus atrophaeus*	7±0.08	R-V	-	+	+	K+	5	-	-	+	+
RK 1022	*Bacillus-GC group*	6.5±0.12	S-W	-	+	+	Z+	6	-	-	+	+
RK 1104	*Bacillus megaterium*	6.5±0.12	S-W	-	+	+	Z+	5	-	-	+	+
RK 1239	*Bacillus subtilis*	6.5±0.12	S-W	-	+	+	Z+	5	-	-	+	+
RK 506	*Bacillus subtilis*	6±0.16	T-X	-	+	+	Z+	3	-	-	+	+
RK 601	*Serretia fonticola*	6±0.08	T-X	+	+	+	Z+	5	+	-	+	+
RK 877	*Aeromonas salmonicida*	5±0.00	U-X	+	+	-	-	6	-	+	+	+
RK 1274	*Peanibacillus macerans*	4.5±0.04	V-X	-	+	+	Z+	5	-	-	+	+
RK 1275	*Bacillus coagulans*	4.5±0.12	V-X	-	+	+	Z+	3	-	-	+	+
RK 981	*Zobellia uliginosa*	4±0.08	WX	-	+	+	K+	3	-	-	+	+
RK 1058	*Arthrobacter agilis*	4±0.16	WX	-	+	+	Z+	6	-	+	+	+
RK 1095	*Paenibacillus larvae*	3.5±0.12	X	-	+	+	Z+	5	-	-	+	+
FDG 97	Not determined	12.5±0.20	G-L	+	+	+	K+	6	-	-	+	+
RK 1238	Not determined	8±0.0	P-T	-	+	-	Z+	5	-	-	+	+
RK 1752	Not determined	8±0.16	P-T	-	+	+	Z+	3	-	-	+	+
RK 999	Not determined	7.5±0.20	Q-U	-	+	+	Z+	4	-	-	+	+
RK 952	Not determined	6.5±0.12	S-W	+	+	+	Z+	6	-	-	+	+
RK 1977	Not determined	37.5±0.20	A	-	+	+	Z+	5	-	+	+	+
RK 1978	Not determined	30±0.82	B	-	+	+	Z+	3	-	-	+	+
Strain	**MIS**	**Hyperparasitic Effect**		**Conventional Tests**								
		ASA [11] (mm)		**KOH[2]**	**K[3]**	**NH[4]**	**N[5]**	**P[6]**	**L[7]**	**O[8]**	**PA[9]**	**HA[10]**
RK 593	*Bacillus cereus*	78.5±0.69	A	-	+	+	K+	6	-	-	+	+
FDG 105	*Bacillus mycoides*	70±1.22	AB	-	+	+	Z+	3	-	-	+	+
FDG 137	*Bacillus cereus*	70±0.82	AB	-	+	+	K+	6	-	-	+	+
RK 587	*Photorhabdus luminescens*	70±0.82	AB	+	+	+	Z+	5	-	-	+	+
RK 504	*Bacillus megaterium*	65±1.22	BC	-	+	+	K+	5	-	-	+	+
FDP 8	*Bacillus thuringiensis*	65±1.22	BC	-	+	+	K+	6	-	-	+	+
RK 38	*Sphingomonas capsulata*	65±0.10	BC	+	+	+	Z+	6	-	-	+	+
RK 1786	*Photorabdus luminescens*	65±0.41	BC	+	+	+	K+	3	-	-	-	+
RK 23	*Bacillus mycoides*	63±0.65	B-D	-	+	+	Z+	5	-	-	+	+
RK 75	*Bacillus cereus*	62.5±0.61	B-D	+	+	+	Z+	6	-	-	+	+
FDG 110	*Bacillus mycoides*	62.5±0.20	B -D	-	+	+	K+	5	-	-	+	+
RK 159	*Plesiomonas shigelloides*	56±0.33	C-F	-	+	+	K+	6	-	-	+	+
RK 574B	*Stenotrophpmonas maltophilia*	53.5±0.12	D-G	-	+	+	Z+	5	-	-	+	+
RK 301	*Bacillus cereus*	52.5±0.20	D-G	+	+	+	K+	5	-	-	+	+
RK 142	*Pseudomonas putida*	48±2.29	F-H	-	+	+	K+	3	-	-	+	+
RK 1395	*Serretia odorifera*	43±0.57	G-J	-	+	-	Z+	6	-	-	+	+
RK 52	*Pseudomonas syringae*	40±1.22	H-L	+	+	+	K+	5	-	-	+	+
RK 1079	*Pseudomonas agarici*	40±1.22	H-L	-	+	+	-	6	+	+	+	+
PM 18	*Pseudomonas chlororaphis*	36±1.96	I-M	+	+	+	K+	5	-	-	+	+
RK 1364	*Varivorax paradoxus*	32.5±1.02	J-N	-	+	-	-	6	-	-	-	+
RK 1094	*Vibrio hollisae*	30±0.41	K-O	+	+	+	Z+	5	-	+	+	+

Table 1. Bioagent bacterial strains' antibiosis and hyperparasitic effects against 1B pathogen, and conventional test results (continued)

Strain	MIS	Hyperparasitic Effect		Conventional Tests								
		ASA [11] (mm)		KOH[2]	K[3]	NH[4]	N[5]	P[6]	L[7]	O[8]	PA[9]	HA[10]
RK 1066	*Dunganella zoogloeoides*	29±0.49	L-P	-	+	-	-	6	-	-	+	+
RK 993	*Brevibacillus centrophor*	28±1.63	M-P	+	+	+	Z+	5	-	-	+	+
RK 1338	*Bacillus cereus*	26±1.14	M-P	-	+	+	Z+	6	-	-	+	+
RK 570A	*Bacillus cereus*	25±0.82	MQ	-	+	+	K+	3	-	-	-	+
RK 54	*Pseudomonas viridiflava*	23.5±1.35	N-R	-	+	+	Z+	5	-	-	+	+
RK 1433	*Paenibacillus macerans*	23±0.98	N-R	-	+	+	Z+	3	-	-	+	+
RK 1036	*Bacillus megaterium*	19±1.14	O-R	-	+	-	Z+	5	-	-	+	+
RK 1223	*Brevibacterium epidermidis*	12.5±0.45	R	-	+	+	K+	6	+	-	+	+
RK 1429	Not determined	70±1.63	AB	-	+	-	Z+	3	+	-	+	+
IA 1	Not determined	67.5±0.61	AB	-	+	+	Z+	6	-	-	+	+
RK 1417	Not determined	65±2.04	BC	-	+	+	Z+	6	-	-	+	+
RK 1416	Not determined	61±1.14	B-E	+	+	+	K+	6	-	-	+	+
RK 1305	Not determined	60±0.41	B-E	-	+	+	K+	6	-	-	+	+
RK 1414	Not determined	50.5±1.27	E-H	-	+	+	K+	6	-	-	+	+
RK 1413	Not determined	46.5±0.86	F-I	-	+	+	K+	6	-	-	+	+
RK 1407	Not determined	40.5±2.0	H-K	-	+	+	Z+	6	-	-	+	+
RK 1458	Not determined	20±0.24	O-R	+	+	+	K+	5	+	-	+	-
RK 1278	Not determined	18±0.98	P-R	+	+	+	Z+	6	-	-	+	+
RK 1102	Not determined	14±0.65	QR	-	+	+	Z+	5	-	-	+	+

1: AIZ: Average inhibition zone (mm), 2: KOH: potassium hydroxide test (+: positive, -: negative), 3: K: catalase test (+: positive, -: negative), 4: NH: Starch hydrolysis (+: positive, -: negative), 5: N: Nitrogen fixation (K: strongly positive, Z: weak positive, -: negative), 6: P: Phosphate solubilization (1: (+++++), 2: (++++), 3: (+++), 4: (++), 5: (+) 6: (-) Phosphate test scale values), 7: L: Levan test (+: pozitif, -: negatif), 8: O: Oxidase testi (+: positive, -: negative), 9: PA: Pectolytic activity (+: positive, -: negative), 10: HA: Hemolytic activity (+: positive -: negative), 11: ASA: Average spreading areas (mm)

3.3. Semi-in vivo biocontrol activity tests results

It was determined that ninety eight of one hundred and six bioagent bacterial strains were found to be effectively caused pectolytic activity in carrot slices and squash fruit. As a result of the semi-*in vivo* biocontrol activity test, eight bioagent strains that did not show pectolytic activity could be evaluated. The statistical analysis results of the bioagents used in the study on the pathogen inhibition of gall formation in carrot slices and squash fruit are given in *Table 2*.

***Table 2*. Semi-*in vivo* biocontrol activity test results**

Application	Carrot Slices Test		Squash Fruit Test	
1B+ RK 1986	1.78±0.47	E	0.26±0.04	H
1B+ RK 570A	2.89±0.82	D	0.35±0.03	G
1B+ RK 1074	3.44±0.99	CD	0.46±0.05	F
1B+ RK 1086	3.78±0.63	B-D	0.59±0.03	E
1B+ RK 1224	3.89±0.92	B-D	0.68±0.03	E
1B+ RK 957	4.12±0.31	BC	0.82±0.05	D
1B+ RK 1364	4.56±0.68	AB	0.98±0.05	C
1B+ RK 1786	4.78±0.63	AB	1.16±0.07	B
1B	5.44±0.83	A	1.61±0.28	A
CV:	0.29		0.12	
LSD:	1.08		0.09	

It was observed that the most effective strain suppressing tumor formation in carrot slices and pumpkin fruit was RK 1986, followed by RK 570A. The image of RK 1986, the most effective strain, is given in *Figure 1*.

3.4. Molecular identification test results of pathogen and bioagent bacteria

DNAs of pathogen and bioagent bacterial strains were purified by PCR amplification and sequence analysis of the purified products was performed. The obtained sequences were compared with the sequence analyses in the GenBank and identified at the species level. The most effective bioagent strain RK 1986 (Genbank Number:

MN967303) was determined to be *Bacillus mojavensis* and 1B pathogen strain (Genbank Number: MN967438) *Rhizobium radiobacter* as a result of a semi-*in vivo* test.

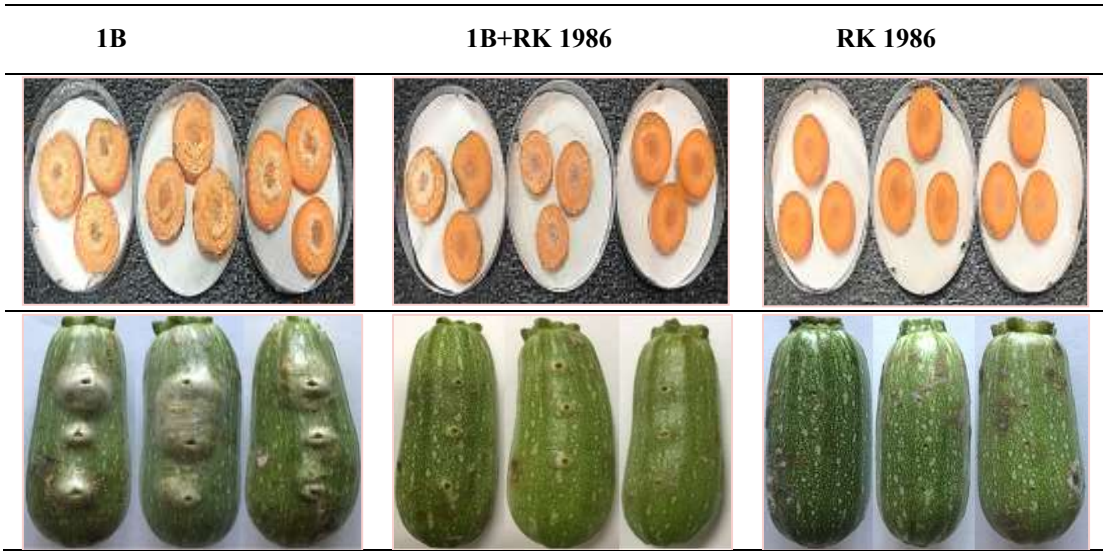

Figure 1. The most effective bioagent bacteria RK 1986 strain view on carrot slices and squash fruits

4. Discussion

The fact that the crown gall disease has spread all over the world has an effective mechanism against the plant defense system and Ti plasmid has made it difficult to control the disease. Biological control, which is an alternative control method, has gained importance due to the inadequacy of the control against the agent (Frikha-Gargouri et al., 2017).

K-84 and K-1026 strains have been used effectively as biological control agents against crown gall for ~40 years. However, since these bioagents are ineffective against some *R. radiobacter* strains, there is a need to identify new biological control agents. In recent years, it has been determined by different researchers that bioagents of different genera (*Bacillus*, *Curtobacterium*, *Pseudomonas*, *Brevibacillus*, *Paenibacillus*, *Serretia*, *Stenotrophomonas*) have been successfully used against crown gall (Dandurishvili et al., 2010; Gupta et al., 2010; Tolba and Soliman, 2013). The result of this study has demonstrated that the obtained data show parallelism with the bacterial species found to be effective by other researchers, and it has been determined that the development of the agent is suppressed *in vitro* and semi-*in vivo* conditions. It has been determined that the most effective bioagent strains belong to the genus *Bacillus* and it has been reported that species belonging to this genus are used effectively against a wide variety of plant diseases (Commare et al., 2002; Kim et al., 2003; Tozlu et al., 2018; Tekiner et al., 2019; Tekiner et al., 2020). This situation is due to ubiquitous, high colonization capabilities, ability to form endospores, and production of lytic enzyme-lipopeptide-antibiotic of *Bacillus* genus (Frandberg and Schnurer, 1994; Jiang et al., 2001; Parke and Gurian-Sherman, 2001; Zhang and Dou, 2002; Schallmey et al., 2004; Hardoim et al., 2008; Kotan et al., 2009; Tiwari and Thakur, 2014). It was determined that it inhibited the development of the pathogen at different levels among strains belonging to the same species in *in vitro* test results.

Researchers have reported that it may be caused by features such as whether the strains are epiphytic or endophytic, their biochemical structures, and their genetic diversity (Araujo et al., 2005; Aktan, 2018). MIS diagnoses of effective bioagent bacteria were supported by conventional test results. Bioagent bacteria directly prevent the development of plant diseases; They use mechanisms such as fixing nitrogen, dissolving phosphate, producing siderophores, competing for carbon sources, and promoting plant hormones (Kotan et al., 2009). In addition to suppressing the development of the disease, some of the effective strains within the scope of the study were found to fixation nitrogen and dissolved phosphate. Different researchers have reported that strains with these characteristics can increase plant growth as well as suppress the development of the disease (De Freitas et al., 1997; Gokce and Kotan, 2016; Mohammadi, 2018; Banerjee et al., 2018).

The strains that were effective as a result of the *in vitro* test were found to be low or highly effective. However, since *in vitro* tests have certain limitations, it is important to support *in vitro* tests with *in vivo* tests (Inam-ul-Haq et al., 2003). For this reason, strains that were effective *in vitro* were tested on carrot and squash fruits. In general, it was determined that the tested bioagent strains were effective semi-*in vivo* and significantly reduced tumor formation. There are other studies in which *in vitro* and *in vivo* tests give consistent results in studies on the biological control of crown gall disease. However, it has been reported in different studies that such a correlation may not always be the case (Gupta et al., 2010; Tolba and Soliman, 2013; Limanska et al., 2015; Bozkurt and Soylu, 2019). In this study, it was determined that the strains that were low effective *in vitro* were found to be highly effective in semi-*in vivo* studies.

5. Conclusions

As a result, the most effective bioagent strain RK 1986 (*B. mojavensis*; antibiosis effect) was a promising candidate in preventing crown gall and was found to be effective against crown gall for the first time. In addition to being the second study in our country for the biological control of crown gall, it is the first study in which the squash fruit test was used. It has been determined that the use of squash fruit is more advantageous than the carrot slice test since it causes symptoms earlier. In this respect, this study is a guide to research. As a future study, it is important to contribute to the literature to determine the disease prevention potentials and mechanisms of action of bioagent strains by testing the effective bioagents on seedlings under greenhouse conditions.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Tekiner Aydın, N., Kotan, R.; Design: Tekiner Aydın, N.; Data Collection or Processing: Tekiner Aydın, N.; Statistical Analyses: Tekiner Aydın, N.; Literature Search: Tekiner Aydın, N.; Writing, Review and Editing: Tekiner Aydın, N., Kotan, R.

References

Abdallah, B. D., Tounsi, S., Gharsallah, H., Hammami, A. and Gargouri, F. O. (2018). Lipopeptides from *Bacillus amyloliquefaciens* strain 32a as promising biocontrol compounds against the plant pathogen *Agrobacterium tumefaciens*. *Environmental Science and Pollution Research,* 25: 36518-36529.

Agrios, G. N. (1997). Plant Pathology. Academic Press, U.S.A.

Aktan, Z.C. (2018). *Determination of in vitro effects of antagonist and plant growth promoting bacteria against soilborne fungal disease agents on almond trees*. (MsC. Thesis) Hatay Mustafa Kemal University The Institute of Science, Hatay, Turkey.

Araujo, F. F., Henning, A. A. and Hungria, M. (2005). Phytohormones and antibiotics produced by *Bacillus subtilis* and their effects on seed pathogenic fungi and on soybean root development. *World Journal of Microbiology and Biotechnology,* 21(8-9):1639-1645.

Banerjee, G., Gorthi, S. and Chattopadhyay, P. (2018). Beneficial effects of bio-controlling agent *Bacillus cereus* IB311 on the agricultural crop production and its biomass optimization through response surface methodology. *Annals of the Brazilian Academy of Sciences,* 90(2): 2149-2159.

Bozkurt, I. A. and Soylu, S. (2019). Determination of antagonistic potential of epiphytic and endophytic bacterial strains against apple crown gal disease agent *Rhizobium radiobacter*. *Journal of Tekirdag Agricultural Faculty,* 16(3): 349-361.

Cazelles, O., Epard, S. and Sımon, J. L. (1991). The effect of disinfection with oxyquinoline sulfate of the Berl. X Rip. 5C rootstock on the expression of crown gall in grape propagation. *Revue Suisse de Viticulture d'Arboricet d'Horticulture,* 23: 285-288.

Commare, R. R., Nandakumar, R., Kandan, A., Suresh, S., Bharthi, M., Raguchanger, T. and Samiyappan, R. (2002). *Pseudomonas fluorescens* based formulation for the management of sheath blight disease and leaf folder insect in rice. *Crop Protection,* 21: 671-677.

Dandurishvili, N., Toklikishvili, N., Ovadis, M., Eliashvili, P., Giorgobiani, N., Keshelava, R., Tediashvili, M., Vainstein, A., Khmel, I., Szegedi, E. and Chernin, L. (2010). Broad-range antagonistic rhizobacteria *Pseudomonas fluorescens* and *Serratia plymuthica* suppress *Agrobacterium* crown gall tumors on tomato plants. *Journal of Applied Microbiology,* 110: 341-352.

De Freitas, J. R., Banerjee, M. R. and Germida, J. J. (1997). Phosphate solubilizing rhizobacteria enhance the growth and yield but not phosphorus uptake of canola (*Brassica napus* L). *Biology and Fertility of Soils,* 24: 358-364.

Eastwell, K. C., Sholberg, P. L. and Sayler, R. J. (2006). Characterizing bacterial biocontrol agents for supression of *Rhizobium vitis*, a casual agent crown gall disease grapevines. *Crop Protection,* 25: 1191-1200.

EPPO (2019). European and Mediterranean Plant Protection Organization (EPPO). www.eppo.org (Accessed Date: 13.05.2019).

Farrand, S. K. and Wang, C. (1992). Do We Really Understand Crown Gall Control by *Agrobacterium radiobacter* strain K84? In: Tjamos ES et al (eds.) Biological Control of Plant Diseases. Plenum Press, New York, U.S.A.

Frandberg, E. and Schnurer, J. (1994). Chitinolytic properties of *Bacillus pabuli* KI. *Journal of Applied Bacteriology,* 76(4): 361-367.

Frikha-Gargouri, O., Ben Abdallah, D., Ghorbel, I., Charfeddine, I., Jlaiel, L., Triki, M. A. and Tounsi, S. (2017). Lipopeptides from a novel *Bacillus methylotrophicus* 39b strain suppress *Agrobacterium* crown gall tumours on tomato plants. *Pest Management Science,* 73(3): 568-574.

Gloyer, W. O. (1934). Crown gall and hairy root of apples in nursery and orchard. *Bulletin of the New York State Agricultural Experiment Station*, 638: 1-30.

Gokce, A. Y. and Kotan, R. (2016). Investigation of biological control possibilities of wheat root rot disease caused by *Bipolaris sorokiniana* (Sacc.) using PGPR and bio-control bacteria in controlled condition. *Plant Protection Bulletein,* 56(1): 49-75.

Goodman, R. N., Grimm, R. and Frank, M. (1993). The influence of grape rootstocks on the crown gall infection process and on tumor development. *American Journal of Enology and Viticulture,* 44: 22-26.

Guerinot, M.L. and Colwell, R.R. (1985). Enumeration, isolation, and characterization of N_2-fixing bacteria from seawater. *Applied and Environmental Microbiology,* 50(2): 350-355.

Gupta, A. K. and Kamal, B. (2006). Pre-planting application of soil sterilants and herbicides for management of crown gall disease on 'colt' cherry rootstock. *Indian Journal Agricultural Science,* 76: 426-429.

Gupta, A. K., Khosla, K. and Bhardwaj, S. S. (2007). Biological control of crown gall of stone fruits. *Indian Phytopathology,* 61: 385.

Gupta, A. K., Khosla, K., Bhardwaj, S. S., Thakur, A., Devi, S., Jarial, R. S., Sharma, C., Singh, K. P., Srivastava, D. K. and La, R. (2010). Biological control of crown gall on peach and cherry rootstock Colt by native *Agrobacterium radiobacter* strains. *The Open Horticulture Journal,* 3: 1-10.

Hammami, I., Rhouma, A., Jaouadi, B., Rebai, A. and Nesme, X. (2008). Optimization and biochemical characterization of a bacteriocin from a newly straind *Bacillus subtilis* strain 14B for biocontrol of *Agrobacterium* spp. strains. *Letters in Applied Microbiology,* 48:253-260.

Hardoim, P. R., Van Overbeek, L. S. and Van Elsas, J. D. (2008). Properties bacterial endophytes and their proposed role in plant growth. *Trends Microbiology,* 16: 463-471.

Inam-ul-Haq, M., Javed, M., Ahmad, R. and Rehman, A. (2003). Evaluation of different strains of *Pseudomonas fluorescens* for the biocontrol of *Fusarium* wilt of chickpea. *Pakistan Journal of Plant Pathology,* 2: 65-74.

Jiang, Y. M., Zhu, X. R. and Li, Y. B. (2001). Postharvest control of litchi fruit rot by *Bacillus subtilis*. *Lebensmittel-Wissenschaft Und-Technologie-Food Science and Technology,* 34(7): 430-436.

Khmel, I. A., Sorokina, T. A., Lemanova, N. B., Lipasova, V. A., Metlitski, O. Z., Burdeinaya, T. V. and Chernin, L. S. (1998). Biological control of crown gall in grapevine and raspberry by two *Pseudomonas* spp. with a wide spectrum of antagonistic activity. *Biocontrol Science and Technology,* 8(1): 45-57.

Kim, H. S., Park, J., Choi, S. W., Choi, K. H., Lee, G. P., Ban, S. J., Lee, H. L. and Kim, C. S. (2003). Isolation and characterization of *Bacillus* strains for biological control. *Journal of Microbiology,* 41: 196-201.

Klement, Z., Mavridis, A., Rudolph, K., Vidaver, A., Perombelon, M. C. and Moore, L. W. (1990). Inoculation of Plant Tissues Methods in Phytobacteriology, Akademiai Kiado, Budapest, Hungary.

Kotan, R. and Tozlu, E. (2021). Determination of bactericidal effects of some pesticides on useful and pathogenic bacteria. *Journal of Tekirdag Agricultural Faculty,* 18(2): 197-212 (In Turkish).

Kotan, R., Dikbas, N. and Bostan, H. (2009). Biological control of post harvest disease caused by *Aspergillus flavus* on stored lemon fruits. *African Journal of Biotechnology,* 8(2): 209-214.

Kovacs, N. (1956). Identication of *Pseudomonas pyocyanea* by the oxidase reaction. *Nature,* 170-173.

Lazo, G. R., Roffey, R. and Gabriel, D. W. (1987). Pathovars of *Xanthomonas campestris* are distinguishable by restriction fragment length polymorphism. *International Journal of Systematic and Evolutionary Microbiology,* 37: 214-217.

Lelliot, R. A. and Stead, D. E. (1987). Methods for the Diagnosis of Bacterial Diseases of Plants. Black Well Scientific Puplication, U.S.A.

Limanska, N., Korotaeva, N., Biscola, V., Ivanytsia, T. and Merlich, A. (2015). Study of the potential application of lactic acid bacteria in the control of ınfection caused by *Agrobacterium tumefaciens*. *Journal of Plant Pathology and Microbiology,* 6(8): 292.

Mohammadi, P. (2018). *Evaluation of biological control of (Clavibacter michiganensis subsp. michiganensis (Smith) Davis et al.) bacterial wilt and canker of tomato by antagonistic bacteria.* (Ph.D. Thesis) Atatürk University, The Institute of Science, Erzurum, Türkiye.

Moore, L. W. and Canfield, M. (1996). Biology of *Agrobacterium* and management of crown gall disease. In: Hall R (ed) Principles and practice of managing soilborne plant pathogens, APS Press, Minnesota, U.S.A.

Moore, L. W., Bouzar, H. and Burr, T. J. (2001). *Agrobacterium*. In: Schaad NW, Jones JB, Chun W (eds.) Laboratory Guide for Identification of Plant Pathogenic Bacteria. American Phytopathological Society Press, Minnesota, U.S.A.

Moore, L. W. (1988). Use of *Agrobacterium radiobacter* in agricultural ecosystems. *Microbiological Science,* 5: 92-95.

Nautiyal, C. S. (1999). An efficient microbiological growth medium for screening phosphate solubilizing microorganisms. *FEMS Microbiology Letters,* 170: 65-270.

Parke, J. L. and Gurian-Sherman, D. (2001). Diversity of the *Burkholderia cepacia* complex and implications for risk assessment of biological control strains. *Annual Reviews Phytopathology,* 39: 225-258.

Peluso, R., Raio, A., Morra, F. and Zoina, A. (2003). Physiolgical, biochemical and molecular analyses of Italian collection of *Agrobacterium tumefaciens* strain. *Eurepean Journal of Plant Pathology,* 109: 291-300.

Rhouma, A., Ferchichi, H., Hofsa, M. and Boubaker, A. (2004). Efficacy of the non pathogenic *Agrobacterium* strains K84 and K1026 against crown gall in Tunisia. *Phytopathologia Mediterranea,* 43(2): 167-176.

Schallmey, M., Singh, A. and Ward, O. P. (2004). Developments in the use of *Bacillus* species for industrial production. *Canadian Journal of Microbiology,* 50: 1-17.

Tekiner Aydın, N. and Kotan, R. (2022). Pathogenicity of different *Rhizobium radiobacter* (*Agrobacterium tumefaciens*) isolates and their identification with conventional methods. *KSU Journal of Agriculture and Nature,* 25(Suppl 1): 149-157.

Tekiner, N., Kotan, R., Tozlu, E. and Dadasoglu, F. (2019). Determination of some biological control agents against *Alternaria* fruit rot in quince. *Alınteri Journal of Agricultural Sciences,* 34(1): 25-31.

Tekiner, N., Tozlu, E., Kotan, R. and Dadasoglu, F. (2020). Biological control of *Botrytis cinerea* and *Alternaria alternata* with bioagent bacteria and fungi under *in vitro* conditions. *Fresenius Environmental Bulletein,* 29(1): 640-649.

Tiwari, K. and Thakur, H. K. (2014). Diversity and molecular characterization of dominant *Bacillus amyloliquefaciens* (JNU-001) endophytic bacterial strains straind from native neem varieties of Sanganer region of Rajasthan. *Journal of Biodiversity, Bioprospecting and Development,* 1: 115.

Tolba, I. H. and Soliman, M. A. (2013). Efficacy of native antagonistic bacterial strains in biological control of crown gall disease in Egypt. *Annals of Agricultural Science,* 58(19): 43-49.

Tozlu, E., Tekiner, N., Kotan, R. and Ortucu, S. (2018). Investigation on the biological control of *Alternaria alternata*. *Indian Journal of Agricultural Sciences,* 88(8): 1241-1247.

Vrain, T. C. and Copeman, R. J. (1987). Interactions between *Agrobacterium tumefaciens* and *Pratylenchus penetrans* in the roots of two red raspberry cultivars. *Canadian Journal of Plant Pathology,* 9: 236-240.

Zhang, J. and Dou, H. (2002). Evaluation of *Bacillus subtilis* as potential biocontrol agent for postharvest green mold control on Valencia orange. *Proceedings of the Florida State Horticultural Society,* 115: 60-64.

Zhang, C. M., Lu, S. H., Wei, C. M. and Zhao, J. H. (1991). Bacterium strain 1-1-4 *Pseudomonas fluorescens* for biocontrol of peach crown gall disease. *Acta Agriculturae Shanghai,* 7(4): 65-69.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Location Quotient of Organic Agriculture in Türkiye

Türkiye'de Organik Tarımın Yoğunlaşma Katsayısının Belirlenmesi

Zeki BAYRAMOĞLU[1], Kemalettin AĞIZAN[2*], Süheyla AĞIZAN[3]

Abstract

The main objective of the study is to determine in which provinces organic agriculture is clustered in Türkiye. Location quotient is one of the most widely used indices in regional concentration measurements and expresses the degree of specialization of a certain production activity within a country/region/sector or the relative concentration of a certain production activity in a certain region. In this direction, within the scope of the study, it is aimed to determine the location quotient of organic agriculture, which provides competitive advantage throughout Türkiye, and it is envisaged to determine the location quotient in this direction. In determining the location quotient, the amount of production, which is one of the best indicators of economic performance, was used. As a matter of fact, the amount of production is the most important indicator showing which production activity is more dominant and the location quotient to be calculated takes a value between 0 and infinity (∞). If the relevant production activity has a score greater than 1, it indicates that the activity is the main production activity that is concentrated/specialised in the region. However, if the score is less than 1, it indicates that the activity is a local one that is not sufficiently concentrated/specialised in the region. Following the analysis, Eastern Anatolia and Central Anatolia are the regions with the highest concentration of organic agriculture production. The top 10 provinces with the most concentrated organic agriculture production are Van (7), Ağrı (6), Ankara (6), Bayburt (6), Erzurum (6), Çanakkale (5), Kars (5), Muş (5), Niğde and Sivas. The most widely produced crops are alfalfa (18), wheat (16), tomato (15), apple (14), maize (12), barley (12), hazelnut (9), sainfoin (9), olive (9), oat (9) and vetch (9). Localized and intensified organic farming systems have proven effective in generating high income per unit of land, optimizing agricultural land utilization, and ensuring sustainability. They also provide specialized labour forces, sector-specific inputs, and the use of advanced technologies. Therefore, it is believed that the formations will enhance the economic, social, and environmental sustainability of the region by increasing productivity and promoting the growth of organic agriculture. This will lead to significant benefits for the region's development.

Keywords: Regional economic activity, Organic agriculture, Location quotient

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Öz

Çalışmanın temel amacı, Türkiye'de organik tarımın hangi illerde kümelendiğini belirlemektir. Konum katsayısı, bölgesel yoğunlaşma ölçümlerinde en yaygın kullanılan endekslerden biridir ve belirli bir üretim faaliyetinin bir ülke/bölge/sektör içindeki uzmanlaşma derecesini veya belirli bir üretim faaliyetinin belirli bir bölgedeki göreli yoğunlaşmasını ifade eder. Bu doğrultuda çalışma kapsamında Türkiye genelinde rekabet avantajı sağlayan organik tarımın konum katsayısının belirlenmesi amaçlanmış ve bu doğrultuda konum katsayısının belirlenmesi öngörülmüştür. Konum katsayısının belirlenmesinde ekonomik performansın en iyi göstergelerinden biri olan üretim miktarı kullanılmıştır. Nitekim üretim miktarı hangi üretim faaliyetinin daha baskın olduğunu gösteren en önemli göstergedir ve hesaplanacak konum katsayısı 0 ile sonsuz (∞) arasında bir değer alır. İlgili üretim faaliyetinin 1'den büyük bir skora sahip olması, ilgili faaliyetin bölgede yoğunlaşmış/uzmanlaşmış ana üretim faaliyeti olduğunu gösterir. Ancak puanın 1'den küçük olması, faaliyetin bölgede yeterince yoğunlaşmamış/uzmanlaşmamış yerel bir faaliyet olduğunu gösterir. Analiz sonucunda, Doğu Anadolu ve Orta Anadolu organik tarım üretiminin en yoğun olduğu bölgelerdir. Organik tarım üretiminin en yoğun olduğu ilk 10 il sırasıyla Van (7), Ağrı (6), Ankara (6), Bayburt (6), Erzurum (6), Çanakkale (5), Kars (5), Muş (5), Niğde ve Sivas'tır. En yaygın olarak üretilen ürünler yonca (18), buğday (16), domates (15), elma (14), mısır (12), arpa (12), fındık (9), korunga (9), zeytin (9), yulaf (9) ve fiğdir (9). Yerelleştirilmiş ve yoğunlaştırılmış organik tarım sistemlerinin birim arazi başına yüksek gelir elde etmede, tarımsal arazi kullanımını optimize etmede ve sürdürülebilirliği sağlamada etkili olduğu kanıtlanmıştır. Ayrıca uzmanlaşmış işgücü, sektöre özgü girdiler ve ileri teknolojilerin kullanımını da sağlamaktadırlar. Bu nedenle, oluşumların verimliliği artırarak ve organik tarımın büyümesini teşvik ederek bölgenin ekonomik, sosyal ve çevresel sürdürülebilirliğini geliştireceğine inanılmaktadır. Bu da bölgenin kalkınması için önemli faydalar sağlayacaktır.

Anahtar Kelimeler: Organik tarım, Bölgesel ekonomik faaliyet, Yoğunlaşma katsayısı

1. Introduction

Due to developments in international trade, the competitiveness of regions with abundant production factors based on cheap production has come to an end. Accordingly, the need has increased to review and redefine the competitiveness of regions that can be considered economically stagnant and to determine the factors that improve this strength. In line with this need, the regional competitiveness of companies is calculated, which shows their ability to offer the goods and services they produce to international markets due to low costs and quality.

Since each province has a different demographic structure, infrastructure, natural wealth, socio-cultural structure and agricultural structure, there are differences in the development, income and expenditure distribution, industrialization and social and economic development indicators of the provinces. Regional development strategies are important to reduce these differences between the provinces. Regional development strategies aim to determine the development potential of regions and eliminate development disparities between regions. By ensuring social and economic development, regional disparities are reduced and socio-economic development is achieved throughout the region. The development of the underdeveloped region, which is a part of the economic system, also supports the development of the upper region. This situation serves the same purpose by expressing the harmony between regional and national development. (Bayraktutan, 1994).

The determination of the primary sector in a region in the economy is generally determined by the distribution of the employment structure of workers in that region across sectors. This distribution among main and non-main sectors can be calculated not only by employment, but also by the number of enterprises, production value, labor wages, production volume or foreign trade volume. Three methods are commonly used to examine these economies. The first of these methods is the hypothetical method. This is a qualitative method in which the sectors are hypothetically determined main on sector knowledge, experience and experience in determining the dominant sector in the region. The second method is the minimum requirements method, in which comparisons are made with regions of a similar size and conclusions are drawn on the basis of similarities. The third method is the location quotient method, which is a quantitative analysis. This method uses various indicators to determine the predominant sector or production activity in a region. These indicators are generally quantitative data such as employment, production volume, production value, wages and number of companies. The main objective of this study is to identify the organic agricultural products concentrated in each province. To achieve this goal, the study calculates concentration ratios main on the production values of organic products in each province, revealing which organic product is the primary production activity in each province. When interpreting the specialization of provinces and production activities, it is not sufficient to evaluate each province on its own. For this reason, a location quotient is needed that allows both regional and production activities to be interpreted together, taking into account the share of each product volume in the total country. In addition, the calculated coefficient can easily be interpreted as a specialization ratio, as it compares the provinces and production activities with each other and with the country (Öztürk, 2018).

The location quotient has been used in the international literature to calculate concentration in many different sectors and regions (Leigh, 1970; Miller et al., 1991; Chiang, 2009; Campaniaris et al., 2015; Weterings and Marsili, 2015; Brosnan, 2017)and in Türkiye, the differences between regions have been examined by using the location quotient especially in entrepreneurship (Öztürk, 2018), manufacturing industry (Eser and Köse, 2005; Falcioğlu and Akgüngör, 2008; Yavan and Şahin, 2014; Altuğ, 2017), production activities (Öz, 2004), agriculture sector (Kazancık, 2007), logistics sector (Deliktaş and Çelik, 2019), textile sector (Urhan and Sandal, 2019) and education sector (Çiftçi, 2018).

The location quotient is a widely used measure in the agricultural sector for identifying the main sectors and sub-sectors by province and district. This measure has been studied by various authors. However, while calculating the location coefficient, agricultural income is sometimes used in some studies, employment and production values are used in other studies. (Wicaksono, 2011; Irham and Mulyo, 2016; Kartikawati and Sundari, 2019; Kim et al., 2019; Lee, 2020; Anwar et al., 2021; Sausan et al., 2022). Some studies have used location quotient with micro data to measure the economic potential of a region (Aliyu et al., 2023) and to investigate the characteristics of agricultural community activities by region (Lee, 2020). In some studies, it is emphasized that producing in regions with high LQ values increases specialization. (Kim et al., 2019). Therefore, this coefficient was used in the study to identify regions where organic agriculture is more advantageous. The study tested the hypothesis that there is a difference between provinces with high production and provinces with high concentration. For this reason, the

location coefficient was calculated to investigate the homogeneity of organic production activities among provinces in Türkiye. We aimed to determine the reasons for the differentiation of this distribution by geographical units and how these differences contribute to the agricultural sustainability of the enterprises and the region. Identifying the regions where organic agriculture is concentrated can reveal potential opportunities for its development.

This paper focuses on the amount of production as the main variable, which is an indicator of the economic size and importance of a sector or activity. Unlike other empirical studies, subjective evaluations are excluded from this analysis. This paper focuses on the amount of production as the main variable, which is an indicator of the economic size and importance of a sector or activity. Using output as a variable can reveal the efficiency, effectiveness, and competitiveness of a sector or activity in a region compared to other regions or countries. This information can be valuable for regional development and planning.

2. Materials and Methods

The data used in the study were taken from the Organic Farming Information System (OTBIS) of the Ministry of Agriculture and Forestry and the production data for the year 2022 were analyzed. With the help of statistics for each province and product, the location quotient of organic agriculture in Türkiye was analyzed. In this context, the location quotient used in the study shows the degree of specialization of a certain production activity within the country/region/sector and expresses the relative concentration of a certain production activity in a certain region. This method, developed by Hildebrand and Mace (1950),was first used to determine in which sectors the labor force was concentrated in Los Angeles, USA. This coefficient is determined by the following formula for sector i/production activity operating in the region at the time.

$$LQ_i = \left(\frac{e_i}{e_T} / \frac{E_i}{E_T}\right) * 100 \quad \text{(Eq 1).}$$

LQ stands for the location quotient, "e" stands for the provinces of Türkiye, "E" stands for Türkiye, "i" stands for the volume of production in the respective production activity and "T" stands for the total volume of production of organic products. In determining the location quotient, the production volume was used, which is one of the most meaningful indicators of economic performance. The scale of production is the most important indicator showing which production activity is more dominant, and this coefficient to be calculated takes a value between 0 and infinity (∞). If the corresponding production branch is greater than 1, it means that this production branch is the most important specialised production branch in the region, and if it is less than 1, it means that this production branch is the local production branch that is not sufficiently specialised in the region (*Table 1*) (Yardımcı, 2014; Alkan and Bilim, 2021). As a result of the analysis, it was determined which organic products are considered basic production or local production in which regions.

Table 1. Location quotient group values and clustering status

Group	LQ	Cluster Status
1	Less than 0.50	None
2	between 0.50-0.99	Very Low
3	Between 1.00-1.09	Centre
4	1.10-1.24	High
5	1.25 and above	Very high

3. Results and Discussion

3.1. Organic agriculture in Türkiye: area and production distribution by province

Regional economic differences in the agricultural sector show the imbalances between agricultural production and income levels in different regions. These differences result from the interaction of many factors and include many variables that influence the agricultural economy. Economic differences are usually caused by a combination of factors such as geography, climate, soil structure, investment opportunities, technological infrastructure, agricultural policy and marketing opportunities. Alternative agricultural systems are discussed to eliminate these differences, in other words, to reduce economic disparities between regions.

Alternative farming systems in the agricultural sector include cultivation practices such as organic farming, good agricultural practices, greenhouse production systems, underwater cultivation, etc. Among these practices, organic farming is recognized as the most important nature-friendly, environmentally friendly and sustainable agricultural approach. Organic farming is described as "an agricultural system that takes into account human and animal health, considers the soil, water and other environmental factors with a holistic approach, prohibits the use of chemical agents, contributes to the reconstruction of the ecosystem and thus protects the ecological balance. At the same time, organic farming is referred to as "certified production" because it is certified and controlled within the framework of international and national legislation (Kirazlar, 2001; Demir and Gül, 2004; Turhan, 2005; Çakmakçı and Erdoğan, 2005; Ayla, 2011; Merdan and Kaya, 2013; Demiryürek, 2016; Çetin et al., 2020; Süzer, 2020; Bayramoğlu et al., 2021).

Table 2. Total number of organic agriculture farmers, production area and production amount by province

City's	Number of Farmers	Total Area (hectare)	Production Amount (Tonnes)	City's	Number of Farmers	Total Area (hectare)	Production Amount (Tonnes)
Adana	76	8779.61	20541.99	Kahramanmaraş	118	765.46	6831.76
Adıyaman	92	450.31	6559.48	Karaman	103	261.70	1299.21
Afyonkarahisar	812	3068.74	37207.09	Kars	930	17281.14	86611.43
Ağrı	842	21185.48	52852.95	Kastamonu	32	7217.65	3515.33
Aksaray	4	7.92	190.13	Kayseri	42	92.66	6367.94
Amasya	7	62.16	124.27	Kırıkkale	3	8.11	70.46
Ankara	56	3773.37	19676.93	Kırklareli	6	27.74	79.43
Antalya	44	4761.34	15470.02	Kırşehir	5	69.01	142.25
Artvin	2035	2767.02	3353.47	Kilis	297	2217.65	5464.24
Aydın	6606	38802.67	140741.10	Kocaeli	11	107.98	1374.89
Balıkesir	148	2108.38	3012.03	Konya	394	1959.10	20375.42
Bartın	124	191.51	593.71	Kütahya	27	171.33	564.72
Batman	10	363.78	1682.52	Malatya	893	4629.08	49046.97
Bayburt	28	99.65	582.05	Manisa	1526	11200.27	167891.20
Bilecik	68	90.42	1432.70	Mardin	160	7473.98	53452.38
Bitlis	82	1514.18	6661.81	Mersin	123	588.83	8672.81
Bolu	8	38.38	969.68	Muğla	510	2860.38	6717.18
Burdur	21	165.41	470.36	Muş	425	6834.66	24273.60
Bursa	82	326.38	3225.14	Nevşehir	25	121.42	259.71
Çanakkale	275	2063.48	8999.59	Niğde	313	7270.45	164311.30
Çorum	5	7.21	43.03	Ordu	1149	3035.85	7074.73
Denizli	22	122.39	1086.73	Osmaniye	1	19.54	33.42
Diyarbakır	78	194.52	248.45	Rize	10566	3913.44	47820.89
Düzce	289	857.88	3220.00	Sakarya	324	736.91	2264.53
Edirne	2	35.74	35.12	Samsun	1352	4424.54	27199.25
Elazığ	92	666.77	5307.12	Sinop	30	1541.07	559.66
Erzincan	80	767.78	5618.95	Sivas	327	7743.30	18791.74
Erzurum	55	983.07	3702.77	Şanlıurfa	198	6857.73	32676.20
Eskişehir	13	622.26	11188.81	Tekirdağ	5	59.04	318.70
Gaziantep	68	887.83	2628.67	Tokat	52	101.94	995.66
Giresun	19	109.08	157.64	Trabzon	1700	1977.87	3625.97
Gümüşhane	3	1.15	2.05	Tunceli	96	352.56	1068.22
Hatay	48	337.74	2551.61	Uşak	5	18.63	51.00
Iğdır	1	1.88	15.04	Van	51	594.70	2465.24
Isparta	21	100.51	1390.37	Yalova	13	68.19	118.15
İstanbul	14	60.53	431.41	Yozgat	5	196.48	184.91
İzmir	1552	13499.27	34868.41	Zonguldak	832	1425.45	3747.52

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Organic farming, which is one of the alternative agricultural systems that produce enough to meet the needs of the population without disturbing the ecological balance and polluting the environment, has ushered in a new phase of structural change in the production process. This structural change has gained momentum due to the high awareness of healthy living in the countries. It is believed to play an important role in reducing inter-regional disparities due to environmental protection, quality production, sustainable use of renewable resources, protection of human health, rural development and increased income. The multiplier effect of organic farming, its contribution to employment in rural areas and the fact that trade in organic products is more profitable demonstrate the impact of this agricultural production system on the rural economy and regional development. Organic agriculture is seen as a potential solution to increase the subsistence income of smallholders (Smith and Marsden,

2004; Blanc and Kledal, 2012), while increasing the agricultural motivation of operators who benefit from state support, enabling them to contribute to the environment and rural development (De Master, 2012). A study conducted in Kenya found that organic agriculture has a positive impact on poverty reduction (Ayuya et al., 2015). Another common view on this issue is that organic agriculture increases employment. Studies conducted in the UK (Lobley et al., 2009), Japan (McGreevy, 2012) and Türkiye (Yolcu, 2013) have found that organic agriculture has a positive impact on rural development by increasing employment.

In 2022, Türkiye's organic farming sector saw 36,431 farmers producing 1.153.161.20 tonnes of organic products on 214.101.6 hectares. Rize has the highest number of farmers engaged in organic agriculture, with 10.566 farmers (*Table 2*). Aydın has the largest cultivated area, with 6.606 farmers producing 140.741.10 tonnes of organic products on 38.802.67 hectares. Manisa has the highest production potential. In Manisa, 1526 farmers produced 167891.20 tonnes of organic products on 11200.27 hectares. The highest productivity per cultivated area was found in Kayseri province, with 68.73 tonnes per hectare, while the highest productivity per enterprise was determined in Eskişehir province, with 860.68 tonnes.

Table 3. Number of farmers, production area and production amount by organic products in Türkiye

City's	Number of Farmers	Total Area (hectare)	Production Amount (Tonnes)	City's	Number of Farmers	Total Area (hectare)	Production Amount (Tonnes)
Grape	1766.00	5683.35	127562.61	Soya Bean	29.00	740.13	4731.20
Wheat	2762.00	31138.14	110667.42	Silage Maize	52.00	162.58	4584.43
Olive	8120.00	37085.37	100474.93	Strawberry	272.00	405.64	4572.27
Apple	824.00	6020.91	89785.22	Pistachio	218.00	1668.01	4417.88
Hawthorn	22.00	3156.17	79740.39	Walnut	892.00	2297.73	4297.33
Maize	315.00	3810.51	68519.14	Lentil	138.00	2305.54	4275.34
Fig	4106.00	11365.09	66283.38	Lemon	92.00	96.86	4269.92
Barley	1968.00	15881.70	57905.54	Erik	356.00	694.20	4242.57
Apricot	1348.00	4829.11	53317.98	Chickpea	296.00	1818.68	3131.95
Tea	11575.00	3729.75	48515.95	Tangerine	95.00	119.08	3040.59
Hazelnut	6982.00	14261.65	34562.34	Carrot	61.00	51.83	2975.41
Alfalfa	978.00	5514.24	32283.15	Pear	257.00	1773.67	2828.78
Pomegranate	281.00	1795.08	29131.99	Potato	98.00	65.15	2654.48
Oats	771.00	4524.92	19579.94	Mulberry	204.00	2332.31	2366.08
Tomato	273.00	266.39	16920.23	Beet (Sugar)	61.00	65.07	2115.26
Cherry	1147.00	1453.52	16885.57	Cucumber	160.00	22.89	2036.38
Sainfoin	671.00	3992.65	16261.69	Broccoli	81.00	73.85	2014.81
Vetch	294.00	2308.59	14151.68	Watermelon	122.00	53.97	1938.87
Cotton	197.00	3213.25	13859.00	Beans	276.00	210.80	1930.73
Carob (Harnup)	10.00	4241.39	12975.40	Pine Nuts	675.00	8016.87	1721.50
Sour cherry	892.00	2442.19	12557.06	Cauliflower	73.00	25.83	1481.60
Meadow Grass	729.00	3694.55	10448.01	Eggplant	143.00	14.91	1333.39
Chestnut	1524.00	2636.14	8193.62	Artificial Meadow Pasture	7.00	268.25	1294.51
Pepper	198.00	83.73	8166.02	Banana	19.00	15.89	1125.07
Sunflower	113.00	2200.52	5514.39	Triticale	60.00	303.44	1040.70
Orange	93.00	143.59	5503.37	Others	4503.00	13192.82	18014.78
Almond	268.00	1833.18	4959.28				

TOB (2022)

Türkiye cultivates 246 types of organic products, including grapes, wheat, olives, apples, hawthorn, corn, figs, pear, barley, apricots, and tea. The top three organic crops produced in Türkiye, with a production of over 100,000 tonnes, are grapes, wheat, and olives. The table in the source text shows that organic grapes are produced on 5684.35 hectares by 1766 farmers, with a total production of 127562.61 tonnes. Only 3.07% of the farmers produce organic grapes, which constitute 2.65% of the total organic agricultural area and 11.06% of the total production. Manisa is the leading region in organic grape production, with 1,086 farmers producing 120,926.39 tonnes on 4652.23 hectares of land. Manisa's climate is ideal for grape cultivation due to its location in the Aegean Region, which is characterized by mild winters and hot summers. The number of sunny days, temperature, and rainfall in Manisa are all favorable for grape growth. Additionally, the fertile soils in Manisa are rich in minerals. Manisa province has accumulated knowledge in traditional grape cultivation, which provides an important advantage in transitioning to organic grape cultivation. Additionally, its proximity to major ports such as Izmir Port and a large city offers advantages for marketing and distributing organic grapes. Currently, organic wheat accounts for 4.81% of the total number of farmers, 14.54% of the total cultivated area, and 9.60% of the total production. Organic

wheat is predominantly produced in the Eastern Anatolia Region. Organic wheat production is particularly prominent in the provinces of Kars, Mardin, Ağrı, Muş and Şanlıurfa, which account for 81.21% of the total production. This is due to the fertile soils and natural mineral wealth of these regions, as well as the limited use of chemicals resulting from fewer industrial activities. Additionally, colder winters limit the presence of certain pest species and diseases in these areas. In addition, these regions are rich in *Triticum boeoticum* (2n=14, AA) and *Aegilops speltoides* (2n=14, BB), as well as the tetraploid wheat species *Triticum dicoccoides*, which is a close relative of durum wheat, and archaeological excavations have determined that it has a rich biodiversity in terms of local wheat varieties. (Aktaş et al., 2018). Organic olives are the second most cultivated product after organic grapes and wheat. In total, 100.474.93 tonnes of organic olives are produced on 37,085.37 hectares by 8,120 farmers. Approximately 65% of these olives are produced in Aydın province. The Mediterranean climate is preferred by organic olives, which is characterized by mild winters and hot summers. Olive trees are sensitive to cold winters and frosts, which can cause damage in regions with harsh winter conditions. The optimal temperature range for olive tree growth is between 10°C and 35°C. Regions with an average temperature of 15°C and above and rainfall between 300 and 600 mm per year are considered suitable for olive cultivation. Olive trees are typically cultivated in microclimate areas at an altitude of 400-1000 m. Therefore, the soils of Aydın province are deemed suitable for olive tree cultivation (Çolakoğlu and tunalıoğlu, 2010).

3.2. Location quotient in organic agriculture

Regionally concentrated clusters are recognized as explanatory parameters of economic development. These clusters are both the cause and result of innovations and technologies, particularly entrepreneurship. As concentration increases, the supply of physical and intangible capital elements required by enterprises, particularly input supply, becomes more accessible, accelerating development and setting an example for new initiatives. However, organic agriculture clusters are also viewed as a potential outcome of expanding organic production areas. These clusters involve entrepreneurs or pioneer farmers in the region taking on production and marketing risks. Within the scope of this study, we calculated the location quotient to investigate the homogeneity of organic production activities across provinces in Türkiye. We aimed to identify the reasons for the differentiation of this distribution by geographical units and how these differences contribute to the agricultural sustainability of enterprises and the region.

Merely having a high share of production activities within provincial borders is insufficient for sustainable production in a region. This is because a production activity with a high production amount in one province may not have a relative advantage when compared with other provinces. To determine the main production activities in a province, it is important to evaluate their sustainability by comparing their relative positions with other provinces, rather than solely relying on the absolute position of the relevant product within the province. The production potentials, sustainability, and superiority of the provinces were investigated using the location quotient calculation. Table 4 shows the relative positions of provinces in Türkiye regarding the concentration levels of organic agricultural products. The Aegean Region (33.94%) and Central Anatolia Region (21.07%) have the highest concentration of organic agriculture production in Türkiye. However, the Eastern Anatolia Region has the highest concentration of organic agriculture production activities in terms of geographical regions. Table 4 and Figure 1 show that the top 10 provinces for organic agriculture production are Van (7), Ağrı (6), Ankara (6), Bayburt (6), Erzurum (6), Çanakkale (5), Kars (5), Muş (5), Niğde (5), and Sivas (5). The crops with the highest concentration of production activities are alfalfa (18), wheat (16), tomato (15), apple (14), corn (12), barley (12), hazelnut (9), sainfoin (9), olive (9), oat (9), and vetch (9). One of the main findings is that the crops identified in Türkiye can be key or basic production activities.

Table 4 shows that the coefficient value is above 1, indicating that the related production activities are above the average in Türkiye. However, it is worth noting that the coefficient value does not necessarily reflect the quality of the production. Organic agriculture is more commonly produced in the Aegean and Central Anatolia regions due to factors such as soil and climate conditions, cultural and traditional approaches, employment opportunities, and government policies (Kılıç et al., 2023). For instance, although Isparta and Karaman provinces are prominent in intensive apple cultivation using traditional methods, they do not produce organic apples. Conversely, Afyonkarahisar, Eskişehir, Tokat, Erzincan, Kahramanmaraş, and Niğde are leading in organic apple production. This disparity is due to the agricultural transformation processes in these provinces. Organic agriculture is often concentrated in regions outside of the top conventional agriculture producers due to production and marketing

challenges, as well as the profitability of conventional agriculture. Soil and climate conditions, environmental and health awareness, consumer demands, and infrastructure facilities are among the factors that influence provinces' approaches to organic agriculture. It is worth noting that the Black Sea region is the most suitable for traditional tea and hazelnut production, and it is also where organic hazelnut and tea products are concentrated. For the sustainability of agricultural production, it is necessary to adopt an approach in which enterprises carrying out similar or related activities concentrate in a certain region and cooperate with each other to gain an advantage. This approach ensures knowledge and experience sharing, cooperation, and solidarity, as well as the use of technology, market access, and environmental sustainability. It also contributes to reducing socio-economic differences between regions.

In this study, we calculated the concentration coefficient of organic agriculture in Türkiye and investigated the organic agriculture potentials of the provinces. To determine in which provinces organic agriculture is more advantageous, we used the location quotient. Similarly, location quotient has been used in many studies to determine the concentration levels of products according to regions. In these studies, employment, income and trade indicators have been used to determine which products should be produced more (Restiatun, 2009; Basuki and Mujiraharjo, 2017). According to the results obtained from the literature, the potential commodity to be developed is different from each region (Sausan et al., 2022). This may be due to the comparative advantages of the potential commodity from the natural resources that support it or the competitive advantages of the potential commodity from its ability to compete with others (Rozaki et al., 2021). Therefore, a location coefficient value of more than one means that the commodity in the specified region has the potential to be developed (Humaidi and Kertayoga, 2022). Higher value means higher potential. Kim et al. (2019) suggest that the production rate should be above 1% of the national scale and 10% of the provincial scale and the LQ value should be above 2.0, considering the agricultural characteristics of the products. Although this value is not a criterion, it can be considered as an important threshold value in terms of specialization of agricultural products. Lee (2020) found that the results of the LQ analysis show that the specialized regions are different for each activity. Therefore, as a result of the differentiation of LQ values in each region and production activity, LQ values can be used to create strategies for regional planning or community activation. At the same time, LQ value is also used to determine the export potential of products (Darmanto et al., 2020). Accordingly, the export potential of certain products in regions with high LQ values can be evaluated.

Our analysis revealed that Türkiye's organic agriculture concentration coefficients are low, indicating that Türkiye should better evaluate its organic agriculture potential. Türkiye has a suitable climate, soil, water, and biodiversity resources for organic agriculture. Additionally, there is an increasing demand for organic products in both domestic and foreign markets. Therefore, the development of organic agriculture is crucial for regional development and competitiveness. This agricultural method does not harm the environment or human health, limits the use of chemical inputs, and preserves soil fertility and biodiversity. Organic agriculture can efficiently use regional resources, prevent rural depopulation, revitalize local economies, improve regional income distribution, ensure regional branding, and strengthen regional identity. Türkiye should develop policies and strategies to increase the concentration coefficient of organic agriculture.

The LQ value was calculated to identify a region as a superior commodity with the idea that it can sustainably compete with other regions in the production of the same commodity. The LQ value can show a comparison of a region's ability to produce agricultural commodities compared to regional agricultural commodity production. With the LQ value, the ability of a region to produce a commodity can be seen. Therefore, a sectoral approach is needed to identify leading sectors. Finding the results of the main agricultural sub-sector that will become the capability of the sector is necessary to achieve sustainable development results. For this reason, according to the results of our analysis Türkiye's organic agriculture concentration coefficients are low, indicating that Türkiye should better evaluate its organic agriculture potential. Türkiye has a suitable climate, soil, water, and biodiversity resources for organic agriculture. Additionally, there is an increasing demand for organic products in both domestic and foreign markets. Therefore, the development of organic agriculture is crucial for regional development and

Table 4. Location quotient of organic agriculture by province

City/Crops	Grape	Wheat	Olive	Apple	Hawthorn	Maize	Fig	Barley	Apricot	Tea	Hazelnut	Alfalfa	Pomegranate	Oats	Tomato	Chery	Sainfoin	Wetch	Cotton	Carob	Sour Cherry	Meadow Grass
Adana	0.01	0.00	0.02	0.57	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.06	17.53	0.00	0.01	0.11	0.00	0.00	0.00	0.09	0.47	0.00
Adıyaman	0.11	0.00	0.06	0.00	0.00	0.00	0.06	0.17	0.00	0.00	0.00	0.00	30.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Afyon	0.00	0.41	0.00	3.18	0.00	0.03	0.00	0.69	0.04	0.00	0.00	0.46	0.00	0.19	0.32	20.22	0.00	0.14	0.00	0.00	14.55	0.36
Ağrı	0.00	3.80	0.00	0.02	0.00	0.00	0.00	3.65	0.00	0.00	0.00	6.41	0.00	0.07	0.00	0.00	7.23	1.09	0.00	0.00	0.00	5.15
Aksaray	0.03	0.00	0.00	1.87	0.32	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Ankara	0.06	0.98	0.00	0.43	0.00	0.05	0.00	1.19	0.50	0.00	0.00	3.14	0.00	2.79	4.86	1.38	0.79	0.05	0.00	0.00	0.05	8.92
Antalya	0.01	0.12	0.02	0.00	0.00	0.00	0.00	0.10	0.02	0.00	0.00	0.01	0.56	0.00	0.41	0.13	0.02	0.02	0.00	72.23	0.00	0.00
Artvin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.41	25.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aydın	0.01	0.10	5.34	0.01	0.00	0.64	6.41	0.03	0.01	0.00	0.00	0.25	0.17	0.01	0.08	0.06	0.00	0.18	3.50	0.00	0.00	0.01
Balıkesir	0.00	0.10	4.69	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	10.08	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Bartın	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Batman	0.00	8.84	0.00	0.03	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bayburt	0.00	0.67	0.00	0.00	0.00	0.00	0.00	1.14	0.00	0.00	0.00	11.13	0.00	8.07	0.00	0.00	4.07	6.12	0.00	0.00	0.00	2.80
Bilecik	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.04	36.48	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bitlis	0.00	1.40	0.00	0.17	0.00	0.00	0.00	0.89	0.02	0.00	0.00	17.21	0.00	0.00	0.00	0.00	12.69	0.00	0.00	0.00	0.00	6.81
Bolu	0.00	0.25	0.00	0.00	0.00	1.05	0.00	0.34	0.00	0.00	0.00	0.50	0.00	0.21	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Burdur	0.00	2.07	0.01	0.27	0.00	1.23	0.00	0.89	0.00	0.00	0.00	0.38	0.00	0.38	2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bursa	0.01	0.01	0.05	0.04	0.00	0.01	0.02	0.00	0.01	0.00	0.00	2.02	0.02	0.00	2.25	0.98	0.17	0.11	0.00	0.00	0.21	0.00
Çanakkale	1.05	0.02	3.43	0.03	0.00	2.81	0.00	0.46	0.01	0.00	0.00	5.74	0.01	0.52	0.01	0.03	0.00	1.14	0.00	0.00	0.01	0.00
Çorum	0.04	0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Denizli	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.64	0.00	0.00	0.00	0.00	1.17	11.93	0.00	0.00	0.00
Diyarbakır	5.79	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Düzce	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	33.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elazığ	0.52	0.15	0.00	0.01	0.00	0.00	0.00	0.78	16.60	0.00	0.00	0.10	0.00	0.00	0.29	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Erzincan	0.01	0.89	0.00	5.93	0.00	0.00	0.00	1.99	0.42	0.00	0.00	0.67	0.00	2.62	0.00	0.38	0.03	0.00	0.00	0.00	22.59	0.07
Erzurum	0.00	1.73	0.00	0.14	0.00	0.00	0.00	0.74	0.00	0.00	0.00	11.73	0.00	7.27	0.00	0.00	3.30	2.88	0.00	0.00	0.00	6.60
Eskişehir	0.04	0.00	0.00	11.85	0.00	0.28	0.00	0.01	0.01	0.00	0.00	0.00	0.04	0.13	0.30	0.01	0.00	0.00	0.00	0.00	0.43	0.00
Gaziantep	0.05	1.08	4.73	0.00	0.00	0.44	0.04	1.12	0.00	0.00	0.00	0.00	1.66	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.00	0.00
Giresun	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	32.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gümüşhane	0.00	6.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hatay	0.00	0.06	6.68	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	11.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iğdır	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isparta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
İstanbul	0.08	0.82	0.00	0.60	0.00	0.09	0.05	0.21	0.06	0.00	0.04	0.05	0.02	0.00	7.90	0.22	0.00	0.92	0.00	0.00	0.26	3.79
İzmir	0.64	0.03	3.12	0.01	0.00	0.44	7.14	0.00	0.03	0.00	0.00	0.05	0.30	0.00	1.47	0.09	0.00	0.03	0.00	0.00	0.00	0.00
K.Maraş	0.13	0.02	0.18	5.77	0.00	0.00	0.00	0.08	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Continued

Karaman	3.45	0.47	0.00	0.00	0.00	7.26	0.00	0.06	2.19	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00
Kars	0.00	3.43	0.00	0.00	0.00	0.01	0.00	7.03	0.02	0.00	0.00	0.80	0.00	10.07	0.00	0.00	5.39	3.47	0.00	0.00	0.00	0.01
Kastamonu	0.00	0.15	0.00	3.07	0.21	0.00	0.00	0.02	0.00	0.00	0.00	0.43	0.00	0.53	0.00	1.99	0.24	0.00	0.00	0.00	2.69	0.00
Kayseri	0.10	0.00	0.00	0.04	0.00	0.01	0.00	0.05	0.06	0.00	0.00	0.30	0.00	0.00	0.79	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Kırıkkale	0.00	0.00	0.00	0.13	0.00	0.03	0.00	0.52	0.00	0.00	0.00	0.41	0.00	0.00	10.20	0.14	0.00	0.00	0.00	0.00	0.00	0.00
Kırklareli	0.04	0.33	0.00	1.21	0.00	2.25	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	18.88	0.80	0.00	0.00	0.00	0.00	0.84	0.00
Kırşehir	0.21	1.51	0.00	1.78	0.07	0.00	0.00	0.45	0.11	0.00	0.00	0.00	0.00	0.00	4.91	0.29	0.00	0.00	0.00	0.00	0.45	0.00
Kilis	0.07	0.00	11.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kocaeli	0.00	0.25	0.00	0.03	0.00	3.94	0.01	0.08	0.00	0.00	0.02	1.77	0.01	16.85	0.78	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Konya	0.06	0.62	0.00	1.28	0.00	0.29	0.00	0.81	0.00	0.00	0.00	0.08	0.00	0.07	0.33	13.73	0.00	0.00	0.00	0.00	17.92	0.00
Kütahya	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.63	0.00	0.00	0.00	10.22	0.00	0.00	0.00	0.00	64.29	0.00
Malatya	0.03	0.12	0.00	0.04	0.00	0.00	0.00	0.06	20.53	0.00	0.00	0.14	0.00	0.27	0.11	0.07	0.04	0.00	0.00	0.00	0.00	0.00
Manisa	6.51	0.05	0.50	0.00	0.00	1.03	0.00	0.06	0.00	0.00	0.00	0.10	0.85	0.08	5.15	0.06	0.00	0.66	1.34	0.00	0.00	0.00
Mardin	0.00	4.05	0.00	0.00	0.00	8.36	0.00	0.48	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.00
Mersin	0.01	0.04	2.09	0.04	0.00	0.06	0.00	0.00	0.11	0.00	0.00	0.15	0.10	0.00	2.98	0.23	0.42	0.00	0.00	3.89	0.00	0.00
Muğla	0.50	0.01	7.62	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	4.40	0.00	0.26	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Muş	0.02	5.14	0.00	0.06	0.00	0.00	0.00	3.02	0.01	0.00	0.00	3.41	0.00	0.27	0.01	0.03	1.06	0.91	0.00	0.00	0.00	22.27
Nevşehir	0.63	0.67	0.00	0.42	0.00	0.00	0.00	0.00	1.58	0.00	0.00	1.05	0.00	0.02	3.81	1.47	0.00	0.00	0.00	0.00	0.05	0.00
Niğde	0.02	0.05	0.00	4.56	7.01	1.01	0.00	0.02	0.06	0.00	0.00	1.32	0.00	0.04	0.00	0.21	0.00	2.30	0.00	0.00	0.12	0.00
Ordu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Osmaniye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.77	20.44	0.00	0.00	0.00	0.00	0.00	0.00
Rize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.23	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sakarya	0.00	0.05	0.00	0.02	0.00	1.97	0.00	0.03	0.00	0.00	25.93	0.26	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.00
Samsun	0.00	0.09	0.00	0.01	0.00	4.78	0.00	0.00	0.00	0.00	15.49	0.00	0.00	0.00	0.01	0.01	0.00	8.15	0.00	0.00	0.00	0.07
Sinop	0.34	0.00	0.00	2.36	0.03	0.00	1.28	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	6.96	0.00	0.00	0.00	0.00	1.27	0.00
Sivas	0.00	4.05	0.00	0.01	0.00	0.17	0.00	4.68	0.42	0.00	0.00	1.68	0.00	5.00	0.00	0.01	7.80	0.17	0.00	0.00	0.00	0.65
Şanlıurfa	0.00	2.98	0.05	0.02	0.00	2.10	0.00	1.14	0.00	0.00	0.00	0.00	7.62	0.00	0.00	0.00	0.00	0.00	11.89	0.00	0.00	0.00
Tekirdağ	5.42	0.42	0.00	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.00	3.58	0.00	1.30	0.64	0.15	1.34	0.00	0.00	0.00	0.00	0.00
Tokat	0.05	0.35	0.00	3.98	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.51	0.00	0.32	0.32	0.04	0.42	0.00	0.00	0.00	36.81	0.00
Trabzon	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	6.61	22.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.48
Tunceli	0.01	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.98	0.00	0.00	0.00	0.00	0.20	0.53	0.00	0.00	0.00	0.15
Uşak	0.00	5.12	0.00	0.00	0.00	0.00	0.00	1.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Van	0.00	1.54	0.00	2.40	0.00	0.16	0.00	1.34	0.02	0.00	0.00	10.17	0.00	0.00	4.67	0.00	3.36	0.00	0.00	0.00	0.00	17.06
Yalova	0.00	0.77	0.19	0.11	0.03	0.04	0.06	0.00	0.00	0.00	0.06	9.17	0.17	7.78	0.04	0.00	0.00	3.10	0.00	0.00	0.00	0.23
Yozgat	0.03	3.65	0.00	0.00	0.00	0.03	0.00	2.73	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zonguldak	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.00	32.17	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00

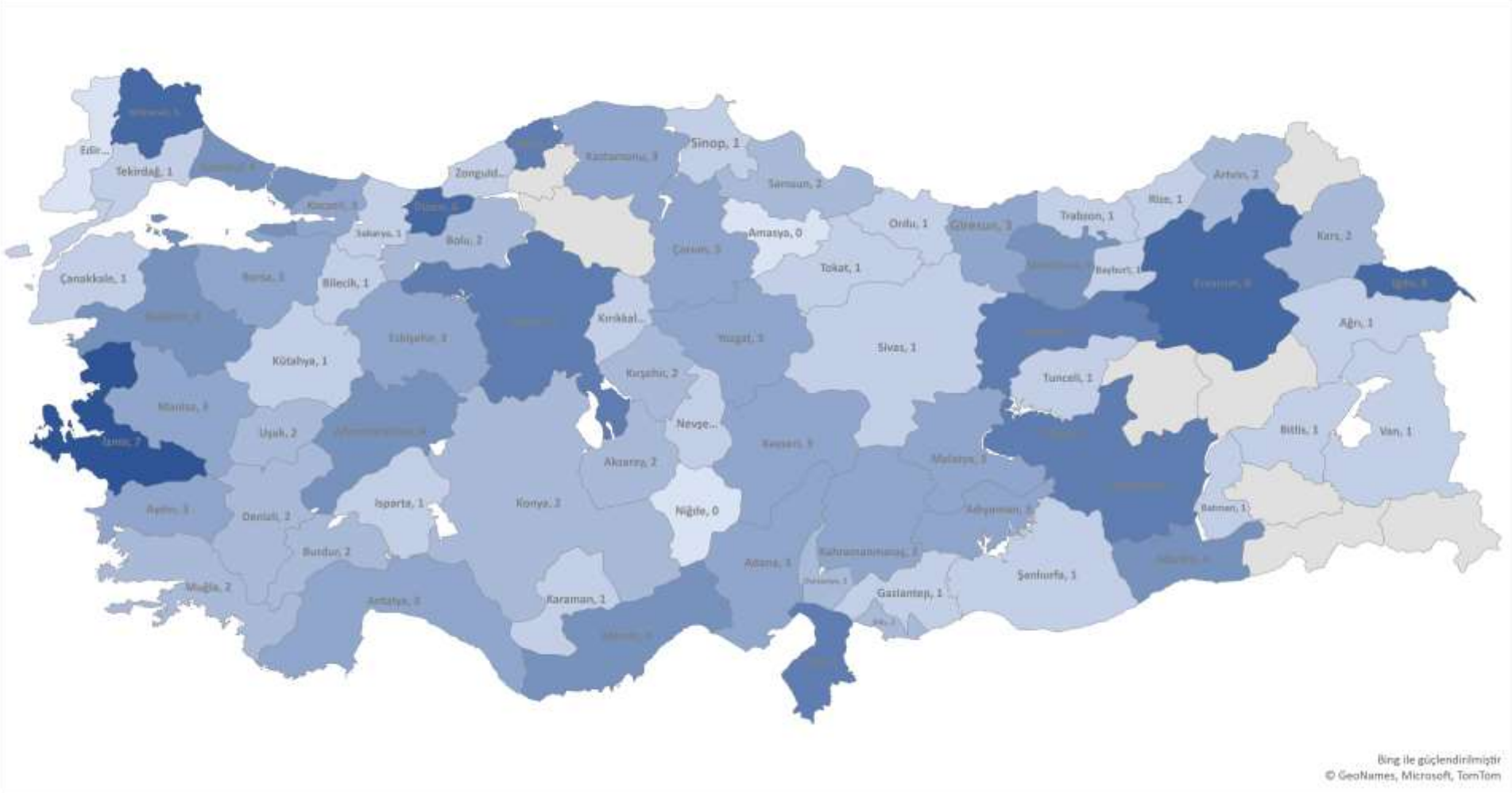

Figure 1. Concentration of organic agricultural products by province

competitiveness. This agricultural method does not harm the environment or human health, limits the use of chemical inputs, and preserves soil fertility and biodiversity. Organic agriculture can efficiently use regional resources, prevent rural depopulation, revitalize local economies, improve regional income distribution, ensure regional branding, and strengthen regional identity. Türkiye should develop policies and strategies to increase the concentration coefficient of organic agriculture.

4. Conclusions

The theory of economies of location aims to support regional economic development by making the best use of local resources and advantages and increasing the economic resilience of communities through the location of economic activities in a particular region and the establishment of strong links between businesses, suppliers, service providers, and consumers in that region. This approach utilizes natural resources and the labour force more efficiently, mitigates the impact of global external shocks, preserves regional identity and culture, and is considered an important tool for balancing the regional economy.

The study calculated the location quotient in the organic farming sector. This coefficient is important for regional economic development, strengthening local businesses, promoting environmental sustainability, increasing economic resilience, protecting local identity and culture, and encouraging the adoption and promotion of organic farming as a sustainable agricultural model that contributes to the local economy, environment and social well-being. According to the theory of location economies, businesses in the same sector can cluster in certain regions due to economies of scale, positive externalities and knowledge creation and transfer. In order to ensure regional sustainability and increase specialization in production activities, it is necessary to investigate the technical suitability of locally produced organic agricultural products. Regional suitability maps should be developed to identify the basins and products suitable for organic farming in each region. To improve soil management, maintenance, harvesting and marketing, it is recommended to organize training activities based on main production activities at regional level. In addition, strategies and action plans for production and research activities should be developed. Investment incentive certificates can be prepared to support production activities, and financial support can be provided to enterprises with these certificates. Support can also be provided for the construction of processing and storage facilities, branding and geographical indications. Group certifications in accordance with international standards should be developed, and various institutions and organizations should organize training for organic agricultural producers to strengthen promotion activities. Input and product price support mechanisms should be put in place during transition periods in the organic agriculture sector. In this context, to ensure regional sustainability and increase specialization in production activities;

- Investigating the technical feasibility of regionally concentrated organic agricultural products
- Organizing training activities on land management, maintenance, harvesting and marketing operations according to basic production activities at regional level
- Establishing a strategy and action plans for production and research activities in organic agriculture at local and regional level
- Increasing technical and market information resources by developing training modules for organic agriculture producers and preparing trainings for "beginner", "transition" and "production period" producers
- To increase organization according to basic production activities, subsidies are given to organizations at the beginning of the production period,
- Preparing investment incentive certificates to support basic production activities and providing financial support to enterprises with these certificates,
- Only allowing the opening of facilities with processing, production, marketing, export, etc. activities in districts with basic production activities and providing the necessary infrastructure such as cold storage, packing house, etc. with support
- Contributing to the creation of added value by providing information on branding in districts with basic production activities,
- Development of group certifications to reduce certification costs,
- Realization of certification procedures in international standards,

- Organizing trainings for organic agriculture producers by various institutions and organizations in order to increase promotional activities
- Training on crop rotation, green fertilization and similar practices should be planned at the production stage according to the regions.

As a result, specialized labour, sectoral inputs and similar technologies are used in localized/intensified organic farming formations, which play an important role in providing high income per unit area, optimal use of agricultural land and ensuring sustainability. Therefore, it is expected that the benefits arising from these formations will contribute to the economic, social and environmental sustainability of the region by increasing productivity and will also provide significant benefits for the development of organic agriculture.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Bayramoğlu, Z.; Design: Ağızan, S.; Data Collection or Processing: Ağızan, S., Ağızan, K.; Statistical Analyses: Ağızan, K.; Literature Search: Ağızan, K.; Writing, Review and Editing: Ağızan, S., Ağızan, K.

References

Aktaş, H., Özberk, F., Erol, O., Baloch, F. S., Doğan, S., Kahraman, M. and Çığ, F. (2018). Potential and sustainable conservation of wheat genetic resources in Southeastern Anatolia Region of Turkey. *Bahri Dağdaş Journal of Crop Research*, 7(2): 47-54. (In Turkish).

Aliyu, A.A., Dukiya, M. D. J. J. and Umaru E.T. (2023). Classification of Settlements by economic potentials in the southern region of Niger State: A location quotient approach. *Structure and Environment*. *15*(3): 125-132. (In Turkish).

Alkan, A. and Bilim, Z.O. (2021). Regional concentration in Turkish cement industry with Location Quotient approach. *Bitlis Eren University Journal of Social Sciences*, 10(1): 101-113. (In Turkish).

Altuğ, F. (2017). Innovative specialisation trends in innovation activities in Turkey: Manufacturing industry patent indicators of Istanbul, Ankara and Izmir regions. *Journal of Geographical Sciences,* 15(2): 157-166. (In Turkish).

Anwar, C., Mappatoba, M., Syamsuddin, H. and Taqwa, E. (2021). Determining selected prime agriculture commodities through three methods. *Journal of Environmental Management and Tourism,* 12(3): 677-683.

Ayla, D. (2011). *Organic agriculture in Turkey.* (MSc Thesis). Karadeniz Technical University, Institute of Science and Technology, Trabzon, Türkiye. (In Turkish).

Ayuya, O. I., Gido, E. O., Bett, H. K., Lagat, J. K., Kahi, A. K. and Bauer, S. (2015). Effect of certified organic production systems on poverty among smallholder farmers: Empirical evidence from Kenya. *World Development,* 67: 27-37.

Basuki, M. and Mujiraharjo, F. N. (2017). Analisis sektor unggulan Kabupaten Sleman dengan metode shift share dan location quotient. *Jurnal Sains, Teknologi dan Industri,* 15(1): 52-60.

Bayraktutan, Y. (1994). Regional Imbalance and regional development. *Atatürk University Journal of Economics and Business Administration*. 10(3-4): 183-214. (In Turkish).

Bayramoğlu, Z., Ağızan, K., Ağızan, S., Bozdemir, M., Ataiyibiner, A. and Akgöz, B. (2021). Dissemination of Organic Agriculture in Marginal Agricultural Areas and Contribution to Sustainability. Atlas Publishers, Konya, Türkiye. (In Turkish).

Blanc, J. and Kledal, P. R. (2012). The Brazilian organic food sector: Prospects and constraints of facilitating the inclusion of smallholders. *Journal of Rural Studies*, 28(1): 142-154.

Brosnan S. (2017). Crime concentration in Ireland in 2012: A Location quotient approach. *Irish Journal of Applied Social Studies,* 17(1): 76-93.

Campaniaris, C., Murray, R., Hayes, S. and Jeffrey, M. (2015). Evidence-based development of a strategy for Canadian apparel SMEs. *Journal of Fashion Marketing and Management*, 19(3): 299-314.

Chiang, S. H. (2009). Location quotient and trade. *The Annals of Regional Science*, 43(2): 399-414.

Çakmakçı, R. and Erdoğan, U. (2005). Organic Agriculture. Atatürk University Ofset Facilities Publishers, Erzurum, Türkiye.

Çetin, M., Saygin, S. and Demir, H. (2020). The impact of agricultural sector on environmental pollution: a cointegration and causality analysis for the Turkish economy. *Journal of Tekirdağ Faculty of Agriculture*, 17(3): 329-345. (In Turkish).

Çiftçi, M. (2018). Regional specialisation in academic employment, academic labour market and faculty rotation in Turkey. *EKEV Academy Journal,* 22(73): 233-262. (In Turkish).

Çolakoğlu, C. A. and Tunalıoğlu, R. (2010). Determination of the Relationship between Olive Production and Climate Data in Aydın Province. *Journal of Adnan Menderes University Faculty of Agriculture,* 7(1): 71-77. (In Turkish).

Darmanto, E. B., Pratiwi, Y. S. and Nugroho, H. S. W. (2020). Location quotient analysis of agricultural sector and subsector in East Java 2010-2017 (A reference for law and policy on economics, nutrition and public health). *Indian Journal of Forensic Medicine and Toxicology,* 14(1): 234-238.

De Master, K. (2012). Designing dreams or constructing contradictions? European Union multifunctional policies and the Polish organic farm sector. *Rural Sociology,* 77(1): 89-109.

Deliktaş, E. and Çelik, N. (2019). Determination of competitive sectors in TRB2 Region. *Journal of Izmir Katip Çelebi University Faculty of Economics and Administrative Sciences,* 2(1): 29-44. (In Turkish).

Demir, A. and Gül, U. (2004). Organic Agriculture. *Agricultural Economics Research Institute-Bakış,* 3(5): 1-4. (In Turkish).

Demiryürek, K. (2016). Organic Agriculture and Economics. DOKAP Publishers, Giresun, Türkiye. (In Turkish).

Eser, U. and Köse, S. (2005). Turkey Industry in terms of ındustrial localisation and concentration: Analysis of provincial manufacturing ındustries. *Ankara University SBF Journal*, 60(2): 97-139.

Falcioğlu, P. and Akgüngör, S. (2008). Regional specialisation and industrial concentration patterns in the Turkish manufacturing industry: An assessment for the 1980-2000 period. *European Planning Studies,* 16(2): 303-323. (In Turkish).

Hildebrand, G. and Mace, A. (1950). The employment multiplier in an expanding industrial market: Los Angeles County, 1940-47. *The Review of Economics and Statistics,* 32(3): 241-249.

Humaidi, E. and Kertayoga, I. P. A. W. (2022). Preparation of a Map of Leading Food Commodities in the Lampung Province Using the Location Quotient (LQ) Method. *2nd International Conference on Agriculture and Applied Science*. *1*8 November, P. 1-5, Bandar Lampung, Indonesia.

Irham, I. and Mulyo, J. H. (2016). Contribution of agricultural sector and sub sectors on Indonesian economy. *Ilmu Pertanian (Agricultural Science),* 18(3): 150-159.

Kartikawati, D. and Sundari, M. (2018). The Role of Agriculture, Forestry and Fishery Sector in the Development of Malinau District (Location Quotient and Shift Share Approach). *The 1st International Conference on Environmental Sciences (ICES2018),* 15–16 November, West Sumatra, Indonesia

Kazancik, B. (2007). Regional Development and Sector-Region Agglomerations. *Regional Development and Governance Symposium,* 25-26 October, P. 393-414, İzmir, Türkiye. (In Turkish).

Kılıç, A., Kuzucu, M. and Gökçen, İ. S. (2023). Investigation of the nutritional status of agricultural soils in Kilis province. *Journal of Tekirdağ Agricultural Faculty,* 20(3): 631-641. (In Turkish).

Kim, S., Suh, K., Kim, Y., Kim, C. and Jung, C. (2019). Quantitative evaluation on geographical ındication of agricultural specialty products using location quotient (LQ) index. *Journal of the Korean Society of Agricultural Engineers,* 61(2): 75-83.

Kirazlar, N. (2001). Ecological (Organic) Agriculture Legislation. *Turkey 2nd Ecological Agriculture Symposium,* 14-16 November, P. 11-19, Antalya, Türkiye (In Turkish).

Lee, J. (2020). Analysis of the status of agricultural communities and location quotient (LQ) using regional survey data in 2015 census of agriculture, forestry, and fisheries. *Journal of Korean Society of Rural Planning,* 26(2): 83-93.

Leigh, R. (1970). The use of location quotients in urban economic base studies. *Land Economics,* 46(2): 202-205.

Lobley, M., Butler, A. and Reed, M. (2009). The contribution of organic farming to rural development: An exploration of the socio-economic linkages of organic and non-organic farms in England. *Land Use Policy*, 26(3): 723-735.

McGreevy, S.R. (2012). Lost in translation: incomer organic farmers, local knowledge, and the revitalisation of upland Japanese hamlets. *Agriculture and Human Values,* 29(3): 393-412.

Merdan, K. and Kaya, V. (2013). Economic analysis of organic agriculture in Turkey. *Journal of Atatürk University Institute of Social Sciences,* 17(3): 239-252. (In Turkish).

Miller, M. M., Gibson, L. J. and Wright, N. G. (1991). Location quotient: A basic tool for economic development analysis. *Economic Development Review,* 9(2): 65-68.

Öz, Ö. (2004). Spatial distribution and competitive structure of economic activities in Turkey. *METU Studies in Development,* 31(2): 211-241.

Öztürk, S. (2018). Evaluation of women entrepreneurship in Turkey within the framework of economic and cultural norms. *Journal of Entrepreneurship and Development,* 13(1): 1-11. (In Turkish).

Restiatun, R. (2009). Identifikasi Sektor Unggulan Dan Ketimpangan Antarkabupaten/Kota Di Provinsi Daerah Istimewa Yogyakarta. *Jurnal Ekonomi & Studi Pembangunan,* 10(1): 77-98.

Rozaki, Z., Wijaya, O. and Wardana, C. (2021). Agriculture Development Based on Regional Potency in Kulonprogro Regency. I*nternational Geography Seminar*. 31 August, P. 1-6, Lor in Hotel Solo, Indonesia.

Sausan, A., Cahyani, A., Ashidieq, F., Risqa, M., Bahri, M., Wahyudi, R., Gitanto, V. and Putri, R. (2022). Location Quotient Analysis of the Agricultural Sector in Yogyakarta, Indonesia. *2nd International Conference on Smart and Innovative Agriculture (ICoSIA 2021),* 10 March, P. 5-9, Yogyakarta, Indonesia.

Smith, E. and Marsden, T. (2004). Exploring the 'limits to growth' in UK organics: Beyond the statistical image. *Journal of Rural Studies*, 20(3): 345-357.

Süzer S. (2020). Organic (Ecological) Agriculture. https://arastirma.tarimorman.gov.tr/ttae/Sayfalar/Detay.aspx?SayfaId=66 (Accessed Date: 18.05.2021) (In Turkish).

TOB (2022). Organic Agriculture Statistics. https://www.tarimorman.gov.tr/Konular/Bitkisel-Uretim/Organik-Tarim/Istatistikler (Accessed Date: 18.04.2022) (In Turkish).

Turhan, Ş. (2005). Sustainability in agriculture and organic agriculture. *Journal of Agricultural Economics,* 11(1 and 2): 13-24. (In Turkish).

Urhan, F. B. and Sandal, E. K. (2019). Spatial pattern of Turkey textile ındustry: Comparative localisation coefficient analysis for 2009-2015. *International Journal of Geography and Geography Education,* 40: 172-189. (In Turkish).

Weterings, A. and Marsili, O. (2015). Spatial concentration of industries and new firm exits: Does this relationship differ between exits by closure and by M&A? *Regional Studies,* 49(1): 44-58.

Wicaksono, I. A. (2011). the analysis of location quotient on sector and subsector of agriculture among the sub districts in Purworejo Regency. *Mediagro,* 7(2): 11-18.

Yardımcı, A. (2014). Clustering trends of Ankara Industry according to capacity reports. *Ekonomik Yaklasim,* 25(92): 55-67. (In Turkish).

Yavan, N. and Şahin, M. (2014). Analysis of Regional Concentration and Diversification in Turkish Industry with Different Indices. *TÜCAUM VIII. Geography Symposium*. 06-08 February, P. 23-24, Geoagiu-Bai, Romania. (In Turkish).

Yolcu, N. (2013). *Organic agriculture and employment creation potential of organic agriculture in Turkey*. (MSc. Thesis) Karadeniz Technical University. (In Turkish).

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluation of Attitudes and Knowledge Levels of Olive Producers in the Application of Agricultural Pharmaceuticals (Mardin Province)

Mardin İli Zeytin Üreticilerinin Tarımsal İlaç Ürünlerinin Uygulamasında Tutum ve Bilgi Seviyelerinin Değerlendilirlenmesi

Mehmet KAPLAN[1*]

Abstract

Olives are one of the essential nutrients in human nutrition and health, thanks to the vitamins they contain. There are many diseases, pests and weed species in olive gardens that cause a loss of productivity and quality of this important nutrient. Producers use different methods in plant protection practices to combat these existing pests. This study was conducted to determine the awareness levels of olive producers about plant protection practices in Derik district of Mardin province, where olive production was intense in 2020. For this purpose, the information collected through a 20-question survey method conducted face to face with a total of 90 producers in 15 villages through simple random sampling was evaluated on a percentage basis. According to the results of the current study, it was determined that the olive farmers had high education levels, and the majority of them had other non-agricultural incomes besides agriculture. Those engaged in olive cultivation consult plant protection dealerships and the provincial/district Directorate of Agriculture and Forestry in choosing plant protection products and adjusting their dosage. They stated that the brand and active ingredients are important features in the selection of chemical pesticides, and while they apply pesticides in advance for precautionary purposes without seeing the pests and diseases, they do not use the same pesticides against the same diseases and pests every year and apply the recommended dosage. Producers pay attention to the waiting time between the last spraying and harvest time due to the fact that chemical pesticides leave residues on the products, and they take protective measures for their own health during chemical pesticide application. In order to solve the plant protection problems faced by farmers in the agricultural field, cultural measures are generally applied along with chemical control. However, it is inevitable that chemicals will create many negative situations for human and environmental health over time. For this reason, it is important to carry out an effective, economical and environmentally friendly struggle using appropriate methods in plant protection practices in order to avoid being exposed to undesirable side effects.

Keywords: Plant protection problems, Survey, Olive, Mardin

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Öz

Zeytin içerdiği vitaminler sayesinde insan beslenmesinde ve sağlığında yer alan temel besin maddelerin birisidir. Zeytin bahçelerinde bu önemli besin maddesinde verim ve kalite kaybına neden olan, birçok hastalık, zararlı ve yabancı ot türü bulunmaktadır. Üreticiler mevcut olan bu zararlılarla mücadelede bitki koruma uygulamalarında farklı yöntemleri kullanmaktadırlar. Bu çalışma 2020 yılında zeytin üretiminin yoğun olarak yapıldığı Mardin ili Derik ilçesi zeytin üreticilerinin bitki koruma uygulamalarında farkındalık düzeylerini belirlemek amacıyla yapılmıştır. Bunun için, basit tesadüfi örneklemeyle 15 köyde, toplam 90 adet üreticiyle yüz yüze yürütülen 20 soruluk anket metoduyla toplanan bilgiler yüzde oran üzerinde değerlendirmeler yapılmıştır. Çalışma sonuçlarına göre zeytincilik yapan çiftçilerin, eğitim düzeylerinin yüksek ve çoğunluğunun tarımla birlikte tarım dışı başka gelirleri olduğu belirlenmiştir. Zeytincilikle uğraşanların bitki koruma ürünlerini seçiminde ve dozunu ayarlamasında bitki koruma bayiliklerine ve Tarım ve Orman il/ilçe Müdürlüğüne danışmaktadırlar. Kimyasal ilaç seçiminde marka ve etken maddelerinin önemli bir özellik olup, zararlı ve hastalıkları görmeden tedbir amaçlı önceden ilaç uygularken her yıl aynı hastalık ve zararlılara karşı aynı zirai ilacı kullanmadıkları ve tavsiye edilen dozu uyguladıklarını ifade etmişlerdir. Üreticilerin kimyasal ilaçların ürünler üzerinde kalıntı bıraktıklarından dolayı son ilaçlama ile hasat zamanı arasındaki bekleme zamanına özen gösterdikleri ve Kimyasal ilaç uygulama esnasında kendi sağlığı açısından koruyucu önlemleri almaktadırlar. Bununla birlikte ilaçlamadan önce herhangi bir kalibrasyon yapmadıkları ve kullandıkları kimyasal ilaçları karıştırarak uyguladıklarını, ilaçlama sonrasında ise ilaçlama aletlerini temizledikleri ve kullanılan kimyasalların boş kaplarını ve ambalajlarını çevreye rastgele atmadıklarını bildirmişlerdir. Çiftçiler, tarımsal alanda karşılaştıkları bitki koruma sorunlarını çözmede genellikle kimyasal mücadele ile birlikte kültürel tedbirleri de uygulamaktadır. Ancak kimyasalların zamanla insan ve çevre sağlığı açısında birçok olumsuz durum yaratması kaçınılmazdır. Bu sebeple arzu edilmeyen yan etkilere maruz kalmamak için bitki koruma uygulamalarında uygun olan yöntemleri kullanarak etkin, ekonomik ve çevreci bir mücadele yapılması önemlidir.

Anahtar Kelimeler: Bitki koruma sorunları, Anket, Zeytin, Mardin

1. Introduction

Olive, which is one of the basic foods in people's lives, is consumed in the form of cooking, oil, shampoo, cream, etc. in the cosmetic sector. It is evaluated in different forms.

There is a total of 23.054.310 tons of olive production in the world in 2021, and countries such as Spain, Greece, Italy, Turkey, Morocco, Syria, Tunisia, Algeria, Egypt, and Portugal are important olive producers in this production. Türkiye ranks 3rd in the world with an olive production of 1.738.680 tons (Anonymous, 2021a).

Due to Turkey's favorable climatic and geographical conditions, olives are grown primarily in the Aegean, Marmara, Mediterranean, Southeastern Anatolia and Black Sea regions Mete et al., 2023. The total olive production area is 2.976.000 tons with 163.034.684 olive trees in an area of 9.011.261 decares (Anonymous, 2022). Mardin province, which is an important olive production region of the Southeastern Anatolia Region, has a total of 745.999 olive trees, 466.195 of which are fruit-bearing and 279.804 of which are non-fruitful, in an area of 20.123 decares, yielding 4.620 tons of product (Anonymous, 2022).

There are many harmful factors that directly and indirectly cause quantity and quality losses in olive production areas. The constant demand for increased food production has led to the intensive use of chemical fertilizers, pesticides, agricultural machinery, and other natural resources (Güngörmez et. al., 2022). In previous years, many studies on the detection and damage of pests in the olive fields of our country have been carried out in the Aegean, Marmara, Mediterranean, and Southeastern Anatolia (Bodenheimer, 1941; Nizamlıoğlu and Gökmen, 1964; İyriboz, 1968; Kaya, 1979; Keçecioğlu, 1984; Güçlü et al., 1995; Kaçar and Ulusoy, 2005; Kaplan, 2019). The commercial market value of agricultural products damaged by harmful species decreases as a result of consumers not choosing them and not eating them (Alabouid and Bayhan, 2022). Chemical warfare is an indispensable form of struggle used all over the world due to its easy application against pests in agricultural areas and rapid results. However, uncontrolled and haphazard applications of pesticides used in chemical warfare negatively affect human and environmental health. While pesticides make a great contribution to increasing efficiency and quality in agricultural production, on the other hand, pesticides mix with soil, water and air, threatening the existence of living organisms. Farmers generally prefer the chemical warfare method to solve plant protection problems, and unconscious pesticide applications bring about many negativities in terms of human and environmental health (Kaplan and Saltuk, 2021). They reported that most of the producers in Mardin Province are unaware of the harmful insect species that significantly negatively affect the development and efficiency of agricultural production (Kaplan and Bayhan, 2017). Chemicals employed unintentionally to combat harmful elements can lead to the development of resistance in target pests over time, resulting in residues in food products. Conversely, the natural balance among living organisms is disrupted by the eradication of beneficial non-target species, which contributes to the emergence of previously unimportant pests as major ones. Additionally, phytotoxicity can occur in plants. Given the significant role that plant protection problems and practices play in agricultural production, a survey was conducted among olive producers.

2. Materials and Methods

In the study, data was obtained in the form of questions and answers with 20-question survey forms from enterprises producing conventional olives in Derik district of Mardin province. In Mardin province, determined as the research area of the study in 2020, there are a total of 261 farm holdings olives registered in the Farmer Registration System (FRS). (Anonymous, 2021b). Since it is not possible to conduct a study by interviewing all of the farmers operating in Mardin province, the number of farmers surveyed was calculated using the formula below using the "simple random sampling method" (Çiçek and Erkan, 1996). In the study, the sampling volume was determined within 5% error and 95% confidence limits and the number of farmers to be surveyed was determined as 90 people (Kaplan and Baran, 2021).

3. Results and Discussion

3.1. Socio-Economic Characteristics of Olive Producers

When the demographic structure of the participants in the survey study in Mardin province is examined, all olive producers are male, 14% of them are literate, 40% are primary school graduates, 13% are secondary school graduates, 10% are high school graduates and 23% are Collage/University. He was determined to be a graduate of

a college/university (*Table 1*). In the past years, the importance given to agricultural production in the region was low and the people operating in this field were uneducated. The increase in human population in the world and the demand for agricultural products have increased. Therefore, in recent years, with the development of technology and the increase in the quality of life, there has been an increase in the number of educated and conscious people involved in agricultural activities, as in every professional field. As a result of the study, the high number of university graduates in agricultural activities in Mardin is a result of this situation. In parallel with this, 63.3% of apple farmers in Antalya have completed primary school and 14.4% have completed college (Kızılay and Akçaöz, 2009; Çelik and Karakaya, 2017) determined that 20% of those engaged in apple production are literate and illiterate producers, 25% are primary school graduates, 10% are secondary school graduates, 15% are high school graduates and 10% are university graduates. It was determined that 5% of peanut producers in Siirt were illiterate, 56% were secondary school graduates, 26% were high school graduates and 13% were college/university graduates (Dilmen et al., 2020). They reported that all vineyard producers in Mardin are male, 20% of them are illiterate, 64% are primary school graduates, 12% are secondary school graduates, 4% are high school graduates (Kaplan and Baran, 2021).

It was reported that 82% of olive producers in Mardin province have social security and 42% have income other than agriculture (*Table 1*). The reason why most of those engaged in farming have high social security is that they work in the public sector as well as engage in trade. In Seyhan and Yüreğir, 53.6% of the farmers have social security, while 70.5% do not have any income other than agriculture (Emeli, 2006); In Manisa, 64% of farmers have social security, while 66% do not have any other income than agriculture (Karataş and Alaoğlu, 2011); In Nevşehir, 73.5% of the farmers have social security, 26.5% do not have social security, 31.2% have income other than agriculture, and 68.8% do not have income other than agriculture (Erdoğan and Gökdoğan, 2017); They reported that 73.9% of the vineyard producers in Mardin (Savur) province have social security and 55.6% have income other than agriculture (Kaplan and Baran, 2021).

Table 1. Demographic information of olive producers surveyed in Mardin province

(%) Characteristic	Rate (%)
Gender	
Male	100
Female	0
Level of Education	
Illiterate	-
lliterate	14
Primary School	40
Secondary School	13
High School	10
College/University	23
Occupational status	
Farmer	73
Tradesman	12
Manuel Worker	-
Civil Servant	5
Pensioner	10
Social Security	
Yes	82
No	18
Non-Agricultural Income	
Yes	42
No	58

3.2. Knowledge, Attitude And Behavior of Producers Regarding Plant Protection Products

In Mardin province, 63.75% of olive producers make their recommendations and choices based on the provincial and District Directorate of Agriculture and Forestry, 34.50% look at pharmaceutical dealers, and 1.75% look at their own experience and neighbors (*Table 2*). Among the studies similar to this study, Tücer et al. (2004) stated that 65% of the viticulturalists in Manisa Saruhanlı district preferred pesticides based on the Agricultural Organization, 16% based on their experience, 11% based on plant protection dealers and 8% based on their neighbors; Kızılay and Akçaöz, (2009), according to the recommendation of apple growers in Antalya, 54% of them choose pesticides from plant protection dealers, and 10% of them from consultant agricultural engineers; according to Kızılaslan and Somak (2013), 54% of the producers choose their pesticides, 3 of them reported that they got information from agricultural pesticide dealerships, 30% based on their own knowledge and experience, and 15.7% from agricultural district directorate officials. According to Erdoğan and Gökdoğan (2017), 88.9% of the farmers in Nevşehir came from plant protection dealerships. 7.9% said they acted according to their own knowledge and experience, 2.1% said they acted according to advice from agricultural organizations, 0.5% looked at their neighbors and 0.5% said they acted according to the advice of the agricultural engineer who advised them; Çelik and Karakaya (2017) determined that 30.4% of apple producers choose pesticides by consulting subject experts of agricultural organizations, 24.4% by looking at their neighbors and acquaintances, and 21.2% choose pesticides based on their own experience. They stated that they decided to choose pesticides according to the Provincial/District Directorates of Forestry, 52.50% according to plant protection dealerships, 2% according to the consultancy Agricultural Engineer, and 12.5% according to their own knowledge and their neighbors (Kaplan and Baran, 2021).

Table 2. Awareness level of producers about who they get their pesticide advice from

From whom do you get pesticide (fungicide, herbicide and insecticide) advice?	Rate (%)
Vendor	34.50
District Directorate of Agriculture and Forestry	63.75
Own-experience and neighbour	1.75
Consultant Agricultural Engineer	

When purchasing pesticides (fungicides, herbicides and insecticides) used against diseases and pests, 25% of olive producers choose according to whether they have been used before, 35.50% according to their recommended effective substance, 18% according to their brand and 21.50% according to their cheapness. It was determined that they did (*Table 3*). According to Boyraz et al. (2005), 78% of apple farmers choose pesticides according to the density of pests and diseases, 11% according to the prices of pesticides, and 6% according to spraying costs; Çelik and Karakaya (2017) stated that when apple producers buy pesticides, 50.9% of them decide based on the mechanism of action of the pesticide, 28.7% based on the prices of the pesticides, and 20.4% based on the brand of the pesticide. Kaplan and Baran (2021) found that in the selection of pesticides used by viticulture farmers in Mardin against diseases and pests, 10% were based on the pesticide they used before, 20.6% on the suggested active ingredient, 28% on the brand of the drug, and 41.4% on the pesticide. They stated that they did it because it was cheap.

Table 3. Features they pay attention to when purchasing pesticides (Herbicide, Insecticide and Fungicide)

What kind of situations do you pay attention to when purchasing pesticides (Herbicides, Insecticides and Fungicides)?	Rate (%)
Previous use	25
Recommended active substance	35.60
Brand	18
Price	21.40

66% of the growers in Mardin Derik district, which has a great potential for olive production, do not always use the same pesticide against the same diseases and pests, while 34% always use the same pesticide (*Table 4*). Kaplan and Baran (2021) stated that 63.5% of grape growers do not always use the same pesticides in the fight against the same diseases and pests, while 26.5% constantly use the same pesticides.

Table 4. Producers' knowledge levels regarding using the same pesticides against the same diseases and pests

Do you always use the same pesticides for the same diseases and pests?	Rate (%)
Yes	34
No	66

A successful chemical control against pests and diseases in the agricultural field is primarily achieved by spraying at the appropriate time and number. Therefore, while the highest effect is achieved from the pesticides, the pesticide costs are reduced to economical levels. In response to the question of how olive producers decide when to spray pesticides against diseases and pests; 15.8% of the producers detect diseases and pests when they first see them, 40.60% according to the recommendations of experts in the provincial/district directorates of agriculture and forestry, 30.6% by consulting agricultural pesticide dealers, and 9% detect diseases and pests. and 4% reported that they decided the time to spray pesticide based on other farmers around them (*Table 5*). Here, 15.8% of the farmers reported that they sprayed pesticides when they first encountered diseases and pests. In this case, it can be thought that farmers who know the pests and diseases have the essential technical knowledge, although they do not have enough knowledge.

In generally, the application times of the drugs are considered correct considering the development periods of the plants. However, it does not seem possible for manufacturers to determine the exact application time of drugs by taking into account the biology of pests and diseases. Because it requires technical knowledge and experience on this subject, this can be done with training given by subject experts of agricultural organizations.

In similar studies by Yücel et al. (1995), 42.15% of the agricultural producers in Harran district of Şanlıurfa province reported that they decided to spray pesticides based on their experience, 9.80% by looking at their surroundings, 34.31% by applying to agricultural organizations, and 13.72% by consulting agricultural pesticide dealers. Üremiş et al. (1996), in a survey conducted in the Çukurova region, 38.64% of the farmers responded according to their experience and dealers' statements, 35% according to their experience, 19.09% according to dealer statements, 5.45% according to the recommendations of technical organizations, 1.82% stated that the dosage and timing of the drugs used were adjusted according to the drug label. Zeren and Kumbur (1998) started that 40.18% of the farmers determined pesticide doses and application times according to the recommendations of the pharmaceutical seller, 29.92% according to their experience, and 16.23% followed the drug labels. İnan and Boyraz (2002) determined that 44.20% of the agricultural producers in the Konya region determined the spraying time based on their own experience, 24.20% on the advice of agricultural pesticide dealers, 20% by consulting the growers in the vicinity, and 11.60% by applying to the provincial/district directorates of agriculture. In a survey conducted by Kadıoğlu (2003) in Tokat province, 58.74% of farmers decided on the time of spraying based on agricultural engineers, 29.14% decided on their own, 6.20% based on advice from pesticide dealers and 5.81% on the advice of agricultural pesticide dealers. Stated that they benefited from other farmers around them. Boyraz et al. (2005), 35% of apple farmers stated that they sprayed for pests or diseases when they first saw them, and 22% stated that they applied pesticides using predictive and early warning methods. Karaçayır (2010) reported that 43.2% of apple farmers in Karaman province applied pesticides before encountering pests, and 56.8% reported that they decided to spray after they first encountered pests. Karataş and Alaoğlu (2011) stated that 56% of grape growers in Manisa resorted to spraying when they first encountered diseases or pests, and 34% of them resorted to spraying without seeing the diseases and pests. Kaplan and Baran (2021), when 17% of grape growers in Mardin province first encountered diseases or pests, 25% according to the recommendations of the Provincial/District Directorate of Agriculture and Forestry, 36% by consulting agricultural pesticide dealerships, 12% of them reported that they did not decide on the time to spray without encountering diseases or pests, and 10% of them stated that they did not decide on the time of spraying by looking at other producers around them.

In deciding on the dosage for the use of chemical pesticides against pests in olive fields, 61% of the farmers rely on plant protection dealers, 31.75% on the Provincial/District Directorates of Agriculture, 2% on their own knowledge and 5.5% on their neighbors' experiences. They did (*Table 6*). Özkan et al. (2003) found that 41.71% of citrus farmers act according to the drug's package insert, and 27.81% act according to their own knowledge and experience when deciding on the drug dosage; Kalıpçı et al. (2011), in Konya province, 8.3% of farmers consult

Table 5. Knowledge levels of olive producers about determining the time for monitoring pests and diseases in olive orchards pests

How do you decide when to spray against pests and diseases in olive orchards?	Rate (%)
Vendor	40.60
District Directorate of Agriculture and Forestry	30.60
First sighting of pests and disease	15.80
Before sighting of any disease and pests	9
Looking at other producers	4

the drug's package insert, 26.6% their own information, 11.6% their neighbor's advice, 33.3% consult their plant protection dealers, 10% in adjusting the drug dose. 8% of them did so by asking the recommendations of the Provincial/District Directorates of Agriculture, 3.3% of them did so by asking the Chambers of Agriculture, and 5.8% of them did so according to the recommendation of the consulting agricultural engineer; Gedikli (2012) asked the plant protection dealers and Agricultural Engineers of 33.33% of the farmers to choose the pesticide dose; Gözener et al. (2017), in choosing the drug dose of farmers, 90.28% rely on the recommendations of pharmaceutical-fertilizer dealers, 59.72% on the usage labels of the drugs, 40.28% on their own knowledge and experience, 1% on 39% of the Food, Agriculture and Livestock Provincial/District Directorates do it according to the recommendations of the subject experts and 1.39% according to the severity of the diseases; Kaplan and Baran (2021), While producers in Mardin province decide on the dosage of pesticides in chemical warfare against pests in their vineyards, 68% consult the plant protection dealer, 20.8% consult the Provincial/District Directorates of Agriculture, 7.2% consult their own experiences and 5% consult their surroundings. Reported that they made dose adjustments.

Table 6. Knowledge level regarding the dosageof pesticides

How do you adjust the dosage of pesticides (insecticides, fungicides and herbicides)?	Rate (%)
Vendor's advice	61
District Directorate of Agriculture and Forestry	31.75
Own experiences	2
Neighbour's advice	5.5

In terms of knowledge about the suggested dose of the pesticide, it was reported that 91.6% of the olive producers used the recommended dose, 4.2% used a dose above the suggested dose, and 4.2% used a dose below the recommended dose (*Table 7*). Using the appropriate dose recommended by olive producers in chemical control is likely to increase the success rate in combating pests. Similar to the results of this study, Tücer et al. (2004) found that 72% of viticulture farmers used the recommended dose, 26% applied a dose above the recommended dose, and 2% applied a dose they deemed appropriate; According to Kalıpçı et al. (2011), 33.3% of the producers make their drug dose selection according to the recommendations of plant protection dealers. Peker (2012) stated that 88% of farmers in Konya province employed the suggested dose, 8% increased the drug dose to get better results, and 4% applied a dose below the recommended dose; Erdoğan and Gökdoğan (2017) reported that 50.7% of farmers used the recommended dose and 50.3% used more than the recommended dose; Akar and Tiryaki (2018) stated that 71.4% of the producers follow the recommendations of plant protection dealerships in selecting drug doses; Kaplan and Baran (2021) reported that 87.8% of Mardin vineyard producers applied the recommended dose, and 12.2% applied a dose above the recommended dose. Contrary to these studies, Boz et al. (1998) stated that 64.47% of farmers in Aydın province used a dose higher than the recommended dose.

Table 7. Information levels regarding the recommended dosage of the pesticide

Usage of pesticide (fungicide, herbicide and insecticide) according to the recommended dosage?	Rate (%)
Recommended dosage	91.6
Exceeding recommended dosage	4.2
Below the recommended dose	4.2

Considering the opinions of olive producers in Mardin regarding the pesticide residue problem; 34.20% reported that pesticides left residue on the products, 45.80% reported that they left little residue on the product,

and 20% reported that they did not leave any residue on the product (*Table 8*). Özkan et al. (2003), 70.4% of producers in Antalya stated that they left pesticide residues on their products, 10.4% stated that pesticide residues were removed by washing, and 19.2% reported that they had no idea about this issue. Karaçayır (2010), 34.3% of those who produce apples say that pesticides may leave residues on the product, 23.8% say that all agricultural chemicals leave residues, 18.1% say that they will not leave residues when the recommended dose of agricultural chemicals are applied, 13.4% think that residues can be removed by washing, and 10.4% stated that pesticides do not leave residue; Kalıpçı et al. (2011) repoted 70.4% of farmers in Antalya province reported that they left pesticide residues on their products, 10.4% were unaware that cleaning removes pesticide residues. 19.2% did not know. Erdoğan et al. (2017), in Adıyaman, 38.7% of almond growers reported that their products left pesticide residues, 32.3% reported that they left little residue, and 29% reported that there were no residues in their products. Peker (2012) stated that 80% of tomato producers in Konya say that pesticides do not leave residues on the products, 20% say pesticides leave residues, and 40% say pesticide residues will disappear with washing. Akar and Tiryaki, (2018) 23.3% of the producers in Antalya say that pesticide residues on the products will disappear by washing, 24.9% say that pesticides do not leave residues, 34.1% say that some pesticides may leave residues, and 17.7% do not have information about pesticide residues. They stated. Regarding the pesticide residue of peanut producers in Siirt, 33% of the producers reported that it was destroyed by rain washing, 39% did not have information about the residue, 16% reported that pesticides left residue and 12% reported that their pesticides did not leave residue (Dilmen et al., 2020).

Table 8. The knowledge levels of the growers about the pesticides leaving residue on the products

Do you know that pesticides leave residues on products?	Rate (%)
Leaves a residue	34.20
Leaves little residue	45.80
Leaves no residue	20

79% of the producers who use pesticides in their olive groves stated that they attach importance to the waiting time in pesticides, 8.50% do not care, and 12.50% sometimes care (*Table 9*). It is an important result that the majority of producers comply with the waiting period. Boyraz et al. (2005), while 71% of apple farmers paid attention to the time to wait between the last spraying and harvest time, 29% reported that they did not pay attention to this. Karaçayır (2010) determined that 43.2% of the farmers pay attention to the waiting times between the last spraying and harvest, 32.8% know the waiting time but do not pay attention, and 24% do not know the waiting time. Erdoğan and Gökdoğan (2017) reported that 80% of potato growers pay attention to the waiting time between the last pesticide application time and the harvest time, and 20% do not pay attention to the waiting time. Gözener et al. (2017), 91.67% of the growers reported that they did not know the time from the last spraying to the harvest, 6.94% of them knew and did not pay attention to this period, and 1.39% of them knew and paid attention to the time. Akar and Tiryaki (2018) determined that 87.3% of the farmers in Antalya comply with the waiting periods between the last spraying and harvest, 12.7% of them do not comply with the time period between the last spraying and harvest. Kaplan and Baran (2021) stated that 88.6% of the wine famersusing pesticides in Mardin paid attention to the pesticide waiting times, while 11.4% stated that they did not.

Table 9. The knowledge levels of the famers about the time they should wait between the last spraying and the harvest time

Do you pay attention to the waiting time of pesticides?	Rate (%)
Yes	79
No	8.50
Sometimes	12.50

During spraying in Mardin, 58.34% of olive growers stated that they used protective clothing and masks, 12.50% of them sometimes used them, and 29.16% of them never used them. It has been reported that more than half of the olive growers comply with the protective measures and act carefully when spraying (*Table 10*). However, Özkan et al. (2003) found that 68.8% of farmers took protective measures at the time of pesticide application, while 31.2% did not; Tücer et al. (2004), 57.82% of gowers used protective clothing and equipment when spraying, 42.18% did not; According to the study conducted by Akbaba (2010), 61% of the producers used masks during

spraying; Bayhan et al. (2015) found that 76% of manufacturers take protective measures during spraying and 24% do not take any protective measures; Erdoğan and Gökdoğan (2017) stated that 84.7% of the breeders did not wear protective clothing and masks at the time of drug application, while 15.3% took protective measures. According to Akar and Tiryaki (2018), 42.1% of the farmers in Antalya use protective clothing and equipment while using pesticides, while 31.7% do not use them because they do not consider it important; Kaplan and Baran (2021) stated that 48% of vineyard growers use protective equipment during spraying in Mardin, 16% use it occasionally and 36% do not use any protective equipment.

Table 10. Producers' knowledge levels regarding protective measures to be taken during pesticide application

How do you take care of your health while spraying? (Using protective clothing, mask, glasses and gloves during application)	Rate (%)
I always use	58.34
I sometimes use	12.50
I never use	29.16

When asked what do you do with empty pesticide containers after spraying, olive producers reported that 7.5% of the participants washed and reused them, 51.60% threw them away, 27.5% burned them and 13.4% randomly threw them into the environment (*Table 11*). Similar studies on the subject have found that farmers exhibit different attitudes and behaviors. Özkan et al. (2003), 7.45% of farmers burned empty pesticide packages, 21.81% threw them away, 14.36% buried them in the ground, and 7.45% randomly threw them around; Tücer et al. (2004), 60.54% of the producers randomly throw their empty pesticide packages into the environment, 4.98% reuse them for various purposes, 19% bury them in the ground and 15.48% destroy them by burning; Erturk et al. (2012), 35.6% of growers buried empty pesticide containers under the ground, 34.6% threw them into the garden/field, and 29.8% left them in the trash; Akbaba (2010) stated that 61.1% of farmers in the Çukurova region collect empty pesticide containers in one area and then destroy them by burning them; Karataş and Alaoğlu (2011) found that 65.3% of viticulturalists destroy empty agricultural chemical containers by burning them, 24% hrow them around haphazardly, and 10.7% put them under the ground; Çelik and Karakaya (2017) reported that 50% of apple producers in Bingöl collected the empty pesticide packages and containers in a suitable area and destroyed them by burning them, 30% put them in garbage bins and 20% collected them in a corner of the garden. Akar and Tiryaki (2018) reported that in Antalya province, 8.5% of the producers randomly threw the empty medicine containers into their surroundings, 55% burned them, 10% put them under the ground, 26.2% put them in bags and put them in the trash, and 0.3% put them in the trash. He stated that he used it again for different purposes. Kaplan and Baran (2021) found that in Mardin, 2% of the vineyard producers demolished and reused the pesticide containers emptied after spraying, 15.6% buried them in the ground, 20% threw them into garbage bins, and 24.3% buried them somewhere. They stated that they collected and burned them and 38.1% of them threw them around haphazardly.

Table 11. Producers' knowledge levels regarding the evaluation of empty pesticide containers

What do they do with empty pesticide (fungicide, herbicide and insecticide) containers?	Rate (%)
Wash it for further use	7.5
Bury in the ground	-
Put in trash	51.60
Burn	27.50
Randomly throw around	13.40

It was determined that 83% of the olive producers cleaned the spraying equipment after spraying, 12% sometimes cleaned it and 5% did not clean it (*Table 12*). Tücer et al. (2004) While 85.42% of grape producers in Manisa clean their sprayers after spraying, 14.58% do not; Ertürk et al. (2012), 69.2% of agricultural producers in Iğdır stated that they washed the sprayer after spraying, 27.9% said they washed it occasionally, and 2.9% did not wash it; Erdoğan et al. (2017), after spraying in almond orchards, 90.3% of the growers cleaned the sprayer, 6.5% never cleaned it and 3.2% cleaned it occasionally; Kaplan and Baran (2021), 78.3% of grape producers reported

that they cleaned the sprayer after spraying, 14% reported that they cleaned it occasionally, and 7.7% did not clean it.

Table 12. Producers' knowledge levels about cleaning the sprayer after spraying

Do you wash the sprayer after spraying?	Rate (%)
Yes	83
Sometimes	12
No	5

It was started that 17.5% of those engaged in olive production applied pesticides by mixing them, 38.5% occasionally applied them as a mixture, and 44% never used them as a mixture (*Table 13*). As a matter of fact, similar to the study by Boyraz et al. (2005) found that 83% of apple growers did not apply pesticides in mixtures, and 17% did not apply them in mixtures; Peker (2012) stated that 56% of farmers apply pesticides in mixtures, 24% apply pesticides without mixing, and 20% occasionally use pesticides in mixtures; Erdoğan and Gökdoğan (2017) reported that 56.1% of farmers use pesticides in mixtures, and 43.9% use pesticides without mixing; Erdoğan et al. (2017), 78.5% of almond growers use pesticides in mixtures, 19.4% occasionally use them in mixtures, and 2.1% never use them in mixtures; Kaplan and Baran (2021) stated that 56.5% of vineyard producers use pesticides by mixing them, 16.5% use them by mixing occasionally, and 28% use pesticides without mixing them at all.

Table 13. Knowledge levels of producers about the mixing and use of pesticides

Do you mix pesticides?	Rate (%)
I mix pesticides	17.5
I sometimes mix pesticides	38.5
I never mix pesticides	44

To the question of how farmers producing olives in Mardin store pesticides; It was determined that 72.4% of the farmers kept it in cool warehouses and shelters, 14.6% in a suitable place in their homes and 13% in medicine warehouses (*Table 14*). Peker (2012) reported in a study that 64% of farmers keep pesticides in cool warehouses, 22% in a suitable place in their homes, and 10% in medicine warehouses. Çelik and Karakaya (2017) reported that 50% of apple producers keep the pesticides they use in barns, or in a shelter, 35% in a special cupboard and 15% reported that they store it somewhere in the house. Akar and Tiryaki (2018), 1.3% of farmers in Antalya store pesticides in a suitable area of their homes, 22% in a private They reported that they kept it in a cabinet, 4% on shelves in a special room, 5% in barns and animal shelters, 57.7% in their warehouses, 8.2% bought as much as they would use, and 1.8% reported that they kept it in other places.

Table 14. Knowledge levels of farmers regarding the preservation of pesticides

Where do you preserve pesticides?	Rate (%)
Cool warehouse, warehouse, barn etc. in shelters	72.40
In a convenient place in their home	14.60
In drug stores	13

It was reported that 66.2% of the producers applied chemical control, 14.84% applied cultural control, 11% applied biotechnical control methods and 2.62% did not apply any method (*Table 15*). It was reported that in Tokat, which is similar to this conflict, 43.58% of the farmers chose cultural measures, 33.33% mechanical warfare and 23.07% physical warfare instead of chemical warfare (Kadıoğlu, 2003). 83.3% of farmers use chemical warfare to combat pests, diseases and weeds (Akar and Tiryaki, 2018); It was reported that 71% of vineyard growers applied chemical control, 12.9% cultural control, 8% mechanical control, 5% physical control and 3.1% biotechnical control methods (Kaplan and Baran, 2021).

While 78% of olive producers answered "I agree" to the statements regarding the pesticides they use may be harmful to human and environmental health and other living organisms, 19% of the producers stated that they did not know that they were harmful and 3% did not agree that they were harmful (Chart 16). Akbaba (2010), in a survey conducted in Adana, reported that more than 70% of farmers "fully agreed" with the statement that the

pesticides they use could harm human and environmental health and other living organisms. Jallow et al. (2017) stated in their research that 71% of 250 producers stated that the pesticides used were harmful to health and 65% were harmful to the environment. Akar and Tiryaki (2018) found that 87.5% of growers agreed with the statement regarding the harmful effects of pesticides in agriculture. While 70% of the producers stated that they completely agreed with the claims about the harmful effects of pesticides on the environment and other living organisms, they reported that there were no producers who strongly disagreed with the claims about the harmful effects of pesticides on the environment and other living organisms.

Table 15. Awareness levels of producers regarding methods of combating diseases, pests and weeds

What control methods do you use against pests, diseases and weeds?	Rate (%)
Chemical control	66.20
Cultural control	14.84
Mechanic control	-
Physical control	-
Biotechnical control	11
Biologic control	-
None	7.96

Table 16. Producers' opinions about the negative effects of pesticide use on human and environmental health

Are pesticides hazardous to human and environmental health?	Rate (%)
I agree	78
I don't agree	3
I don't know	19

4. Conclusions

Unconscious and untimely chemical control against harmful organisms in agricultural production areas has negative effects on human and environmental health. Therefore, in order to prevent these negative situations from occurring, a survey was conducted with olive producers in Mardin province in order to raise awareness in the application of plant protection products in olive gardens. When faced with problems related to plant protection and applications, which have an important place in these areas, the knowledge levels of the relevant producers were determined, as were who they consulted and what they did to solve the problems, and what they paid attention to in the selection and application of plant protection products. As a result of the study, it was determined that 66.2% of the producers resorted to chemical control against existing diseases, pests and weeds in the olive fields, and 63.75% of the producers consulted the Provincial and District Directorate of Agriculture and Forestry in pesticide selection and dosage application. They stated that the majority of producers pay attention to the required waiting period between the last spraying time and the harvest time, since pesticides leave residues on the products. However, they knew that they definitely agreed with the idea that pesticides would be harmful to human and environmental health and other non-target living organisms. They stated that they took the necessary protective measures for their own and environmental health during the spraying and that they took care in cleaning the spraying equipment, storing pesticides and destroying empty boxes.

As a result, it is extremely important that plant protection activities are designed to reduce the possible negative effects on the agroecosystem and biological balance in terms of sustainable agricultural production. The fight against the main diseases and pests in olive groves should be carried out within the framework of integrated pest management; In cases where chemical control is inevitable, it will be beneficial to use selective pesticides that are relatively safe for human and environmental health. Thus, if practices that reduce the use of chemical pesticides are preferred, pesticide residues and pests will be prevented from gaining resistance to pesticides, the natural balance between human and environmental health as well as living things will be preserved, and there will be a certain level of reduction in the production costs of the producers.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

There is no conflict of interest between the article authors.

Authorship Contribution Statement

Concept: Kaplan, M.; Design: Kaplan, M.; Data Collection or Processing: Kaplan, M.; Statistical Analyses: Kaplan, M.; Literature Search: Kaplan, M.; Writing, Review and Editing: Kaplan, M.

References

Akar, Ö., and Tiryaki, O. (2018). Investigation of the knowledge level and sensitivity of producers about pesticide use in Antalya province. *Süleyman Demirel University Faculty of Agriculture Journal*, 13(1):60-70.

Akbaba, B. Z. (2010). *Evaluation of citrus cultivation and insecticide use in Adana province*. (Master's Thesis) Çukurova University, Institute of Science and Technology, Department of Plant Protection, Adana, Türkiye.

Alabouid, A. and Bayhan E. (2022). Determination of The Loss Ratio on Some Melon Varieties From The Melon Fly, *Myiopardalis pardalina* (Bigot, 1891) (Diptera: Tephritidae). *Journal of Tekirdağ Agriculture Faculty,* 19(2): 404-411.

Anonymous (2021a). Food and Agriculture Organization of the United Nations (FAO), https://www.fao.org/faostat/en/#data/QCL (Accesed Date:12.08.2023)

Anonymous (2021b). Turkey Statistical Institute (TUIK) https://biruni.tuik.gov.tr (Accesed Date: 24.07.2022)

Anonymous (2022). Turkey Statistical Institute. (TUIK) https://biruni.tuik.gov.tr/medas/?locale=tr (Accesed Date:10.08.2023)

Bayhan, E., Sağır, A., Uygur, F. N., Bayhan, S. Ö., Eren, S. and Bayram, Y. (2015). GAP Determination of plant protection problems in cotton areas of the region. *Türkiye Entomology Bulletin*, 5(3):135-146.

Bodenheimer, F. S. (1941). A Study on Insects Harmful to Agriculture and Trees in Turkey and The Fight Against Them. Ed.; Naci Kenter, 1958, Bayur press, Ankara, 347.

Boz, Ö., Erol, T., Benlioğlu, S. and Öncüer, C. (1998). Aydın Socio-economic evaluation of agricultural control practices in the province. *Türkiye Entomology Bulletin*, 22(2): 123-136.

Boyraz, N., Kaymak, S. and Yiğit, F. (2005). General evaluation of chemical control practices of apple producers in Eğridir district. *Journal of Selçuk University Faculty of Agriculture*, 19(36): 37-51.

Çelik, A. and Karakaya, E. (2017). Evaluation and economic analysis of the knowledge, attitudes and behaviors of apple producers in Adaklı district of Bingöl province in the use of agricultural pesticides. *Turkish Journal of Agriculture and Natural Sciences*, 4(2): 119–129.

Çiçek, A. and Erkan, O. (1996). Research and Sampling Methods in Agricultural Economics. Gaziosmanpaşa University Faculty of Agriculture Publications No:12, Lecture Notes Series No:6, Tokat.

Dilmen, H., Pala, F. and Özer Dilmen, M. (2020). Determining the knowledge level of Pistachio (*Pistacia vera* L.) producers on agricultural control: Turkey, Siirt Province Example. *Turkish Journal of Agricultural Research*, 7(1): 1-8.

Emeli, M. (2006). *A research on the practical problems of plant protection methods in the Seyhan and Yüreğir basins*. (Master's Thesis) Çukurova University, Institute of Science and Technology, Department of Plant Protection, Adana, Türkiye.

Erdoğan, O. and Gökdoğan, O. (2017). Plant protection practices of potato producers in Nevşehir province. *Batı Akdeniz Agricultural Research Institute Derim Journal*, 34(1): 51-60.

Erdoğan, O., Tohumcu, E., Baran, M. F. and Gökdoğan, O. (2017). Evaluation of pesticide practices of almond producers in Adıyaman province. *Turkish Journal of Agriculture - Food Science and Technology*, 5(11): 1414-1421.

Ertürk, Y. E., Bulak, Y. and Uludağ, A. (2012). Environmental sensitivity of agricultural enterprises in Iğdır province in pesticide applications. *Journal of History, Culture and Art Research*, 1(4): 393-401.

Gedikli, O. (2012). *Evaluation of the problems faced by the producers of spruce, Bafra and Terme districts of Samsun province in terms of plant protection and the factors affecting the use of agricultural pesticides*. (Master's Thesis) Atatürk University, Institute of Science and Technology, Department of Plant Protection, Erzurum, Türkiye.

Gözener, B., Sayılı, M. and Çağlar, A. (2017). Use of pesticides in tomato cultivation in Kazova Region of Tokat province. *Turkish Journal of Agriculture-Food Science and Technology*, 5(5): 451-458.

Güçlü, Ş., Hayat, R. and Özbek, H. (1995). Phytophagous and predatory insect species found on olive (*Olea europaea* L.) in Artvin and its surroundings. *Turkish Journal of Entomology*, 19(3): 231-240.

Güngörmez, M., Tan, F., Baran, M. F. (2022). Energy consumption in alfalfa production: A comparison between harvesting systems in Turkey. *Journal of Tekirdağ Agricultural Faculty*, 20(1), 80-93.

İnan, H. and Boyraz, N. (2002). General evaluation of Konya farmers' use of pesticides. *Selçuk University Faculty of Agriculture Journal*, 16(30): 88-101.

İyriboz, N. S. (1968). Olive Pests and Diseases. Republic of Turkey Ministry of Agriculture General Directorate of Agricultural Control and Agricultural Quarantine Publications, İzmir, 112.

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y. and Thomas, B. M. (2017). Pesticide knowledge and safety practices among farm workers in Kuwait: results of a survey. *International Journal of Environment Research and Public Health*, 14(4): 340.

Kaçar, G. and Ulusoy, R. (2005). Studies on the population development of Prays oleae (Bern.) (Lepidoptera: Hyponomeutidae). *Çukurova University, Faculty of Agriculture Journal*, 22(1): 73 – 80.

Kadıoğlu, İ. (2003). A research on the agricultural control activities of producers in Tokat province. *Journal of Gaziosmanpaşa University Faculty of Agriculture*, 20(1): 7-15.

Kaplan, M. and Bayhan, E. (2017). Determination of damage rates of Thysanoptera species in some vineyard areas of Mardin Province. *Journal of Tekirdağ Agricultural Faculty*, 14(1): 1-8.

Kaplan, M. (2019). Insect species, their distribution and density that are harmful in olive groves in Mardin province. *Journal of Iğdır University Institute of Science and Technology*, 9(4): 1901-1907.

Kaplan, M. and Baran, M.F. (2021). Determining the awareness levels of vine growers in mardin province with regards to crop-protection practises. *Erwerbs-Obstbau*, 63(1): 131–140 https://doi.org/10.1007/s10341-021-00591-5

Kaplan, M. and Saltuk, B. (2021). Determination of the environmental effects of plant protection products in fighting pests in greenhouse vegetable production: Batman province example. *International Journal of Scientific and Technological Research*, 7(1): 1-16.

Kalıpçı, E., Özdemir, C. and Öztaş, H. (2011). Investigation of farmers' education and knowledge level and environmental sensitivity regarding pesticide use. *TÜBAV Scientific Magazine*, 4(3):179-187.

Karaçayır, H. F. (2010). *Extension approaches in the use of pesticides in agricultural enterprises producing apples: The example of Karaman province*. (Master's Thesis) Selçuk University Institute of Science and Technology, Department of Agricultural Economics, Konya, Türkiye.

Karataş, E. and Alaoğlu, Ö. (2011). Plant protection practices of producers in Manisa province. *Ege University Faculty of Agriculture Journal*, 48(3): 183-189.

Kaya, M. (1979). Investigations on Secondary Pests of Olive Trees, Their Recognition, Damage Patterns and Population Densities in Important Olive Areas of The Aegean Region. Izmir Regional Pest Control Research Institute Directorate Research. Work Series No:312, 1-45.

Keçecioğlu, E. (1984). Research on The Identification, Brief Biology and Natural Enemies of The Olive Cottonbug *Euphyllura olivina* (Costa) (Homoptera: Aphalaridae), Which Damages Olives in Antalya and Its Surroundings. Ministry of Agriculture, Forestry and Rural Affairs, General Directorate of Agricultural Protection and Agricul. Quarantine No:1, Ankara, 19.

Kızılaslan, N. and Somak, E. (2013). Awareness level of producers in the use of agricultural pesticides in viticulture enterprises in Erbaa district of Tokat province. *Gaziosmanpaşa Journal of Scientific Research*, (4): 79-93.

Kızılay, H. and Akçaöz, H. (2009). Examination of economic loss in the use of pesticides and fertilizers in apple cultivation: An example of Antalya province. *Journal of Agricultural Sciences Research*, 2(1): 113-119.

Mete, N., Gülen, H., Çetin, Ö., Hakan, M., Güloğlu, U., Kaya, H. and Uluçay, N. (2023). Frost Tolerances of Turkish Olive (*Olea europaea* L.) Cultivars. *Journal of Tekirdag Agricultural Faculty*, Ziraat Fakültesi Dergisi, 20 (2): 293-305.

Nizamlıoğlu, K. and Gökmen, N. (1964). Insects That Damage Olives in Turkey. Yenilik Press, İstanbul, 160.

Özkan, B., Vuruş Akçaöz, H. and Karadeniz, C.F. (2003). Producer attitudes and behaviors towards the use of pesticides in citrus production in Antalya province. *Anadolu, Journal of AARI*, 13(2): 103-116.

Peker, A. E. (2012). Environmental sensitivity analysis for the use of pesticides in tomato production in Konya province. *Journal of Iğdır University Institute of Science and Technology*, 2(1): 47-54.

Tücer, A., Polat, İ., Küçüker, M. and Özercan, A. (2004). Determining the problems in agricultural pesticide applications in Saruhanlı vineyard areas of Manisa province. *Anadolu Journal of AARI*, 14(1): 128-141.

Üremiş, İ., Karaat, Ş., Gönen, O., Canıhoş, E., Kütük, H., Ekmekçi, U., Çetin, V., Aytaş, M. and Kadıoğlu, İ. (1996). General Evaluation of Pesticide Use in The Çukurova Region. *II. National Pest Control Symposium*, 18-20 November, s: 73-79, Ankara, Türkiye.

Yücel, A., Çıkman, E. and Yücel, M. (1995). Farmers' Perspective on Agricultural Struggle in The Harran Plain Before The Southeastern Anatolia Region (GAP) Was Put Into Practice. *GAP Region Plant Protection Problems and Solution Suggestions Symposium*, 27-29 April, Şanlıurfa, Türkiye.

Zeren, O. and Kumbur, H. (1998). Research on agricultural pesticide marketing, usage techniques and effectiveness in Içel province. Türk-Koop Ekin, 2-5: 62-68.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Characteristics and Biological Activities of Bioactive Peptides Derived from Bulgur Waste*

Bulgur Atıklarından Elde Edilen Biyoaktif Peptitlerin Özellikleri ve Biyolojik Aktiviteleri

Hema Aso RASHID[1], Hüseyin BOZKURT[2], Çiğdem AYKAÇ[3*]

Abstract

Bulgur is one of the ready or semi-ready to eat cereals produced from wheat specifically Triticum durum variety. Residues of bulgur processing are known as bulgur waste that rich in some food components. Protein is one of the main components of bulgur that may remain in the wastes. This study was carried out to obtain and investigate the properties of bioactive peptides of bulgur waste proteins. Protein isolated from bulgur waste was hydrolyzed enzymatically to bioactive peptides and their potential activity against oxidation stress, microbial inhibition and hypertension control was determined. The bulgur waste proteins extracted from samples were hydrolyzed at different time intervals using pepsin, trypsin, chymotrypsin and protease under the optimum conditions of enzymes and o-phthalaldehyde (OPA) method was used to determine the degree of hydrolyses. The highest rate of hydrolysis efficiency was observed by protease as 10.08% at 240 min treatment while, the highest antioxidant capacity was measured with chymotrypsin (526.35% at 240 min) by 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) and with trypsin (151.93 % at 240 min) by 2,2-diphenyl-1-picrylhydrazyl (DPPH) methods. Trypsin hydrolysates showed the highest antibacterial activity against *Escherichia coli* whereas pepsin hydrolysates exhibited the highest activity against *Staphylococcus aureus*. It has been observed that trypsin, chymotrypsin and protease hydrolysates have higher antihypertensive effects than protease hydrolyzates. The highest antihypertensive effect was obtained with protein hydrolyzate obtained by hydrolysis with chymotrypsin for 180 minutes. As a result, the novel peptides indicated to offer the selected biological effects, suitable to use as a food additive for different purposes in industrial applications.

Keywords: Bulgur waste, Bioactive peptides, Antioxidant activity, Antimicrobial activity, Antihypertensive activity

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*This study was summarized from the Hema Aso RASHID's MSc thesis.

Öz

Bulgur, buğdayın özellikle *Triticum durum* çeşidinden üretilen, yemeye hazır veya yemeye yarı hazır tahıllardan biridir. Bulgur işleme sırasında oluşan kalıntılar, bazı gıda bileşenleri açısından zengin bir içeriği sahip olup bulgur atığı olarak bilinmektedir. Protein, bulgur işlemi sonrası atıklarda yer alan ana bileşenlerden biridir. Bu çalışma bulgur üretimi sonrası oluşan bulgur atığı proteinlerinden biyoaktif peptitlerin elde edilmesi ve özelliklerinin araştırılması amacıyla yapılmıştır. Bulgur atıklarından izole edilen protein, enzimatik olarak biyoaktif peptitlere hidroliz edildi. Aynı zamanda bulgur atıklarından izole edilmiş ve hidroliz edilen proteinin oksidasyon stresine, mikrobiyal inhibisyona ve hipertansiyon kontrolüne karşı potansiyel aktiviteleri belirlendi. İlk olarak bulgur atığı proteinleri ekstrakte edilmiş ve ardından enzimlerin kendilerine özgü optimum koşulları altında pepsin, trypsin, kimotripsin ve proteaz kullanılarak farklı zaman aralıklarında hidrolize edilmiştir. Bulgur atığı proteinlerinin enzimatik hidroliz derecesinin belirlenmesinde o-ftalaldehit (OPA) yöntemi kullanılmıştır. En yüksek hidroliz etkinliği 240 dk muamelesinde %10,08 ile proteaz ile gözlenirken, en yüksek antioksidan kapasite 2,2'-azino-bis(3-etilbenzotiazolin-6-sülfonik asit) (ABTS) yöntemi ile kimotripsin (240 dk'da %526,35) ve 2,2-difenil-1-pikrilhidrazil (DPPH) yöntemi ile de trypsin (240 dakikada %151.93) olarak ölçülmüştür. Enzimatik hidrolizle elde edilen protein hidrolizatlarının antimikrobiyal etkisine bakıldığında, Tripsin hidrolizatları Escherichia coli'ye karşı en yüksek antibakteriyel aktiviteyi gösterirken, pepsin hidrolizatları Staphylococcus aureus'a karşı en yüksek aktiviteyi gösterdi. Tripsin, kimotripsin ve proteaz hidrolizatlarının antihipertansif etkilerinin proteaz hidrolizatlarına göre daha yüksek olduğu görülmüştür. En yüksek antihipertansif etki, kimotripsin ile 180 dakika boyunca hidroliz yoluyla elde edilen protein hidrolizatı ile elde edildi. Sonuç olarak, yeni peptitlerin, endüstriyel uygulamalarda farklı amaçlarla gıda katkı maddesi olarak kullanılmaya uygun, farklı biyoaktif özelliklere sahip, amaca yönelik seçilmiş biyolojik etkiler sunduğu belirlendi.

Anahtar Kelimeler: Bulgur atığı, Biyoaktif peptitler, Antioksidan aktivite, Antimikrobiyal aktivite, Antihipertansif aktivite

1. Introduction

For hundred years ago the relationship between health and nutrition are familiar to popularity which environmentally long-life term or healthy life instantaneously impacted by nutrition (Kussmann et al., 2010). Proteins are fundamental food macromolecules that accessible in all living cells which offer valuable nutrition as a source of essential amino acids and energy either from animal or plant sources. Collected proteins from the plant sources are preferable for human consumption and promoting health because contains absolute bioactive and medicinal compounds when compared to animal proteins (Sarmadi and Ismail, 2010). Food protein and peptides have unique biological activities and this feature offers high nutritional value to foods containing significant amount of protein (Hartmann and Meisel, 2007; Moller et al., 2008). In the last decades, researchers interested in an inactive or encrypted substance in the peptide's residue known as bioactive peptides. These peptides identified as a food component that influence ultimately on human health specifically that are a fragment of the protein that has a favorable effect on body condition and function (Kitts and Weiler, 2003). The biologically active peptides are inert in a latent state within the protein sequence provide numerous different health benefits. The structure and composition of these short chains of peptides residue regulate the activity of the bioactive peptides that generally consists of 2-20 amino acids (Erdmann et al., 2008). Within the positive physiological influences of the bioactive peptides abbreviated in antioxidative, antihypertensive, antimicrobial, opioid agonistic, prebiotic, mineral binding, immunomodulatory, antithrombotic and hypo-cholesterolemic activities. The peptides chain that provides the mentioned functionalities released from the protein sequence to obtain the active form of it.

Bioactive peptides are a certain protein fraction that except it is ordinary appropriate nutrition benefits demonstrate pharmacological features in the human body (Hartmann and Meisel, 2007). These beneficial health effects show a wide range of physiological effects including antioxidant, antihypertensive and antimicrobial activities. The valuable health effects of antioxidants performed as a body protector against the reactive oxygen species (ROS) molecules. Many studies demonstrated that the antioxidant peptides usually have 5-16 amino acid fractions. And their composition, hydrophobicity and structure associate with the diverse levels of functionality (Saadi et al., 2015). The principle of the antioxidants actions is prevention of oxidative reactions by scavenging free radicals (You et al., 2009; Demirci et al., 2021; Tahmaz et al., 2022). Therefore, antioxidants are vital biological molecules to block oxidations by free radicals and protect health system. Biologically active peptides in protein sequence may show higher activity even than the parent protein. The angiotensin-converting enzyme (ACE) inhibitors have a crucial role in promoting health and regulating blood pressure. Diets that are rich in bioactive peptides pretended to cure hypertension in the first stages in other word heal pre-hypertensive (Pins and Keenan, 2006; Fluegel et al., 2010). Peptides performed high capability in food to inhibit ACE activity from this point of view the peptides known as antihypertensive peptides utilized to prevent or handling hypertension (Udenigwe and Aluko, 2012). These peptides are apart in destroying a number of microorganisms such as bacteria and fungi, too. One of the most natural and crucial portions of the immunity is the availability of antimicrobial peptides on the surface of internal organs especially small intestine and lungs incessantly exhibited a number of possible pathogens (Douglas et al., 2001). Prevention and manage to spread of diseases in the body by bioactive peptides that behave like an antimicrobial agent and react with the hosts or by promoting definite response of the immune system in these two forms perform the mechanism of action (Hancock and Sahl, 2006).

Cereal grains are essential in human diet. They are used for different purposes such as energy supply, as well as contributing to the nutrition of animals. Cereal protein described as a precious source of biologically active peptides. Particularly, bulgur is produced from Triticum durum wheat variety beside the desirable taste it has many health benefits. Bulgur production especially in the milling processes generates a quantity of waste like wheat germ and wheat bran, besides the main product. Wheat germ contains protein, dietary fiber, minerals and precious amount of vitamin E and B group vitamins (Amado and Arrigoni, 1992). Also, wheat bran is a rich source of fiber, B vitamin groups and minerals (Preuckler et al., 2014).

This article explains the current knowledge about bioactive peptides. It was carried out (1) to obtain bioactive peptides from bulgur waste products by hydrolysis with different enzymes, (2) to determine the biological activities of obtained bioactive peptides and (3) to reveal the reuse capability of by-products from wheat industries.

2. Materials and Methods

2.1. Materials

The waste of bulgur was supplied from a factory in Gaziantep, Türkiye. Enzymes used in this study were trypsin from porcine pancreases (1 BAEE Unit of Trypsin activity will produce 0.001 absorbance increase per minute at 253 nm, BAEE is Benzyl L-arginine ethyl ester), pepsin from porcine gastric mucosa (1 Unit will produce 0.001 absorbance increase per minute at 280 nm), α-chymotrypsin from bovine pancreas (1 Unit will hydrolyze 1µmole BTEE per minute at pH 7.8 and 25°C, BTEE is N-Benzoyl-L-tyrosine ethyl ester) and protease from Bacillus specious (1 Unit of protease is the amount of enzyme needed to produce 1 mg of tyrosine per minute at 660 nm). Sodium hydroxide (NaOH), Potassium sulfate (K_2SO_4), Cuppersulfate ($CuSO_4$), sulfuric acid (H_2SO_4), hydrochloric acid (HCl), Tris(hydroxymethyl)aminomethane (Tris), tri-sodium citrate dehydrate, o-phthalaldehyde (OPA), 2,2′-azino-bis(3- ethylbenzothiazoline-6-sulphonic acid) (ABTS), potassium persulphate, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ethanol, Angiotensin Converting Enzyme from rabbit lung (ACE), N-Hippuryl-His-Leu hydrate – powder were purchased from Sigma-Aldrich Company (USA).

2.2. Determination of Bulgur Waste Characteristics

Moisture, ash, fat and protein contents of wastes of bulgur were determined according to the AOAC (1990) with at least duplicate runs. Moisture content was determined by heating at 105°C in oven until constant weight was obtained. Protein content was determined by Kjeldahl method with digestion (400°C for 40 min), distillation (FOSS, 2200 Hoganas, Sweden) and titration steps (nitrogen factor 5.7). Ash content was determined by burning the sample at 550°C up to constant weight. Fat content was determined by Soxhelet (Gerhardt, SE-416, Germany) extraction method.

2.3. Extraction of Bulgur Waste Protein

The accessible quantity of protein from the wastes of bulgur was extracted by alkali solution treated by 0.1N NaOH and the sample to solvent ratio was (1:10 w/v). The sample was stirred within the buffer for two hours and then centrifuged at 10000 rpm (Eppendorf centrifuge 5810R) for 20 minutes at the room temperature. The extracted protein was concentrated by freeze dryer (CHRIST ALPHA 1-4 LD Plus, Germany) and kept in -18°C until next use.

2.4. Enzymatic Hydrolysis of Bulgur Waste Protein

The extracted and concentrated protein was subjected to enzymatic hydrolysis by use of 1 mL of protein mixture diluted in 1 mL deionized water with proteolytic enzymes. Protein hydrolysis was performed about 4 hours in shaking incubator (INNOVA 40, New Brunswick, New Jersey, USA) using 3 units of trypsin (by use of sodium citrate buffer at pH 2 and at 37°C), chymotrypsin (using Tris buffer at pH 8 and at 37°C), pepsin (using Tris buffer at pH 8 and at 37°C) or protease (using Tris buffer at pH 8 and at 50°C) enzymes. These mentioned hydrolysis conditions were regulated according to the optimum conditions. Enzymatic hydrolysis reaction was terminated by heating at 95°C for 20 min, followed by cooling to room temperature in an ice bath. Then the hydrolysates were centrifuged at 6000 rpm for 15 min and the collected supernatant was stored at -18°C until use.

2.5. Degree of Hydrolyses

The degree of hydrolysis was determined by using OPA method (Spellman et al., 2003). About 3 mL deionized water was mixed with 75 µl OPA reagent and 10 µl of sample and shaked about 5 seconds then after two minutes the absorbance was read at 340 nm. The degree of hydrolysis was calculated by Equation 1:

$$DH\ (\%) = ((ABS\ x\ 1.934\ x\ d))/c \quad \text{(Eq. 1)}$$

where ABS is the absorbance of samples, d is the dilution factor, and c the protein content of the sample (g/L).

2.6. Antimicrobial Activity of Hydrolyzed Peptides

Escherichia coli (25322 ATCC) and *Staphylococcus aureus* (25923 ATCC) were used to determine the antimicrobial properties of peptides against Gram-negative and Gram-positive bacterial species. These microorganisms were retained on nutrient agar plate and recovered by sub-culturing in nutrient broth for 24 hours. About 0.1 mL stock solution of each microorganism was inoculated on plate count agar. The sterile paper discs, 1cm diameter, were prepared and dipped into the hydrolyzed samples for around one minute then semi-dried in room

temperature. Semi-dry paper discs were stabilized on the plate count agar that contain microorganisms and incubated for 48 hours at 37°C to verify inhibition zone diameter (mm).

2.7. Antioxidant Activity of Hydrolyzed Peptides

It is necessary to combine more than one method to evaluate the antioxidant activity of foodstuffs (Nuutila et al., 2003; Georgetti et al., 2006). Antioxidant activities of the hydrolyzed peptides were determined by the methods of DPPH and ABTS radical scavenging activity.

2.7.1. DPPH Radical Scavenging Activity

The antioxidant activity of the hydrolyzed peptides was determined by use of DPPH free radical scavenging activity illustrated by Yang et al. (2008). DPPH radical stock solution, 0.1 mM, was prepared in 95% ethanol. Two milliliters of stock solution was mixed well with two milliliter of each sample and kept at room temperature for 30 minutes in the dark place. Absorbance values of the samples were read at 517 nm by UV visible spectrophotometer (OPTIMA SP-3000nano, Tokyo, Japan). Absorbance value of control was obtained through use of ethanol and DPPH without the sample. DPPH radical scavenging activity was calculated by Equation 2.

$$DPPH\ radical\ scavenging\ activity\ \% = [1 - (Absorbance\ of\ sample)/(Absorbance\ of\ control)] \times 100 \quad \text{(Eq. 2)}$$

2.7.2. ABTS Radical Scavenging Activity

ABTS radical scavenging activity was measured according to the method described by Re et al. (1999) with some modifications. ABTS stock solution was prepared by mixing 7 mM ABTS and 2.45 mM potassium persulfate at a ratio of 1:1 and it was left in dark place at room temperature for 12-16 hours. Before analysis, the mixture was diluted with 10 mM phosphate buffered saline solution at pH 7.4 to adjust the absorbance at 0.8±0.1 at 734nm. After these modifications 1 mL of the hydrolyzed sample was mixed with 1 mL of diluted ABTS stock solution. Mixture was rested for 10 min at room temperature and the absorbance was measured by UV visible spectrophotometer (OPTIMA, SP-3000nano, Tokyo, Japan) at 734 nm. ABTS scavenging activity was then calculated by the Equation 3:

$$ABTS\ scavenging\ activity\ (\%) = (Absorbance\ of\ control - Absorbance\ of\ sample)/(Absorbance\ of\ control) \times 100 \quad \text{(Eq. 3)}$$

where, absorbance of the control determined through replacing the sample by 1 mL deionized water.

2.8. Antihypertensive Activity of Hydrolyzed Peptides

The antihypertensive activity was measured by a modified method as described by Cushman and Cheung (1971). About 40 µL of sample was added to a mixture of buffered substrate solution that containing 100 µL of borate buffer pH 8.3 contains 300 mM NaCl and 6 mM hippurylhistidyl-leucine (HHL). The reaction was started by the addition of 20 µL of ACE solution (0.1 U/mL) incubated at 37°C for 45 minutes. The reaction was stopped by adding 200 µL of 1M HCl. Then, 1.5 mL of ethyl acetate was added to separate the released hippuric acid and centrifuged at 2500 rpm for 10 minutes. About 1 mL of the supernatant was transferred into a test tube and removing of the ethyl acetate was achieved by vacuum evaporate at 60°C for 60 minutes. The remaining sample was dissolved in 2 mL deionized water and the absorbance was determined at 228 nm using spectrophotometer. The inhibition activity was calculated by Equation 4:

$$ACE\ inhibitory\ activity\ \% = [(Aa - A)/(Aa - Ab)] * 100 \quad \text{(Eq. 4)}$$

where, Aa is the absorbance of the replaced sample by borate buffer, Ab is the absorbance of the replaced sample and ACE by borate buffer, and A is the absorbance of sample, ACE and HHL.

2.9. Statistical Analysis

Oneway of analysis of variances (ANOVA) was applied by SPSS (19) to indicate the significance difference between time of hydrolysis and type of enzyme at $\alpha = 0.05$ level. Duncan's multiple range tests was also carried out to determine difference between studied groups. Time of hydrolysis and type of enzyme has been used as an independent parameter. They compared with one way ANOVA using degree of hydrolysis, DPPH, ABTS, ACE and inhibition of *Staphylococcus aureus* and *Escherichia coli*.

3. Results and Discussion

The bulgur waste contains both bran and flour which remains from the wheat. These residues can contain varying amounts of moisture, which may vary according to the manufacturing processes. The moisture content of the bulgur waste samples was found to be 12.15%, while the whole bulgur samples had 11.21 % of moisture similar to that reported in Tacer Caba et al. (2011).

The amount of ash in the waste of bulgur was 3.55 % (d.b) whereas the whole bulgur contains only 0.92 % (d.b). Large variations in the ash content of the main product and waste components have been reported previously (Tacer Caba et al, 2011).

The quantity of fat of the bulgur waste was found to be 4.58 % while the whole bulgur samples had 1.20%. The high fat content of bulgur waste could be due to the presence of the main oil-containing part, germ, in the waste.

The main component turned to the bioactive peptides is the protein. The protein content of bulgur waste was determined by Kjeldahl method as 2.92 % (d.b). Whereas, the amount of protein in the whole bulgur sample was 16.34 % according to the dry base matter. At the same time, the protein content in the whole bulgur reported by Özboy and Köksel (1998) was varied from 11.5% to 16.6% (d.b). The bulgur waste components were similar to whole bulgur from wheat sources that contain fat, carbohydrate, minerals and protein. Changes in the moisture, ash, oil and protein contents of the wastes and whole bulgur may have resulted from the distribution of the components.

3.1. Degree of Hydrolysis

Identifying the degree of hydrolysis is one of the main popular guides to define the functional characteristics of the cleaved peptide bonds from the hydrolyzed proteins (Kristinsson and Rasco, 2000). The enzymes specificity shows effectiveness on the hydrolysis processes such as pepsin cleaves peptide bonds of protein from carboxylic sides of glutamic acid, tryptophan, phenylalanine, leucine and tyrosine (Lin et al., 2012).

Bulgur waste protein was hydrolyzed for 4 h under the optimum conditions of enzymes including pepsin, trypsin, chymotrypsin and protease. The degree of hydrolysis was determined by the OPA method (*Table 1*). OPA method illustrates the enzymes ability to generate smaller peptides and display the activity of the biological peptides. When pepsin was used, the degree of hydrolysis decreased after 120 min with time, the hydrolysis was the highest at 120 min. The hydrolysis of wheat by pepsin enzymes was reported by Nagy et al. (2009) that increasing time increased the degree of hydrolysis within entire 120 minutes as parallel to our results. Trypsin usually cleaves primary amino acids of the lysine and arginine (Salami et al., 2008). Degree of hydrolysis was not affected ($P>0.05$) by hydrolysis time when trypsin was used.

Mainly breakage of the long polypeptides to smaller peptides by chymotrypsin start by the availability of lateral chains as phenylalanine, leucine, tryptophan and tyrosine at C-terminal of hydrophobic or aromatic amino acids (Salami et al., 2008). Various enzymes attack to different the amino acids sequence of protein or peptides in the structure of bulgur waste that resulted in different degree of hydrolysis and products. The degree of hydrolysis of bulgur waste proteins with chymotrypsin increased significantly ($P<0.05$) with time during 4 h incubation. The extraction of protein from the main source, the sort of utilized enzymes for hydrolysis, the available amount of peptides in desirable concentration and the degree of hydrolysis may affect the activity of every single peptide (Wang et al., 2010).

The protease enzyme was also used in the hydrolysis of bulgur waste proteins. Protease had significant effect ($P<0.05$) on the rate of proteolysis. The degree of hydrolysis increased gradually ($P<0.05$) with time (*Table 1*). Protease cleaves peptide bonds on aromatic amino acids of leucine, phenylalanine, tyrosine and tryptophan (Rao et al., 1998). The notable proficiencies of protease examined by previous studies to provide high proportions of hydrolysis rate in protein especially for legume proteins (Yust et al., 2003; Li et al., 2005). The great activity may regard to the ability to hydrolyze the denatured proteins by the side of original protein, the suitable range of pH and temperature, the specificity of the substrate and stability versus auto-proteolysis alongside with the other general difficulties for of each proteases (Baldyga and Bourne, 1999).

When the effects of four enzymes were compared with respect to degree of hydrolysis, it can be said that degree of hydrolysis increased with time when pepsin, trypsin, chymotrypsin and protease were used.

Table 1. Degree of hydrolysis, DPPH, ABTS and ACE activity of bulgur waste hydrolysate obtained by treatment of different proteolytic enzymes

	Time (min)	Pepsin	Trypsin	Chymotrypsin	Protease
Degree of Hydrolysis (%)	60	1.85 ± 0.09^{bA}	7.52 ± 0.38^{aB}	1.42 ± 0.07^{aA}	7.10 ± 0.35^{aB}
	120	2.13 ± 0.11^{cA}	7.24 ± 0.36^{aC}	3.83 ± 0.19^{bB}	8.80 ± 0.44^{bC}
	180	1.42 ± 0.07^{aA}	7.81 ± 0.39^{aC}	4.26 ± 0.21^{cB}	9.79 ± 0.49^{cD}
	240	1.28 ± 0.06^{aA}	7.24 ± 0.36^{aC}	3.99 ± 0.19^{bB}	10.08 ± 0.40^{cD}
DPPH radical scavenging activity (%)	60	83.98 ± 4.20^{abA}	146.41 ± 7.32^{aB}	141.16 ± 7.06^{aB}	121.27 ± 6.06^{aC}
	120	78.73 ± 3.94^{aA}	145.86 ± 7.29^{aB}	145.86 ± 7.29^{aB}	138.95 ± 6.95^{bB}
	180	91.44 ± 4.57^{abA}	146.41 ± 7.32^{aB}	130.66 ± 6.53^{aC}	144.48 ± 7.22^{cB}
	240	109.12 ± 5.46^{cA}	151.93 ± 7.60^{aB}	139.78 ± 6.99^{aC}	133.70 ± 6.69^{bC}
ABTS scavenging activity (%)	60	258.79 ± 12.94^{aA}	405.73 ± 20.29^{aB}	443.01 ± 22.15^{aB}	379.01 ± 18.95^{aC}
	120	346.51 ± 17.33^{bA}	403.53 ± 20.18^{aAB}	477.00 ± 23.85^{abB}	449.35 ± 22.47^{bB}
	180	354.19 ± 17.71^{bA}	409.02 ± 20.45^{aB}	487.97 ± 24.40^{bC}	412.61 ± 20.63^{abB}
	240	387.08 ± 19.35^{bA}	398.28 ± 19.46^{aA}	526.35 ± 26.32^{cB}	486.10 ± 24.31^{cB}
ACE inhibitory activity (%)	60	8.71 ± 0.44^{abA}	20.43 ± 1.02^{bB}	21.14 ± 1.06^{aB}	21.00 ± 1.05^{aB}
	120	8.57 ± 0.43^{abA}	17.57 ± 0.88^{aB}	17.57 ± 0.37^{bB}	23.43 ± 0.17^{abC}
	180	9.29 ± 0.46^{bcA}	27.86 ± 0.39^{cB}	28.29 ± 1.41^{cB}	22.29 ± 0.11^{aC}
	240	10.86 ± 0.54^{cA}	24.14 ± 1.21^{cB}	16.14 ± 0.80^{bC}	24.00 ± 0.35^{bB}

* Small letters show significant difference of time on degree of hydrolysis by one way ANOVA at $\alpha = 0.05$ level. Capital letters (A, B, C and D) show significant difference among pepsin, trypsin, chymotrypsin and protease enzymes at each time on degree of hydrolysis at $\alpha = 0.05$ level.

3.2. Antioxidant Activity of Hydrolyzed Peptides

3.2.1. DPPH Radical Scavenging Activity

Several positive effects can occur during or after enzymatic hydrolysis such as improvement of radical scavenging activity which directly related to antioxidant activity of hydrolyses (Aleman et al., 2011). The primary consideration that related directly to the rate of antioxidant activity is the type of enzymes utilized in hydrolysis. The DPPH activity of the bulgur waste hydrolysate obtained with different hydrolysis times, by trypsin and chymotrypsin were non-significant ($P>0.05$). However, pepsin and protease showed a significantly positive ability to produce an anti-oxidative peptide during the hydrolysis period ($P<0.05$) (*Table 1*). Winata and Lorenz (1996) found that the addition of protein isolates to milk was enhanced the antioxidant activity of milk.

3.2.2. ABTS Radical Scavenging Activity

The use of enzymes for hydrolysis resulted in the formation of different peptides having various antioxidant activities, as given in *Table 1*. Such as, chymotrypsin exhibited the most significant ($P<0.05$) increase on the formation of bioactive peptides leading to have high ABTS activity. These outcomes may be due to the capability of chymotrypsin to cleave peptides only at the C-terminal of leucine, tryptophan, phenylalanine, and tyrosine of hydrophobic or aromatic amino acids. The type and amount of free amino acids, the types of enzymes, and the solubility of the hydrolysate affect the formation of the bioactive peptide that scavenge ABTS radicals (Phanturat et al., 2010).

3.3. Antihypertensive Activity

Angiotensin-I converting enzyme (ACE) take a part in adjustment of human blood pressure (Raghavan and Kristinsson, 2009). The presence of hydrophobic amino acids in the C-terminal side particularly proline, phenylalanine, tryptophan and tyrosine have a great impact on the ACE inhibitory activity (Haque and Chand, 2008). Besides, the availability of isoleucine and valine at the N-terminal provide a positive influence on the ACE inhibitory activity. *Table 1* summarizes the changes in ACE inhibitory activity of the hydrolysates. Bioactive peptides produced from pepsin, protease, trypsin and chymotrypsin hydrolysis had significant ($P<0.05$) effect on the formation of antihypertensive active peptides.

3.4. Antimicrobial Activity of Hydrolyzed Peptides

The antimicrobial activities have been demonstrated to exhibit the protein fractions ability to inhibit growth of microorganisms. The four diverse enzymes break down the protein fractions into smaller peptides. The entire hydrolyzed samples examined against Gram positive bacteria (*Staphylococcus aureus*) and Gram negative bacteria (*Escherichia coli*) by evaluating the growth inhibition zone (mm) of each portion.

The protein hydrolysates showed antimicrobial activity on both *Escherichia coli,* and *Staphylococcus aureus*. *Table 2* shows the effects of each protein hydrolysates on the *Escherichia coli* and *Staphylococcus aureus* by the extent of inhibition zone with increasing hydrolysis time. The least antimicrobial effect against *Escherichia coli* was observed in peptides obtained by hydrolysis of pepsin and chymotrypsin while the highest effect was observed in peptides obtained as a result of hydrolysis with trypsin for 240 minutes. Bulgur waste protein hydrolysates were found to be more effective against *Staphylococcus aureus* than that of *Escherichia coli* (*Table 2*). All of the hydrolysates obtained from proteolysis of bulgur waste protein by trypsin, chymotrypsin, pepsin and protease showed antimicrobial effect against *Staphylococcus aureus*. The most effective one was the hydrolysate obtained as a result of hydrolysis with pepsin for 60-180 minutes. Bueno-Gavila et al (2019) reported that the antimicrobial hydrolysate obtained from bovine casein had the highest antimicrobial activity against *Enterococcus faecalis*. The enrichment of milk with antimicrobial peptides was significantly reduced the bacterial load level to an acceptable level (Sivakumar and Dhanalakshmi, 2016).

Table 2. Effect of bioactive peptides obtained from bulgur waste by treatment of different proteolytic enzymes on Staphylococcus aureus and Escherichia coli with increasing hydrolysis time*

Time (min)	Pepsin		Trypsin		Chymotrypsin		Protease	
	E. coli	*S. aureus*	*E. coli*	*S. aureus*	*E. coli*	*S. aureus*	*E. coli*	*S. aureus*
60	+	++++	+	++	+	+	++	+++
120	+	++++	++	+++	+	+++	+	++
180	+	++++	++	+++	+	+++	++	++
240	++	++	+++	++	+	++	+	++

*+ less effective, ++ moderate effective, +++ effective, ++++ high effective

4. Conclusions

In this study, the waste of bulgur analyzed to discover available amounts of protein especially bioactive peptides. The moisture, ash, fat and protein contents of the bulgur waste were found as 12.15%, 3.55 %, 4.58 % and 2.92 %, respectively. Bioactive peptides were obtained by hydrolyzing of bulgur waste with proteolytic enzymes pepsin, trypsin, chymotrypsin and protease. The highest rate of hydrolysis was found by use of trypsin and protease. Increasing hydrolysis time increased degree of hydrolysis when protease was used. Bioactive peptides provided by trypsin hydrolysis can easily inhibit Gram negative bacteria, *Escherichia coli*. All of the bulgur waste protein hydrolysates obtained by trypsin, chymotrypsin, pepsin and protease hydrolysis showed antimicrobial activity against *Staphylococcus aureus*. It was found that all bioactive peptides have ABTS scavenging activity and the highest activity belongs to the peptides obtained by chymotrypsin hydrolysis. The higher DPPH activity of the bulgur waste hydrolysate obtained by trypsin and chymotrypsin than that of other proteolytic enzymes ($P<0.05$). Antihypertensive activity of the pepsin, trypsin and chymotrypsin increased versus with time. As a result, the bioactive peptides can be produced to offer the selected biological effects, suitable to use as a food additives for industrial applications.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Bozkurt, H., Aykaç, Ç.; Design: Bozkurt, H., Aykaç, Ç.; Data Collection or Processing: Rashid, H.A.; Statistical Analyses: Rashid, H.A., Bozkurt, H.; Literature Search: Rashid, H.A., Aykaç, Ç.; Writing, Review and Editing: Rashid, H.A., Bozkurt, H., Aykaç, Ç.

References

Aleman, A., Gimenez, B., Montero, P. and Gomez-Guillen, M. (2011). Antioxidant Activity of Several Marine Skin Gelatins, *LWT Food Science Technology*, 44: 407–413.

Amado, R. and Arrigoni, E. (1992). Nutritive and Functional Properties of Wheat Germ. *International Food Ingredients,* 4: 30–34.

AOAC (1990). Official Methods of Analysis, 15th Edition. Association of Official Analysis Chemists, Washington DC., U.S.A.

Baldyga, J. and Bourne J. R. (1999). Turbulent Mixing and Chemical Reactions. Wiley, New York, U.S.A.

Bueno-Gavila, E., Abellan, A., Giron-Rodriguez, F., Cayuela, J. M., Salazar, E., Gomez, R. and Tejada, L. (2019). Bioactivity of hydrolysates obtained from bovine casein using artichoke (*Cynara scolymus* L.) proteases. *Journal of Dairy Science,* 102: 10711–10723.

Cushman, D. W. and Cheung, H. S. (1971). Spectrophotometric assay and properties of the angiotensin-converting enzyme of rabbit lung. *Biochemical Pharmacology,* 20: 1637–1648.

Demirci, A. Ş., Sözeri Atik, D., Palabıyık, İ. and Gülcü, M. (2021) Bioactive properties of commercial reishi mushroom products in powder form. *Journal of Tekirdag Agricultural Faculty*, 18(2): 273-281.

Douglas, S. E, Gallant, J. W, Gong, Z. and Hew, C. (2001). Cloning and developmental expression of a family of pleurocidin-like antimicrobial peptides from winter flounder, *Pleuronectes americanus* (Walbaum). *Developmental and Comparative Immunology,* 25: 137–147.

Erdmann, K., Cheung, B. W. Y. and Schroeder, H. (2008). The possible roles of food-derived bioactive peptides in reducing the risk of cardiovascular disease. *Journal of Nutritional Biochemistry,* 19: 643–654.

Fluegel, S. M., Shultz, T. D., Powers, J. R., Clark, S., Barbosa-Leiker, C., Wright, B. R., Freson, T. S., Fluegel, H. A., Minch, J. D. and Schwarzkopf, L. K. (2010). Whey beverages decrease blood pressure in prehypertensive and hypertensive young men and women. *International Dairy Journal,* 20: 753–760.

Georgetti, S. R., Casagrande, R., Vicentini, F. T. M. C., Verri Jr, W. A. and Fonseca, M. J. V. (2006). Evaluation of the antioxidant activity of soybean extract by different in vitro methods and investigation of this activity after its incorporation in topical formulations. *European Journal of Pharmaceutics and Biopharmaceutics,* 64(1): 99–106.

Haque, E. and Chand, R. (2008). Antihypertensive and Antimicrobial Bioactive Peptides from Milk Proteins, *European Food Research and Technology*, 227(1): 7-15.

Hancock, R. E. W. and Sahl, H. G. (2006). Antimicrobial and host-defense peptides as new anti-infective therapeutic strategies. *National Biotechnolgy,* 24(12): 1551–1557.

Hartmann, R. and Meisel, H. (2007). Food-derived peptides with biological activity: from research to food applications. *Current Opinion in Biotechnology,* 18(2): 163–169.

Kitts, D. D. and Weiler, K. (2003). Bioactive proteins and peptides from food sources. applications of bioprocesses used in isolation and recovery. *Current Pharmaceutical Design,* 9: 1309–1323.

Kristinsson, H. G. and Rasco, B. A. (2000). Fish protein hydrolysates: Production, biochemical and functional properties. *Critical Reviews in Food Science and Nutrition,* 40: 43–81.

Kussmann, M., Panchaud, A. and Affolter, M. (2010). Proteomics in nutrition: Status quo and outlook for biomarkers and bioactives. *Journal of Proteome Research,* 9: 4876–4887.

Li, G. H., Le, G. W., Liu, H. and Shi, Y. H. (2005). Mung-bean protein hydrolysates obtained with alcalase exhibit angiotensin I-converting enzyme inhibitory activity. *Food Science and Technology International*, 11(4): 281-287.

Lin, S., Tian, W., Li, H., Cao, J. and Jiang, W. (2012). Improving antioxidant activities of whey protein hydrolysates obtained by thermal preheat treatment of pepsin, trypsin, alcalase and flavourzyme. *International Journal of Food Science and Technology,* 47: 2045–2051.

Moller, N. P., Scholz-Ahrens, K. E., Roos, N. and Schrezenmeir, J. (2008). Bioactive peptides and proteins from foods: Indication for health effects. *European Journal of Nutrition,* 47: 171–182.

Nagy, A., Marciniak-Darmochwał, K., Krawczuk, S., Mierzejewska, D., Kostyra, H. and Gelencser, E. (2009). Influence of glycation and pepsin hydrolysis on immunoreactivity of albumin/globulin fraction of herbicide resistant wheat line. *Czech Journal of Food Sciences,* 27: 320–329.

Nuutila, A. M., Puupponen-Pimiä, R., Aarni, M. and Oksman-Caldentey, K. M. (2003). Comparison of antioxidant activities of onion and garlic extracts by inhibition of lipid peroxidation and radical scavenging activity. *Food Chemistry,* 81(4): 485–493.

Özboy, Ö. and Köksel, H. (1998). The effects of bulgur production on various chemical properties of wheats. *The Journal of Food*, 23(6): 449–457.

Phanturat, P., Benjakul, S., Visessanguan, W. and Roytrakul, S. (2010). Use of pyloric caeca extract from bigeye snapper (*Priacanthus macracanthus*) for the production of gelatin hydrolysate with antioxidative activity, *LWT-Food Science and Technology*, 43: 86–97.

Pins, J. J. and Keenan, J. M. (2006). Effects of whey peptides on cardiovascular disease risk factors. *Journal of Clinical Hypertension,* 8:775–782.

Preuckler, M., Siebenhandl-Ehn, S., Apprich, S., Höltinger, S. and Haas, S. (2014). Wheat-bran based biorefinery: Composition of wheat bran and strategies of functionalization. *LWT- Food Science and Technology,* 56(2): 211–221.

Raghavan, S. and Kristinsson, H. G. (2009). ACE-inhibitory activity of tilapia protein hydrolysates, *Food Chemistry*, 117(4): 582-588.

Rao, M. B., Tanksale, A. M., Ghatge, M. S. and Deshpande V. V. (1998). Molecular and biotechnological aspects of microbial proteases. *Microbiology and Molecular Biology Reviews,* 62(3): 597–635.

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M. and Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine,* 26: 1231–1237.

Saadi, S., Saari, N., Anwar, F., Abdul Hamid, A. and Ghazali, H. M. (2015). Recent advances in food biopeptides: production, biological functionalities and therapeutic applications. *Biotechnology Advances,* 33: 80–116.

Salami, M., Yousefi, R. and Ehsani, M. R. (2008). Kinetic characterization of hydrolysis of camel and bovine milk proteins by pancreatic enzymes. *International Dairy Journal,* 18: 1097–1102.

Sarmadi, B. H. and Ismail, A. (2010). Antioxidative peptides from food proteins: A review. *Peptides,* 31: 1949–1956.

Spellman, D., McEvoy, E., O'Cuinn, G. and FitzGerald, R. J. (2003). Proteinase and exopeptidase hydrolysis of whey protein: Comparison of the TNBS, OPA and pH stat methods for quantification of degree of hydrolysis. *International Dairy Journal,* 13: 447–453.

Sivakumar, G. M. and Dhanalakshmi, B. (2016). Betel leaf extract as shelf life extender of raw milk. *International Journal of Science, Environment*, 5: 2832-2836.

Tahmaz, H., Yüksel Küskü D., Soylemezoglu G. and Çelik H. (2022) Phenolic compound and antioxidant capacity contents of *Vitis labrusca* L. genotypes. *Journal of Tekirdag Agricultural Faculty*, 19(2): 318-331.

Tacer Caba, Z., Boyacioglu, M. H. and Boyacioglu, D. (2011). Bioactive healthy components of bulgur. *International Journal of Food Sciences and Nutrition,* 63(2): 250–256.

Udenigwe, C. C. and Aluko, R. E. (2012). Food protein-derived bioactive peptides: Production, processing, and potential health benefits. *Journal of Food Science,* 77(1): R11–R24.

Wang, L., Mao, X., Cheng, X., Xiong, X. and Ren, F. (2010). Effect of enzyme type and hydrolysis conditions on the in vitro angiotensin i-converting enzyme inhibitory activity and ash content of hydrolysed whey protein isolate. *International Journal of Food Science and Technology,* 45: 807–812.

Winata, A. and Lorenz, K. (1996). Antioxidant potential of 5-n-pentadecylresorcinol. *Journal of Food Processing and Preservation*, 20(5): 417-429.

Yang, B., Zhao, M. M., Shi, J., Yang, N. and Jiang, Y. M. (2008). Effect of ultrasonic treatment on the recovery and DPPH radical scavenging activity of polysaccharides from longan fruit pericarp. *Food Chemistry,* 106: 685–690.

You, L., Zhao, M., Cui, C., Zhao, H. and Yang, B. (2009). Effect of degree of hydrolysis on the antioxidant activity of loach (*Misgurnus anguillicaudatus*) protein hydrolysates. *Innovative Food Science and Emerging Technologies,* 10(2): 235–240.

Yust, M. M., Pedroche, J., Girón-Calle, J., Alaiz, M., Millán, F. and Vioque J. (2003). Production of ACE inhibitory peptides by digestion of chickpea legumin with alca-lase. *Food Chemistry,* 81: 363–369.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Genetic Diversity of Tobacco Mosaic Virus (TMV) Isolates from Tobacco Growing Fields of Western Anatolia, Türkiye

Batı Anadolu Bölgesi Tütün Üretim Alanlarından Elde Edilen Tütün Mozaik Virüsü (TMV) İzolatlarının Genetik Çeşitliliği

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Abstract

Tobacco mosaic virus (TMV) is an important plant virus in agriculture. It is the first evidence of the existence of viruses in history. Studies on the genetic diversity of the CP gene of TMV, which plays a leading role in host interaction, are limited both in our country and worldwide. Genetic diversity analyses were conducted on ten isolates of the full CP gene region of TMV obtained from the most intensive tobacco cultivation areas in Türkiye, and compared with global isolates. TMV infection was detected in 32 out of 300 plants collected from the Aegean and Marmara regions (Çanakkale, Balıkesir, İzmir, Manisa, Uşak, Aydın and Denizli) between 2019 and 2020 using conventional molecular techniques. To genetically characterize the virus, 10 samples were selected from each region, and the complete CP gene region sequences were determined. The aligned CP gene region sequences of TMV from Türkiye and its global isolates exhibited nucleotide homology ratios ranging from 87.7% to 100%, with amino acid ratios ranging from 88.7% to 100%. The Türkiye isolates displayed similarity rates of 98.5% to 100% at the nucleotide level and 98.7% and 100% at the amino acid level. In phylogenetic analysis, the 196 known isolates of TMV registered in GenBank, belonging to the CP gene region, were divided into two main clades (I and II) and two subclades (Ia and Ib). Türkiye isolates were clustered in the major branch with the main clade I and subclade Ia isolates. Therefore, genetic analyses were performed on the CP gene region isolates obtained from different parts of the world and a wide range of hosts, including the isolates obtained from Türkiye. The results showed high genetic stability, similar to many tobamoviruses.

Keywords: TMV, Tobacco, RT-PCR, Phylogenetic analyses, Genetic diversity

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Öz

Tütün mozaik virüsü (TMV), tarımda yaygın olarak görülen önemli bir bitki virüsüdür. Tarihte virüslerin varlığının ilk kanıtıdır. Konakçı etkileşiminde öncü rol oynayan TMV' nin CP geninin genetik çeşitliliğine ilişkin çalışmalar hem ülkemizde hem de dünyada sınırlıdır. Bu çalışma kapsamında, ülkemizin en yoğun tütün üretimi yapılan bölgelerinden elde edilen 10 TMV izolatı ile gen bankasında bulunan küresel varyantların genetik çeşitlilik analizleri yapılması gerçekleştirilmiştir. Ege ve Marmara bölgelerinden (Çanakkale, Balıkesir, İzmir, Manisa, Uşak, Aydın and Denizli) 2019-2020 yılları arasında toplanan 300 bitkiden 32'sinde konvansiyonel moleküler teknikler kullanılarak TMV enfeksiyonu tespit edilmiştir. Genetik karakterizasyon için her bölgeyi temsil edecek şekilde 10 TMV izolatı seçilerek CP gen bölgesine ait nükleotid dizilimlerinin tamamı elde edilmiştir. Türk ve global TMV izolatlarının CP gen bölgesi dizilerinin çoklu dizi analizleri sonucunda nükleotid benzerlik oranları %87.7 ile 100 arasında, amino asit benzerlik oranlarının ise %88.7 ile 100 arasında değişen değerler gösterdiği belirlenmiştir. Türk izolatlarının kendi içlerinde ise nükleotit düzeyinde %98.5 ile 100, amino asit düzeyinde ise %98.7 ile 100 arasında benzerlik oranları gösterdiği görülmüştür. Gen bankasında kayıtlı tüm bilinen TMV izolatlarının (n=196) CP gen bölgesine göre gerçekleştirilen filogenetik analizleri sonucunda iki ana gruba (I ve II) ve bunlardan da birincisinin de iki alt gruba (Ia ve Ib) ayrıldığı belirlenmiştir. Türk izolatlarının Ia alt grubu içinde I ana grubuna ait olduğu görülmüştür. Bu analizler ile dünyanın farklı coğrafyalarından ve geniş bir konukçu yelpazesinden elde edilen izolatların yanı sıra Türkiye'den elde edilen izolatların da CP gen bölgesine göre genetik analizleri gerçekleştirilmiştir. Gerçekleştirilen bu çalışmaların sonucunda; birçok tobamovirus'larda olduğu gibi TMV'nin de yüksek genetik kararlılık gösterdiği belirlenmiştir.

Anahtar Kelimeler: TMV, Tütün, RT-PCR, Filogenetik analiz, Genetik çeşitlilik

1. Introduction

Türkiye has a long-standing tradition of cultivating tobacco (*Nicotiana tabacum*), a crop that rapidly spread in the New World and has been one of the significant agricultural products produced for many years (Gül et al., 2009). The tobacco, which has adapted significantly to temperate climate conditions, is primarily cultivated in the Marmara and Aegean regions of Türkiye, accounting for approximately 90% of its production (TURKSTAT, 2023). Globally, recognized as Turkish or Oriental tobacco in the world market, due to its distinctive aroma.

Tobacco plants are susceptible to various phytopathogens, including viruses, which can negatively impact the quality and quantity of the plant's leaves. It is important to note that viruses cannot be effectively controlled through direct means. The global spread of both established and newly developed tobamoviruses has significantly affected the production of various crops (Smith and Dombrovsky, 2020). Among these tobamoviruses, tomato brown rugose fruit tobamovirus (ToBRFV) has recently caused a significant reduction in the production of Solanaceae plants (Luria et al., 2017). On the other hand, infections caused by the tobacco mosaic tobamovirus (TMV) pathogen, one of the oldest known viruses and a pioneer in the field of virology, continue to be common in growing areas (Gibbs, 1999).

The genome of TMV is a single-stranded positive-polarity RNA molecule, termed (+) ssRNA, and has a compact size of 6.4 kilobases (kb) in length (Goelet, 1982). One feature that distinguishes TMV within the *Virgaviridae* family is its undivided genome structure, a characteristic not shared by other genera in the family (King et al., 2012). Virions are typically about 300–310 nm in length and 18 nm in diameter (King et al., 2012). Studies of TMV strains have revealed a complex genome consisting of at least three non-structural proteins (P183, P126 replication proteins and the 30 kD MP movement protein), a 54 kD protein of unknown function and the coat protein (17.6 kD-CP coat protein) (Okada, 1999; Zaitlin, 1999). These genomic features play a major role in the life cycle of TMV and its interactions with host plants and are the subject of ongoing virology research.

TMV is transmitted mechanically through contaminated tools or hands, and it also spreads systemically through plant vascular tissues, causing widespread infection (Sacristán et al., 2011). The virus's stable particle structures are widely believed to be the reason for the difficulty in controlling TMV in tobacco cultivation fields (Alonso et al., 2013). On the other hand, research has shown that both tobacco mild green mosaic virus (TMGMV) and TMV exhibit limited genetic diversity. This suggests that the viruses can infect new hosts without undergoing significant adaptive evolution, regardless of their habitat or host plant taxonomy (Zamfir et al., 2023). However, there is currently no comprehensive study on the genetic diversity of TMV in our country. This study aimed to determine the incidence of TMV in Western Anatolia, which is one of Türkiye's most intensive tobacco cultivation areas. Additionally, we conducted a molecular evolutionary characterization of its structural gene, the coat protein (CP gene).

2. Materials and Methods

2.1. Virus sources

Field studies were carried out within the scope of the TUBITAK project (119O625), which aims to determine the genetic diversity of TMV. The studies were carried out in tobacco production areas in Türkiye's Marmara and Aegean regions between 2019 and 2020. A total of 7 provinces were in the study: Çanakkale, Balıkesir, İzmir, Manisa, Uşak, Aydın, and Denizli. Samples were taken from plants showing virus and virus-like symptoms in randomly selected sampling areas.

2.2. Molecular assay

TMV was identified at the species level using reverse transcription polymerase chain reaction (RT-PCR) methods. The CTAB method with minor modifications, as previously detailed by Li et al. (2008), was used to extract total nucleic acid (TNA) from plant leaves. the cDNA Synthesis Kit (Takara, Japan) was used to generate complementary DNA (cDNA) libraries from the extracted TNA, along with a random hexamer primer (5′–NNNNNN–3′). The cDNA libraries were used in amplification procedures with the 2X Emerald PCR Master Mix (Takara, Japan) and gene-specific primer pairs Forward (5'-AGTGATGTCCGTAAAGGGA-3') and Reverse (5'-CGTTATCGTACGYACCACG-3') (Karanfil et al., 2023). The outcomes were validated through agarose gel electrophoresis stained with 1.5% Ethidium Bromide (EtBr) and visualized using a UV imager.

2.3. Sequencing studies and phylogenetic inference

To determine the nucleotide sequences of TMV isolates within the CP gene regions, we employed the PCR products resulting from the amplification studies. These products were cloned using the T-A cloning kit from Promega (USA) and underwent bidirectional sequencing through the Sanger sequencing method using the M13F-R universal primer pair for each gene region. The raw sequence data obtained were subsequently assembled using the CLC Main Workbench V.20.3 software. To classify the complete CP gene region of TMV objectively, we determined genetic similarity ratios between sequence pairs using the Sequence Demarcation Tool Version 1.2 (SDTv1.2) software (Muhire et al., 2014).

Phylogenetic relationships were determined by analysing the complete CP gene region of ten TMV isolates identified in this study, as well as 196 global isolates available in GenBank. The nucleotide sequences of the CP gene were aligned using the ClustalW algorithm in MEGA 11 software (Tamura et al., 2021). The phylogenetic trees were constructed using the Neighbour-Joining (NJ) statistical method, following the Tamura-3 parameter model (Tamura, 1992). Uniform rates of complete deletion were applied to the entire CP gene region of TMV. To increase the reliability of the main nodes, 1000 bootstrap tests supported the analyses. Tobamoviruses, including pepper mild mottle virus (PMMoV; access no AF1037777, South Korea), tomato mosaic virus (TomV; access no MZ323245, China), and tobacco mild green mottle virus (TMGMV; access no MH636301, China), were used as outgroups. The phylogenetic outcomes were also represented graphically using the Interactive Tree of Life (iTOL) v5 online software (Letunic and Bork, 2021).

3. Results and Discussion

3.1. Symptomatology and disease prevalence

During the field research, 300 plant samples displaying typical virus and virus-like symptoms were collected from the primary tobacco-producing areas in Western Anatolia, namely the Marmara and Aegean regions. Almost all the collected samples exhibited various degrees of mosaics, including mild and severe symptoms (*Figure 1*). In addition to the mosaic symptoms, a small number of plants also displayed stunting symptoms. Molecular testing using species-specific primers detected TMV infection in 32 out of 300 tobacco plants (10.66% infection rate) (*Table 1*). Additionally, as a result of amplification studies, fragments of 703 bp were obtained for the fully encoded CP gene region of TMV (*Figure 2*).

Figure 1. TMV-infected tobacco plant exhibiting mosaic symptoms of varying severity

Table 1. The number of tobacco mosaic virus isolates in the collected samples.

Region	Province	No of TMV isolates	No of collected samples
Marmara	Çanakkale	8	20
	Balıkesir	13	38
Aegean	İzmir	-	35
	Manisa	1	64
	Uşak	9	41
	Aydın	-	40
	Denizli	1	62
Total		32	300

Figure 2. Complete encoded CP gene region of TMV with a size of 703 bp

Research on tobamoviral genetic variability has enhanced our understanding of genetic diversity in viruses, elucidating the mechanisms responsible for its generation (Fraile and García-Arenal, 2018). Furthermore, it has provided insights into the factors influencing viral population dynamics (Karanfil et al., 2023). Thus, this study sheds light on the genetic diversity of the CP gene region, which plays a crucial role in the complex interaction between host and virus.

Symptoms of tobamovirus infections can vary depending on the virus species, the host plant, and environmental conditions. Infected plants typically exhibit leaf deformation, mosaic patterns, and mottled appearances on their leaves (Melcher et al., 2021). The severity of these symptoms can range from mild to severe, depending on the tobamovirus and its impact on the leaves or fruits of the host plant (Fraile et al., 1997). The existence of TMV and its symptoms have been known in our country since 1969 (Erdiller, 1969). TMV has been known to cause significant losses in yield and quality, particularly in economically valuable crops such as eggplant, pepper, tobacco, and tomatoes (Erdiller, 1969; Erkan and Yorgancı, 1988; Çulal-Kılıç et al., 2017). Infections caused by the agent in these plants often result in symptoms such as mosaic patterns, blistering and deformation of leaves, as well as reduced fruit size and mottling. However, recent advancements have shown that these symptoms are not exclusively caused by TMV. It has been demonstrated that both tobamoviruses and members of other genera can induce similar symptoms. Recent studies conducted in Türkiye have reported that tobamoviruses frequently cause single or multiple infections, often co-occurring with viruses from the same genus (Karanfil et al., 2023; Balsak et al., 2022). These infections are typically documented as symptoms of leaf yellowing, deformations, and mosaics on tobacco and pepper (Karanfil et al., 2023; Balsak et al., 2022). Randa-Zelyüt et al. (2022) reported the first description of 16Sr XII-A (stolbur group) phytoplasma infections causing abnormalities in tobacco leaves in Türkiye. The infected tobacco isolates used in this study were described in the study on TMGMV by Karanfil et al. (2023). Tobacco plants infected with TMV or multiple infections exhibited moderately mosaic symptoms. Therefore, it is hypothesized that the prevalence of TMV infections in our country is quite low, and the symptoms it causes are not severe. This hypothesis is supported by findings from a study that examined the prevalence and severity of TMV infections in cucurbits (Karanfil, 2022).

3.2. Molecular evolutionary inferences and sequence similarities

Molecular evolutionary analysis indicated that the TMV isolates (n=206) were grouped into two main clades (I and II) at the CP gene level, with strong bootstrap support (≥90). Furthermore, clade I was divided into two subgroups, I-a and I-b. The I-a subclade consisted of isolates from Indonesia, Finland, the United Kingdom,

Thailand, Spain, Germany, Canada, Italy, the United States, Vietnam, South Korea, Japan, India, Brazil, and China, making it the largest subclade (n=194). All 10 novel TMV isolates obtained from this study, along with 3 isolates from the eastern region of Türkiye, were positioned within subclade I-a (n=194). Subclade I-b (n=6) encompassed six isolates originating from Germany and South Africa. The main clade II (n=6) comprised six TMV CP gene isolates, which originated from Germany, Russia, China, the United States, Taiwan, and Mexico (*Figure 3*).

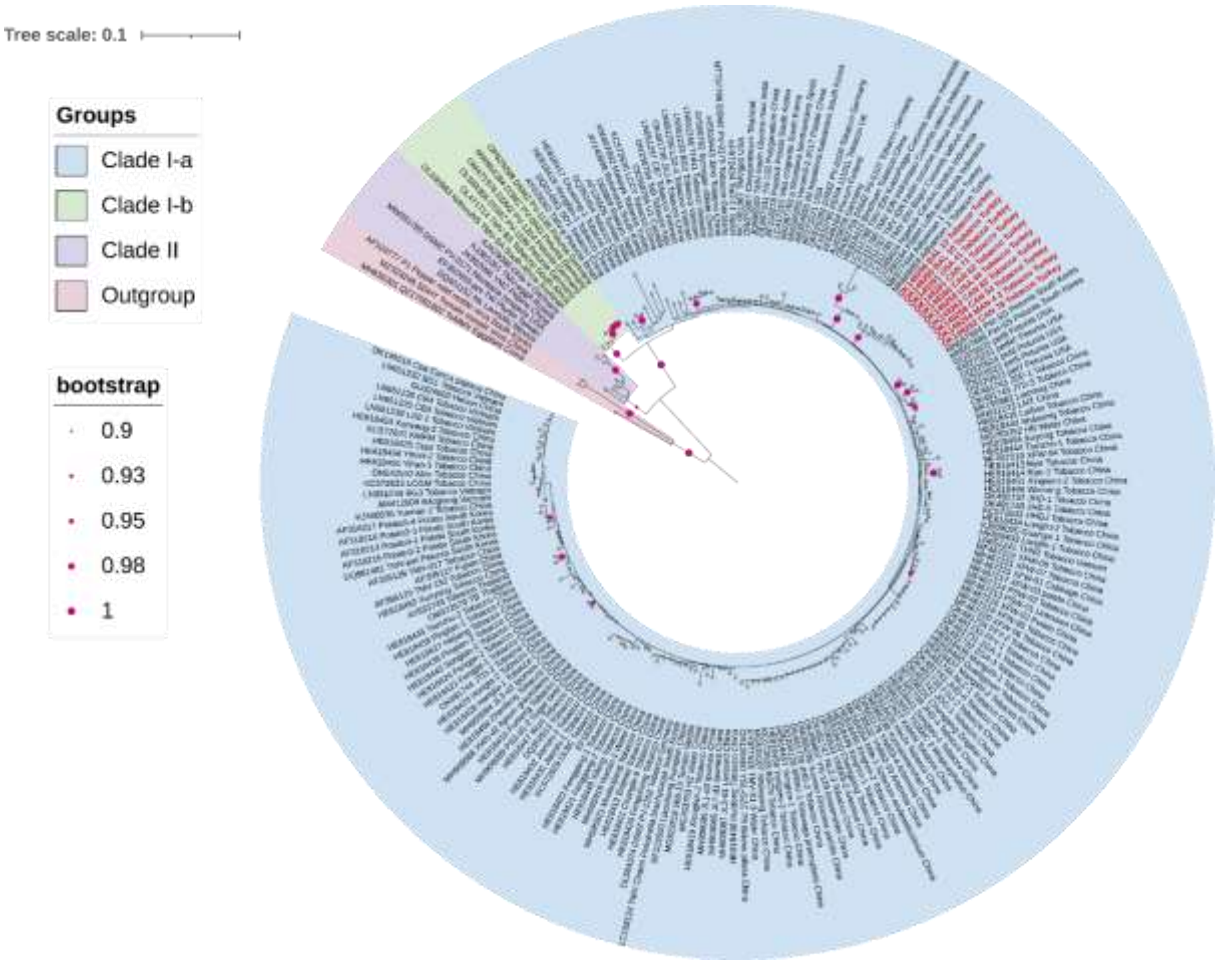

Figure 3. Phylogenetic relationship of tobacco mosaic virus isolates

The nucleotide sequence data for the entire CP gene region of ten randomly selected TMV-infected samples from both the Marmara and Aegean regions have been submitted to GenBank with accession numbers OK149254-63. The nucleotide similarity rates among the ten novel Turkish isolates obtained in this investigation ranged from 98.5% to 100% for the CP gene of TMV (*Figure 4*). The amino acid similarity rates among the ten novel Turkish isolates ranged from 98.7 to 100 % (*Figure 5*). Subgroup I-a isolates had nucleotide similarity ranging from 99.8% to 87.9% among themselves, while subgroup I-b isolates had nucleotide similarity ratios ranging from 99.2% to 99%. Main clade II isolates had a similarity ratio between 95.4% and 96% nucleotide among themselves. The nucleotide sequence similarity ranged from 87.7% to 100% among global isolates. Furthermore, the homogeneity of amino acid ranged from 88.7% to 100%. These results indicate that there was no significant variation among the isolates.

RNA genomes encode the RNA-dependent RNA polymerase (RdRp) enzyme for the replicating of many plant RNA viruses. Due to the lack of proofreading activity in this process, a high rate of nucleotide sequence errors occurs (Drake and Holland, 1999). Mutation rates were first reported for tobacco mosaic virus and ranging from 10^{-3} to 10^{-6} nucleotide substitutions per site per round of replication in viruses that infect animals or bacteria (Malpica et al., 2002; Sanjuán et al., 2009; Sanjuán et al., 2010). Our study revealed that TMV isolates clustered in Clade II had more mutations in the CP gene and showed 86% nucleotide homogeneity with isolates clustered in other branches. On the other hand, isolates that form subsets of the main clade I exhibit nucleotide homogeneity

of over 88%. These findings, obtained for the CP gene of TMV, support the hypothesis that some RNA viruses exhibit less genetic variation (Nichol, 1996). Studies have reported genetic stability in some RNA virus populations, including turnip yellow mosaic virus (TYMV), tobacco mild green mosaic virus (TMGMV), and tomato brown rugose fruit virus (ToBRFV) (Skotnicki et al., 1993; Karanfil et al., 2023; Güller et al., 2023).

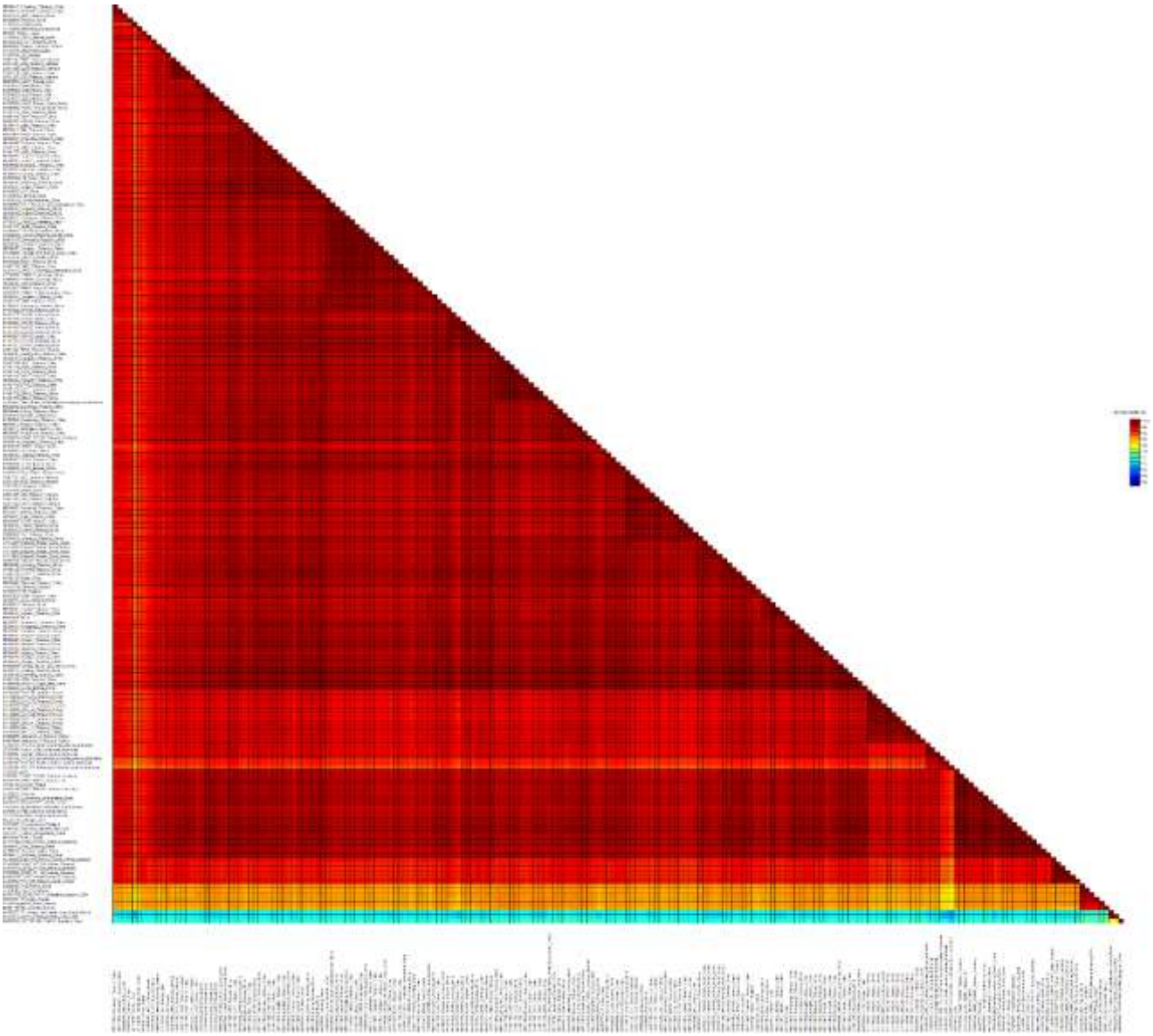

Figure 4. Similarity rates of tobacco mosaic virus isolates based on nucleotide sequences of the coat protein gene region

Phylogenetic analysis of the fully encoded CP gene region of TMV revealed that it is divided into two main groups: Clade I and II. The main group of Clade I is further divided into two subgroups (Ia and Ib). Previous studies have reported that TMV diverged into three branches (Alishiri et al., 2013; Kimaru et al., 2020). Molecular evolutionary analyses (n=206) were conducted using available isolates in GenBank to provide a detailed molecular characterization of both the main and subgroup branches. The main branches emerging in the phylogenetic trees did not reflect any geographical origin or host species from which the isolates were obtained (Alishiri et al., 2013). The low genetic diversity supports this, as does the determination that TMV isolates from different host species have the same dominant genotype. This suggests that host species do not contribute to the differentiation of the virus population, as observed in other plant viruses (Garcia-Arenal et al., 2001).

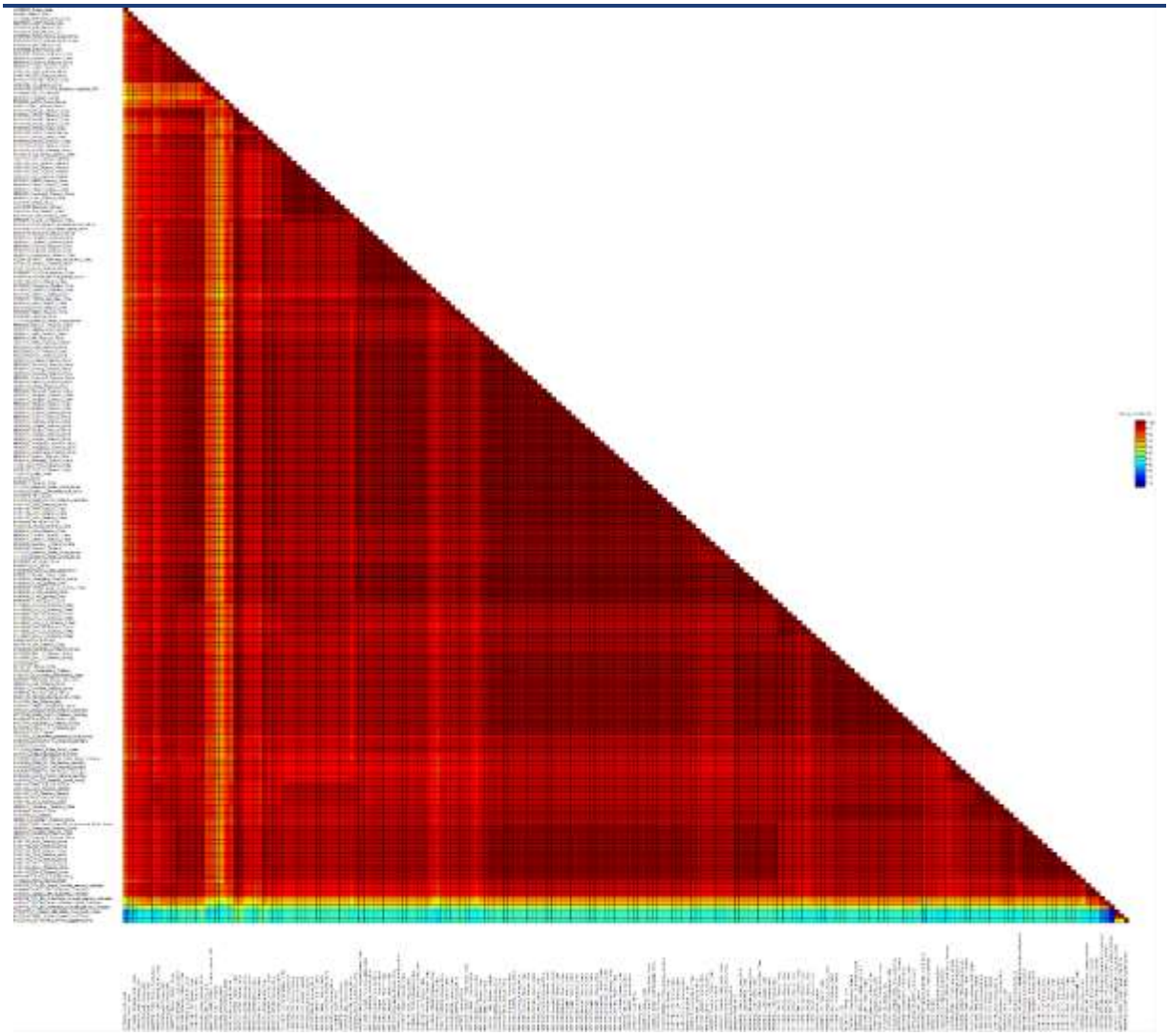

Figure 5. Similarity rates of tobacco mosaic virus isolates based on amino acid sequences of the coat protein gene region

4. Conclusions

The study comprehensively analyzed the genetic diversity of the complete CP gene of TMV, which plays a crucial role in host interaction. The results indicate that TMV isolates obtained from Türkiye do not exhibit a high level of diversity and global isolates also demonstrate genetic stability.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Randa-Zelyüt, F.; Design: Randa-Zelyüt, F., Karanfil, A.; Data Collection or Processing: Karanfil, A.; Statistical Analyses: Randa-Zelyüt, F.; Literature Search: Randa-Zelyüt, F., Karanfil, A.; Writing, Review and Editing: Randa-Zelyüt, F., Karanfil, A.; Korkmaz, S.

References

Alishiri, A., Rakhshandehroo, F., Zamanizadeh, H. R. and Palukaitis, P. (2013). Prevalence of tobacco mosaic virus in Iran and evolutionary analyses of the coat protein gene, *The Plant Pathology Journal*, 29(3): 260.

Alonso, J. M., Górzny, M. Ł. and Bittner, A. M. (2013). The physics of tobacco mosaic virus and virus-based devices in biotechnology. *Trends Biotechnology*, 31(9): 530-8.

Balsak, S.C., Avcu, S.G. and Buzkan, N. (2022). Detection and Molecular Characterization of Tobacco mild green mosaic virus Isolates Infecting Peppers in Turkey, *Journal of Agriculture and Nature*, 25(2): 490-496.

Çulal-Kılıç, H., Çıkrıkçı, M.Ö., Yardımcı, N. (2017). Determination of Tobacco mosaic virus in tobacco fields in Denizli province, Turkey. *Scientific Papers. Seres A., Agronomy*, LX: 215-219.

Drake, J. W. and Holland, J. J. (1999). Mutation rates among RNA viruses. *Proceedings of the National Academy of Sciences*, 96(24): 13910-13913.

Erdiller, G. (1969). *Studies on the symptoms, agents, transmission routes, and damage levels of tobacco mosaic disease in central and eastern black sea tobacco.* (PhD. Thesis) Ankara University, Graduate School of Natural and Applied Sciences, Ankara, Türkiye. (In Turkish).

Erkan, S. and Yorgancı, Ü. (1988). The preliminary investigations as to virus diseases on eggplants. *Journal of Turkish Phytopathology*, 17 (3): 91.

Fraile, A. and García-Arenal, F. (2018). Tobamoviruses as models for the study of virus evolution. *Advances in Virus Research*, 102: 89-117.

Fraile, A., Escriu, F., Aranda, M. A., Malpica, J. M., Gibbs, A. J. and García-Arenal, F. (1997). A century of tobamovirus evolution in an Australian population of Nicotiana glauca. *Journal of Virology*, 71(11): 8316–8320.

Garcia-Arenal, F., Fraile, A. and Malpica, J. M. (2001). Variability and genetic structure of plant virus populations. *Annual Review of Phytopathology*, 39: 157−186.

Gibbs, A. J. (1999). Evolution and origins of tobamoviruses. *Philosophical Transactions of the Royal Society of London Series B*, 354(1383): 593–602.

Goelet, P., Lomonossoff, G. P., Butler, P. J. G., Akam, M. E., Gait, M. J. and Karn, J. (1982). Nucleotide sequence of tobacco mosaic virus RNA. *Proceedings of the National Academy of Sciences of the United States of America*, 79: 5818–5822.

Gül, U., Arısoy, H., Sivük, H. and Ataseven, Y. (2009). Comparison of profitableness between tobacco and some products in scope of alternative product project. *Journal of Tekirdag Agricultural Faculty,* 6(3): 215-226.

Güller, A., Usta, M. and Randa-Zelyüt, F. (2023). Genetic diversity and population structure of tomato brown rugose fruit virus (ToBRFV) variants from Antalya province, Turkey. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 51(3): 13356.

Karanfil, A. (2022). Prevalence and Genetic Diversity of Tobacco Mosaic Virus Isolates Infecting Squash Plants in Marmara Region of Turkey. *Journal of Advanced Research in Natural and Applied Sciences*, 8(2): 163-170.

Karanfil, A., Randa-Zelyüt, F. and Korkmaz, S. (2023). Population structure and genetic diversity of tobacco mild green mosaic virus variants in Western Anatolia of Turkey. *Physiological and Molecular Plant Pathology*, 125: 102008.

Kimaru, S. L., Kilalo, D. C., Muiru, W. M., Kimenju, J. W. and Thuku, C. R. (2020). Molecular detection of cucumber mosaic virus and tobacco mosaic virus infecting African Nightshades (*Solanum scabrum* Miller). *International Journal of Agronomy*, 2020: 8864499, 1-7.

King, A.M., Lefkowitz, E., Adams, M. J. and Carstens, E. B. (2012). Virus Taxonomy: Ninth Report of the International Committee on Taxonomy of Viruses, Elsevier, 9.

Letunic, I. and Bork, P. (2021). Interactive Tree of Life (iTOL) v5: an online tool for phylogenetic tree display and annotation. *Nucleic Acids Research*, 49(W1): W293–W296.

Li, R., Mock, R., Huang, Q., Abad, J., Hartung, J. and Kinard, G. (2008). A reliable and inexpensive method of nucleicacid extraction for the PCR-based detection of diverse plant pathogens. *Journal of Virological Methods*, 154(1-2): 48–55.

Luria, N., Smith, E., Reingold, V., Bekelman, I., Lapidot, M., Levin, I., Elad, N., Tam, Y., Sela, N., Abu-Ras, A., Ezra, N., Haberman, A., Yitzhak, L., Lachman, O. and Dombrovsky, A. (2017). A new Israeli Tobamovirus isolate infects tomato plants harboring Tm-22 resistance genes. *PLOS ONE*, 12(1): e0170429.

Malpica, J. M., Fraile, A., Moreno, I., Obies, C. I., Drake, J. W. and García-Arenal, F. (2002). The rate and character of spontaneous mutation in an RNA virus. *Genetics*, 162(4): 1505-1511.

Melcher, U., Lewandowski D. J. and Dawson, W. O. (2021). Tobamoviruses (Virgaviridae), Elsevier, 734-742, Amsterdam, The Netherlands.

Muhire, B. M., Varsani, A. and Martin, D. P. (2014). SDT: A Virus Classification Tool Based on Pairwise Sequence Alignment and Identity Calculation. *PLoS ONE*, 9(9): e108277.

Nichol, S. (1996). Life on the edge of catastrophe. *Nature*, 384: 218–219.

Okada, Y. (1999). Historical overview of research on the tobacco mosaic virus genome: genome organization, infectivity and gene manipulation. *Philosophical Transactions of The Royal Society of London, Series B, Biological Sciences*, 29; 354(1383): 569-82.

Randa-Zelyüt, F., Santosa, A. I. and Karanfil, A. (2022). 'Candidatus Phytoplasma solani' (Subgroup 16SrXII-A) Associated with *Nicotiana tabacum* leaf abnormality in Turkey. *Journal of Tekirdag Agricultural Faculty*, 19(3): 571-581.

Sacristán, S, Díaz, M., Fraile, A. and García-Arenal, F. (2011). Contact transmission of Tobacco mosaic virus: a quantitative analysis of parameters relevant for virus evolution. *Journal of Virology*, 85(10): 4974-81.

Sanjuán, R., Agudelo-Romero, P. and Elena, S. F. (2009). Upper-limit mutation rate estimation for a plant RNA virus. *Biology Letters*, 5(3): 394-396.

Sanjuán, R., Nebot, M. R., Chirico, N., Mansky, L. M. and Belshaw, R. (2010). Viral mutation rates. *Journal of Virology*, 84(19): 9733-9748.

Skotnicki, M. L., MacKenzie, A. M., Ding, S. W., Mo, J. Q. and Gibbs, A. J. (1993). RNA hybrid mismatch polymorphisms in Australian populations of turnip yellow mosaic tymovirus. *Archives of Virology*, 132: 83–99.

Smith, E. and Dombrovsky, A. (2020). Aspects in Tobamovirus Management in Intensive Agriculture. Eds: Snježana Topolovec-Pintarić, IntechOpen, Zagreb, Crotia. https://doi.org/10.5772/intechopen.87101

Tamura, K., Stecher, G. and Kumar, S. (2021). MEGA11: Molecular evolutionary genetics analysis version 11. *Molecular Biology and Evolution*, 25;38(7): 3022-3027.

Tamura, T. (1992). Estimation of the number of nucleotide substitutions when there are strong 631 transition-transversion and G + C-content biases. *Molecular Biology and Evolution*, 9: 678–687.

TURKSTAT (2023). https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr (Accessed Date: 20 September 2023)

Zaitlin, M. (1999). Elucidation of the genome organization of tobacco mosaic virus. Evolution and origins of tobamoviruses. *Philosophical Transactions of the Royal Society of London. Series B*, 354: 587-591.

Zamfir, A. D., Babalola, B. M., Fraile, A., McLeish, M. and Garcia-Arenal, F. (2023). Tobamoviruses show broad host ranges and little genetic diversity among four habitat types of a heterogeneous ecosystem. *Phytopathology*, 113(9): 1697-1707.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Modeling the Rehydration Behavior of Oven and Vacuum Oven Dried Shrimp at Different Rehydration Temperatures and Determination of Quality Parameters

Farklı Rehidrasyon Sıcaklıklarında Etüv ve Vakumlu Etüvde Kurutulmuş Karideslerin Rehidrasyon Davranışının Modellenmesi ve Kalite Parametrelerinin Belirlenmesi

Ali Can ERŞAN[1], Azmi Seyhun KIPÇAK[2], Nurcan TUĞRUL[3*]

Abstract

In this study, shrimps dried by oven (OD) and vacuum oven (VOD) in the previous study, were rehydrated at temperatures of 30, 40 and 50°C and the kinetics of rehydration during this time were examined and curves are modeled. In rehydration kinetic studies, rehydration contents, rehydration rates, moisture ratio and effective moisture diffusions were calculated. Modeling was done based on Peleg and Two-Term mathematical models from the obtained rehydration curve data, and the results were evaluated statistically using the reduced chi-square (χ^2), coefficient of determination (R^2) and root mean square error (RMSE) definitions. Color measurements were chosen as quality parameter analysis and interpretations were made based on the total color changes. When the results were examined, it was observed that all samples reached equilibrium in the 180 and 150 minutes in oven drying and vacuum-oven drying, respectively and the sample with the highest rehydration value was observed in the one dried at 80°C in a vacuum-oven drying and rehydrated at 50°C. Since the drying time of the samples dried in the vacuum oven was shorter, their pores were less narrowed and thus they experienced more rehydration. It was observed that the samples were rehydrated more as the rehydration temperature increased. Since the rehydration rate, moisture content and effective moisture diffusivity values are in parallel with the rehydration contents the same increase occurred at these parameters. Looking at the mathematical modeling results, the Peleg model gave better results in samples rehydrated at 30 and 40°C, and the Two-Term model gave better results in samples rehydrated at 50°C. From the total color changes as expected vacuum-dried shrimps total color changes were less than the oven-dried shrimps and the color changes increased as the rehydration temperature increases due to the increase in the lightness values.

Keywords: Shrimp, Effective moisture diffusivity, Rehydration ratio, Seafood, Rehydration kinetics

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Öz

Bu çalışmada, önceki çalışmada etüv (EK) ve vakumlu etüvde (VEK) kurutulan karidesler 30, 40 ve 50°C sıcaklıklarda rehidrate edilmiş ve bu süre zarfındaki rehidrasyonun kinetiği incelenerek eğriler modellenmiştir. Rehidrasyon kinetiği çalışmalarında rehidrasyon içerikleri, rehidrasyon oranları, nem oranı ve etkili nem difüzyonları hesaplanmıştır. Elde edilen rehidrasyon verilerinden Peleg ve İki parametreli matematiksel modelleri baz alınarak modelleme yapılmış ve sonuçlar indirgenmiş ki-kare ($\chi 2$), belirleme katsayısı (R2) ve ortalama kare hatası (RMSE) kullanılarak istatistiksel olarak değerlendirilmiştir. Kalite parametre analizi olarak renk ölçümleri seçilmiş ve toplam renk değişimlerine göre yorumlar yapılmıştır. Sonuçlar incelendiğinde tüm numunelerin etüvde kurutmada ve vakumlu etüvde kurutmada sırasıyla 180 ve 150 dakikada dengeye ulaştığı ve vakum etüvünde kurutulup rehidrate edilen numunelerin daha fazla rehidrasyon değerine ulaştıkları görülmüştür. En yüksek rehidrasyon değerine sahip numunenin ise 80°C'de vakum etüvünde kurutulan ve 50 °C'de rehidrate edilen numunede olduğu ortaya çıkmıştır. Vakumlu etüvde kurutulan numunelerin kuruma süresi daha kısa olduğundan gözenekleri daha az daraldığı için rehidrasyon değerlerinde beklendiği üzere artış meydana gelmiştir. Rehidrasyon sıcaklığı arttıkça numunelerin daha fazla rehidrate edildiği gözlenmiştir. Rehidrasyon oranı, nem içeriği ve efektif nem yayılım değerleri rehidrasyon içerikleri ile paralel olduğundan bu parametrelerde de benzer miktarlarda artış meydana gelmiştir. Matematiksel modelleme sonuçlarına bakıldığında Peleg modelinin 30 ve 40°C'de rehidrate edilen numunelerde, iki parametreli modelinin ise 50°C'de rehidrate edilen numunelerde daha iyi sonuçlar verdiği ortaya çıkmıştır. Renk analizlerinde toplam renk değişimlerinden vakumla kurutulan karideslerde beklendiği gibi toplam renk değişimi fırında kurutulan karideslere göre daha az olarak ortaya çıkmış ve rehidrasyon sıcaklığı arttıkça açıklık değerlerinin artmasına bağlı olarak renk değişimleri de artmıştır.

Anahtar Kelimeler: Karides, Etkili nem yayılımı, Rehidrasyon oranı, Deniz Ürünleri, Rehidrasyon kinetiği

1. Introduction

Shrimp is one of the popular commercial seafood due to its flavor and nutritional value. Global Seafood Alliance indicates that world's farmed shrimp production in 2023 is expected to be at around 5.6 million metric tons (Gautam et al., 2021; Li et al., 2019; GSA, 2023). It contains high amounts of nutrients such as protein, free amino acids, calcium, and vitamins (Gao et al., 2023; Azizpour et al., 2016). High moisture and protein content cause shrimp to spoil quickly. For this reason, it must be preserved with the most appropriate method immediately after harvest (Murali et al., 2021; Abedini et al., 2022). Shrimps can be stored into dried, frozen, boiled, and fried forms. Storage conditions like time and temperature, would affect dried products quality and cause many complicated reactions (Wang et al., 2024; Zhang et al., 2020).

Drying is the most used food preservation method and is suitable to a many kind of seafood like shrimps. Several drying methods like conventional drying, infrared drying, microwave drying, solar drying, freeze drying are applied to prolong the shelf life of seafoods. Drying process reduce the post-harvest loss, the moisture level to prevent microbial growth, retard enzymatic reactions causing spoilage of food and increase the shelf-life (Akonor et al., 2016; Murali et al., 2023; Nanan et al., 2023). Between drying methods, hot air drying is one of the most frequently used methods because of the low investment cost and basic drying (Wang et al., 2023). Rehydration means to moistening of dried matter. It is a crucial determinative point in choosing the storage processes and processing. Dried foods need to be rehydrated before eating because the nutritional properties are influenced by dehydration followed by rehydration. One of the important properties of products that are dried is rehydration. Dried food is moistened, restoring their original structure and taste. Morphological structure, chemical composition, drying process, dipping medium, temperature and time are factors affected rehydration (Kumar et al., 2020; Nayi et al., 2023; Wang et al., 2016). Drying is a complicated process described by interactions of contemporaneous heat and mass transfer. Food product attitude through drying is determined from the drying kinetics analyses. To define and optimize the drying process several mathematical models have been used in the literature (Nayi et al., 2023; Ersan and Tugrul, 2021).

There are lots of study about food drying, but there are few studies about shrimp drying. Ultrasound assisted rehydration study was conducted by Riyanto et al. (2023) on sea cucumber also Jiang et al. (2022) examined hot air drying process of sea cucumber. Aktas et al. (2013) studied effects of different drying methods on drying kinetics and color parameters of strawberry tree (*Arbutus unedo* L.) fruit. Ozyalcin and Kipcak (2023) studied rehydration kinetics and characteristics of mussels with traditionally drying. Achaglinkame et al. (2020) studied the sensory and rehydration features on the freeze-dried snails. Arslan et al. (2020) infrared drying kinetics and color qualities of organic and conventional sweet red peppers. Seabass drying kinetics and mathematical modelling are studied by Ozyalcin et al. (2023). Lin et al. (2022) studied the drying of Pacific white shrimps by microwave method by applying salting pre-treatment. Alfiya et al. (2022) studied shrimps drying by solar and microwave drying technologies. In this study, oven (OD) and vacuum oven dried (VOD) shrimps were rehydrated at 30, 40 and 50°C, rehydration kinetics are examined, and curves are modeled. It was seen that vacuum-oven dried samples gave better results than the oven dried samples at all rehydration temperatures.

2. Materials and Methods

2.1. Samples and equipment

In a previous study, Ersan and Tugrul (2021) examined the characteristic drying kinetics and behavior of shrimps dried in a conventional oven and a vacuum oven. Products dried in OD and VOD at 60, 70 and 80°C are rehydrated in this study.

2.2. Experimental method

Rehydration experiments were carried out with 4.8 ± 0.05 grams of dried products in both methods. In the experimental procedure, dried products were put in distilled water beakers (1:100 (weight dried sample: volume water)). Rehydration temperatures were determined as 30, 40 and 50°C. Hot Plate with Magnetic Stirrer was used to heat the beaker at 300 rpm. Every 30-minute, rehydrated products were taken from the beaker and water on the shrimp surface were dried ordinary filter paper. Then weighted with a digital balance until reaching the equilibrium rehydration content.

2.3. Rehydration content and rehydration rate calculations

Rehydration rates and contents are the most important properties for dried food where rrehydration contents (kg water / kg dry matter) were calculated using equation (1). By using equation (2), rehydration rate (R_R) (kg water / kg dry matter . s), which is the rehydration contents per unit time in the product were determined (Kipcak et al., 2014. Sevim et al., 2019):

$$R_c = \frac{w_r - w_d}{w_d} \quad \text{(Eq. 1)}$$

$$R_R = \frac{R_{c\,(\Delta t+t)} - R_{c\,(t)}}{\Delta t} \quad \text{(Eq. 2)}$$

2.4. Diffusion of water inside shrimps

In rehydration kinetic studies in the literature, it is assumed that water is transported through a matrix from the center to the surface by simple mass transport (diffusion with constant spread) (Benseddik et al., 2019). Therefore, the concentration gradient is expressed by water content and directly affects mass transfer. The ratio of moisture (MR) (dimensionless) can be reported as a formula given below (Kipcak and Ismail, 2021):

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \text{(Eq. 3)}$$

The solution of Fick's second law by analytical means comes with the assumptions given in Ersan and Tugrul (2021), Kipcak and Ismail (2018) and by using cylindrical coordinates equation (4) obtained as:

$$MR = \frac{8}{\pi^2}\left[\sum_{n=1}^{\infty} \frac{4}{a^2\, a_n^2} exp\, \frac{K a^2 a_n^2\, t}{\pi^2}\right]\left[\sum_{\mathrm{n=0}}^{\infty} \frac{4}{(2n+1)^2} \exp\left[-\mathrm{K}(2\mathrm{n}+1)^2 t \left(\frac{\mathrm{a}}{l}\right)^2\right]\right] \quad \text{(Eq. 4)}$$

The first terms of the equations are neglected as they do not affect the results, so equation (4) can be written as equation (5):

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \frac{D_{eff} \times \pi^2}{a^2} \times \left(\frac{a}{l}\right)^2 \times t \quad \text{(Eq. 5)}$$

From the curve of ln(MR) versus t graph, , Effective Moisture Diffusion Coefficient (D_{eff}) can be calculated by using the slope.

2.5. Evaluation of the mathematical modelling

Peleg model (PM) and Two-Term model (TTM) equations (Equations 6–7) of were used on the experimental data, respectively (Kipcak, 2017; Demirhan and Ozbek, 2011)

$$\mathrm{MR} = \mathrm{a} + \mathrm{t}/(k_1 + k_2 \times \mathrm{t}) \quad \text{(Eq. 6)}$$

$$\mathrm{MR} = \mathrm{a} \times \exp(k_0 \times \mathrm{t}) + \mathrm{b} \times \exp(k_1 \times \mathrm{t}) \quad \text{(Eq. 7)}$$

The computer software used for modelling calculations nonlinear regressions based on the Levenberg-Marquardt algorithm (Statistica 6.0; Statsoft Inc., Tulsa, OK). The best model was determined by using statistical analyses of; reduced chi-square (χ^2), coefficient of determination (R^2) and root mean square error (RMSE) (equations (8-10)) (Kipcak et al., 2014; Benseddik et al., 2019):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(RR_{exp,i} - RR_{pre,i})^2}{\sum_{i=1}^{N}\left(\frac{RR_{exp,i}}{\frac{\sum_{i=1}^{N} RR_{exp,i}}{N}} - RR_{exp,i}\right)^2} \quad \text{(Eq. 8)}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(RR_{exp,i} - RR_{pre,i})^2}{N-n} \quad \text{(Eq. 9)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(RR_{exp,i} - RR_{pre,i})^2}{N}} \quad \text{(Eq. 10)}$$

From the values of R^2, χ^2 and RMSE most appropriate model were chosen (Kipcak et al., 2019; Kipcak and Doymaz, 2020; Kipcak and Ismail, 2021).

2.6. Color measurement

For aquatic products that has been dried and rehydrated, its color is the most important criterion for the consumer in terms of the quality of the product. The L parameter refers to the darkness or measurable value of the Hunter color policy product (0 for black, 100 for white). The parameter a refers to the redness and greenness values of the products, and the parameter b refers to the yellowness and blueness values of the products. To determine these color parameters, a colorimeter device was used before and after the rehydration processes. Before the color analysis for each product, the device was calibrated with a calibration kit. Color measurements were recorded for shrimp rehydrated at different temperatures in both methods. The total variation in color (ΔE) of rehydrated products was calculated using Equation (11) (Kipcak et al., 2014).

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad \text{(Eq. 11)}$$

where L_o, a_o and b_o are the color values of dried samples. L, a and b color parameters of samples were measured from five points of every sample just after rehydration processes.

3. Results and Discussion

3.1. Rehydration curves

Figure 1 shows the rehydration ratio and R_R curves after rehydration of shrimps dried by two different methods. It can be seen from the obtained rehydration ratio curve that all rehydrated products reach equilibrium in 180 and 150 min at OD and VOD, respectively. In both methods, rehydration rates increase as the drying and rehydration temperature increase. The reason for increasing the rehydration rate as increasing the temperature of drying can be due by the decreasing drying times, which achieved at high temperatures and therefore the decrease in the collapse of the pores of the shrimps. In addition, since drying times are shorter in a vacuum oven than in an oven, the rehydration rates are expected to increase more.

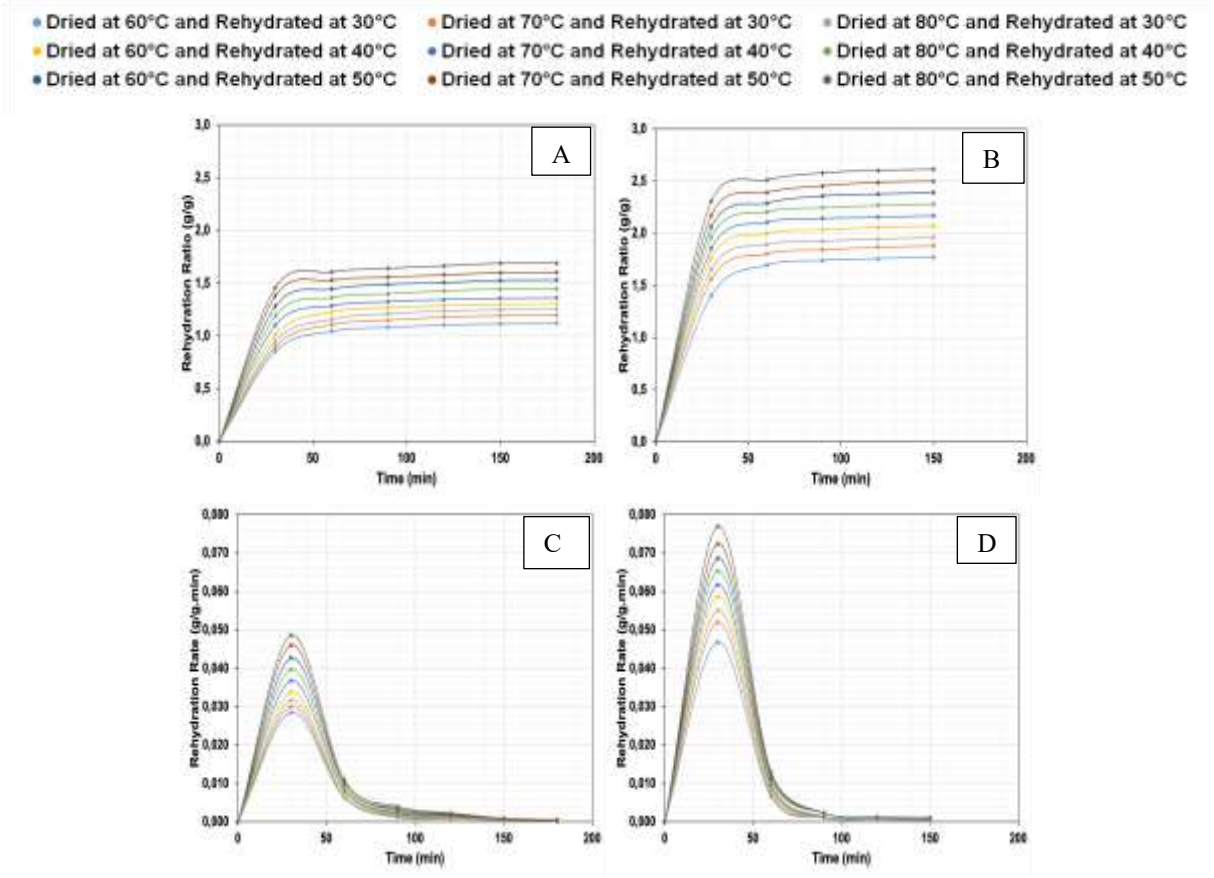

Figure 1. $R_C/R_{C,0}$ plots of A. OD shrimp, B. VOD shrimp, and R_R plots of C. OD shrimp, D. VOD shrimp

The maximum rehydration ratio was acquired for products 80°C dried and 50°C rehydrated. Rehydration ratios for OD and VOD methods were obtained as 1.6901 g/g and 2.6135 g/g, respectively. Minimum rehydration ratio were procured at products 60°C dried and 30°C rehydrated. Rehydration ratios for OD and VOD methods were obtained as 0.8525 g/g and 1.4038 g/g, respectively. Maximum R_R appear on the R_R curve (peak values) between 0 and 30 minutes. This area can be named the increasing R_R period region. The period among 30 and 180 minutes can be named the decreasing R_R period. For OD and VOD methods, the values of maximum acquired in the products 80°C dried and 50°C rehydrated are calculated as 0.0486 and 0.0769 g/g.min, respectively. The lowest peak values were determined as 0.0285 and 0.0468 g/g.min for the products 60°C dried and 30°C rehydrated, respectively.

3.2. Diffusion mass transfer coefficient results

For comparison and calculation of D_{eff} values, sample graphs of ln (MR) versus time and versus D_{eff} are given in *Figure 2*, respectively. In *Table 1*, the slope obtained from the plot of ln (MR) versus t and the calculated D_{eff} values are given. D_{eff} values are estimated in the range of 1.3-1.43×10^{-8} m^2/s, 1.54-1.63×10^{-8} m^2/s, for OD and VOD, respectively. It is seen that D_{eff} values increase as the rehydration rate increases. Higher D_{eff} values are obtained in the vacuum oven method compared to the drying oven method as expected from the data presented in *Figure 1*.

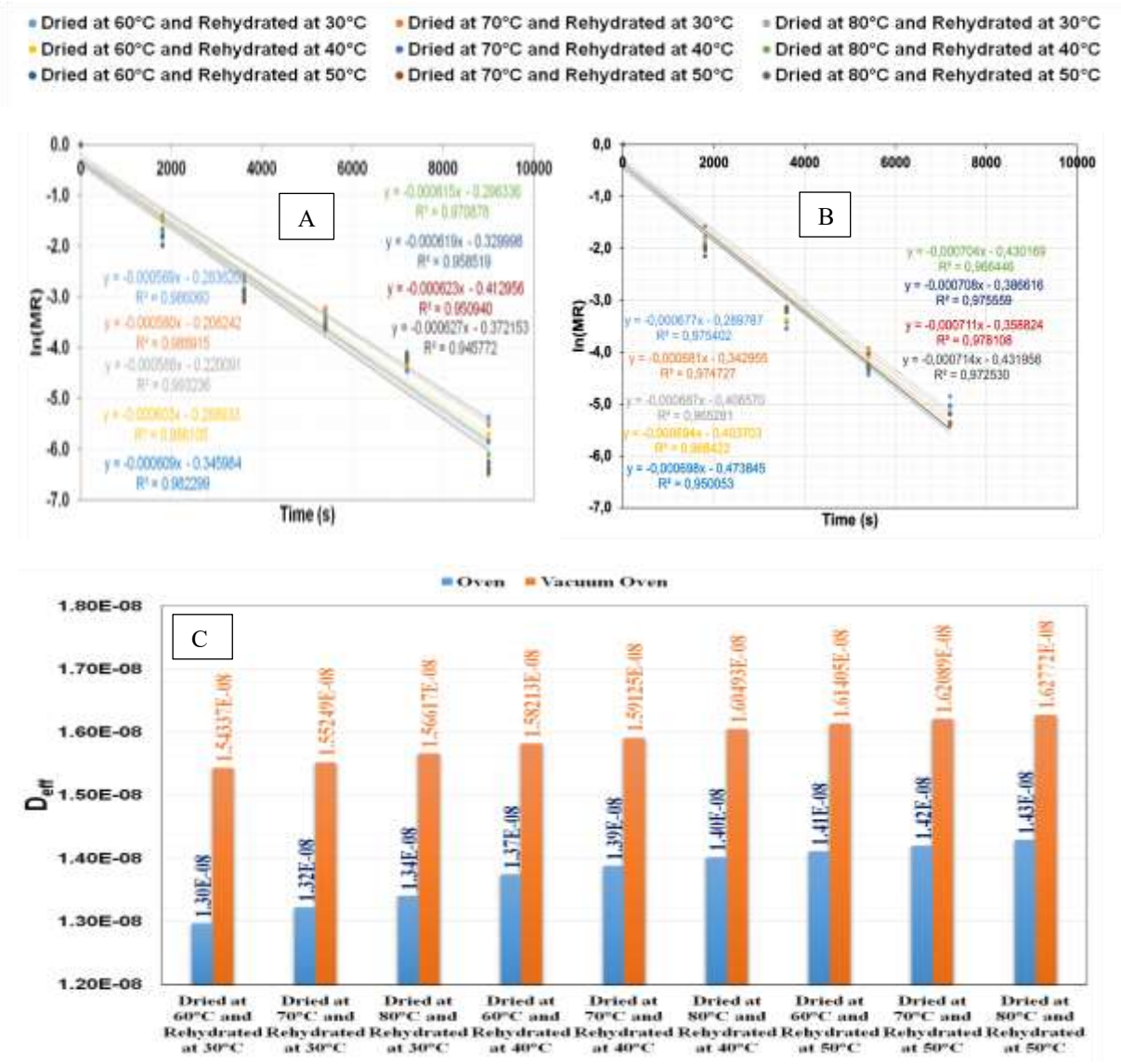

Figure 2. Logarithmic form of moisture ratio against time plot of D_{eff} for a. OD shrimp, b. VOD shrimp and c. D_{eff} versus dried and rehydrated temperatures bar graph

Table 1. Effective moisture diffusivities

	OD		VOD	
	Slope	**D_{eff} (m^2/s)**	**Slope**	**D_{eff} (m^2/s)**
Dried @ 60°C & Rehydrated @ 30°C	-0.000569	1.3×10^{-8}	-0.000677	1.54×10^{-8}
Dried @ 70°C & Rehydrated @ 30°C	-0.000580	1.32×10^{-8}	-0.000681	1.55×10^{-8}
Dried @ 80°C & Rehydrated @ 30°C	-0.000588	1.34×10^{-8}	-0.000687	1.57×10^{-8}
Dried @ 60°C & Rehydrated @ 40°C	-0.000603	1.37×10^{-8}	-0.000694	1.58×10^{-8}
Dried @ 70°C & Rehydrated @ 40°C	-0.000609	1.39×10^{-8}	-0.000698	1.59×10^{-8}
Dried @ 80°C & Rehydrated @ 40°C	-0.000615	1.40×10^{-8}	-0.000704	1.60×10^{-8}
Dried @ 60°C & Rehydrated @ 50°C	-0.000619	1.41×10^{-8}	-0.000708	1.61×10^{-8}
Dried @ 70°C & Rehydrated @ 50°C	-0.000623	1.42×10^{-8}	-0.000711	1.62×10^{-8}
Dried @ 80°C & Rehydrated @ 50°C	-0.000627	1.43×10^{-8}	-0.000714	1.63×10^{-8}

3.3. Mathematical modelling results

As a result of the calculations, it was seen that the PM and TTM determined among the mathematical models were compatible with the experimental rehydration rate values. *Table 2* demonstrate that, the experimental data were appropriate good with the R^2 values higher than 0.99. Among the models TTM were fitted better than PM. For the product by 80°C OD and 30°C rehydrated, the highest R^2 and lowest χ^2 and RMSE values were calculated according to the PM with values of 0.998672, 0.0004 & 0.0154, respectively. For the product by 80°C VOD and 30°C rehydrated the highest R^2 and lowest χ^2 & RMSE are found by TTM with the values of 0.99999, 0.000010 & 0.000009.

For product by 80°C OD and 40°C rehydrated the highest R^2 and lowest c^2 and RMSE values are calculated by TTM with the values of 0.999926, 0.0002 & 0.0099, respectively. For the product by 80°C VOD and 30°C rehydrated, the highest R^2 and lowest c^2 and RMSE values are found by TTM with the values of 0.999999, 0.000002 & 0.0008. For the product by 80°C OD and 50°C rehydrated, the highest R^2 and lowest χ^2 and RMSE values are found by TTM with the values of 0.999929, 0.000055 & 0.0048, respectively. For the product by 80°C VOD and 50°C rehydrated at the highest R^2 and lowest χ^2 and RMSE values are found by TTM with the values of 0.99992, 0.000143 & 0.0078. Calculated R_R and experimental R_R are shown in *Figure 3* and *Figure 4* for both methods. The plots obtained are on the 45° meaning that the models were fitted very good to the experimental data obtained.

3.4. Color Values

L, a and b values of rehydrated products are given in *Table 3* gives. L value changes relate to decreasing rehydration temperatures for the OD and VOD. L values change between 31.10 and 33.99, 34.78 and 36.01, 38.43 and 40.03 for the OD 30 °C, 40 °C and 50 °C, respectively. The highest and the lowest redness values attained in the OD 30 °C and VOD 50 °C, respectively. Redness values, a, for the oven method changed between 0.98 and 0.76 and for the VOD method between-3.21 and-3.76. The highest and the lowest yellowness values for b were obtained in VOD 50 °C and OD 30 °C, respectively. Yellowness values, b, for VOD 30 °C changed between 3.31 and 3.95 and for the OD 30 °C between -4.16 and -4.62.

As expected, the total color change in VOD shrimp was less than that in OD shrimp, and as the rehydration temperature increased, the color changes increased due to the increase in lightness values.

4. Conclusions

Shrimps dried by oven and vacuum oven were rehydrated at the temperatures between 30-50°C. Kinetic studies; rehydration contents, rehydration rates, moisture ratio and effective moisture diffusions were evaluated and from the effective moisture diffusions curve Modeling was done based on Peleg and Two-Term mathematical models. Best model was selected statistically using R^2, χ^2) and RMSE. Quality analysis of color measurements were applied and interpretations were made based on the total color changes. From the results obtained in this study it is seen that the rehydration experiments were finished at 180 and 150 min at OD and VOD, respectively. The highest and the lowest rehydration rates were observed in the samples of 80°C vacuum-oven dried and rehydrated at 50°C and 60°C oven-dried and rehydrated at 30°C. Vacuum-dried samples leads to take more

Table 2. Model coefficients and statistical data

Rehyd. Temp. (°C)	Model	Parameter	OD			VOD		
			Temp. (°C)			Temp. (°C)		
			60	70	80	60	70	80
30	Peleg	R^2	0.998364	0.998533	0.998672	0.998024	0.999109	0.999125
		RMSE	0.015302	0.0154	0.0154	0.026157	0.0187	0.0193
		χ^2	0.000410	0.0004	0.0004	0.001197	0.0006	0.0007
		a	-0.000617	-0.000698	-0.000685	-0.000748	-0.000346	-0.000299
		k_1	9.468.547	9.450.920	8.854.537	5.304.961	3.997.953	3.478.465
		k_2	0.827416	0.772380	0.737940	0.520963	0.500106	0.482224
	Two-Term	R^2	0.949421	0.952001	0.951923	0.994143	0.997547	0.99999
		RMSE	0.085087	0.0883	0.0926	0.045031	0.0310	0.0021
		χ^2	0.016893	0.018184	0.020019	0.004732	0.002241	0.000010
		a	156.040	443.635	382.176	-207.826	-191.753	-190.261
		k_0	0.009	0.0087	0.0086	0.03594	0.05027	0.06621
		b	-155.974	-442.946	-381.450	210.093	192.775	190.256
		k_1	0.009	0.0093	0.0095	0.00132	0.00028	-0.00019
40	Peleg	R^2	0.998255	0.999140	0.999589	0.999335	0.999094	0.999429
		RMSE	0.018432	0.0135	0.0099	0.017817	0.0219	0.0182
		χ^2	0.000595	0.0003	0.0002	0.000556	0.000836	0.000582
		a	-0.000661	-0.000339	-0.000205	-0.000249	-0.000290	-0.000224
		k_1	7.555.117	5.988.077	5.281.367	3.131.028	2.883.560	2.650.427
		k_2	0.714010	0.694083	0.657530	0.458421	0.437431	0.417196
	Two-Term	R^2	0.947413	0.978440	0.999926	0.999994	0.999995	0.999999
		RMSE	0.101195	0.0677	0.0042	0.001711	0.0016	0.0008
		χ^2	0.023894	0.010683	0.000041	0.000007	0.000006	0.000002
		a	486.930	160.714	136.055	-199.913	-212.092	-220.802
		k_0	0.009	0.00122	-0.00036	0.06875	0.06783	0.07095
		b	-486.852	-156.612	-136.050	199.911	212.089	220.802
		k_1	0.009	0.03215	0.06607	-0.00023	-212.092	-0.00022
50	Peleg	R^2	0.999741	0.999899	0.999899	0.99974	0.99991	0.999927
		RMSE	0.008324	0.0057	0.0057	0.012869	0.0080	0.0074
		χ^2	0.000121	0.0001	0.0000	0.000290	0.000113	0.000097
		a	-0.000146	-0.000052	-0.000052	-0.000158	-0.000087	-0.000061
		k_1	4.529.770	3.373.687	3.373.687	2.536.293	2.275.392	1.919.479
		k_2	0.624671	0.571313	0.571313	0.398597	0.383182	0.368116
	Two-Term	R^2	0.999927	0.999952	0.999929	0.999934	0.999937	0.99992
		RMSE	0.004412	0.0038	0.0048	0.006480	0.0066	0.0078
		χ^2	0.000045	0.000033	0.000055	0.000098	0.000102	0.000143
		a	144.137	151.564	158.880	-228.425	-236.463	-248.687
		k_0	-0.00035	-0.00033	-0.00037	0.07367	0.07868	0.08280
		b	-144.129	-151.562	-158.876	228.435	236.471	248.695
		k_1	0.06972	0.07688	0.07871	-0.00031	-0.00039	-0.00035

moisture and rehydration temperatures also increased the rehydration capacity. The effective moisture diffusivities are obtained between 1.3- 1.43×10^{-8} m^2/s and 1.54- 1.63×10^{-8} m^2/s for the vacuum and oven dried samples respectively at the rehydration temperatures between 30-50°C. From the modelling at 30 and 40°C Peleg model gave the best results with the R^2 values between 0.998024 and 0.999125, respectively. And at 50°C Two-Term model gave the best results with the R^2 values between 0.999920 and 0.999952. For the quality analysis of total

color change values, oven-dried samples total color changes (5.38 - 9.91) were higher than the vacuum-oven dried samples (2.70 - 9.46). As a result, for the quality analysis and maximum rehydration values vacuum-oven dried samples gave better results the oven dried samples at all rehydration temperatures.

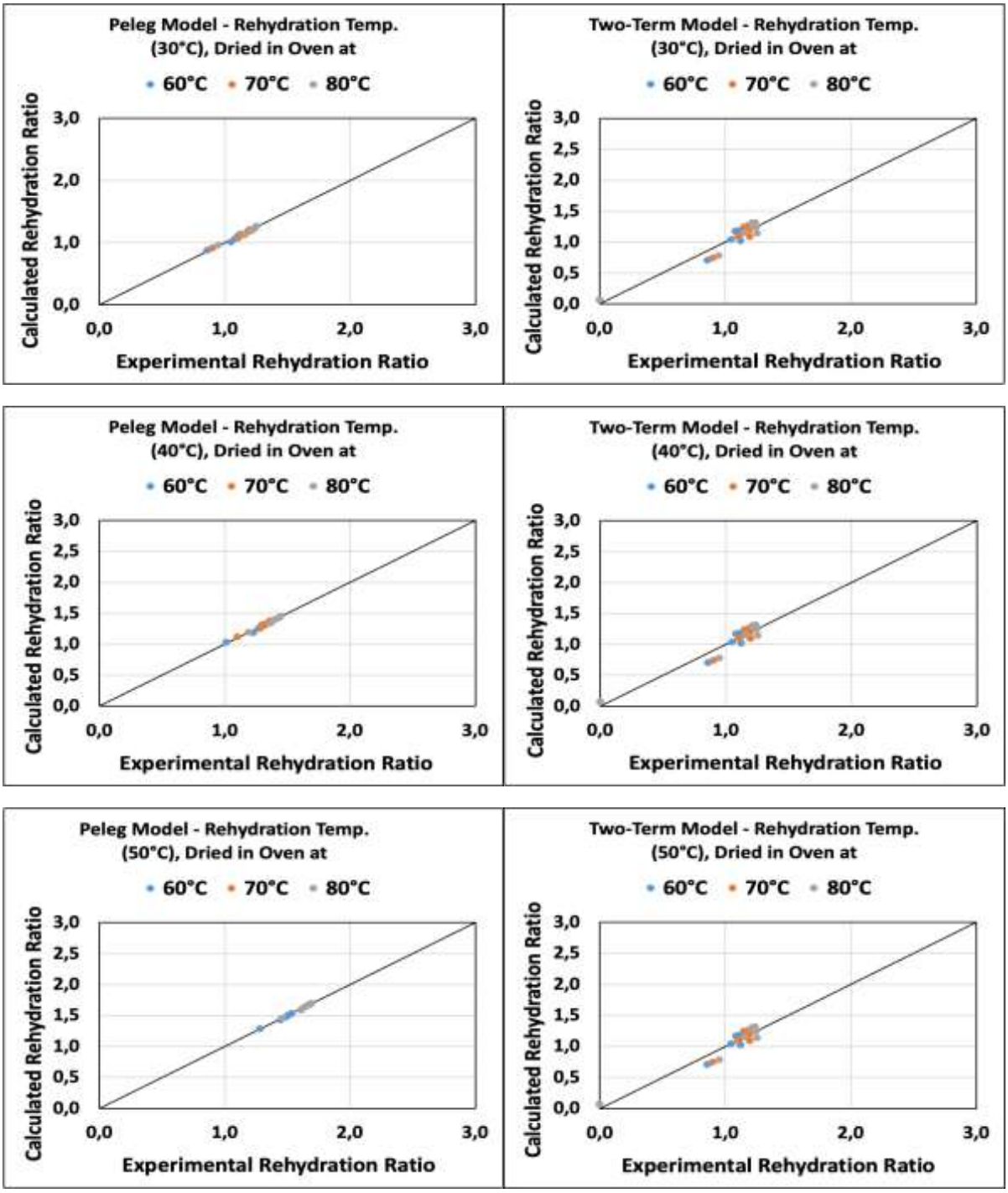

Figure 3. Exp. and calc. $R_C/R_{C,0}$ values obtained from the PM and TTM for OD shrimp

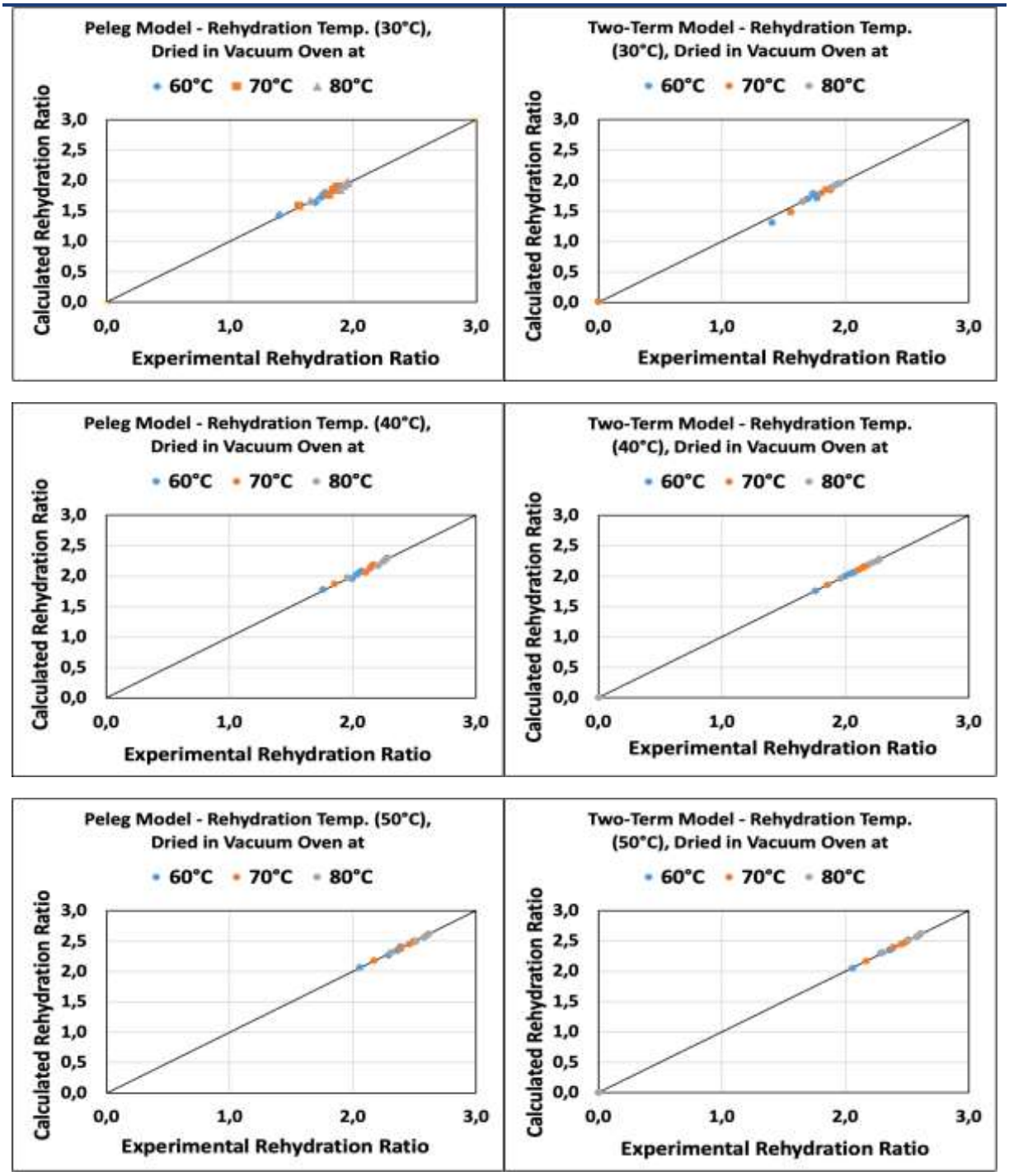

Figure 4. Exp. and calc. $R_C/R_{C,0}$ values obtained from the PM and TTM for VOD shrimp

Table 3. Color values of rehydrated shrimp different temperatures with OD and VOD

	L	a	b	
Dried Sample Oven 30°C	25.76	1.49	-4.98	
		Oven 30°C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	31.10	0.98	-4.62	5.38
70	32.31	0.89	-4.5	6.59
80	33.99	0.76	-4.16	8.30
	L	**a**	**b**	
Dried Sample Oven 40°C	27.59	0.56	-3.8	
		Oven 40°C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	34.78	-0.4	-3.61	7.26
70	35.69	-0.53	-2.99	8.21
80	36.01	-0.94	-2.72	8.62
	L	**a**	**b**	
Dried Sample Oven 50°C	30.4	0.21	-2.63	
		Oven 50°C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	38.43	-1.08	-1.93	8.16
70	39.02	-1.17	-1.57	8.79
80	40.03	-1.39	-0.91	9.91
	L	**a**	**b**	
Dried Sample Vacuum Oven 30°C	39.12	-1.25	-0.78	
		Vacuum-Oven 30 °C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	41.75	-1.76	-0.44	2.70
70	42.56	-2.1	-0.6	3.55
80	44.57	-2.29	0.68	5.74
	L	**a**	**b**	
Dried Sample Vacuum Oven 40°C	43.67	-1.96	1.35	
		Vacuum-Oven 40 °C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	47.22	-2.55	1.58	3.61
70	49.59	-2.82	2.18	6.04
80	50.34	-3.13	3.01	6.97
	L	**a**	**b**	
Dried Sample Vacuum Oven 50°C	46.06	-2.14	2.23	
		Vacuum-Oven 50 °C		
Temperatures (°C)	**L**	**a**	**b**	**ΔE**
60	50.75	-3.21	3.31	4.93
70	53.58	-3.48	3.87	7.81
80	55.25	-3.61	3.95	9.46

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Design: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Data Collection or Processing: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Statistical Analyses: Erşan, A. C., Kıpçak A. S.; Literature Search: Erşan, A. C., Kıpçak A. S., Tuğrul, N.; Writing, Review and Editing: Erşan, A. C., Kıpçak A. S., Tuğrul, N.

References

Abedini, E., Hajebzadeh, H., Mirzai, M. A., Alahdadi, A. A., Ahmadi, H. M., Salehi, M. A. and Zakeri, M. (2022). Evaluation of operational parameters for drying shrimps in a cabinet hybrid dryer. *Solar Energy,* 233: 221-229.

Achaglinkame, M. A., Owusu Mensah, E., Boakye, A. A. and Oduro, I. (2020). Effect of size and drying time on the rehydration and sensory properties of freeze-dried snails (achatina achatina). *International Journal of Food Science,* 2020: 5714140: 1-5.

Aktas, T., Orak, H., Hasturk S. F. and Ekinci, N. (2013). Effects of different drying methods on drying kinetics and color parameters of strawberry tree (arbutus unedo l.) fruit. *Journal of Tekirdag Agricultural Faculty,* 10(2): 1-12.

Akonor, P. T., Ofori, H., Dziedzoave, N. T. and Kortei, N. K. (2016). Drying characteristics and physical and nutritional properties of shrimp meat as affected by different traditional drying techniques. *International Journal of Food Science.,* 2016:7879097: 1-5.

Alfiya, P. V., Rajesh, G. K., Murali, S., Delfiya, A. D. S., Samuel, M. P. and Prince, M. V. (2022). Quality evaluation of solar and microwave dried shrimps – A comparative study on renewable and dielectric heating methods. *Solar Energy*, 246: 234-244.

Arslan, A., Soysal, Y. and Keskin, M. (2021). Infrared drying kinetics and color qualities of organic and conventional sweet red peppers. *Journal of Tekirdag Agricultural Faculty,* 18(2): 260-272.

Azizpour, M., Mohebbi, M. and Khodaparas, M. H. H. (2016). Effects of foam-mat drying temperature on physico-chemical and microstructural properties of shrimp powder. *Innovative Food Science & Emerging Technologies,* 34: 122-126.

Benseddik, A., Azzi, A., Zidoune, M. N., Khanniche, R. and Besombes, C. (2019). Empirical and diffusion models of rehydration process of differently dried pumpkin slices. *Journal of the Saudi Society of Agricultural Sciences,* 18(4): 401–410.

Demirhan, E. and Ozbek, B. (2011). Thin-layer drying characteristics and modeling of celery leaves undergoing microwave treatment. *Chemical Engineering Communications,* 198(7): 957-975.

Ersan, A. C. and Tugrul, N. (2021). The drying kinetics and characteristics of shrimp dried by conventional methods. *Chemical Industry & Chemical Engineering Quarterly,* 27(4): 319−328.

Gao, Y., Qiao, S., Lin, Y., Xie, Y., Ai, Z., Mowafy, S., Li, J. and Li, X. (2023). Effects of high-humidity hot air impingement cooking on physicochemical properties and microstructure of Pacific white shrimp (*Penaeus vannamei*). LWT-Food Science and Technology, 182: 114836.

Gautam, R. K., Kakatkar, A. S., Mishra, P. K., Kumar, V. and Chatterjee, S. (2021). Development of shelf-stable, ready to cook (RTC) intermediate moisture (IM) shrimp and its shelf life extension using hurdle technology. *Journal of Agriculture and Food Research,* 6: 100199.

GSA (2023). Global Seafood Alliance Annual Farmed Shrimp Production Survey. https://www.globalseafood.org/advocate/annual-farmed-shrimp-production-survey-a-slight-decrease-in-production-reduction-in-2023-with-hopes-for-renewed-growth-in-2024/ (Accessed Date: 9.10.2023).

Jiang, P., Jin, W., Liu, Y., Sun, N., Zhu, K., Bao, Z. and Dong, X. (2022). Hot-air drying characteristics of sea cucumber (*Apostichopus japonicus*) and its rehydration properties. *Journal of Food Quality,* 2022: 5147373.

Kipcak, A. S., Ismail, O., Doymaz, I. and Piskin, S. (2014). Modeling and investigation of the rehydration kinetics of acrylamide-sodium acrylate hydrogel. *Journal of Chemistry,* 2014: 281063: 1–8.

Kipcak, A. S. (2017). Microwave drying kinetics of mussels (*Mytilus edulis*). *Research on Chemical Intermediates,* 43: 1429-1445.

Kipcak, A. S. and İsmail, O. (2018). Comparison of the microwave drying kinetics of culture and natural asparagus. *Acta Scientiarum. Technology,* 40(1): e39922.

Kipcak, A. S., Doymaz, İ. and Derun, E. M. (2019). Infrared drying kinetics of blue mussels and physical properties. *Chemical Industry & Chemical Engineering Quarterly,* 25(1): 1-10.

Kipcak, A. S. and Doymaz, İ. (2020). Microwave and infrared drying kinetics and energy consumption of cherry tomatoes. *Chemical Industry & Chemical Engineering Quarterly,* 26(2): 203-212.

Kipcak, A. S., Derun, E. M., Tugrul, N. and Doymaz, İ. (2021). Drying characteristics of blue mussels by traditional methods, *Chemical Industry & Chemical Engineering Quarterly,* 27(3): 279-288.

Kipcak, A. S. and İsmail, O. (2021). Microwave drying of fish, chicken and beef samples. *Journal of Food Science and Technology,* 58(1): 281-291.

Kumar, N., Kachhadiya, S. and Nayi, P. (2020). Storage stability and characterization of biochemical, rehydration and color characteristics of dehydrated sweet corn kernels. *Journal of Stored Products Research,* 87: 101619.

Li, D., Xie, H., Liu, Z., Li, A., Li, J., Liu, B., Liu, X. and Zhou, D. (2019). Shelf life prediction and changes in lipid profiles of dried shrimp (*Penaeus vanname*i) during accelerated storage. *Food Chemistry,* 297: 124951.

Lin, Y., Gao, Y., Li, A., Wang, L., Ai, Z., Xiao, H., Li, J. and Li, X. (2022). Improvement of pacific white shrimp (*Litopenaeus vannamei*) drying characteristics and quality attributes by a combination of salting pretreatment and microwave. *Foods,* 11(14): 2066.

Murali, S., Delfiya, A. D. S., Kumar, S. K., Kumar, L. R. G., Nilavan, E. S., Amulya, P. R., Krishnan, S. V., Alfiya, P. V. and Samuel, M. P. (2021). Mathematical modeling of drying kinetics and quality characteristics of shrimps dried under a solar–lpg hybrid dryer. *Journal of Aquatic Food Product Technology,* 30(5): 561–578.

Nanan, K., Eiamsaard, S., Chokphoemphun, S., Kumar, M., Pimsarn, M. and Chuwattanakul, V. (2023). Influence of bed height and drying temperature on shrimp drying characteristics using a fluidized-bed dryer. *Case Studies in Thermal Engineering,* 48: 103144.

Nayi, P., Kumar, N., Kachchadiya, S., Chen, H. H., Singh, P., Shrestha, P. and Pandiselvam, R. (2023). Rehydration modeling and characterization of dehydrated sweet corn. *Food Science & Nutrition,* 11: 3224–3234.

Ozyalcin, Z. O. and Kipcak, A. S. (2023). Rehydration characteristics and kinetics of traditionally dried mussels at different temperatures. *Sigma Journal of Engineering and Natural Sciences,* 41(4): 858−867.

Ozyalcin, Z. O., Kipcak, A. S. and Tugrul, N. (2023). The effect of various methods on the drying kinetics and mathematical modelling of seabass (dicentrarchus labrax). *Journal of Aquatic Food Product Technology,* 32(4): 384–395.

Riyanto, B., Ramadhan, W. and Moesriffah, R. (2023). Effect of ultrasound assisted rehydration on the quality of dried sea cucumber. *Fisheries and Aquatic Sciences,* 26(9): 535-547.

Sevim, S., Derun, E. M., Tugrul, N., Doymaz, I. and Kipcak, A. S. (2019). Temperature controlled infrared drying kinetics of mussels. *Journal of the Indian Chemical Society,* 96: 1233-1238.

Wang, Y., Yue, J., Liu, Z., Zheng, Y., Deng, Y., Zhao, Y., Liu, Z. and Huang, H. (2016). Impact of far-infrared radiation assisted heat pump drying on moisture distribution and rehydration kinetics of squid fillets during rehydration. *Journal of Aquatic Food Product Technology,* 25(2): 147–155.

Wang, L., Zang, M., Zhao, X., Cheng, X., Li, X. and Bai, J. (2023). Lipid oxidation and free radical formation of shrimp (*Penaeus vannamei*) during hot air drying. *Journal of Food Measurement and Characterization,s* 17: 3493–3504.

Wang, L., Zang, M., Cheng, X., Wang, S., Zhao, X., Zhao, B. and Li, D. (2024). Evaluation of changes in the lipid profiles of dried shrimps (Penaeus vannamei) during accelerated storage based on chemical and lipidomic analysis. LWT-Food Science and Technology, 191: 115564.

Zhang, D., Ji, H., Liu, S. and Gao, J. (2020). Similarity of aroma attributes in hot-air-dried shrimp (*Penaeus vannamei*) and its different parts using sensory analysis and GC–MS. *Food Research International,* 137: 109517.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Understanding the Nexus of Extension Teaching Methods and Adoption of Improved Agricultural Production Technologies: Empirical Evidence from Cowpea Farmers in Kogi State, Nigeria*

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Abstract

This study assessed the nexus of extension teaching methods and the adoption of improved production technologies. A three-staged sampling technique was used in selecting two hundred (200) cowpea farmers. Primary data obtained using the Kobocollect toolbox was analyzed with adoption score/index and ordered probit regression model. Findings from this study showed that 79 % of the respondents were males while 21 % were females. The mean age among cowpea farmers was 49 years. Furthermore, 90.5 % of the respondents adopted the recommended seed rate, 87 % adopted the recommended planting date, and 84.5 % adopted the recommended weeding time. Most (20.5 %) of the respondents had an adoption score and index of 8 and 0.57; while 1.5 % of the cowpea farmers recorded an adoption score and adoption index of 10 and 0.7. Also, 45 % of the cowpea farmers were in the low adoption category, and 27.5 % of each of the sampled cowpea farmers were found in the medium and high adoption category. Individual extension teaching method (β = 1.192), mass extension teaching method (β = -0.189), a combination of individual, group and mass extension teaching methods (β = 0.044), gender (β = -0.124), farming experience (β = -0.019), and income (β = -0.00000276) significantly influenced the extent of adoption of recommended cowpea production practices. The study concluded that individual, and a combination of individual, mass and group extension teaching methods have positive effects on the extent of adoption of recommended cowpea production practices. Amongst others, the study recommended the use of these teaching methods by both private and public extension agents in disseminating information on improved farming practices.

Keywords: Adoption, Cowpea, Extension teaching methods, Kogi State, Probit regression model, Smallholder farmers

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*This study was summarized from Damilola Omojola Shaibu's MSc thesis.

1. Introduction

Nigerian agriculture is dominated by smallholder farmers (FAO, 2018). This characteristic has resulted in low harvest because most farmers cannot access or in some cases, pay for improved farming technologies with its multiplier effect on productivity and income (Ezeh et al., 2012; Uzokwe, 2015). As a result of low harvest and return, the levels of investment in farms have been very low, leading to abject poverty among these farmers (Eze, et al., 2010; Shaibu et al. 2023). Consequently, the improved farming technologies that are needed to increase food production and preservation do not get to smallholder farmers appropriately. The extension officers are mandated to reach out to the farmers to help them in their decision-making. The method used in reaching out to the farmers is as important as the technologies to be disseminated to the farmers.

Rees et al. (2000) and Garforth (2001) argued that agricultural knowledge and information of smallholders are complex, diverse, and vary from area to area, depending on the area's agroecology and agricultural enterprises. Their studies indicated the necessity for a comprehensive investigation of extension teaching methods at agroecological or sub-national levels, even along various agricultural enterprises. There is thus a need to empirically establish the nexus of agricultural extension teaching methods and the adoption of agricultural production technologies with a focus on cowpea farmers.

Farmers are often blamed for poor adoption of extension services because they are averse to change and hold traditional values. Additionally, the successes or failures of extension delivery services are usually measured with respect to the level of adoption without considering the effectiveness of the extension agents (Adejo, et al., 2019) and the method adopted in reaching out to farmers. According to Nwalieji and Nnabueze, (2018); the ability to communicate, the attitude of the extension worker, the frequency of contact with farmers, and field responsibility are the features of an effective extension agent. These conditions, however, depend on how the improved technologies are spread to the farmers. The effectiveness of technology adoption such as improved seeds also depends on effective communication which is critical to information dissemination (Oladele, 1999; Nogay and Azabagaoglu, 2024); for communication to be effective, there must be feedback. The feedback reveals if the communication and the methods used have any effect on the adopters of technologies.

Most studies have focused more on the effectiveness of extension agents and service delivery (Ahmed and Adisa, 2017; Nwalieji and Nnabueze, 2018; Ebenehi and Ahmed, 2019) without particular attention to the effects of the methods used in delivering extension services to the farmers, specifically, cowpea farmers in Kogi State. A good extension method carefully selected especially where the farmers have little to no formal education can motivate the farmers to participate in the extension activities. Obibuaku and Hursh (1994) studied extension message-delivering methods in Nigeria without focusing on the effects of the extension methods on farmers' adoption of innovation. Tenebe and Mundi (2008) attempted to assess the effects of extension teaching methods in Bauchi State, Nigeria, but the findings were based on simple descriptive statistics. Aside from geographical differences, the present study used advanced econometric tools, such as the ordered probit regression model to establish the relationship between extension teaching methods and farmers' extent of adoption of recommended cowpea production practices with an expected influence on increased productivity.

Furthermore, cowpea was chosen in this study due to its significance as an important legume crop in Nigeria and its contribution to the country's economy. Nigeria remains a leading producer of cowpeas in the world with a production of 3.6 million tons in 2021, over 45% of global production (FAOSTAT, 2023). Despite the country's production, Nigeria is still the largest consumer of cowpea grains with significant imports from countries like the Republic of Niger, Chad, and Cameroon (Mohammed et al., 2020). Cowpea farmers in Nigeria reported an average yield of about 600 kg ha^{-1} compared to a recommended yield of 1500-2500 kg ha^{-1} (ICRISAT, 2017).

Cowpea is an important food security crop and contributes to farmers' livelihoods as most of the smallholder farmers depend on this crop for economic and nutritional purposes (Bolarinwa, 2022). The crop is grown for food, vegetables, fodder, green manure, and cover crops, hence, it has implications for farmers' standard of living (Osipitan et al., 2021). According to Nordhagen et al. (2023), cowpea is a major source of protein due to the unaffordability of animal protein sources by the most vulnerable population. The critical role of cowpeas in Nigeria's food security crusade and the country's agri-food system forms part of the essence of this study.

This study aims to assess the nexus of extension teaching methods and the adoption of improved cowpea production technologies in Kogi State, Nigeria. The specific objectives are to:

i. ascertain the extent of adoption of recommended cowpea production practices in the study area;

ii. determine the effects of extension teaching methods on the extent of adoption of recommended cowpea production technologies.

2. Materials and Methods

2.1. Study area

This study area is Kogi State, Nigeria. The State is in North Central, Nigeria and found on latitude $6^0$30'N and $8^0$5'N and longitude $5^0$51'E and $8^0$00'E. The study area has a total population of about 5 million people (using the state projected growth rate of 3%) (NPC, 2006). Kogi State agricultural location has four zones (A, B, C, and D) as delineated by the Kogi State Agricultural Development Project (Kogi ADP) efficient extension administration.

2.2. Population and sampling procedure

The population for this study comprised all the cowpea farmers in Kogi State, Nigeria. The multi-staged sampling technique was used in selecting the respondents (cowpea farmers). In stage one, one (1) extension block was purposively selected from each of the common four agricultural zones in the State. Each block was selected based on the level of cowpea production. This gave four (4) agricultural blocks for the study. The second stage involves the random selection of five (5) extension cells from each block to give twenty (20) extension cells. Stage three involves the random selection of ten (10) cowpea farmers from each cell. A sample size of two hundred (200) respondents was used for the study.

2.3. Data collection

Primary data collected with a semi-structured questionnaire was administered to the respondents using an android-enabled Kobocollect toolbox mobile application. This application enabled accurate data collection from sampled locations and on-the-spot data assessment for relevant correction. Data were collected by the researcher and trained research assistants from the selected agricultural blocks. The research assistants were properly trained on the content of the questionnaire and the use of the Kobocollect toolbox to approach the farmers in their local dialect and apply relevant research ethics. Four (4) research assistants with prior knowledge of the use of the Kobocollect toolbox were carefully selected.

2.3. Data analysis

The data were analysed using descriptive and econometric tools. The extent of adoption of recommended cowpea production technologies by the respondents was determined using the adoption index/score, while the nexus of extension teaching methods and extent of adoption of recommended cowpea production practices was established using the ordered probit regression model.

Following Olumba and Rahji, (2014) and Ajayi et al. (2016), the adoption index was calculated as specified below:

$$AI = \frac{n_{rec}}{N_{rec}} \quad \text{(Eq. 1)}$$

Where n_{rec} = number of recommended cowpea production practices adopted by a particular farmer, and N_{rec} total number of recommended cowpea production practices.

For the adoption score, a cowpea farmer scores one for each recommended practice adopted (Olumba and Rahji, 2014; Ajayi, 2016). Following Agwu (2006), the extent of adoption was obtained from the adoption score as given: high adoption (> 7 score); medium/moderate adoption (score = 4 – 7 score); and low adoption (< 4 score).

The ordered probit model can be generally stated as:

$$Y_i^* = X_i\beta_i + \varepsilon_i \quad \text{(Eq. 2)}$$

Where Y_i* is unobserved. What is observable is:

$$Y = 0 \; if \; Y_i^* \leq 0 \quad \text{(Eq. 3)}$$

$$= 1\ if\ 0 < Y_i^* \leq \mu_1$$

$$= 2\ if\ \mu_i < Y_i^* \leq \mu$$

$$= j\ if\ Y_i^* \geq u_j - 1$$

The observed ordinal variable (dependent variable) takes on values 0– 2, indexing the extent of adoption (high = 2, moderate = 1, low = 0).

β= estimated parameter

Ɛ = error term

Xi = individual farmer's characteristics (these characteristics were selected based on existing studies, theoretical and conceptual frameworks of this study).

X_1 = Individual extension teaching method (1 if used by extension agents, otherwise, 0)
X_2 = group extension teaching method (1 if used by extension agents, otherwise, 0)
X_3 = mass extension teaching method (1 if used by extension agents, otherwise, 0)
X_4 = Indiv+group+mass (1 if used by extension agents, otherwise, 0)
X_5 = gender (1 = male; 0 otherwise)
X_6 = education (years)
X_7 = land ownership (1 = owned/inherited, otherwise, 0)
X_8 = trust in extension agents (1 if the respondent has trust in extension agents, otherwise, 0)
X_9 = age (years)
X_{10} = membership of association (1 if a member of any farming association, otherwise, 0)
X_{11} = farming experience (years)
X_{12} = household size (number)
X_{13} = farm income (₦)
X_{14} = extension visits (number per farming season)
$Ɛ_i$ = error term

3. Results and Discussion

3.1. Socioeconomic characteristics of cowpea farmers

Description of respondents' socioeconomic variables are presented in *Table 1*.

The involvement of more males than females in cowpea production could be associated with the difficult nature of the various activities involved in cowpea production. Such activities include land clearing, bed preparation/ridging, weeding and pest/disease management. The higher involvement of males in cowpea production could also be because of their easy access to land and other productive resources for agricultural purposes. This finding agrees with Ebenehi et al. (2018) when they reported that 81.13 % of crop farmers in Niger State were male. The mean age of 49 years could be seen as an active age required for most agricultural activities. The reported mean age in this study is similar to the mean age of about 51 years as reported by Canan and Uluışık (2024) among Turkish vegetable farmers. The involvement of married respondents in cowpea production could be a plus in the adoption of agricultural innovations for productivity enhancement. Sarı Gedik and Yılmaz (2023) reported that about 77% of young farmers in Türkiye were married. This is evident as household members could serve as the source of readily available labour and help in various production activities on the cowpea farms.

The majority (73.5%) of the respondents had a first-school leaving certificate (primary school education). Education could influence decision-making on cowpea farms as regards recommended practices. Educated cowpea farmers could read and interpret instructions and labels on farming inputs which will enhance their understanding and subsequent adoption. The mean household size among cowpea farmers in the area was seven members. The mean household size recorded in this study is the same as the national average of seven members per household as reported by the National Bureau of Statistics (NBS, 2019). Expectedly, farming (67.5 %) was the major occupation among the respondents. Another major occupational activity engaged by the respondents was trading (24.5 %). This result shows that most of the respondents took farming as their main occupation. This finding is in tandem with Adejo et al. (2019) who reported the same pattern among households in Kogi State. The average farm

size for cowpea production in the area was 2.5 hectares. This confirms the smallholding feature of cowpea farmers in the study area. The finding agrees with Shaibu et al. (2020) who found a mean farm size of 2.49 hectares among crop farmers in Kogi State, Nigeria. The reported number of years spent farming in this study agrees with Idrisa et al. (2012). Increased farming experience is expected to be directly proportional to the adoption of agricultural innovations. The mean annual income of the respondents from cowpea production was ₦92, 320.00 ($194.36).

Table 1: Descriptive Statistics of Cowpea Farmers

Socioeconomic Characteristics	Frequency, n = 200	Percentage	Mean/Mode
A. Sex			
Female	42	79.0	Male
Male	158	21.0	
B. Age (years)			
25 – 35	39	19.5	
36 – 45	24	12.0	
46 – 55	74	37.0	49 years
56 and above	63	31.5	
C. Marital Status			
Married	170	85.0	Married
Unmarried	30	15.0	
D. Educational Qualification			
No formal education	02	1.0	
First School Leaving Certificate (FSLC)	147	73.5	Primary
Secondary School Certificate (SSCE)	21	10.5	education
Tertiary educational certificate	30	15.0	(FSLC)
E. Household size (number of persons)			
1 – 5	69	34.5	
6 – 10	63	31.5	7 persons
11 – 15	68	34.0	
F. Major Occupation			
Farming	135	67.5	Farming
Civil service	16	8.0	
Trading /business/marketing	46	24.5	
G. Farm size (hectares)			
Below 2	50	25.0	
2 – 4	71	35.5	2.5 hectares
Above 4	79	39.5	
H. Farming Experience (years)			
1 – 15	30	15.0	
16 – 30	20	10.0	23 years
30 and above	150	75.0	
~~I.~~ Income from Cowpea Production (~~₦~~ ➔ Naira)	121	60.5	
50, 000 and below	34	17.0	92.320.00
51,000 – 100,000	45	22.5	
Above 100,000			

Source: Field Survey, 2021 NOTE: Naira is Nigeria's official currency. 1 USD = 475 Nigerian Naira (as of the time of survey in 2021).

3.2. Extent of adoption of recommended cowpea production practices

Table 2 shows the frequency count on the adoption of recommended cowpea farming practices by the respondents.

Generally, the result in *Table 2* shows a high level of adoption of most of the recommended cowpea production practices by the respondents. The impressive adoption level found in this study could be associated with cowpea farmers' awareness of these recommended production practices through access to extension services and as observed during engagement with the respondents. This finding corroborates Simon et al. (2013) when they reported a high level of awareness of sustainable agricultural land management practices among farmers in Taraba State, and this led to an adoption rate of over 60%. The authors reported that 95.7% of the respondents were aware of intercropping and posited that the high level of awareness is an added advantage to agricultural extension, as

awareness of a practice is the first step in learning how to use it, followed by the interest stage which urges the clientele to seek more information about the practice.

Table 2: Frequency distribution on the extent of adoption of recommended cowpea production practices

	Recommended Practices	Frequency	Percentage	Ranking/ Remark
i.	Recommended seed rate	181	90.5	1st
ii.	Recommended planting date	174	87.0	2nd
iii.	Recommended weeding time	169	84.5	3rd
iv.	Recommended rate for the application of pesticide	158	79.0	4th
v.	Recommended plant spacing	143	71.5	5th
vi.	Recommended harvesting time	142	71.0	6th
vii.	Recommended storage	121	59.5	7th
viii.	Recommended spacing depth	119	59.5	8th
ix.	Recommended stored pesticides	112	56.0	9th
x.	Use of improved cowpea variety	107	53.5	10th
xi.	Recommended practice for disease control	103	51.5	11th
xii.	Recommended herbicide for weed control	88	44.0	12th
xiii.	Recommended seed treatment before planting	85	42.5	13th
xiv.	Recommended rate of fertilizer application	21	10.5	14th

Source: Field Survey, 2021

Cowpea farmers in the study area highly adopted the recommended seed rate (90.5 %), recommended planting date (87 %), and recommended weeding time (84.5%). Cowpea farmers were familiar with the planting of 2 or 3 cowpea seeds per hole with two major planting periods (onset of early rain and late September). Two weeding regimes were also commonly practised by the respondents using hoes; the first weeding using hand hoes is carried out two weeks after planting followed by a second weeding in six weeks. During the field survey, it was observed that cowpea farmers who adopted the use of herbicide for weed control majorly applied glyphosate and paraquat. This finding agrees with Agwu (2006) who carried out a similar study in Abia State, Nigeria.

The result further indicated that the use of recommended stored pesticides (56 %) was fairly adopted by the respondents. A possible explanation for the adoption of this recommended practice could be farmers' knowledge of such practice. The associated cost of purchasing pesticides and their availability could also form part of the reasons for the fair or moderate adoption of recommended cowpea-stored pesticides. Stored pesticides are chemicals used to control the pests of cowpeas during storage. The recommended pesticides for storage of cowpea include Actelic 25 E.C, Actelic 2% dust, and Phostoxin tablet. It was however observed during the field survey that, cowpea farmers in the study area used recommended cowpea storage structures such as steel drums/tins, polythene bags, and local silos. This finding agrees with Sabo et al. (2014) who reported low adoption of cowpea storage management practices among farmers in Mubi, Nigeria.

The low adoption of recommended herbicide application (44 %), seed treatment (42.5%), and recommended fertilization rate (10.5%) will have implications on output. Herbicides are chemical substances for the control of unwanted plants. Herbicides applied immediately after planting are pre-emergence herbicides; while herbicides applied after weed emergence are post-emergence herbicides. This finding disagrees with Ajanya et al. (2014) in analyzing the adoption of glyphosate herbicide for the control of spear grass in Kogi state. The authors reported that 84.7% of yam farmers adopted the technology. The deviance in this finding and that of Ajanya et al. (2014) could be associated with the focus crop and farmers' economic situation. The result on herbicide however agrees with Okwoche et al. (2011) who reported that 47.72% of rural farmers in Kogi State, Nigeria adopted roundup (glyphosate) generally and with a preference level of 40.57% from among many other types of herbicides. The finding of this study is also in tandem with Imoloame (2013) who reported that 45.3% of crop farmers in Kwara State used more post-emergence herbicides due to the high level of root and tuber crop production in the area.

From *Table 2*, cowpea farmers' adoption score and adoption index were calculated as shown in *Table 3.* The adoption index is the ratio between the number of recommended cowpea production practices adopted by an individual farmer, and the total number of recommended cowpea production practices under study (in this case,

14 recommended cowpea production practices). *Table 3* shows that most (20.5 %) of the respondents had an adoption score and index of 8 and 0.57 respectively; while 1.5 % of the cowpea farmers recorded an adoption score and adoption index of 1 and 0.1, respectively. The adoption score and adoption index recorded in this study are similar to what was reported by Olumba and Rahji (2014) among plantain farmers in Anambra State, Nigeria.

Table 3: Adoption score and adoption index of cowpea farmers

Adoption Score	Adoption Index	Frequency	Percentage
1	0.1	10	5.0
2	0.14	25	12.5
3	0.21	20	10.0
4	0.29	33	16.5
5	0.36	17	8.5
6	0.43	21	10.5
7	0.50	19	9.5
8	0.57	41	20.5
9	0.64	11	5.5
10	0.71	3	1.5
Total		**200**	**100**

Source: Field Survey, 2021

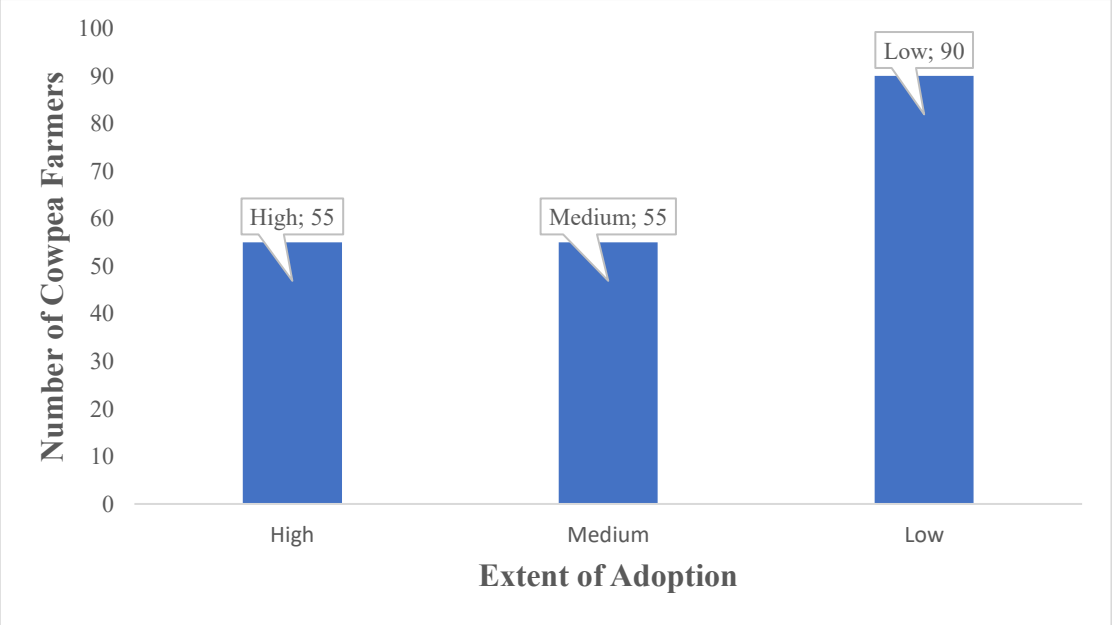

Figure 1: Extent of adoption of recommended cowpea production practices

Figure 1 shows the extent of adoption of recommended cowpea production practices. The categorization was done using the adoption score as presented in *Table* 2. From the result (*Figure 1*), 45 % of the cowpea farmers were in the low adoption category, while 27.5 % of each of the respondents were in the medium and high adoption category.

3.2. Effects of extension teaching methods on the extent of adoption

The output of the ordered probit regression model on the effect of extension teaching methods on the extent of adoption of recommended cowpea production practices among the respondents is presented in *Table 4*. The Log Likelihood Ratio (LR) Chi-square statistics of 78.21 was statistically significant ($p< 0.01$) at a 1 % level of measurement (99 % confidence). This implies that extension teaching methods and other included variables of cowpea farmers influenced their extent of adoption of recommended cowpea production practices. The ordered levels of adoption of recommended production practices by the respondents are reflected in the marginal effects' values. Adoption levels were ordered as low, medium, and high. The adoption score for individual cowpea farmers aided the categorization or grouping of cowpea farmers into these three groups. Estimates of the marginal effects were used because its coefficients have direct interpretation and hence aided discussion of the results. The result

in *Table* 4 shows that the individual, group, and combination of individual, group and mass extension teaching methods generally have a positive influence on the likelihood of the extent of adoption, while the mass extension teaching method was inversely related to the extent of adoption. Five (5) of the included explanatory variables significantly influenced the extent of adoption at various levels. The probability level was at 5 % ($p<0.05$); that is, 95 % confidence level. These significant variables include individual extension teaching method, mass extension teaching method, a combination of individual, group and mass extension teaching methods, gender, farming experience, and income from cowpea production.

The coefficient of the individual extension teaching method was positively signed and significant at a 1 % level of significance. This means that the individual extension teaching method increases the likelihood of cowpea farmers' adoption of recommended production practices. The marginal estimates show that the use of individual extension teaching methods will decrease the likelihood of farmers being found in the; low adoption category by 36.8 % and increase the probability of being found in the medium and high adoption categories by 7.2 % and 29.7 %, respectively. This result further confirms the respondents' position on their preference for the individual extension teaching method method in comparison to the other teaching methods. This finding agrees with Nwalieji and Nnabueze, (2018) and Ebenehi and Ahmed (2019) when they reported that the individual extension teaching method is effective in delivering extension messages among farmers in Anambra and Kogi States, respectively.

Table 4 shows that the coefficient of the mass media extension teaching method is negative and significant at a 5 % level. By implication, the likelihood of adoption of recommended cowpea production practices reduces with the use of mass media in delivering extension messages. This finding could be associated with the respondents' low-level preference for mass media extension teaching methods as compared with other extension teaching methods. The marginal effect analysis indicates that the use of the mass media extension teaching method increases the probability of farmers being found in the low adoption category by 5.9 %; and decreases farmers' likelihood of being found in the medium and high adoption category by 1.1 % and 4.7 %, respectively.

The combined effect of individual, group and mass media extension teaching methods was positively signed and significant at 1 %. By implication, the likelihood of farmers' adoption of cowpea-recommended production practices increases with the combined use of these three extension teaching methods in delivering extension messages. Cowpea farmers in the study area would be quick to adopt recommended production practices when they have access to both individual, group and mass media teaching methods. The outcome of the marginal effect analysis reveals that the likelihood of cowpea farmers being found in the low adoption category decreases with the combined use of these three methods by 1.3 %. Further, the combined use of these three extension teaching methods favours the likelihood of cowpea farmers to be found in the medium and high adoption category by 0.3 % and 1.1 %, respectively.

The coefficient of years spent in cowpea farming as shown *in Table 4* was negative and significant at a 5 % level of significance. By implication, an increase in the number of years spent farming will decrease the likelihood of cowpea farmers adopting recommended cowpea production practices in the study area. Further analysis of the marginal effect shows that an increase in years spent farming will increase the chances of cowpea farmers being found in the low adoption category by 0.6 %. However, an additional year spent in farming cowpea will decrease the probability of cowpea farmers being found in the medium and high adoption category by 0.1 % and 0.5 %, respectively.

The coefficient of income from cowpea production was negative and significant at a 5 % level of significance. By implication, the naira increase in farm income from cowpea production will decrease the likelihood of cowpea farmers adopting recommended cowpea production practices. Further, the probability of cowpea farmers being found in the low and medium adoption categories increases by 0.000085 % and 0.000017 %, respectively, with a naira increase in farmers' income, while the likelihood of cowpea farmers being found in the high adoption category decreases by 0.000069 % with an increase in income from cowpea production.

Table 4: Output of the Ordered Probit Analysis on the Effect of Extension Teaching Method on Farmers' Extent of Adoption

Variables	Ordered Probit Estimate		Low Extent of Adoption		Medium Extent of Adoption		High Extent of Adoption	
	Coeff.	**Prob.**	**dydx**	**Prob.**	**dydx**	**Prob.**	**dydx**	**Prob.**
Individual method	1.192 (0.267)	0.000***	-0.368 (0.072)	0.000***	0.072 (0.021)	0.000***	0.297 (0.064)	0.000***
Group method	0.111 (0.267)	0.678NS	-0.034 (0.082)	0.677NS	0.007 (0.016)	0.679NS	0.028 (0.066)	0.677NS
Mass method	-0.189 (0.085)	0.026**	0.059 (0.026)	0.022**	-0.011 (0.006)	0.039**	-0.047 (0.021)	0.025**
Indiv+group+mass	0.044 (0.008)	0.000***	-0.013 (0.002)	0.000***	0.003 (0.001)	0.005***	0.011 (0.002)	0.000***
Gender	-0.124 (0.073)	0.090NS	0.038 (0.022)	0.083NS	-0.007 (0.005)	0.098NS	-0.031 (0.018)	0.089NS
Education	1.157 (0.783)	0.140NS	-0.358 (0.239)	0.134NS	0.069 (0.048)	0.151NS	0.288 (0.194)	0.138NS
Land ownership	0.055 (0.080)	0.496NS	-0.017 (0.025)	0.494NS	0.003 (0.005)	0.496NS	0.014 (0.020)	0.496NS
Trust	0.044 (0.178)	0.805NS	-0.014 (0.055)	0.805NS	0.003 (0.011)	0.806NS	0.011 (0.044)	0.805NS
Age	0.018 (0.376)	0.962NS	-0.005 (0.116)	0.962NS	0.001 (0.023)	0.962NS	0.004 (0.094)	0.962NS
Membership	0.005 (0.009)	0.606NS	-0.002 (0.004)	0.606NS	0.003 (0.001)	0.612NS	0.001 (0.002)	0.606NS
Farming experience	-0.019 (0.008)	0.021**	0.006 (0.003)	0.018**	-0.001 (0.001)	0.039**	-0.005 (0.002)	0.020**
Household size	-0.581 (0.359)	0.106NS	0.179 (0.109)	0.101NS	-0.035 (0.023)	0.132NS	-0.145 (0.089)	0.103NS
Cowpea farm income	-2.76e-6 (1.28e-6)	0.031**	8.54e-7 (3.84e-7)	0.026**	1.7e-7(8.2e-8)	0.043**	-6.9e-7 (3.2e-7)	0.030**
Extension visits	0.057 (0.052)	0.268NS	-0.018 (0.016)	0.265NS	0.004 (0.003)	0.283NS	0.014 (0.013)	0.266NS
LR Chi^2	78.21	0.000						
Log likelihood	-174.770							
Pseudo R^2	0.183							

Source: Authors' computation from field survey, 2021. Figures in parentheses are standard errors. *** and ** = significant @ 1% and 5% level, respectively. NS = Sot Significant.

4. Conclusions

The adoption of recommended cowpea production practices was relatively high for the recommended seed rate, recommended planting date, and recommended weeding time. The adoption of improved cowpea seed variety was moderate while recommended herbicide application recorded low adoption. The adoption of improved cowpea seed variety is significantly influenced by individual extension teaching method, mass extension teaching method, a combination of individual, group and mass extension teaching methods, farming experience, and income from cowpea production.

Based on findings, discussions and conclusions drawn from this study, the following policy recommendations are made.

1. For cowpea farmers to be found in the high adoption category, extension agents should consider focusing more on the individual extension teaching method in disseminating information on recommended cowpea production practices.

2. Extension agents should enlighten cowpea farmers on the need to adopt the following recommended cowpea production practices; use of improved cowpea seed variety, practice for disease control, herbicide for weed control, seed treatment before planting, and recommended rate of fertilizer application.

3. Since the individual and mass extension teaching methods significantly influenced the adoption of improved cowpea seed variety, it is advisable that extension agents should focus on these methods to enhance adoption rates.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Patrick and Damilola contributed to the project idea, design, and execution of the study. Damilola completed the survey. Ufedo and Damilola designed the instrument, analyzed the data and provided results interpretation. All authors wrote and approved the manuscript.

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References

Adejo, P. E., Ahmed, T. A. and Ebenehi, O. (2019). Appraisal of extension service delivery to goat farmers in Kabba/Bunu Local Government Area of Kogi State, Nigeria. *International Journal of Agriculture and Food Science* 1(1): 27-31.

Agwu, A. E. (2006). Adoption of improved oil palm production and processing technologies in Arochukwu Local Government Area of Abia State, Nigeria. *Agro-science: Journal of Agriculture, Food, Environment and Extension,* 5(1) 25-35.

Ahmed T. A. and Adisa R. S. (2017). Perceived Effectiveness of Agricultural Extension Methods Used to Disseminate Improved Technologies to Rice Farmers in Kogi State, Nigeria. *International Journal of Agricultural Science, Research and Technology in Extension and Education Systems,* 7(1): 27-34.

Ajanya, S., Obinne, C. P. O. and Saliu, O. J. (2014). An analysis of the adoption of glyphosate herbicide for the control of speargrass (*Imperata cylindrica*) by yam farmers in Guinea Savanna Agricultural Zone of Nigeria. *American Journal of Experimental Agriculture,* 4(12): 1718-1730.

Ajayi, F. O. and Adeyemi, A. A. (2016). Factors ınfluencing the adoption of moringa plant cultivation among farming households in South-Western Nigeria: A tobit approach. *International Journal of Innovative Food, Nutrition &Sustainable Agriculture*, 4(4): 15-24.

Bolarinwa, K. A., Ogunkanmi, L. A., Ogundipe, O. T., Agboola, O. O., and Amusa, O. D. (2022). An investigation of cowpea production constraints and preferences among small holder farmers in Nigeria. GeoJournal, 87(4): 2993-3005.

Canan, S. and Uluışık, E. N. (2024). Vegetable losses and waste along the supply chain and farmers' willingness to pay for recycling: towards to green supply chain. *Journal of Tekirdag Agricultural Faculty*, 21(1): 148-165. https://doi.org/10.33462/jotaf.1251261

Ebenehi, O. and Ahmed, T. A. (2019) Perceived relevance of extension methods used to disseminate faro-44 rice variety to rice farmers in Kogi State, Nigeria. *International Journal of Agriculture and Nutrition,* 1(1):19- 21.

Ebenehi, O., Ahmed, T. A. and Barnabas, T. M. (2018). Evaluation of extension services delivery for climate change adaptation by crop farmers in Niger State, Nigeria. Asian *Journal of Agricultural Extension, Economics & Sociology,* 27(1): 1–13.

Eze, C. C., Amanze, B. and Nwankwo, O. (2010). Resource use efficiency in arable crop production among smallholder farmers in Owerri Agricultural Zone of Imo State, Nigeria. *Researcher*, 2(5): 14-20.

Ezeh, C. I., Anyiro, C. O., Ehiemere, I. O. and Obioma, N. Q. (2012). Gender issues on poverty alleviation programmes in Nigeria; the case of the National Fadama 1 Development Project in Abia State, Nigeria. *Agris on-line Papers in Economics and Informatics*, 4(3): 15-20.

FAOSTAT (2023). Crops and Livestock Products. https://www.fao.org/faostat/en/#data/QCL (Accessed Date: 20.05.2024)

Food and Agriculture Organization, FAO (2018). Extension and Communication. http://www.fao.org/3/t0060e/T0060E05.htm (Accesed Date: 12.06.2020)

Garforth, C. (2001). Agricultural knowledge and information systems in Hagaz, Eritrea. *SD Dimensions,* October. http://www.fao.org/sd/2001/KN1001a_en.htm

ICRISAT (2017). Enhancing cowpea productivity and production in drought-prone areas of Sub-saharan Africa. http://tropicallegumes.icrisat.org/wp-content/uploads/2017/12/TL-III-Bulletin-10.pdf

Idrisa, Y. L., Ogunbameru, B. O. and Amaza, P. S. (2012). Influence of farmers' socio-economic and technology characteristics on soybean seeds technology adoption in southern Borno State, Nigeria. *African Journal of Agricultural Research*, 5(12): 1394–1398.

Imoloame, E. O. (2013). Herbicide utilization by farmers in Moro Local Government Area of Kwara State. *International Journal of Agricultural Sciences,* 3(7): 571 – 578.

Mohammed, S. B., Mohammad, I. F., Pangirayi, T. B., Vernon, G., Dzidzienyo, D. K., Umar, M. L., and Umar, S. (2020). Farmers' knowledge, perception, and use of phosphorus fertilization for cowpea production in Northern Guinea Savannah of Nigeria. *Heliyon*, 6(10): e05207. https://doi.org/10.1016/j.heliyon.2020.e05207

National Bureau of Statistics (NBS) (2019). Nigerian Gross Domestic Product Report. www.nigerianstat.gov.ng (Accesed Date: 24.04.2021)

National Population Commission (NPC) (2006*) Population and housing census enumerators manual*. Federal Republic of Nigeria, National Population Commission, Nigeria, pp: 1-16.

Nogay, Y. and Azabağaoğlu, M. (2024). Analysis of factors affecting corn seed preferences of producers: Case of Sakarya Province, Turkey. *Journal of Tekirdag Agricultural Faculty*, 21(1): 125-138. https://doi.org/10.33462/jotaf.1244525

Nordhagen, S., Onuigbo-Chatta, N., Lambertini, E., Wenndt, A. and Okoruwa, A. (2023). Perspectives on food safety across traditional market supply chains in Nigeria. Food and Humanity, 1: 333-342. https://doi.org/10.1016/j.foohum.2023.06.018

Nwalieji, H and Nnabueze, N. (2018). Farmers' perception of effectiveness of agricultural extension agents in Anambra State, Nigeria. *International Journal of Agricultural Science, Research and Technology in Extension and Education Systems,* 8(2):103-110.

Obibuaku, L. O. and Hursh, G. D. (1994). Farm practice adoption in the Eastern States of Nigeria, *Journal of Agricultural Administration* (1): 18-20.

Okwoche, V. A., Obinne, C. P.O. and Onugba, J. A. (2011) Adoption of herbicides and fertilizers among rural farmers of Zone B Area of Kogi State Agricultural Development Project, Kogi State, Nigeria. *Asian Journal of Agricultural Sciences,* 3(5) 389-392.

Oladele, O. J. (1999). *Analysis of the institutional research – extension farmers linkage system in South Western Nigerian*. (Ph.D Thesis-Unpublished) Development of Agricultural Extension and Rural Development, University of Ibadan, Nigeria.

Olumba, C. C. and Rahji, M. A. Y. (2014). An analysis of the determinants of te adoption of improved plantain technologies in Anambra State, Nigeria. *Journal of Agriculture and Sustainability* 5(2): 232 – 245.

Osipitan, O., Fields, J., Lo, S., Cuvaca, I. (2021). Production systems and prospects of cowpea (*Vigna unguiculata* (L.) Walp.) in the United States. *Agronomy*, 11: 2312. https://doi.org/10.3390/agronomy11112312

Rees, D. J., Momanyi, M., Wekundah, J., Ndungu, F., Odondi, J., Oyure, A. O., Andima, D., Kamau, M., Ndubi, J., Musembi, F., Mwaura, L. and Joldersma, R. (2000). Agricultural knowledge and information systems in Kenya: implications for technology dissemination and development. *The Agricultural Research and Extension Network Paper*, http://www.odi.org.uk/agren/papers/agrenpaper_107.pdf (Accessed Date: 11.06.2021).

Sabo, E., R. Bashir, A. Gidado, R. Sani and Adeniji, O. (2014). Investigation on production constraints and adoption of inorganic insecticides and spraying regime in management of cowpea (*Vigna uncuiculata* L. Walp) insects in Mubi zone, Nigeria. *Journal of Agricultural Extension and Rural Development,* 6(1): 11-20. https://doi.org/10.5897/jaerd12.120.

Sarı Gedik, D. and Yılmaz, E. (2023). Determination of the factors affecting the level of benefit from young farmer project support in rural development: Tekirdag Sample, Türkiye. *Journal of Tekirdag Agricultural Faculty*, 20(2): 418-429. https://doi.org/10.33462/jotaf.1165409

Shaibu, U. M., Ibitoye, S. J., Oyibo, F. O., Emeje, C. A. and Shaibu, D. O. (2020). Assessment of crop farmers' willingness to take (WTT) agricultural insurance scheme in Kogi State, Nigeria: Application of turnbull estimator. *Revista e-Agronegocios*, 6(1):1 – 12.

Shaibu, U. M., Umeh, J. C., Abu, G. A., Abu, O. and Egyir, I. S. (2023). Econometric modeling of the nexus of agricultural policy and food security in Nigeria: A dummy variable regression approach. *African Journal of Food, Agriculture, Nutrition and Development*, 23(6): 23763-23785.

Simon, B. P., Ndaghu, A. A. and Yohanna, I. (2013). Awareness of sustainable agricultural land management practices among crop farmers in Northern Part of Taraba State, Nigeria. *Journal of Science and Technology*, 3(5):557-560.

Tenebe, V. A and Mundi N. E. (2008). Comparative Study of Direct Extension Teaching Methods (DET) and Open and Distance Learning (ODL) on Technology Adoption Rate by Cowpea Farmers in Bauchi Nigeria. 2nd ACDE Conference Lagos.

Uzokwe, U. (2015). Contribution of women to household expenditure in rural communities of Ughelli North Local Government Area of Delta State, Nigeria. *Journal of Agriculture and Ecology Research International*, 12(2): 1-6.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Effects of Different Nitrogenous Fertilizers and Potassium Doses on Yield, Yield Components, and Fruit Quality of Tomato Grown in Alkaline and Acidic Soils*

Farklı Azotlu Gübreler ve Potasyum Dozlarının Alkalin ve Asidik Topraklarda Yetiştirilen Domatesin Verim, Verim Unsurları ve Meyve Kalitesine Etkileri

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Abstract

Different nitrogen fertilizers and potassium applications have an important impact on the yield and yield components and fruit-quality parameters of tomatoes in both alkaline and acidic reaction soils. This study investigated the effects of different nitrogenous fertilizers and potassium doses on the yield, yield components, and fruit quality of tomatoes grown on alkaline and acidic soils. The experiment was carried out in the research greenhouse of the Agriculture Faculty, at Selcuk University. It was performed by using two different soil types, three nitrogen fertilizers [ammonium sulfate (AS), ammonium sulfate with inhibitor (AS+inh.), and calcium nitrate (CaNit)], and three different concentrations of potassium sulfate (0, 240, and 480 mg K_2O kg^{-1}). We conducted the study by using a randomized experimental plot design with four replications. According to the research results, the highest fruit yield in alkaline soil was 'inh. AS and 480 mg K_2O kg^{-1}', while the highest fruit yield in acid soils was obtained with 'calcium nitrate and 240 mg K_2O kg^{-1}'. Furthermore, different nitrogen sources and potassium doses significantly affected tomato yield components such as stem diameter, plant height, number of fruits per plant, fruit weight, fruit diameter, fruit hardness, fruit pH, and Brix values. According to the results of the completed soil analysis, the applications demonstrated the importance of accurate and balanced fertilization for high-yield and quality tomato production in different soils. In conclusion, this study highlights the importance of selecting appropriate nitrogen fertilizers and potassium doses to increase tomato yield and yield components in alkaline and acidic soils. It provides valuable insights for tomato farmers and researchers seeking to improve tomato cultivation techniques in different soil conditions.

Keywords: Acidic and Alkaline soil, Fruit quality, Nitrogen, Potassium, Tomato, Yield

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Öz

Farklı azotlu gübreler ve potasyum uygulamaları, alkalin ve asidik reaksiyon topraklarda domatesin verim ve verim unsurları ile meyve kalite parametreleri üzerinde önemli bir etkiye sahiptir. Bu çalışmada, farklı azotlu gübreler ve potasyum dozlarının alkalin ve asidik topraklarda yetiştirilen oturak sofralık domatesin verim, verim unsurları ve meyve kalitesi üzerine etkileri araştırılmıştır. Deneme Selçuk Üniversitesi Ziraat Fakültesi araştırma serasında, iki farklı toprak, üç azotlu gübre [amonyum sülfat (AS), inhibitörlü amonyum sülfat (AS+inh.) ve kalsiyum nitrat (CaNit)] ve üç farklı potasyum dozu (0, 240 ve 480 mg K_2O kg^{-1}; potasyum sülfat) kullanılarak tesadüf parselleri deneme desenine göre dört tekerrürlü olarak yürütülmüştür. Araştırma sonuçlarına göre, alkalin toprakta en yüksek meyve verimi 'inh. AS ve 480 mg K_2O kg^{-1}' interaksiyonundan elde edilirken, asidik toprakta en yüksek meyve verimi 'kalsiyum nitrat ve 240 mg K_2O kg^{-1}' interaksiyonundan alınmıştır. Sonuç olarak, azotlu gübre ve potasyum dozlarının farklı uygulamalarının çeşitli toprak koşullarında domates üretimini artırabileceği ortaya konulmuştur. Ayrıca, farklı azot kaynakları ve potasyum dozları domatesin gövde çapı, bitki uzunluğu, bitki başına meyve sayısı, meyve ağırlığı, meyve çapı, meyve sertliği, meyve pH'sı ve briks değerleri gibi verim unsurlarını da istatistiksel olarak önemli düzeylerde etkilemiştir. Farklı azot kaynakları ve potasyum dozlarının verim ve verim unsurları üzerindeki etkilerinin istatistiksel olarak önemli olduğunu tespit edilmiş olup, yüksek kalitede domates yetiştiriciliği için doğru ve dengeli gübrelemenin önemini ortaya çıkarmaktadır. Sonuç olarak, bu çalışma alkali ve asidik topraklarda domates verimini ve verim unsurlarını artırmak için uygun azotlu gübre ve potasyum dozlarının belirlenmesinin gerektiğini açıklamaktadır. Farklı toprak koşullarında domates yetiştirme tekniklerini geliştirmek isteyen çiftçiler ile araştırmacılar için önemli bilgiler sağlanmıştır.

Anahtar Kelimeler: Alkalin ve asidik toprak, Azot, Domates, Meyve kalitesi, Potasyum, Verim

1. Introduction

Tomatoes (*Lycopersicon esculentum* Mill.) are a highly important vegetable worldwide, offering economic benefits and high yields due to their short growth period. They belong to the Solanaceae family, along with other vegetables like potatoes, peppers, and eggplants. Tomatoes, which are rich in vitamins, originated in Peru and were brought to Europe from Bolivia and Ecuador in the 16th century (Dam et al., 2005). Tomatoes are an important product in greenhouse vegetable cultivation and are highly nutritious. They contain important vitamins and minerals, including thiamine, vitamin A, niacin, ascorbic acid, phosphorus, potassium, calcium, sodium, and iron. According to Sainju et al. (2003), 100 grams of tomatoes contain 0.06 mg of thiamine, 900 IU of vitamin A, 0.7 mg of niacin, 23 mg ascorbic acid, 27 mg phosphorus, 244 mg potassium, 13 mg calcium, 3 mg sodium, and 0.5 mg iron. Nitrogen is an essential nutrient for plants, promoting vegetative growth while reducing generative growth. It is therefore essential to maintain a balanced nitrogen-to-potassium (N/K) ratio in plant tissues. The ideal N/K ratio in leaves is between 1.2 and 1.8, according to Campbell (2000). Potassium is the most important cation in plant physiology in terms of quantity and physiological and biochemical functions (Leigh and Wyn Jones, 1984). Tomato fruits have a high uptake of potassium (K^+) from the soil, especially during the fruit growth period (Huett and Dettmann, 1988). Ideal soils for growing tomatoes are low- to medium-calcareous, salt-free, loamy, and rich in macro- and micronutrients. They should be deep, permeable, and dark in color, especially alluvial soils (Zengin and Özbahçe, 2011). Ceylan et al. (2001) studied the effects of different doses of ammonium nitrate and urea fertilizer on tomato N uptake and accumulation under field conditions. When applying 360 kg N ha^{-1}, they observed the highest levels of nitrate-N and nitrite-N in leaves and fruits during the 1st and 2nd harvests. Furthermore, ammonium nitrate applied resulted in higher nitrate and nitrite accumulation compared to urea applied. Applying 240 kg N ha^{-1} resulted in the highest yield. The effect of two different fertilizer sources as 20-20-0 (0, 1, 1.5 and 2 kg/ha) and Leonardite (0, 2.5, 5 and 7.5 kg/ha) were applied to tomato plants. According to the results of the study, the differences between fertilizer applications were statistically significant in tomato plant stem height, root length, shoot and root fresh weight, shoot and root dry weight and number of leaves (Demirkiran et al., 2012). Reboucas et al. (2015) examined how calcium nitrate, ammonium sulfate, urea, and different amounts of nitrogen (0, 140, 280, and 420 kg N ha^{-1}) affected the quality of tomatoes. They found that increasing nitrogen doses led to a decrease in fruit acidity, while fruit pH and brix values remained unaffected. The type of fertilizer used had different effects. Researchers found that nitrogen fertilizers positively affected the yield components, and they recommended applying nitrate and ammonium to improve quality. In a sandy soil experiment in Cairo, Egypt, Awaad et al. (2016) conducted a study to evaluate the effects of different N sources, including slow-release (urea-formaldehyde) and rapid-release (urea) N, on lettuce yield. The results showed that the application of nitrogen alone or in combination with potassium sulfate resulted in the highest fresh dry weight per plant and total lettuce yield per hectare compared with the control. The combination of urea and potassium sulfate resulted in the highest fresh dry weight per plant. The lettuce plants had the highest contents of P, K, Zn, and Mn when the combination of urea and potassium sulfate was used, while the highest contents of N and Fe were observed with urea fertilizer alone. The lowest nitrate levels were observed with urea alone or urea+potassium sulfate in combination. The highest protein content in the plants was also induced by the combination of urea and potassium sulfate. The study demonstrated that urea-formaldehyde slow-release nitrogen fertilizer significantly improved lettuce yield and quality on sandy soils. Natlia et al. (2018) investigated the effect of nitrogen sources and doses on tomato fruit's nutritional quality. A commercial hybrid tomato (Dominador) was grown in four replications. The treatments included nitrogen fertilizer dosages of 50 and 200 mg L^{-1} with a combination of four sources (urea, ammonium sulfate, ammonium nitrate, and calcium nitrate). The results indicated that the application of urea and ammonium nitrate led to increased pH levels in the tomato fruits. The contents of potassium, lycopene, and carotenoids did not appear to be significantly different depending on the sources and doses of nitrogen used. The study concluded that nitrogen fertilizer sources and doses have a significant impact on the nutritional quality of tomato fruit, affecting some parameters such as brix, pH, titratable acidity, and sodium content. The effects of different levels of potassium and zinc fertilization on the yield and the yield components of the artichoke were studied in the research. Different levels of potassium were applied, including 0, 6, 12, and 18 kg K_2O da^{-1}; K_2SO_4; and 50% K_2O. The results showed that the highest artichoke yield (8.972 kg da^{-1}) was obtained with the application of 18 kg K_2O da^{-1} (Öztürk et al., 2020).

About 80% of the agricultural land in Türkiye has calcareous alkaline soils, while the rest has acidic soils. The effects of different doses of potassium combined with nitrogenous fertilizers such as AS, inh. AS, and CaNit on tomato production in these soils have been the subject of very little scientific research. The study aimed to

investigate the effect of different doses of potassium combined with nitrogen fertilizers on the yield, yield components, and fruit quality of tomato plants. The experiment utilized two types of soil: Konya soil with an alkaline pH and Nevşehir soil with an acidic pH.

2. Materials and Methods

The study was conducted in the greenhouse and laboratory of the Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Selcuk University, Konya. Fidesan Vegetable Company's Mirsini tomato variety was used as the study plant material. Chemical and physical analysis of the soil samples were carried out before the experiment began using the following methods: pH (pH meter with a glass electrode in a mixture of soil: pure water in a ratio of 1:2.5, Richard; 1954), EC (measured in a 1:5 soil: distilled water solution with an EC meter, Bayraklı; 1987), lime (total $CaCO_3$, by the Scheibler Calcimeter, Çağlar; 1949), organic matter (by the Smith-Weldon method, Bayraklı; 1987), texture (Bouyoucos, 1951), inorganic N (NH_4-N + NO_3-N, by the Kjeldahl method, Bremner; 1965), available P (Olsen et al., 1954), extractable K, Ca, Mg, and Na (with 1 N ammonium acetate, pH = 7.0, Jackson (1965), determining by the ICP-AES Varian-Vista device, and the available trace elements Fe, Zn, Mn, and Cu (Lindsay and Norwell, 1978), and reading by the ICP-AES, Soltanpour et al.; 1979), and B micronutrient (in the 0.01 M $CaCl_2$ + 0.01 M mannitol solution extract with the ICP-AES, Soltanpour et al.; 1979, Cartwright et al.; 1983).

According to the analysis results of the two different soil samples (Table 1), the soil from the Selcuk University campus land in Konya City has a slightly alkaline pH of 7.74. It is salt-free and has an excess of lime. The soil is low in organic matter and has a loamy texture. It is deficient in nutrients such as nitrogen (N), potassium (K), magnesium (Mg), iron (Fe), manganese (Mn), and boron (B). However, it has sufficient levels of phosphorus (P), zinc (Zn), and copper (Cu) and high levels of calcium (Ca). The other soil of Nevşehir province has a slightly acidic pH of 5.50. It is also salt-free but has low calcium content. The soil is low in organic matter and has a sandy texture. It is deficient in nutrients such as nitrogen (N), calcium (Ca), magnesium (Mg), and zinc (Zn). However, it has sufficient levels of potassium (K), manganese (Mn), boron (B), and copper (Cu), as well as high levels of phosphorus (P) and iron (Fe) (Table 1). In summary, the soils of Konya and Nevşehir have different pH values and textures. The Konya soil is alkaline with a loamy texture, while the Nevşehir soil is acidic with a sandy texture. Both soils are poor in various nutrients but also have sufficient or high levels of certain nutrients.

Table 1. Some physical and chemical analysis results of the soil samples

Parameters	Results	Results	Parameters	Results	Results
Parameters	**Alkaline (Konya)**	**Acidic (Nevşehir)**	**Parameters**	**Alkaline (Konya)**	**Acidic (Nevşehir)**
pH (1:2.5 soil: water)	7.74 (Slightly alkaline)	5.50 (Slightly acidic)	Extracted K (mg kg^{-1})	86 (Low) (0.22 me 100 g^{-1})	214 (Adequate) (0.55 me 100 g^{-1})
EC (1:5 soil: water, µS cm^{-1})	74 (Saltless)	71 (Saltless)	Extracted Ca (mg kg^{-1})	4.910 (Much) (24.55 me 100 g^{-1})	621 (Low) (3.10 me 100 g^{-1})
Lime (%)	30.6 (Too much)	0.3 (Low)	Extracted Mg (mg kg^{-1})	131 (Low) (1.09 me 100 g^{-1})	100 (Low) (0.83 me 100 g^{-1})
Org. matter (%)	0.7 (Very low)	0.7 (Very low)	Extracted Na (mg kg^{-1})	20.4 (0.09 me 100 g^{-1})	12.0 (0.05 me 100 g^{-1})
Clay (%)	22.6	9.6	Extractable Sodium Percent	0.34 (Good)	1.10 (Good)
Silt (%)	32.0	3.7	Available Fe (mg kg^{-1})	1.33 (Low)	31 (Much)
Sand (%)	45.4	86.7	Available Zn (mg kg^{-1})	1.10 (Adequate)	0.46 (Low)
Texture class	Loamy	Sandy	Available Mn (mg kg^{-1})	1.52 (Low)	13 (Adequate)
Inorg. N (NH_4-N+ NO_3N) (mg kg^{-1})	2.6 (Very low)	10.9 (Low)	Available B (mg kg^{-1})	0.02 (Low)	0.72 (Adequate)
Available P (mg kg^{-1})	8.1 (Adequate)	34 (Much)	Available Cu (mg kg^{-1})	1.34 (Adequate)	0.28 (Adequate)

Table 2. The ratio of the extractable cations to each other

Rates	Results		Ideal	Resolutions	
	Konya	Nevşehir		Konya	Nevşehir
Ca:K	111.6	5.6	12	Give K	Give Ca
Ca:Mg	22.5	3.7	6	Give Mg	Give Ca
Mg:K	4.9	1.5	2	Give K	Give Mg

In the study, we used ammonium sulfate (AS), inhibited ammonium sulphate (AS+inh.; of DOĞATECH company, the fertilizer contents as shown in *Table 3*), and calcium nitrate (CaNit) as sources of nitrogen fertilizer. These fertilizers contain different percentages of nitrogen, with AS and inh. AS both containing 21% N and CaNit containing 15.5% N and 26% CaO. The study supplied potassium sulfate as the potassium source, which provided 51% K_2O. We used triple super phosphate (TSP) with a phosphorus content of 43-45% P_2O_5 for fertilization. Finally, we used Etidot-67 as the source of boron, which contains 20.8% of boron.

Table 3. The source of inhibited ammonium sulphate (AS+inh.): DOĞATECH Stable N-21 and the guaranteed content of this fertilizer according to the following table

Guaranteed Ingredients	(W/W) %
Total Nitrogen (N)	21
Ammonium Nitrogen (NH4-N)	21
Water soluble Sulfur Trioxide (SO_3)	60
Ammonium Inhibitor (DMPB)	0.25

Source: dogatech.com.tr

The experiment was conducted in the research greenhouse of the Soil Science and Plant Nutrition Department, Faculty of Agriculture, Selcuk University. The greenhouse was well-ventilated, with the temperature maintained at 25±3 ºC, solar radiation at 1750±50 kcal m^{-2}, and relative humidity around 60±10%. We used a randomized experimental pot design with four replications, filling the pots with 5 kg of oven-dried soil sieved to 4 mm. Totally 500 mg N kg^{-1} was applied into pot soil as ammonium sulfate (AS), inhibited ammonium sulfate (AS+inh.), and calcium nitrate (CaNit) fertilizer. Of this 250 mg N kg^{-1} at the base of the soil during seedling planting and another 250 mg N kg^{-1} at the top of the soil during the fruit ripening period, was given. For potassium doses, half of the 0, 240, and 480 mg K kg^{-1} was applied at the base during seedling planting, while the other half was given at the top during fruit ripening by the potassium sulfate (PS). According to the results of the soil analysis, the phosphorus and boron fertilizers, which contain deficient nutrients, were applied to the soil as a solution before planting. At transplanting, we supplemented the P levels in all pots to 60 mg P kg^{-1} using TSP fertilizer (45% P_2O_5). While the Konya soil is poor in boron, the Nevşehir soil has sufficient boron. At transplanting, we added Etidot-67 fertilizer as a solution at a rate of 1.5 mg B kg^{-1} into each pot, serving as an alkaline fertilizer for 36 pots of Konya soil. We planted one tomato seedling in each pot and immediately watered them. Depending on weather conditions, irrigation with pure water was carried out at a measured rate, and maintenance activities such as spraying, and grass removal were done as necessary.

The harvest: There were four harvests, the first being 65 days after planting. Tomatoes were picked when they turned red. At the end of the harvesting process, the following measurements were carried out on samples of tomato fruit and plants: In the experiment, the fruits in the pots were weighed after 4 different harvests and the total yield per pot was determined as (g pot^{-1}). Plant stem diameter (thickness): The stem of each plant in each pot was measured 5 cm above the soil and in one direction with a caliper, and the stem diameter (mm) was recorded. Plant height: A meter was used to measure the length (cm) of the plant in each pot. Number of fruits per plant: The number of fruits per plant was determined by taking the arithmetic mean and counting the fruits in each pot until the end of the harvest. Fruit diameter: The diameters of the fruits taken from each pot at each harvest were measured with calipers, and the average fruit diameter (mm) was determined by taking the arithmetic mean. Fruit weight: The average fruit weight (g) was determined by weighing the fruits taken from each pot at each harvest and taking the arithmetic mean. Fruit hardness: The peel hardness (kg cm^{-2}) of the fruits taken from each pot was calculated by measuring around the equatorial plane and outside the carpel wall with a flat-tipped hand penetrometer (Bayraktar, 1970). Fruit pH: The pH of the pulped fruit samples in the laboratory was measured directly with a pH meter without dilution and recorded. Water-soluble dry matter (brix) in fruit: The water-soluble dry matter content (%) was determined three times by taking a teaspoon of the pulped fruit sample in the laboratory, filtering it through filter paper, and dropping a drop of the obtained sample on the prism of the refractometer, and the average result was expressed as % brix (Cemeroğlu, 1992).

Statistical analyses of the yield and yield components and some fruit-quality parameter values obtained as a result of the treatments were evaluated by the randomized plots experimental design and submitted to variance analysis with the MINITAB software.

3. Results and Discussion

This study aimed to investigate different sources of nitrogen and the effect of potassium dosage on tomato yield and yield components in both alkaline and acid soils.

3.1. Effects of different nitrogen sources and potassium doses on yield and yield components of tomato grown in alkaline and acidic soils

3.1.1. The tomato yields

The interaction between the application of nitrogen fertilizer and potassium dosage showed a statistically significant effect (at a 1% level) on tomato production in both alkaline and acidic soils. *Table 4* provides the values and Duncan groups of the treatments' effect on tomato production per pot. *Figure 1* shows that in alkaline soil, the lowest yield (334.10 g pot^{-1}) was obtained from the inh. AS control treatment and the highest yield (549.00 g pot^{-1}) from the 'inh. AS x K_{480}' interaction. Similarly, when considering nitrogen fertilizer in alkaline soil, the highest tomato yield (520.70 g pot^{-1}) was obtained with AS fertilizer (*Table 4*), and tomato yield increased with increasing potassium doses from 0 mg K_2O kg^{-1} dose to 480 mg K_2O kg^{-1} dose. On the other hand, in acidic soil, the lowest yield (408.80 g pot^{-1}) was obtained in the CaNit control treatment, and the highest yield (747.70 g pot^{-1}) was obtained in the 'CaNit x K_{240}' interaction (*Figure 1*). Moreover, considering nitrogen fertilizers, the highest tomato yield (656.00 g pot^{-1}) was found in the inh. AS fertilizer application, and the highest yield (683.90 g pot^{-1}) was found in 240 mg K_2O kg^{-1} dose application as average yield results to different potassium doses (*Table 4*).

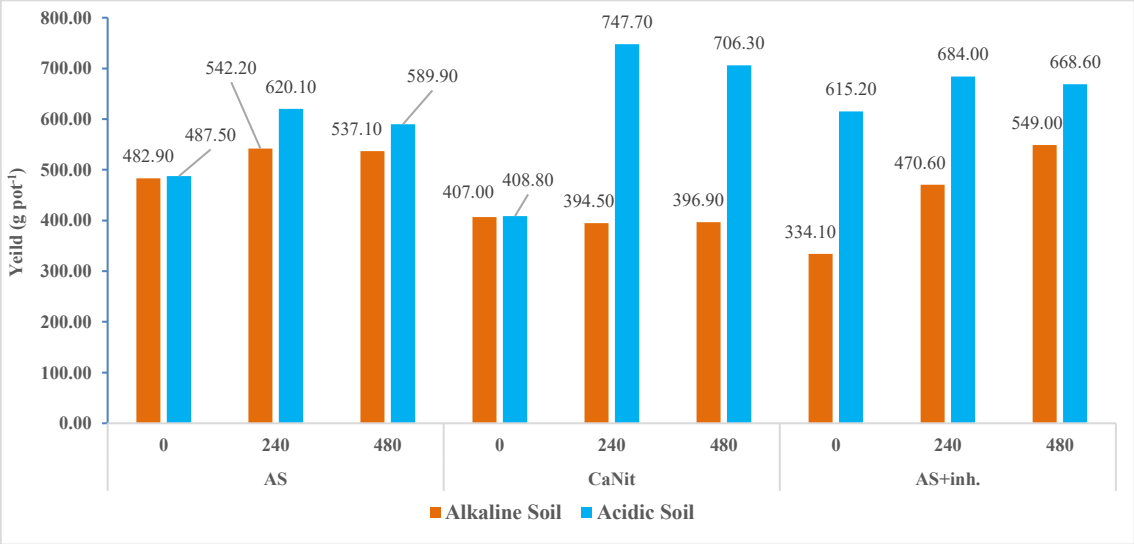


Figure 1. Effects of nitrogenous sources and potassium doses on tomato yield in alkaline and acidic soils

The AS fertilizer is acidic. As a result, it can be easily used in both neutral and calcareous alkaline soils. In the control application of AS+inh. in alkaline soils, because the plant was not able to utilize the slow-release nitrogen effectively, there was an absence of potassium, and these nutrients in the soil were not sufficient for normal plant growth. As expected, fruit weight and, consequently, yield per pot remained low due to poor plant nutrition. In acidic soils, AS+inh. provides nitrogen in a plant-absorbable form for an extended period. Plants slowly and regularly absorb it in a balanced way, without any loss. Fertilizers that include nitrogen in the form of ammonium contain nitrification inhibitors. Their function is to reduce the loss of nitrogen from soils through leaching and denitrification. Additionally, they assist in improving the efficiency of NH_4^+ ions by maintaining soil pH for a long period. The optimal yield was obtained in acidic soils with low calcium levels through 500 mg N kg^{-1}, 840 mg CaO kg^{-1} with CaNit fertilizer, and 240 mg K_2O kg^{-1} with potassium fertilizer. As the nutrient balance of the plant is more optimal with this treatment than with other treatments, fruit weight is increased with this application, and, as a result, higher tomato yields were obtained. In the acidic soil, N, and Ca are low, and K is at a medium level. In terms of K/Ca/Mg balance, K and Mg are required for alkaline soil, while Ca and Mg are required for acidic soil. Ca supplied with CaNit and K supplied with potassium sulfate to the acidic soil may have provided a favorable balance for more optimum growth of the plant. According to Zengin et al. (2009), growing sugar beet by adding

increasing amounts of K and Mg into soils that were similar but had an imbalanced Ca/K and Mg/K balance showed that adding potassium increased the yield and quality of the sugar beet. The results of our study about the weight of fruit in tomatoes correspond closely with the results of some researchers. Karaman and Brohi (1996) demonstrated that using 320 kg N ha^{-1} of ammonium nitrate (AN) fertilizer in colluvial soil resulted in the highest tomato production (46.650 kg ha^{-1}). Kotsiras et al. (2005) reached the highest cucumber production by using a ratio of NO_3:NH_4 at 100:0. In their study, Ashraf et al. (2008) found that the combination of calcium and diammonium phosphate-DAP (200 kg N ha^{-1} +100 kg P_2O_5 ha^{-1}) fertilizers, together with an interaction of 150 mg K kg^{-1}, resulted in a maximum sugarcane yield of 7,320.00 kg ha^{-1}. They also noticed that CaNit fertilizer performed better than urea. In their study, Souri and Dehnavard (2017) investigated the impact of several nitrogen fertilizers (AS, urea, and CaNit) on the nutritional content of tomato leaves and the quality of the fruit. They found that the application of CaNit resulted in the maximum yield of fruit. Since AS fertilizer is an acid fertilizer, it can be easily used in neutral and calcareous alkaline soils. Altıntaş (2017) reported that the highest total productivity, early production, and marketable fruits were obtained for tomato plants in the application of K/N: K/N= 2.5; 110 mg L^{-1} N and 275 mg L^{-1} K).

3.1.2. Stem diameter

The interaction between the 'nitrogen fertilizer and potassium dosage' had a statistically significant (1%) effect on tomato stem diameter in acidic soil. However, in alkaline soil, this interaction never had a statistically significant effect on the stem diameter. The data and Duncan groups related to the impact of treatments on stem diameter are shown in *Table 4*. The statistical analysis in *Table 4* shows that the interaction between 'nitrogen fertilizer and potassium dosage' did not have an important effect on stem diameter in the alkaline soil. The application of various nitrogen fertilizers to the soil resulted in the highest stem diameter (12.08 mm) when AS fertilizer was used. When different potassium dosages were applied, the control treatment produced the highest stem diameter of 11.58 mm. Conversely, the 'AS x K_{240}' interaction led to the lowest stem diameter of 12.33 mm, while the 'CaNit x K_0' interaction resulted in the highest stem diameter of 14.67 mm in the acidic soil (*Figure 2*). Plants have a higher and more rapid uptake of nitrate in acidic pH conditions. Furthermore, the *Table 4* indicates that CaNit fertilizer resulted in the greatest average stem diameter (13.83 mm) when used, while AS+inh. fertilizer had the second-highest stem diameter (13.42 mm).

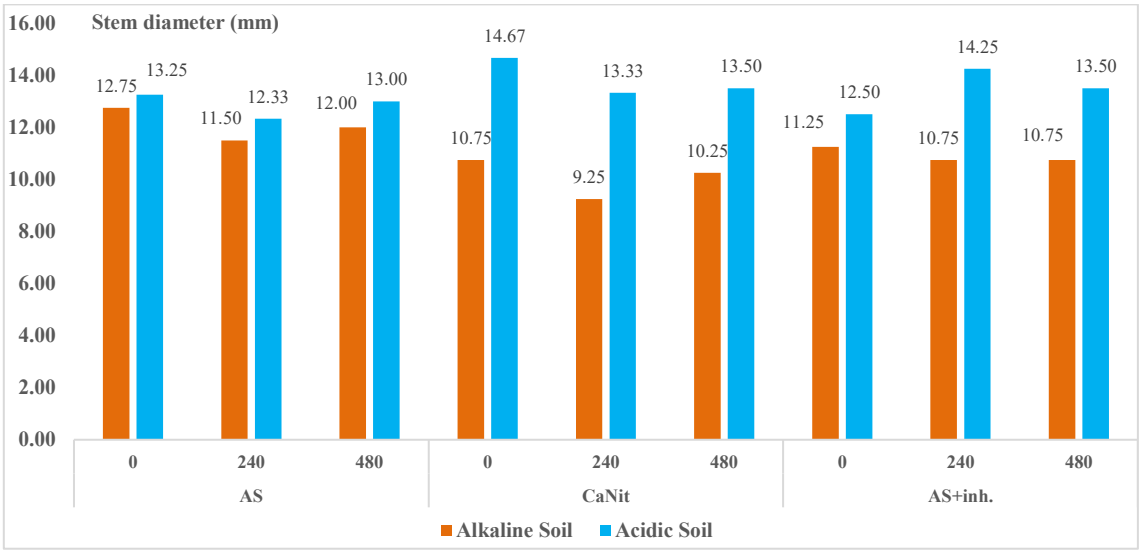


Figure 2. Effects of nitrogenous sources and potassium doses on the stem diameter of tomato in alkaline and acidic soils

Due to high Ca in alkaline soil, the Ca/K/Mg balance may have been upset, and Ca application with CaNit may have resulted in low stem diameter due to insufficient nutrient supply of K and Mg to the plant. According to Haby (1990), for ideal plant growth, Ca:Mg is 6.5:1, Ca:K 13:1 and Mg:K 2:1 (*Table 2*). The study showed that CaNit fertilizer resulted in the highest stem diameter in calcium-poor acidic soil with 500 mg N kg^{-1} and 840 mg CaO kg^{-1}, due to the optimal nutrient balance of the plant. The acidic soil had low levels of N and Ca and moderate levels of K and Mg. The CaNit fertilizer may have provided a favorable balance for optimal plant growth. The

results are similar to previous research, such as the study of Ashraf et al. (2008) on sugarcane plants using CaNit and urea fertilizers, which reported that CaNit gave better results than urea. Demirkiran et al. (2012) found that 20-20-0 and leonardite, two different nitrogen sources, did not have a statistically significant effect on the diameter of tomato stems in neutral soil (pH: 6.8).

3.1.3. Plant height

The relationship between 'nitrogen fertilizer x potassium dose' showed a statistically significant (1%) impact on tomato plant height in soils with alkaline and acidic reactions. The *Table 4* shows that the treatment effects on plant height and Duncan groups. The *Figure 3* shows that the control treatments of AS and inh. AS had the lowest plant height, at 49.50 cm and 51.00 cm, respectively. On the other hand, the 'CaNit x K_{240}' interaction had the highest plant height, at 77.25 cm. In contrast, in the acidic soil, the 'CaNit x K_0' interaction resulted in the lowest plant height of 63.00 cm, while the 'CaNit x K_{240}' interaction led to the highest plant height of 76.00 cm.

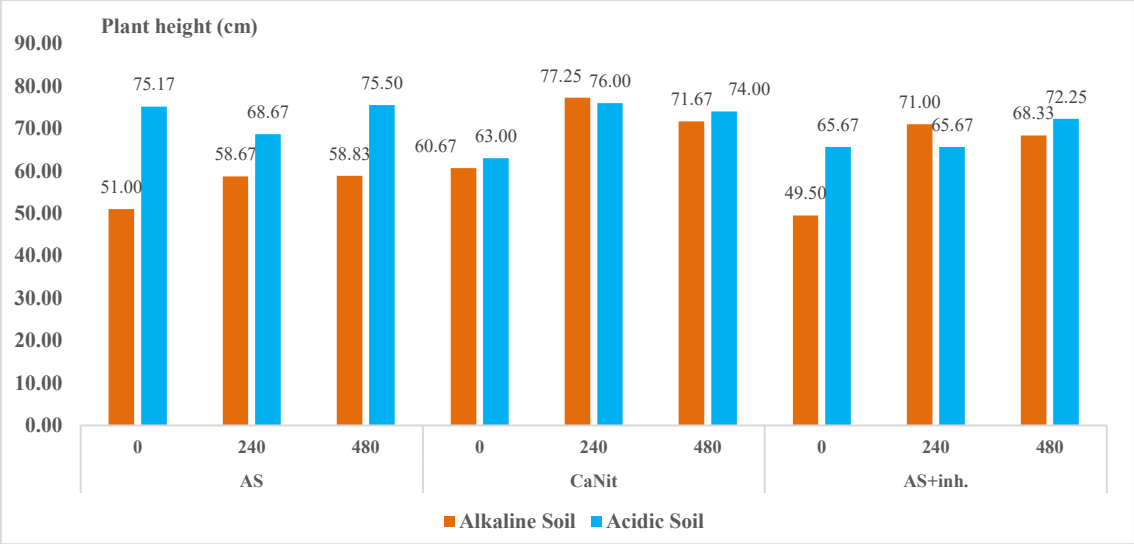


Figure 3. Effects of nitrogenous sources and potassium doses on the plant height of tomato in alkaline and acidic soils

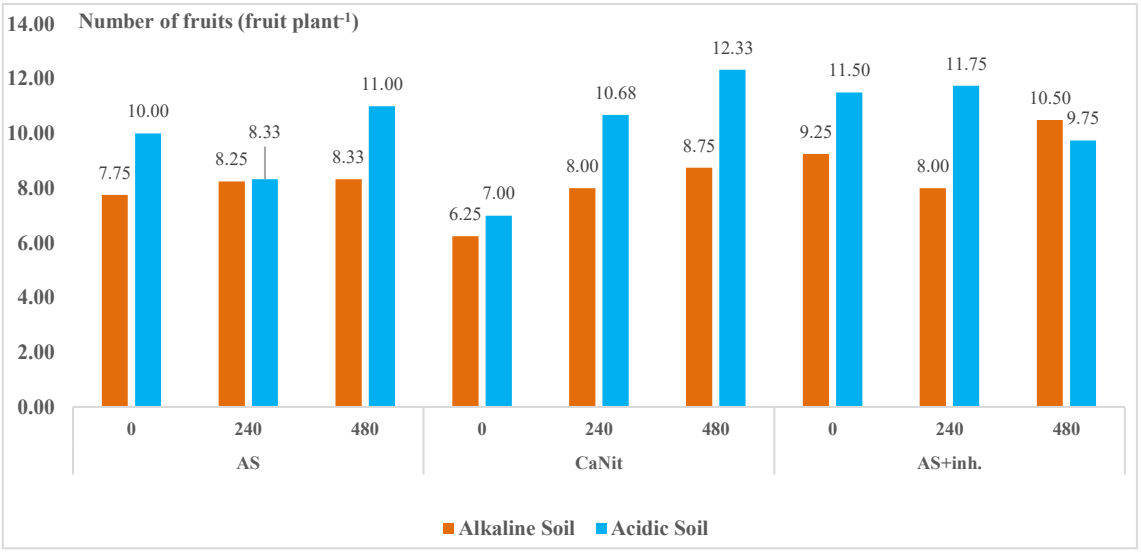
Armstrong (1998) found that the effect of NO_3-N on tomato plant growth was higher than that of NH_4-N. Our results on plant height in tomatoes are similar to the results of some researchers. Souri and Dehnavard (2017) applied AS, CaNit, and urea to tomatoes and obtained the highest plant height from CaNit. Ashraf et al. (2008) applied CaNit and urea fertilizers and a 150 mg K kg^{-1} dose to sugarcane and reported that CaNit gave better results than urea on plant height. Çolpan et al. (2013) obtained the lowest plant height (173.05 cm) at 40 kg K_2O ha^{-1} dose and the highest plant height (181.81 cm) at 160 kg K_2O da^{-1} dose.

3.1.4. Number of fruits

The interaction between nitrogen fertilizer application and potassium dosage had a statistically significant (1%) effect on the number of fruits of tomato plants grown on both alkaline and acidic soils. The values and Duncan groups for the effect of the treatments on the number of fruits in the plant are given in *Table 4*. The CaNit control treatment caused the lowest number of fruits (6.25 pcs $plant^{-1}$), while the 'inh. AS x K_{480}' interaction provided the highest number of fruits (10.50 pcs $plant^{-1}$), as the *Figure 4* shows. The application of inh. AS nitrogen fertilizers to alkaline soil resulted in the highest average number of fruits (9.25 pcs $plant^{-1}$). However, in the acidic soil, the 'CaNit x K_0' interaction caused the lowest fruit number (7.00 pcs $plant^{-1}$), while the 'inh. AS x K_{240}' interaction yielded the highest number of fruits at (11.75 pcs $plant^{-1}$). The number of fruits in the acidic soil had a positive correlation with the increasing rates of potassium, varying from 0-480 mg K_2O kg^{-1}.

The number of fruits in the plant is an important factor in yield and provides an effect on the total tomato production, together with the weight of the fruits. According to Javaria et al. (2012), Potassium application significantly increased number of flowers/plant, fruit set rate, fruit/plant and yield/ha. As a result, they need more potassium fertilization. The study showed that optimum fruit production was obtained with 500 mg N kg^{-1}, 840

mg CaO kg^{-1} with CaNit fertilizer, and 480 mg K_2O kg^{-1} with potassium fertilizer in calcium-deficient acidic soil. The Ca was supplied by CaNit and the K was supplied by potassium sulfate to the acid soil may have provided a favorable balance for optimum plant development. Our results for tomato fruit numbers are similar to those of some researchers. Karaman and Brohi (1996) found the highest number of tomato fruits at a 320 kg N da^{-1} dose of AN fertilizer in colluvial soils. Jung et al. (1994) found the highest number of tomato fruits at a NO_3:NH_4 ratio of 10:0. In other words, nitrate nitrogen increased the number of fruits more than ammonium. In our study, CaNit had



a higher fruit number than other nitrogen fertilizers. Similarly, Gelmez and Müftüoğlu, (2018) they found that the use of AN fertilizer increased the number of fruits of tomato plants.

Figure 4. Effects of nitrogenous sources and potassium doses on the fruit number of tomatoes in alkaline and acidic soils

3.1.5. Fruit diameter

The interaction between the application of nitrogen fertilizer and potassium dosage had a statistically significant (1%) impact on the fruit diameter of tomato plants in both alkaline and acidic soils. The values and Duncan groups of the effects of treatments on fruit diameter are given in *Table 4*. The results show that the 'AS x K_{480}' treatment released the lowest fruit diameter (53.59 mm), whereas the 'CaNit x K_0' interaction obtained the largest fruit diameter (60.64 mm; *Figure* 5) offers this relationship. In contrast, in the acidic soil, the smallest fruit diameter (52.89 mm) was seen in the 'AS x K_{240}' combination, while the largest fruit diameter (59.43 mm) occurred in the 'inh. AS x K_0' combination.

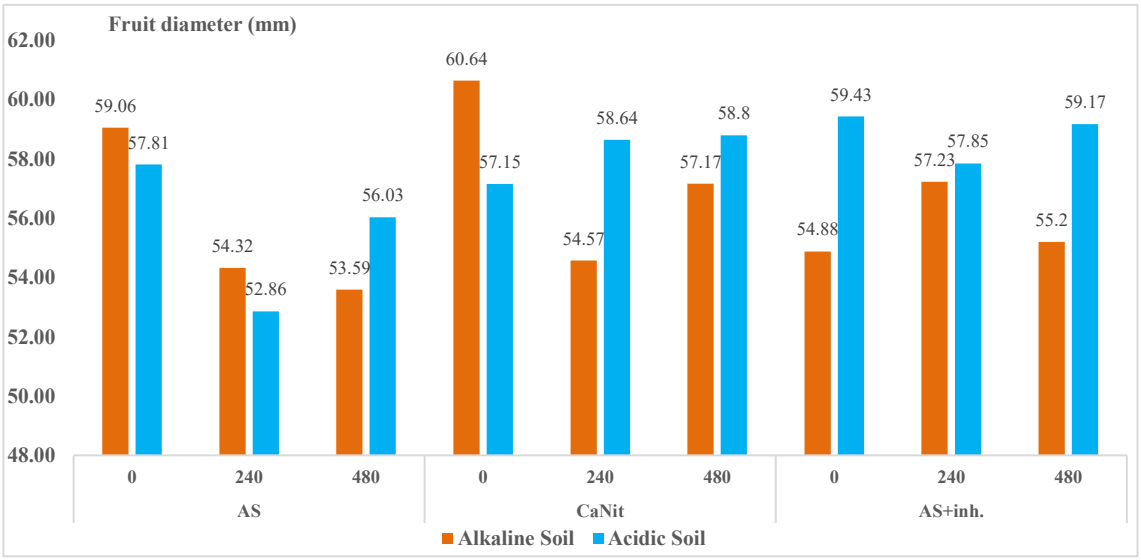


Figure 5. Effects of nitrogenous sources and potassium doses on the fruit diameter of tomato in alkaline and acidic soils

The results of our study about the fruit diameter in tomatoes correspond significantly with the results of some researchers. According to Yağmur et al. (2004), the application of potassium at various dosages (0, 120, 240, and 360 kg K_2O ha^{-1}) resulted in a variety of fruit diameters for tomato plants, weighing between 59.2 and 61.6 mm. Kotsiras et al. (2005) obtained the highest cucumber fruit diameter by applying a NO_3:NH_4 ratio of 100:0. In their study, Woldemariam et al. (2018) observed that the tomato plants showed the largest fruit diameter when treated with a dose of 150 kg K_2O ha^{-1}. At a dose of 200 kg K_2O ha^{-1}, the tomato plants showed the second-highest fruit diameter, whereas the absence of K_2O application resulted in the smallest fruit diameter.

3.1.5. Average fruit weight

The interaction between 'nitrogen fertilizer and potassium dosage' didn't have a statistically significant effect on the average fruit weight of tomatoes in the soil with alkaline pH. The interaction between the nitrogen fertilizer and potassium dosage in acidic soil had a statistically significant (1%) effect on the average weight of tomato fruits. *Table 4* provides the values and Duncan groups for the impact of treatments on average fruit weight.

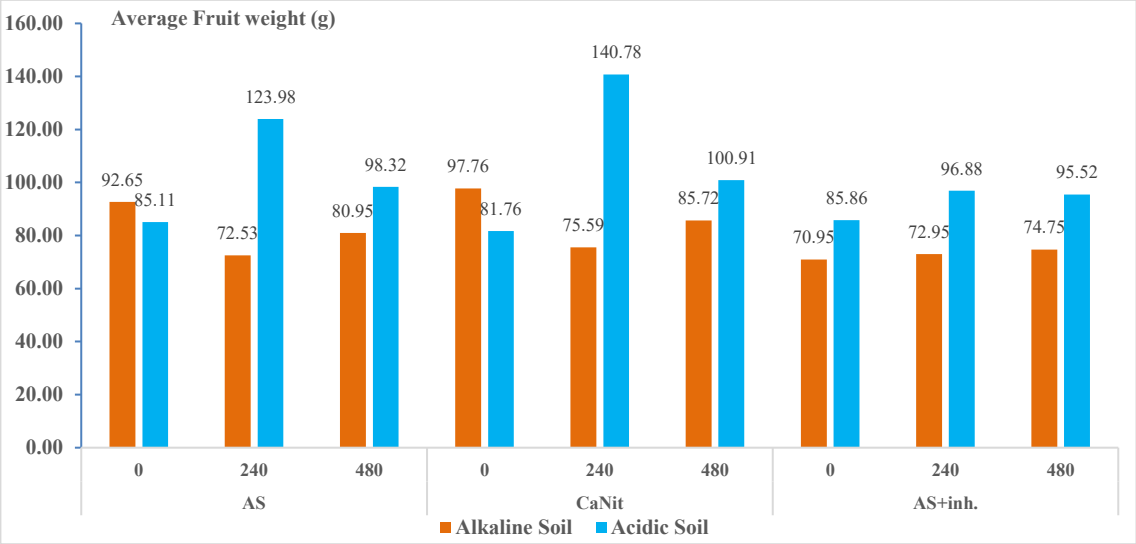


Figure 6. Effects of nitrogenous sources and potassium doses on the average fruit weight of tomato in alkaline and acidic soils

According to the data shown in *Figure 6*, the effect of the interaction between nitrogen fertilizer and potassium dosage on fruit weight was not statistically significant in the alkaline soil condition. The average results of nitrogen fertilizers indicate that the CaNit fertilizer gave the largest fruit weight of 86.35 g, while the second highest fruit weight of 82.04 g resulted from the application of AS fertilizer. The control dosage yielded the largest fruit weight (87.12 g) based on the average results of potassium doses. At the same time, the 'CaNit x K_0' interaction resulted in the lowest fruit weight of 81.76 g, while the 'CaNit x K_{240}' interaction resulted in the largest fruit weight of 140.78 g in acidic soil. The CaNit fertilizer provided the largest fruit weight (107.82 g) based on the average results of various nitrogen fertilizers. Similarly, the K_{240} dosage resulted in the highest fruit weight (120.55 g) based on the average results of different potassium doses (*Table 4*).

Fruit weight remained low due to poor nutrition as the plant had difficulty utilizing the slow-release nitrogen in the inh. AS control treatment was not efficient, and potassium was not fertilized, resulting in insufficient nutrients for normal plant growth. The study found that the highest average fruit weight was obtained with 500 mg N kg^{-1}, 840 mg CaO kg^{-1} with CaNit fertilizer, and 240 mg K_2O kg^{-1} with potassium fertilizer in calcium-deficient acid soils. This was due to the optimum nutrient balance of the plant. The study also showed that K and Mg are necessary for the alkaline soil of Konya, while Ca and Mg are necessary for the acidic soil. The balanced nutritional requirements of Ca and K may have contributed to optimal plant development. Zengin et al. (2009) also reported an increase in sugar beet yield and quality with potassium applications. Our results on fruit weight in tomatoes are like the findings of some researchers. Karaman and Brohi (1996) obtained the highest tomato fruit weight from a 320 kg N ha^{-1} dose of AN fertilizer in colluvial soil. Kotsiras et al. (2005) obtained the highest cucumber fruit weight from the NO_3:NH_4 ratio (100:0). Gelmez and Müftüoğlu, (2018) they found that the use of AN fertilizer increased the number of fruits of tomato plants.

3.2. Effect of Different Nitrogenous Sources and Potassium Doses on Some Fruit Quality of Tomato Plants Grown in Alkaline and Acidic Soils

3.2.1. Fruit hardness

The interaction between the application of nitrogen fertilizer and potassium dosage showed a statistically significant effect (1%) on the fruit hardness in both alkaline and acidic soils. *Table 5* provides the values and Duncan groups that related to the effect of treatments on fruit hardness. In the alkaline soil, the 'AS x K_0' application released the lowest fruit hardness (2.82 kg cm^{-2}), whereas the 'CaNit x K_0' interaction caused the

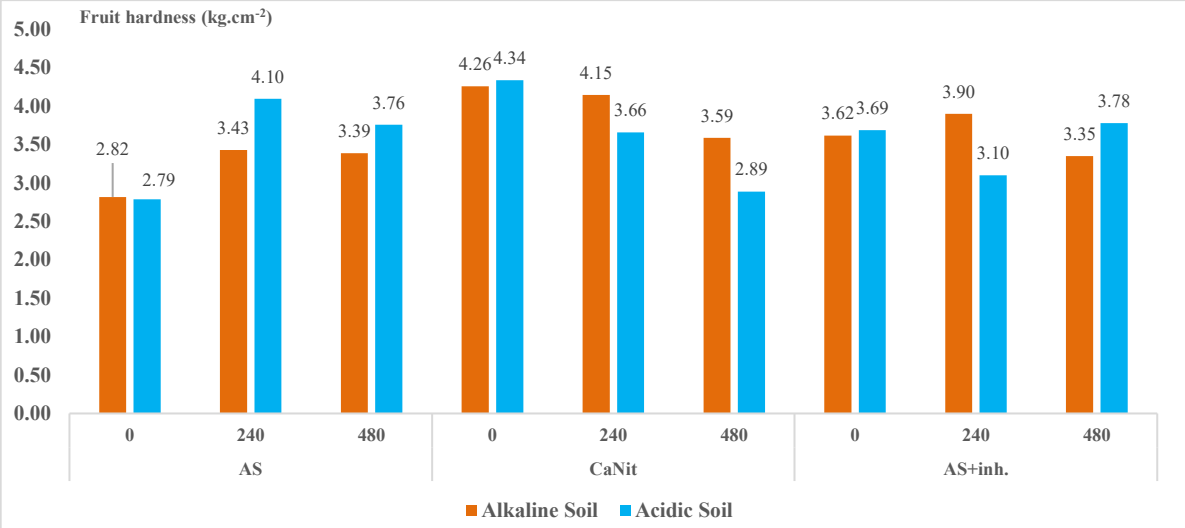


Figure 7. Effects of different nitrogenous sources and potassium doses on the fruit hardness of tomato plants grown in alkaline and acidic soils

highest fruit hardness (4.26 kg cm^{-2}; *Figure 7*). The CaNit fertilizer provided the highest fruit hardness (4.00 kg cm^{-2}) based on the average results of nitrogen fertilizers in the alkaline soil. When applying a potassium dosage of 240 mg K_2O kg^{-1}, the fruit hardness reached the highest value of (3.83 kg cm^{-2}), based on the average values. Conversely, the control treatment with AS led to the lowest fruit hardness at 2.79 kg cm^{-2}, while the 'CaNit x K_0' interaction resulted in the highest fruit hardness at 4.34 kg cm^{-2}. The CaNit fertilizer revealed the highest fruit hardness (3.63 kg cm^{-2}) based on the average results of the nitrogen fertilizers applied to the acid soil. Based on the average results from the potassium dosages, the control, and 240 mg K_2O kg^{-1} treatments showed the highest fruit hardness, measuring at 3.61 kg cm^{-2} and 3.60 kg cm^{-2}, respectively (*Table 5*).

The CaNit applied to the acid soil may have increased the Ca concentration in the peel by maintaining a favorable K/Ca/Mg balance. Kacar et al. (2002) reported that calcium increases sclerenchyma cells and cell wall thickness. Our results on the hardness of the tomato fruit are similar to the results obtained by some researchers. Souri and Dehnavard (2017) obtained the highest fruit hardness from CaNit application among different nitrogen sources (AS, urea, and CaNit) applied to tomato plants.

3.2.2. Fruit pH

The interaction between the application of nitrogen fertilizer and potassium dosage had a statistically significant (1%) impact on the pH of the fruit in both alkaline and acidic soils. *Table 5* provides the values and Duncan groups of the treatments' effects on fruit pH. The *Figure 8* indicates that the 'AS x K_{240}' application had the lowest fruit pH of 4.07, while the 'CaNit x K_0' interaction in alkaline soil had the highest fruit pH of 4.31. The average results of nitrogen fertilizers indicate that CaNit and inh. AS fertilizers had the greatest fruit pH values of 4.21 and 4.19, respectively. Similarly, the average results of potassium dosages show that the control treatment led to the highest fruit pH value of 4.23. However, in soil with high acidity, the 'inh. AS x K_{240}' interaction revealed the lowest fruit pH of 4.17, while the 'CaNit x K_0' interaction resulted in the highest fruit pH of 4.36. The AS fertilizer yielded the highest fruit pH (4.34) based on the average nitrogen fertilizer levels in acid soil. The control dosage gave the highest fruit pH (4.33) based on the average potassium doses. The application of CaNit to the

acidic soil enables calcium absorption, which neutralizes fruit acidity and leads to a rise in the pH of fruits (*Table 5*).

The increase in fruit pH can be related to the neutralization of fruit acidity by the increased absorption of calcium from CaNit in acidic soil. We compared the pH results of our tomato fruit with those obtained by certain studies. According to FAO (1992), the pH level of tomato juice was below 4.5. In their study, Sahin et al. (1998) observed that the pH levels of tomato juice ranged from 4.21 to 5.65. According to Javaria et al. (2012), tomato juice had pH values that varied between 4.57 and 4.87, with 0 mg K kg^{-1} resulting in the highest pH value of 4.87. In their study, Yağmur et al. (2004) reported that the pH levels of tomato juice, when treated with varying dosages of potassium (0, 120, 240, and 360 kg K_2O ha^{-1}), ranged from 4.07 to 4.10. In a study conducted by Nzanza (2006), it was noted that the pH level of tomato juice ranged from 4.0 to 4.5. Furthermore, increasing the concentration of potassium (K) in the nutritional solution resulted in a decrease in the pH of tomato fruit. Fandi et al. (2010) reported that the pH of tomato juice varied between 4.23 and 4.39. Applying CaNit alone into acidic soils with low calcium levels can lead to a good balance of Ca, K, and Mg uptake and higher fruit dry matter because the crop can better use these three macronutrients.

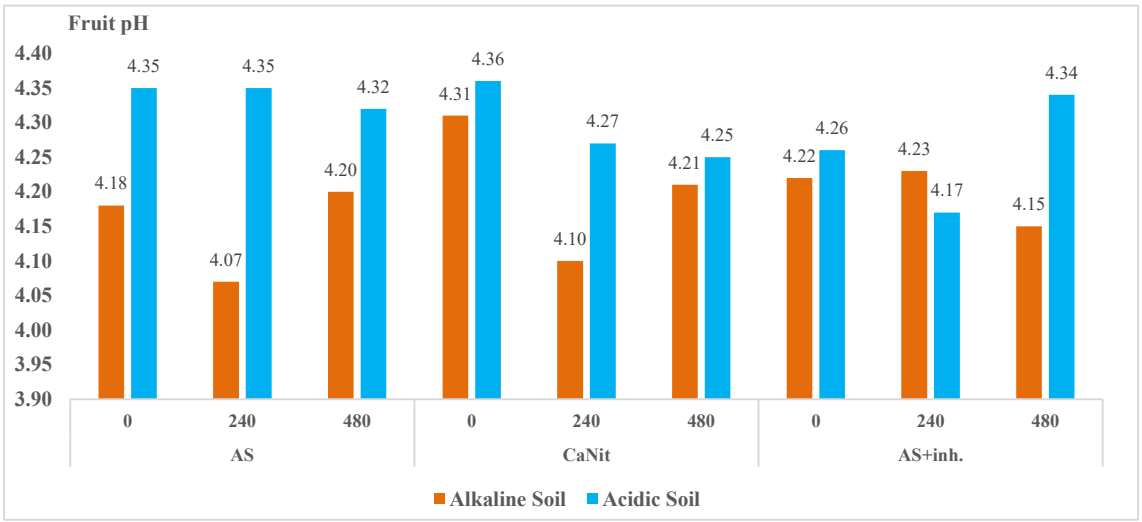


Figure 8. Effects of different nitrogenous sources and potassium doses on the pH of tomato plant fruits grown in alkaline and acidic soils

3.2.3. Fruit brix (dry matter)

The interaction between the nitrogen fertilizer and potassium dosage showed a statistically significant effect (at a 1% level) on the fruit brix in tomato plants in both alkaline and acidic soils. *Table 5* provides the values and Duncan groups for the treatments' impact on brix. *Figure 9* shows that the control treatment of 'CaNit' had the lowest brix (5.01%), while the 'CaNit x K_{240}' interaction had the highest brix (5.39%). The average results of potassium doses

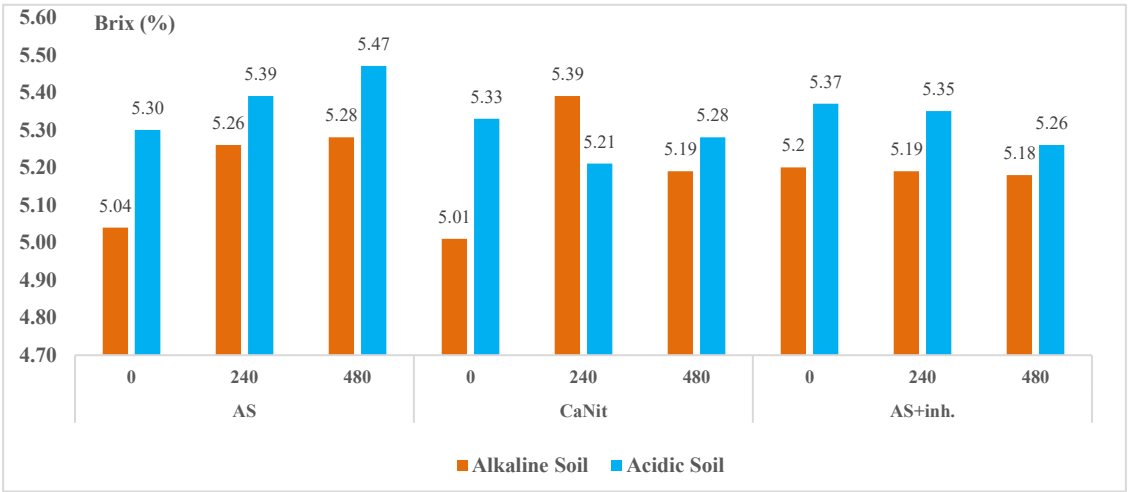


Figure 9. Effects of different nitrogenous sources and potassium doses on Fruit brix (dry matter) tomato plants grown in alkaline and acidic soils

in alkaline soil showed that the highest brix (5.28%) was obtained with a dose of 240 mg K_2O kg^{-1}. The control treatment of AS yielded the lowest brix (5.30%) in acidic soil, while the 'AS x K_{480}' interaction resulted in the highest brix (5.47%). The AS fertilizer yielded the highest brix (5.39%) among the nitrogen fertilizers applied to acidic soil. High brix (water-soluble dry matter) is necessary for tomato flavor and tomato paste yield. FAO (1992) reported that tomato brix values are between 5 and 8%. Our results on brix in tomato fruit are similar to the results of some researchers. Yağmur et al. (2004) obtained tomato brix values between 4.32 and 5.02% with potassium applied at different doses (0, 120, 240, and 360 kg K_2O ha^{-1}). Similarly, in another study, the highest brix (5.25%) was obtained with increasing potassium levels (150, 300, and 450 mg K L^{-1}) at a 450 mg K L^{-1} dose (Öktüren Asri and Sönmez, 2010). Fandi et al. (2010) observed that the brix values of tomatoes varied between 5.6 and 6.4%. Şahin et al. (1998) investigated the effects of different growing media on yield, quality, and plant growth of tomato plants and found that brix values in tomatoes varied between 4.1 and 5.65%. Javaria et al. (2012) reported that brix values in tomatoes varied between 5.0 and 6.97% and found the highest brix value (6.97%) at a dose of 375 mg K kg^{-1}. Şahin et al. (2016) also reported that tomato brix values varied between 5.05 and 5.65%.

Table 4. The effect of various nitrogenous sources and potassium dosages on the yield and yield components of tomato plants grown on different soil types

Soil	N Sources	K doses	*Yield (g pot^{-1})*	*Stem Diameter (mm)*	*Plant height (cm)*	*Number of fruits (fruit plant^{-1})*	*Fruit diameter (mm)*	*Average Fruit weight (g)*
Alkaline Soil	AS	0	482.90 b	12.75 n.s	51.00 e	7.750 bc	59.06 ab	92.65 n.s
		240	542.20 a	11.50 n.s	58.67 d	8.25 bc	54.32 cd	72.53 n.s
		480	537.10 a	12.00 n.s	58.83 d	8.33 b	53.59 d	80.95 n.s
	Mean		**520.70 A**	**12.08 A**	**56.17 C**	**8.11 B**	**55.66 B**	**82.04 A**
	CaNit	0	407.00 c	10.75 n.s	60.67 d	6.25 c	60.64 a	97.76 n.s
		240	394.50 c	9.25 n.s	77.25 a	8.00 bc	54.57 cd	75.59 n.s
		480	396.90 c	10.25 n.s	71.67 b	8.75 ab	57.17 bc	85.72 n.s
	Mean		**399.50 C**	**10.08 B**	**69.86 A**	**7.67 B**	**57.46 A**	**86.35 A**
	AS+inh.	0	334.10 d	11.25 n.s	49.50 e	9.25 ab	54.88 cd	70.95 n.s
		240	470.60 b	10.75 n.s	71.00 b	8.00 bc	57.23 bc	72.95 n.s
		480	549.00 a	10.75 n.s	68.33 c	10.50 a	55.20 cd	74.75 n.s
	Mean		**451.20 B**	**10.92 B**	**62.94 B**	**9.25 A**	**55.77 B**	**72.88 B**
	K0		408.00 C	11.58 a	53.72 C	7.75 b	58.19 A	87.12 A
	K_{240}		469.10 B	10.50 ab	68.97 A	8.10 b	55.37 B	73.69 B
	K_{480}		494.30 A	11.00 b	66.28 C	9.20 a	55.32 B	80.47 AB
					ANOVA			
	N Sources		**	**	**	**	**	**
	K doses		**	*	**	*	**	**
	N sour. x K doses		**	N.S	**	**	**	N.S
Acidic Soil	AS	0	487.50 f	13.25 ab	75.17 a	10.00 ab	57.81 ab	85.11 de
		240	620.10 d	12.33 b	68.67 c	8.33 bc	52.86 c	123.98 b
		480	589.90 e	13.00 ab	75.50 a	11.00 a	56.03 b	98.32 c
	Mean		**565.80 C**	**12.86 b**	**73.11 A**	**9.78 n.s**	**55.57 B**	**102.47 B**
	CaNit	0	408.80 g	14.67 a	63.00 d	7.00 c	57.15 ab	81.76 e
		240	747.70 a	13.33 ab	76.00 a	10.68 ab	58.64 ab	140.78 a
		480	706.30 b	13.50 ab	74.00 ab	12.33 a	58.80 ab	100.91 c
	Mean		**621.00 B**	**13.83 a**	**71.00 B**	**10.00 n.s**	**58.20 A**	**107.82 A**
	AS+inh.	0	615.20 de	12.50 b	65.67 d	11.50 a	59.43 a	85.86 de
		240	684.00 bc	14.25 ab	65.67 d	11.75 a	57.85 ab	96.88 c
		480	668.60 c	13.50 ab	72.25 b	9.75 ab	59.17 ab	95.52 cd
	Mean		**656.00 A**	**13.42 ab**	**67.86 C**	**11.00 n.s**	**58.82 A**	**92.75 C**
	K0		503.80 C	13.47 n.s	67.95 C	9.50 B	58.13 A	84.24 C
	K_{240}		683.90 A	13.31 n.s	70.11 B	10.25 AB	56.45 B	120.55 A
	K_{480}		655.00 B	13.33 n.s	73.92 A	11.03 A	58.00 A	98.25 B
					ANOVA			
	N Sources		**	*	**	N.S	**	**
	K doses		**	N.S	**	**	**	**
	N souc. x K doses		**	**	**	**	**	**

*****: p<0.01, *: p<0.05, N.S: Not Significant***

Table 5. The effect of different nitrogenous sources and potassium doses on some fruit quality of tomato plants grown in alkaline and acidic soils

Soil	N Sources	K doses	*Fruit hardness (kg.cm^{-2})*	*Fruit pH*	*Brix (%)*
Alkaline Soil	AS	0	2.82 g	4.18 cd	5.04 d
		240	3.43 e	4.07 e	5.26 b
		480	3.39 ef	4.20 bc	5.28 b
	Mean		**3.25 C**	**4.15 B**	**5.20 n.s**
	CaNit	0	4.26 a	4.31 a	5.01 d
		240	4.15 b	4.10 e	5.39 a
		480	3.59 d	4.21 bc	5.19 c
	Mean		**4.00 A**	**4.21 A**	**5.20 n.s**
	AS+inh.	0	3.62 d	4.22 b	5.20 c
		240	3.90 c	4.23 b	5.19 c
		480	3.35 f	4.15 d	5.18 c
	Mean		**3.62 B**	**4.19 A**	**5.19 n.s**
	K_0		3.57 B	4.23 A	5.08 C
	K_{240}		3.83 A	4.13 C	5.28 A
	K_{480}		3.45 C	4.18 B	5.22 B
	ANOVA				
	N Sources		**	**	N.S
	K doses		**	**	**
	N Sources x K doses		**	**	**
Acidic Soil	AS	0	2.79 g	4.35 a	5.30 d
		240	4.10 b	4.35 a	5.39 b
		480	3.76 c	4.32 b	5.47 a
	Mean		**3.54 B**	**4.34 A**	**5.39 A**
	CaNit	0	4.34 a	4.36 a	5.33 cd
		240	3.66 d	4.27 c	5.21 f
		480	2.89 f	4.25 d	5.28 de
	Mean		**3.63 A**	**4.29 B**	**5.27 C**
	AS+inh.	0	3.69 cd	4.26 cd	5.37 bc
		240	3.10 e	4.17 e	5.35 c
		480	3.78 c	4.34 a	5.26 e
	Mean		**3.53 B**	**4.26 C**	**5.33 B**
	K_0		3.61 A	4.33 A	5.33 n.s
	K_{240}		3.60 A	4.26 C	5.32 n.s
	K_{480}		3.48 B	4.30 B	5.34 n.s
	ANOVA				
	N Sources		**	**	**
	K doses		**	**	NS
	N Sources x K doses		**	**	**

*****: p<0.01, *: p<0.05, N.S: Not Significant***

4. Conclusions

According to the study results, the effects of different nitrogenous sources and potassium doses on tomato yield, yield components, and some fruit quality parameters in different soils were statistically significant (P<0.01, P<0.05). In the alkaline soil, the highest tomato yield (549.00 g pot^{-1}) was obtained from the 'inh. AS x K_{480}' interaction. According to the average yield results for different nitrogen fertilizers applied into alkaline soil, the highest tomato yield (520.70 g pot^{-1}) was found in AS application, and tomato yield increased with increasing potassium doses from 0 mg K_2O kg^{-1} dose to 480 mg K_2O kg^{-1} dose. In the acidic soil, the highest tomato yield (747.70 g pot^{-1}) was obtained from the 'CaNit x K_{240}' interaction. According to the average yield results of different nitrogen fertilizers applied to acid soils, the highest tomato yield (656.00 g pot^{-1}) was obtained from the inh. AS fertilizer application and based on the average yield results of the potassium doses, the highest tomato yield (683.90 g pot) was obtained from the 240 mg K_2O kg^{-1} dose. The relationship between potassium (K) and nitrogen (N) is essential for the growth and development of tomatoes, since it affects numerous physiological and biochemical processes. Potassium is vital for various plant processes, such as enzyme activation, photosynthesis, and nutrient transport, whereas nitrogen is a crucial constituent of amino acids and proteins. The simultaneous administration of these nutrients can substantially influence tomato growth, yield, and quality. Potassium substantially influences tomato growth and quality; yet its relationship with nitrogen is complex and demands careful management in order to maximize advantages. Maintaining an equilibrium among these nutrients is crucial for optimizing productivity and quality while reducing adverse environmental effects. Nonetheless, excessive application may result in diminishing results and possible environmental harm, underscoring the necessity of targeted nutrient management measurements.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Zengin, M., Gezgin, S.; Design: Zengin, M., Yılmaz, F.; Data Collection or Processing: Nazzal, M., Uzun, F.; Statistical Analyses: Nazzal, M., Uzun, F.; Literature Search: Nazzal, M.; Writing, Review and Editing: Zengin, M., Nazzal, M.

References

Altıntaş, S. (2017). Effects of seedling age, and different levels of N, K and K/N on quality and yield of tomato grown in perlite bag culture. *Journal of Tekirdag Agricultural Faculty,* The Special Issue of 2nd International Balkan Agriculture Congress: 55-61.

Armstrong, D. I. (1998). Potassium Interactions with Other Nutrients. *Better Crops*, 28(3): 12-14.

Ashraf, M. Y., Hussain, F., Akhter, J., Gul, A., Ross, M. and Ebert, G. (2008). Effect of different sources and rates of nitrogen and supra optimal level of potassium fertilization on growth, yield and nutrient uptake by sugarcane grown under saline conditions. *Pakistan Journal of Botany,* 40(4): 1521-1531.

Awaad, M. S., Badr, R. A., Badr, M. A. and Abd-elrahman, A. H. (2016). Effects of different nitrogen and potassium sources on lettuce (*Lactuca sativa* L.) yield in a sandy soil. *Eurasian Journal of Soil Science,* 5(4): 299-306.

Bayraklı, F. (1987). Soil and Plant Analysis. Ondokuz Mayıs University, Faculty of Agriculture, Publication, (17), 199, Samsun, Türkiye. (in Turkish)

Bayraktar, K. (1970). Vegetable Cultivation. Volume II. Ege University. Faculty of Agriculture. Publication No: 169, 480, Izmir, Türkiye. (in Turkish)

Bouyoucos, G. J. (1951). A recalibration of the hydrometer method for making mechanical analysis of soils. *Agronomy Journal,* 43(9): 434-438.

Bremner, J. M. (1965). Inorganic forms of nitrogen. In: Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties, American Society of Agronomy, Eds: Black, C.A., pp. 1179-1237, Madison, Wisconsin, U.S.A.

Campbell, C. (2000). Reference sufficiency ranges for plant analysis in the southern region of the United States. ISBN: 1-58161-394-6. Southern Cooperative Series 53Bulletin #394 July 2000 Updated and reformatted July 2009, https://www.ncagr.gov/agronomi/saaesd/scsb394.pdf (accessed Date 15.09.2018).

Cartwright, B., Rathjen, A., Sparrow, D., Paull, J. and Zarcinas, B. (1983). Boron tolerance in Australian varieties of wheat and barley. In Genetic Aspects of Plant Mineral Nutrition. 2nd *International Symposium on Genetic Aspects of Plant Mineral Nutrition, organized by the University of Wisconsin, Madison,* June 16–20, pp. 139-151. Springer Netherlands.

Cemeroglu, B. (1992). Basic Analysis Methods in Fruit and Vegetable Processing Industry. Biltav Press, Ankara, Turkey. (In Turkish)

Ceylan, S., Mordogan, N., Yoldas, F. and Yağmur, B. (2001). The effect of nitrogen fertilization on yield, nitrogen accumulation and content of nutrients in the tomato plant. *Ege University Faculty of Agriculture Journal,* 38(2/3): 103-110.

Çağlar, K. Ö. (1949). Soil Knowledge. Ankara University Faculty of Agriculture Publications No:10, Ankara. (in Turkish)

Çolpan, E., Zengin, M. and Özbahçe, A. (2013). The effects of potassium on the yield and fruit quality components of stick tomato. *Horticulture, Environment and Biotechnology,* 54(1): 20-28.

Dam, B. V. Goffau, M. D. Lidt de Jeude, J. V. and Naika, S. (2005). Cultivation of tomato: production, processing and marketing. Agrodok; 17. Agromisa/CTA, Wageningen, The Netherlands.

Demirkıran, A. R., Ozbay, N. and Demir, Y. (2012). The effect of leonardite and inorganic fertilizers on the tomato growth. *Turkish Journal of Nature and Science,* 1(2): 48-52.

Fandi, M., Muhtaseb, J. and Hussein, M. (2010). Effect of N, P, K concentrations on yield and fruit quality of tomato (*Solanum Lycopersicum L.*) in tuff culture. *Journal of Central European Agriculture,* 11(2): 179-184.

FAO (1992). Vegetable Juices. http://www.fao.org/docrep/005/Y2515E/y2515e18.htm (Accessed Date: 15.01.2019).

Gelmez, C. and Müftüoğlu, N. M. (2018). Effect of different calcium doses and nitrogen fertilizers on yield and yield characteristic in tomatoes. *Journal of Çanakkale Onsekiz Mart University Graduate School of Natural and Applied Sciences,* 4 (2): 134-148. (in Turkish)

Haby, V. A., Russelle, M. P. and Skogley, E. O. (1990). Testing soils for Potassium, Calcium, and magnesium. In: Soil Testing and Plant Analysis. 3rd ed. Eds: Westerman, R. L., Madison, WI: SSSA, p. 181–227.

Huett, D. and Dettmann, E. (1988). Effect of nitrogen on growth, fruit quality and nutrient uptake of tomatoes grown in sand culture. *Australian Journal of Experimental Agriculture,* 28(3): 391-399.

Jackson, M. L. (1958). Soil Chemical Analysis. Prentice Hall. Inc., Englewood Cliffs, NJ, 498, 183-204.

Javaria, S., Khan, M. and Bakhsh, I. (2012). Effect of potassium on chemical and sensory attributes of tomato fruit. *Journal of Animal & Plant Sciences,* 22(4): 1081-1085.

Javaria, S., Khan, M., Rahman, H. and Bakhsh, I. (2012). Response of tomato (*Lycopersicon esculentum L.*) yield and post-harvest life to potash levels. *Sarhad Journal of Agriculture,* 28(2): 227-235.

Jung, H. B., Ito, T. and Maruo, T. (1994). Effects of shading and NO_3:NH_4 ratios in the nutrient solution on the growth and yield of pepper plants in nutrient film technique culture. *Journal of the Japanese Society for Horticultural Science,* 63(2): 371-377.

Kacar, B., Katkat, A. V. and Öztürk, Ş. (2002). Plant Physiology. Uludağ University Strengthening Foundation Publication, No: 198, Vipaş A.Ş. Publication No: 74. Livane Printing House, Istanbul. p: 563. (in Turkish)

Karaman, M. R. and Brohi, A. R. (1996). Effect of nitrogenous fertilizers applied in different forms on iron, copper, zinc and manganese content of tomato plant (*Lycopersicon Esculentum* L.). *Journal of Agricultural Faculty of Gaziosmanpaşa University,* (1): 397-410.

Kotsiras, A., Olympios, C. and Passam, H. (2005). Effects of nitrogen form and concentration on yield and quality of cucumbers grown on rockwool during spring and winter in southern Greece. *Journal of Plant Nutrition,* 28(11): 2027-2035.

Leigh, R. and Wyn Jones, R. (1984). A hypothesis relating critical potassium concentrations for growth to the distribution and functions of this ion in the plant cell. *New Phytologist,* 97(1): 1-13.

Lindsay, W. L. and Norwell, W. A. (1978). Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal,* (42): 421-428.

Natlia, S. A., Maria, E. D. S. F., Leonardo, A. A., Flvio, L. F. and Natalia, O. S. (2018). Nutritional quality of tomatoes as a function of nitrogen sources and doses. *African Journal of Agricultural Research,* 13(19): 996-1000.

Nzanza, B. (2006). *Yield and quality of tomato as influenced by differential Ca, Mg and K nutrition.* (MSc. Thesis). Conducted at the Department of Plant Production and Soil Science in the Faculty of natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa.

Olsen, S. V., Cole, F. S., Watanable, W. and Dean, L. A. (1954). Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. United States Department of Agriculture Circ no.939, Washington, DC, U.S.A.

Öktüren Asri, F. and Sönmez, S. (2010). Reflection of different applications of potassium and iron fertilization on tomato yield and fruit quality in soilless medium. *Journal of Food Agriculture and Environment,* 8(3-4): 426-429.

Öztürk, B., Zengin, M. and Gökmen Yılmaz, F. (2020). Effects of potassium and zinc fertilization on the yield and yield components of artichoke. *Journal of Tekirdag Agricultural Faculty,* 17(2): 180-190. (in Turkish)

Reboucas, T., Porto, J., Jesus, J. and Moraes, M. (2015). Effects of different nitrogen sources and levels on tomato fruit quality. *Acta Horticulturae,* (1106): 79-84.

Richard, L. A. (1954). Diagnosis and Improvement Saline and Alkaline Soils. USDA Handbook No. 60, Washington, DC, U.S.A.

Sainju, U. M., Dris, R. and Singh, B. (2003). Mineral nutrition of tomato. *Journal of Food, Agriculture & Environment,* 1(2): 176-183.

Soltanpour, P., Workman, S. and Schwab, A. (1979). Use of inductively-coupled plasma spectrometry for the simultaneous determination of macro-and micronutrients in NH_4HCO_3-DTPA extracts of soils. *Soil Science Society of America Journal,* 43(1): 75-78.

Souri, M. K. and Dehnavard, S. (2017). Tomato plant growth, leaf nutrient concentrations and fruit quality under nitrogen foliar applications. *Advances in Horticultural Science,* 32(1): 41-47.

Şahin, S., Ünlükara, A., Geboloğlu, N., Durukan, A. and Karaman, M. R. (2016). Interaction between Nitrogen Doses, irrigation intervals and yield, quality and nutrient elements of leaves in tomato. *Reserach Journal of Agricultural Sciences,* (2): 45-50. (in Turkish)

Şahin, Ü., Özdeniz, A., Zülkadir, A. and Alan, R. (1998). The effects of different growing media on yield, quality and growth of tomato (*Lycopersicon esculentum* Mill.) grown and irrigated by drip irrigation method under the greenhoues conditions. *Turkish Journal of Agriculture and Forestry,* 22(1998): 71-79. (in Turkish)

Woldemariam, S. H., Lal, S., Zelelew, D. Z. and Solomon, M. T. (2018). Effect of potassium levels on productivity and fruit quality of tomato (*Lycopersicon esculentum* L.). *Journal of Agricultural Studies*, 6(1): 104-117.

Yağmur, B., Okur, B. and Ongun, A. (2004). Effects on enhanced potassium doses on yield, quality and nutrient uptake of tomato. *IPI Regional Workshop on Potassium and Fertigation Development in West Asia and North Africa,* 24-28 November, 2004, Rabat, Morocco.

Zengin, M. and Özbahçe, A. (2011). Climate and Soil Requirements of Plants. Atlas Academy Publications. No: 4, ISBN 978-605-61260-3-1, Konya, Türkiye.. (in Turkish)

Zengin, M., Gökmen, F., Yazıcı, M. A. and Gezgin, S. (2009). Effects of potassium, magnesium and sulphur containing fertilizers on yield and quality of sugar beets (*Beta vulgaris* L.). *Turkish Journal of Agriculture and Forestry,* (33): 495-502.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Yeni Bir Mikrodalga Destekli Damıtma Sistemi ile Defne (*Laurus nobilis*) Bitkisinden Uçucu Yağ Elde Edilmesi

Extracting the Essential Oil from Laurel (*Laurus nobilis*) Plant with a New Microwave Assisted Distillation System

Habib DOĞAN[1*], Abdullah GENÇ[2], Muzaffer MUTLU[3]

Öz

Bu çalışmada, dünyadaki ticaret arzının %90'ı ülkemizden gerçekleştirilen Defne (*Laurus nobilis*) bitkisinin, geleneksel buharlı damıtma sistemiyle birlikte, endüstriyel tipte tasarlanan yeni bir mikrodalga destekli damıtma (MDD) sistemi kullanılarak uçucu yağları elde edilmiştir. Literatürdeki tıbbi ve aromatik bitkilerden mikrodalga (MD) desteğiyle damıtma yapılan çalışmalara bakıldığında ya küçük ölçekli laboratuvar cihazı ya da klasik MD fırınlara clevenger ilavesi yapılarak damıtma işleminin gerçekleştirildiği görülmektedir. Ancak, bitki miktarı artıkça elektromanyetik (EM) gücün bitkiye nüfuzu azalacağından dolayı bu küçük ölçekli MD destekli çalışmalar endüstriyel tip damıtma süreçleri için birebir model olmaktan uzak kalacaklardır. Bu amaçla bu çalışmada özgünlük olarak, MD gücün büyük ölçekli sistemlerdeki damıtma süreçlerine etkisini doğru bir şekilde modelleyebilmek için yeni bir endüstriyel tip MDD sistemi tasarlanıp test edilmiştir. Her bir testte 5 kg'lık bitki damıtılmakta olup tasarlanan MDD sisteminde 12 adet magnetron kullanılmıştır. Bu magnetronların farklı güçte çalışması kontrol devresiyle sağlanarak, MD gücünün uçucu yağ verimine ve uçucu yağ bileşenlerine etkileri gözlenmiştir. Yapılan testler sonucunda, MD desteği verilerek yapılan damıtma işlemlerinde, Linalool, Linalyle formate ve β-terpinyl acetate bileşenlerinde dramatik değişimler izlenmiştir. Geleneksel buhar damıtma (BD) sistemine göre uçucu yağ veriminde %10-24'lük bir artış elde edilmiş, süre 100 dk'dan 50 dk'ya düşürülmüştür. %26-35 arası daha az enerji harcanmış ve tüm bunların karşılığında bileşen bazında standart değerlerde uçucu yağ elde edilmiştir. Damıtılma sonucundaki uçucu yağ analizleri GC-MS analizi ile kimyasal olarak analiz edilmiş ve 64 farklı bileşen elde edilmiştir. Bunlardan 29 tanesinin gruplandırılmasıyla yapılan değerlendirmede, monoterpen-oksitlerin %55.68, monoterpen-hidrokarbonların ise %27.96 olduğu, kalan kısmın seskiterpen-oksit, seskiterpen-hidrokarbon ve fenolik bileşenlerden oluştuğu tespit edilmiştir. MW gücünün düşük olduğu testlerde monoterpen-oksitlerin azaldığı, MW gücü arttıkça belli bir oranda yükseldiği tespit edilirken monoterpen-hidrokarbonlarda ise tam tersi bir durum izlenmiştir. Linalool ve linalyl formate bileşenleri MW gücüyle en çok değişen bileşenler olmuştur. Yapılan değerlendirmeler MW desteğinin, endüstriyel tip damıtma süreçlerinde uygulanmasının pozitif etkileri olacağı ve maliyetleri aşağı çekeceği yönündedir.

Anahtar Kelimeler: Defne, *Laurus nobilis*, Mikrodalga destekli damıtma, Uçucu yağ, Mikrodalga güç

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Abstract

In this study, essential oils of Laurel plant (*Laurus nobilis*), 90% of the world trade supply of which is realized from our country, are obtained by using a new industrial-type microwave-assisted distillation (MWAD) system designed together with the traditional steam distillation system. When examining the studies in the literature on MW-assisted distillation from medicinal and aromatic plants, it is seen that the distillation process is carried out either with a small-scale laboratory device or by adding clevenger to conventional microwave (MW) ovens. However, since the penetration of electromagnetic (EM) power into the plant decreases with increasing plant size, these small-scale MW-assisted systems will remain far from being a one-to-one model for industrial-type distillation processes. For this purpose, in this work, a new MWAD system is designed and tested in order to accurately model the effect of MW power on distillation processes in large-scale systems, as a novelty. In each test, 5 kg of plant can be distilled and 12 magnetrons are used in the designed MWAD system. The operation of these magnetrons at different powers is ensured by a control circuit and the effects of MW power on essential oil yield (%) and essential oil components are observed. As a result of the tests, radical changes are observed in some components in the distillation processes performed with MW support. Compared to the traditional steam distillation (BD) system, a 10-24% increase in essential oil yield is achieved, and the time is reduced from 100 min to 50 min. 26-35% less energy is consumed and in return for all this, essential oil is obtained at standard values on a component basis. Essential oil analysis as a result of distillation is chemically analyzed by GC-MS analysis and 64 different components are obtained. In the evaluation made by grouping 29 of them, it is determined that oxygenated monoterpenes are 55.68%, hydrocarbon monoterpenes are 27.96%, and the remaining part consisted of oxygenated and hydrocarbon sesquiterpenes and phenolic components. In tests where low MW power is applied, it is determined that oxygenated monoterpenes decrease and MW power ability increases to a certain extent, while the opposite situation is observed for hydrocarbon monoterpenes. Linalool and linalyl formate components have become the most economical solution with MW power. Evaluations indicate that MW support will yield positive results in the industrial distillation spectrum and reduce costs.

Keywords: Laurel, *Laurus nobilis*, Microwave-assisted distillation, Essential oil, Microwave power

1. Giriş

Covid salgını sonrası bitkisel ürünlere olan talep aşırı şekilde artış göstermiştir. Bunun nedeni çok uzun zamanlardan beri doğal olarak bazı bitkilerin tıbbi amaçlarla yaygın bir şekilde kullanılması olduğu kadar, gelişen teknoloji ile birlikte bitkilerdeki sekonder metobolitlerin çok farklı amaçlar için kullanılabileceğinin ortaya çıkarılmasıdır. Tanenler, flavonoidler, alkaloidler, terpenoidler vs. yönünden çok zengin olan bitkilerde (Allal ve ark., 2019), sekonder metobolitler içerisinde yer alan uçucu yağlar günümüzde endüstride birçok alanda kullanılmaktadır. Bu alanların başında parfümeri, kozmetik, aroma, gıda koruma ve farmakoloji gibi alanlar dikkat çekmektedir.

Ülkemiz, tıbbi ve aromatik bitkiler açısından çok zengin bir coğrafyadadır. Neredeyse tüm Avrupa ülkelerinin sahip olduğu ~12 000 bitki çeşitliliği varken ülkemizde ~4 000'i endemik olmak üzere yaklaşık aynı sayıda bitkiye ev sahipliği yapmaktadır. Aynı zamanda birçok bitkinin en çok yetiştirildiği ve birçoğunun da endemik olarak sadece kendisinde bulunduğu bir gen merkezi konumundadır. Türkiye'nin Dünya çapında yetiştirilme miktarı ve ticaretinin yapıldığı bitkiler açısından liderliğini açık ara sürdürdüğü bir başka bitki de defne bitkisidir. Ticari veriler incelendiğinde dünyadaki defne arzının %90 oranında Türkiye'den yapıldığı, 2021 verilerine göre 45 000 ton defne yaprağı ihracatının gerçekleştirildiği görülmektedir (Anonim, 2022).

Defne, *Lauraceae* familyasına ait *Laurus* cinsinden, her daim yeşil kalan bir bitki olup ülkemizdeki türü "Akdeniz Defnesi" olarak adlandırılan *Laurus nobilis*'dir. Genel olarak Akdeniz havzasında yayılış gösteren bu bitki Ege ve Akdeniz kıyılarının tümü ile yoğunluklu olarak Orta Batı Karadeniz kıyılarında, deniz seviyesinden 1200 m yükseltisine kadar yetişmektedir (Karık ve ark., 2015). Yapılan çalışmalar defne yapraklarının anti-bakteriyel (Kara ve ark., 2020), anti-fungal (Aktepe ve ark., 2019), ağrı kesici, antiseptik ve mide rahatsızlıklarını giderici, diyabeti tedavi edici, migreni önleyici, halsizlik, hazımsızlık, romatizma ve uykusuzluk problemlerine iyi geldiğini ortaya koymaktadır (Ghorbani ve ark., 2023; Özoğul ve ark., 2022; Şevik ve ark., 2022; Tomar ve ark., 2020). Ülkemizde kültürü yapılmayan defnenin değerlendirilmesi Orman Bakanlığı'nın çalışmaları doğrultusunda yürütülmekte, defne yaprağı üretiminin tamamı doğadan toplanılarak yapılmaktadır. Odun dışı orman ürünlerinin değerlendirilmesi noktasında da kırsal kesimlerde ekonomik olarak destek sağlayıcı bir konumda bulunmaktadır (Ayhan ve Erkan, 2023). Defne yaprakları çay olarak tüketildiği gibi yapraklar ve meyvelerindeki yağlar çıkarılarak da değerlendirilmektedir. Bu çıkarılan yağların başka yağlarla karıştırılarak egzama ve romatizma gibi tedavilerde kullanıldığına yönelik çalışmalara da rastlanılmaktadır. Öte yandan çay olarak tüketilmesinin iştah açıcı, kan dolaşımını düzenleyici, soğuk algınlığı ve bademcik iltihaplarına iyi geldiği de raporlanmıştır (Özer ve ark., 2019).

Bu kadar değerli bir tıbbi ve aromatik bitki konumunda olan defnenin yapraklarından uçucu yağ çıkarılması, günümüzde geleneksel su ve buhar damıtma (HD ve BD) yöntemleri ile yapılmaktadır. Bitkilerin aromasını kaybetmeyecek şekilde gölgede kurutulması sonrasında yapılan parçalama işlemiyle bitkinin yaprak ve ince dalları damıtma işlemine sokularak uçucu yağları alınmaktadır. Yapılan çalışmalar defne yapraklarından %0.2-2.5 arasında bir uçucu yağ verimi elde edilebileceğini göstermektedir (Göllükçü ve ark., 2017). Elde edilen yağ analizleri kimyasal olarak incelendiğinde baskın bileşenin 1,8 Cineole olduğu, bunu farklı monoterpen ve seskiterpenlerin izlediği görülmektedir. Defne yapraklarından çıkarılabilecek uçucu yağ miktarı birçok çevresel faktöre göre değişebileceği gibi, içerdiği bileşiklerin oranları da bu çevresel faktörlere göre değişiklik gösterebilmektedir. Çevresel faktörler dışında bitkilerin kurutulması ve damıtma yöntemleri de elde edilecek yağ veriminde etken konumundadır. Geleneksel buharlı damıtma (BD) yöntemlerinde damıtma süresinin daha uzun olması, enerji ve işçilik maliyetlerini de artırdığından bu yöntemlere alternatif modern damıtma yöntemleri geliştirilmiştir. Bu modern damıtma yöntemlerinin başında ultrasonik destekli damıtma (UDD), süper-kritik damıtma (SKD) ve mikrodalga destekli damıtma (MDD) yöntemleri dikkat çekmektedir. SKD yönteminde çok yüksek basınç değerlerinin kullanılması ve çözücü (CO_2) ihtiyacının devam etmesi MDD sistemlerini daha öne çıkarmaktadır (Irakli ve ark., 2023; Kavoura ve ark., 2019; Mróz ve Kusznierewicz, 2023). MDD sistemlerinde buhar dışında herhangi bir ilave çözücüye gerek olmadan damıtma işlemi gerçekleştirildiği için daha sağlıklı ve düşük maliyetli bir durum söz konusudur. 2 450 MHz frekansının su moleküllerinin rezonans frekansıyla titreşim olması sonucu su moleküllerinin kinetik enerjiden ısı enerjisine dönüşmesi, bitkilerin hücrelerinin daha çabuk parçalanmasını ve içlerindeki uçucu yağları bırakmalarının kolaylaşmasını netice vermektedir. 1-300 GHz frekans bandını kapsayan mikrodalgaların (MD) en yoğun kullanıldıkları alanların başında pişirme, kurutma, sterilizasyon

ve pestisit mücadeleleri gelmekte olup, en yaygın kullanımı evlerdeki MD fırınlar olarak karşımıza çıkmaktadır. 1 kW değerindeki magnetronların ~4 kV'luk bir gerilim altında çalıştırılmasıyla elde edilen elektromanyetik (EM) dalgalar, belli bir su molekülüne sahip olan bitkileri de hızlı bir şekilde, homojen bir biçimde ısıtarak (diferansiyel sıcaklık farkı oluşmadan) daha yüksek verimde ve daha hızlı uçucu yağ elde edilmesine imkân sağlarlar. Yapılan çalışmalar uçucu yağ elde etmek için MD enerjini kullanımının yağ kalitesini değiştirmediğini (ana bileşenlerde herhangi bir kayba yol açmadığını), damıtma süresini büyük oranda azaltırken verimi artırdığını ve enerji tasarrufunu artırdığını ortaya konmuştur (Drinić ve ark., 2020; Suttiarporn ve ark., 2020; Marković ve ark., 2018; Jažo ve ark., 2022; Mohamed ve ark., 2022; Zhang ve ark., 2022). Tıbbi ve aromatik bitkilerde MD desteğiyle yapılan çalışmalar genel olarak küçük ölçekli boyutlarda gerçekleştirilmiştir. Çalışmalara bakıldığında klasik MD fırınlara clevenger ilavesiyle damıtma işleminin gerçekleştirildiği görülmektedir. Belirtilen bu çalışmalarda en büyük problem, endüstriyel tip damıtmalarda büyük ölçekli bitki kütlelerinin aynı anda damıtılmaya çalışılması durumunda MD desteğinin küçük ölçekli sistemlerle aynı davranışı göstermeyeceğidir. Bitkilerin miktarı arttıkça EM dalgaların bitkiye nüfuzu azalacak ve bitkinin her bir bölgesinin homojen MD enerjisine maruz kalması mümkün olmayacaktır. Dolayısıyla, küçük ölçekli çalışmalarda MD enerjinin bu tür bir davranışı olmayacaktır. Bu nedenle küçük ölçekli MD destekli çalışmalar endüstriyel tip damıtma süreçleri için birebir model olmaktan uzak kalacaklardır. Bu amaçla bu çalışmada, MD enerjinin büyük ölçekli sistemlerdeki damıtma süreçlerine etkisini doğru bir şekilde modelleyebilmek için yeni bir endüstriyel tip MDD sistemi tasarlanmıştır. Önerilen bu sistemde 100 litrelik bir geleneksel damıtma kazanına 12 adet magnetron 120°'lik açılarla 4×3 konfigürasyonlu dizi şeklinde yerleştirilmiştir. Aynı anda 5 kg miktarda *L. nobilis* bitkisi damıtılabilecek şekilde MD enerji desteği sağlanmıştır. Elde edilen uçucu yağ örneklerinin GC-MS cihazı kullanılarak kimyasal analizleri yapılmıştır. BD sistemi ile önerilen MDD sisteminin performansları uçucu yağ verimi ve yağ kalitesi açısından detaylı incelenmiştir.

2. Materyal ve Metot

2.1. Bitkilerin hazırlanması

Damıtma işlemi gerçekleştirilen *L. nobilis* bitkisi, Karadeniz Ereğli bölgesinden elde edilmiştir. Defne yaprakları 06.09.2024 tarihinde toplanıp getirilmiştir. Yapraklar genelde defnenin üst kısımlarından alınmış olup genç yapraklardan oluşmaktadır. Bitkiler gölgede kurutulduktan sonra son sürgün dalları kalacak şekilde odunsu kısımlarından ayrılmış ve homojen bir karışım sağlandıktan sonra 5kg'lık eşit parçalara bölünerek damıtma gerçekleştirilmiştir. Bu çalışmada kullanılan defne yapraklarının kurutulduktan sonraki nem oranı %25 olarak ölçülmüştür. Çoğu uygulamada defne bitki yaprakları ve dalları kıyılarak damıtma gerçekleştirilirken bu çalışmada parçalama ve kıyılma işlemi yapılmamıştır. Bunun amacı MD desteğinin etkisini görmek olduğundan, referans olarak önce geleneksel ölçüm gerçekleştirilmiş daha sonra MD destekli ölçüm yapılmıştır. *Şekil 1a* ve *Şekil 1b*'de sırasıyla defne bitkisinin yaprakları ve tomurcukları görülmektedir. *Şekil 1c* ve *1d*'de ise sırasıyla kullanılan defne yaprakları ve damıtma kazanından damıtma sonrası çıkarılan defne yaprakları görülmektedir.

2.2. Damıtma sisteminin tasarımı ve damıtma süreçleri

Literatürdeki çalışmalar, MD desteğiyle yapılan damıtma işlemlerinde sürenin geleneksel sistemlere göre oldukça kısaldığını, buna bağlı olarak enerji tasarrufunun arttığını ve toplam maliyetlerin aşağı çekilebileceğini belirtmektedirler. Bu amaçla, *Şekil 2*'deki önerilen sistemin tasarımı yapılmış ve testler gerçekleştirilmiştir. *Şekil 2a*'da gösterilen sistemin BD sisteminden tek farkı damıtma kazanına eklenmiş magnetronlar ve kontrol devresidir. Bu magnetronlar, 220 V AC gerilimden EM enerjiyi elde etmek için kullanılırlar (*Şekil 2c*). *Şekil 2b*'de ise magnetronları kontrol etmek için kullanılan kontrol panelinin içi görülmektedir. *Şekil 2a*'da gösterilen sistemde 100 litrelik buhar kazanı kullanılmış, bu buhar kazanındaki suyu ısıtmak için 2 adet 10 kW'lık maşonlu rezistans kullanılmıştır. Bu rezistanslar kontrol panosu (2) tarafından kontrol edilmektedir. Benzer şekilde damıtma kazanı da (3) 100 litre hacminde tasarlanmıştır. 41 cm çapında 80 cm yüksekliğindedir olup, 5 kg bitki yerleşebilmektedir. Bitkilerin damıtma sonrası rahat bir şekilde çıkarılabilmesi için kazan içerisine platform eklenmiştir. Buhar ve uçucu yağlar eşanjör ünitesinde (4) yoğuşmakta ve florentinde (5) yoğunluk farkına bağlı olarak ayrışmaktadır. Damıtma kazanına bağlanmış magnetronlar kontrol paneli (6) üzerinden devreye alınıp çıkarılmaktadır. Kontrol paneli üç ana kısımdan oluşmaktadır. Bunlar, elektronik kontrol kartları (7), güç kontrol sigortaları (8) ve her bir magnetronu ayrı ayrı beslemek için kullanılan transformatörlerdir (9). Tüm metal malzemeler çelik krom (Steel-1010) malzemeden yapılmış ve et kalınlığı 2 mm olarak seçilmiştir. Sisteme su beslemesi manuel olarak yapılmakta olup, eşanjör ünitesi de şehir

şebekesine bağlıdır. Buhar kazanı 8 bar basınca dayanabilecek şekilde üretilmiş ve ön testleri gerçekleştirilmiştir. Kazan üzerine yerleştirilen emniyet valfleri, sistemin basıncı 4.5 barı geçince açılmaktadır. Ayrıca, damıtma işlemi boyunca damıtma kazanına yaklaşık 1.2 barlık basınçta buhar desteği sağlanmıştır. Uygulanan buhar ve MD desteği ile bitkiden ayrılan uçucu yağlar buhara karışarak eşanjöre ilerlemekte ve buradan da yoğuşarak florentine gitmektedir. Florentine gelen buhar ve uçucu yağ yoğunluk farkına bağlı olarak burada ayrışmakta ve üstte kalan uçucu yağ her bir test sonunda puar aparatı kullanılarak mezür ile uçucu yağ verimi ölçülmektedir.

Figure 1. (a) L. nobilis plant and (b) plant buds (c) dried leaves before distillation and (d) leaves removed from the dillation boiler after distillation process

Şekil 1. (a) L. nobilis bitkisi ve (b) tomurcukları (c) damıtma öncesi kurutulmuş defne yaprakları ve (d) damıtma sonrası damıtma kazanından çıkarılan defne yaprakları

Damıtma kazanı içerisine daha homojen elektrik alan sağlamak amacıyla kazan yüzeyine 12 adet magnetron 4×3 şeklinde yerleştirilmiştir. Defne bitkisi dal ve yapraklarıyla birlikte damıtılmıştır. *Tablo 1*'de görüldüğü gibi referans ölçüm olarak BD yöntemiyle 100 dk'lık bir damıtma işlemi gerçekleştirilmiştir. Daha sonra 150, 300, 450 ve 600 W'lık çeşitli güçlerde magnetron vasıtasıyla MD desteği verilerek damıtma yapılmıştır. Belli aralıklarda kesikli bir şekilde uygulanan MD desteğiyle yapılan her bir damıtma işleminin süresi 50 dk olarak belirlenmiştir.

2.3. GC-MS ile kimyasal analizlerin yapılması

Damıtma sonrası elde edilen uçucu yağlar *Şekil 3a*'da gösterilen 25 ml'lik amber cam şişelere konulup +4°C'de buzdolabında saklanmıştır. Bu numunelerin kimyasal analizleri GC-MS cihazıyla gerçekleştirilmiştir. Analizler Süleyman Demirel Üniversitesi Yenilikçi Araştırımalar Merkezinde (YETEM) bulunan ve *Şekil 3b*'de gösterilen GC-MS cihazlarıyla gerçekleştirilmiştir. Bileşenler Thermo Scientific ISQ 7000 Single Quadrupole Mass Spectrometer cihazına bağlı Thermo Scientific Trace 1300 Gaz Kromatograf cihazı ile kolon kullanılarak analiz edilmiştir: Agilent HP-Innowax (30 m x 0.25 mm i.d. X 0.25 µm film kalınlığı). Taşıyıcı gaz olarak helyum (1.5 mL/dk akış hızı) kullanılmıştır. Enjeksiyon sıcaklığı 250°C ve iyon kaynağı sıcaklığı 230°C olarak belirlenmiştir. Enjeksiyon hacmi 2 µL'dir. 1/5 split oranı kullanılmıştır. Taşıyıcı gaz olarak helyum gazı kullanılmıştır ve gazı akışı 1,5 mL / dk'dır. Cihazın sıcaklık programı 35°C (2 dk), 2°C/dk 100°C (1 dk), 5°C/dk 120°C (1 dk), 5°C/dk 200°C (1 dk), 4°C/dk 220°C (1 dk) olarak belirtilmiştir. Ayrıca, Wiley NIST/EPA/NIH Kütle Spektral Kütüphanesi Sürüm 2.0f. Build Aug 11 2008 bileşikleri tanımlamak için kullanılmaktadır. Kullanılan iyonizasyon modu 70 eV'de elektronik darbe ve kütle aralığı 41-500 m/z'dir. Uçucuların yüzde kompozisyonları FID dedektörü kullanılarak elde edilir. MS, EI iyonizasyon modunda çalıştırılmaktadır.

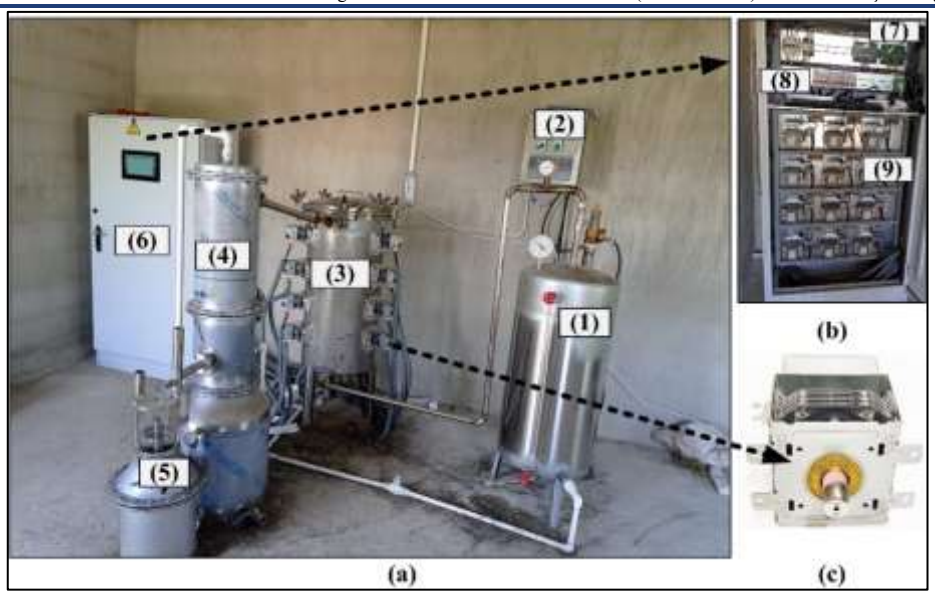

Figure 2. (a) The proposed MWAD system (b) the control panel used to control the magnetrons and (c) the magnetrons

Şekil 2. (a) Önerilen MDD sistemi (b) magnetronları kontrol etmek için kullanılan kontrol paneli ve (c) magnetronlar

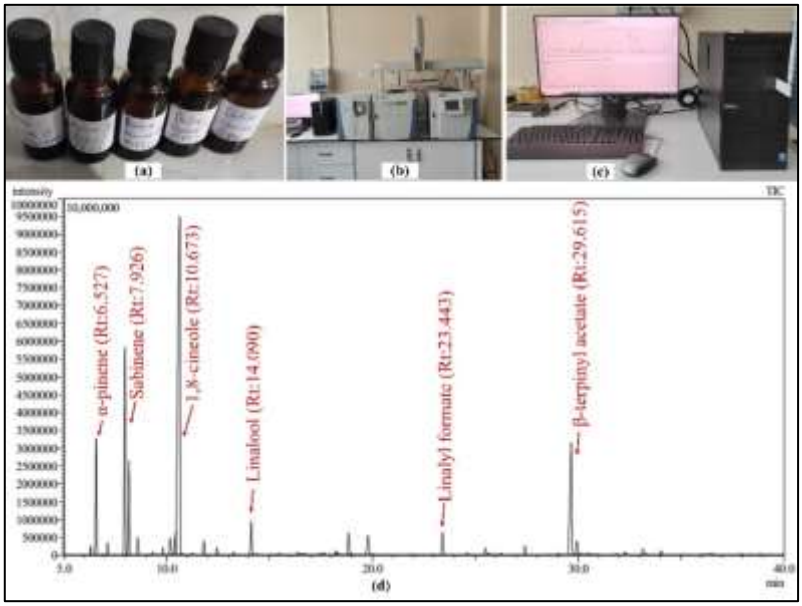

Figure 3. (a) Essential oil samples obtained (b) GC-MS device used (c) obtaining the chemical analysis (d) Chromatogram and main components of essential oil obtained from L. nobilis plant

Şekil 3. (a) Elde edilen uçucu yağ numuneleri (b) kullanılan GC-MS cihazı (c) kimyasal analizin elde edilmesi (d) L. nobilis bitkisinden elde edilen uçucu yağın kromatogramı ve ana bileşenleri

3. Bulgular ve Tartışma

3.1. MD desteğinin etkisinin değerlendirilmesi

Tasarlanan ve testleri *L. nobilis* bitkisi kullanılarak gerçekleştirilen MD destekli damıtma sisteminde elde edilen uçucu yağ verimi *Şekil 4a*'da gösterilmiştir. Buna göre MD desteği verilmesi, defne bitkisinden alınan verimi yaklaşık %10-20 artırmaktadır. Fakat MD gücü 600 W gibi yüksek bir değere çıkarıldığında verim düşmektedir. Bunun fazla ısıtmadan kaynaklı bir durum olduğu düşünülmektedir ki bu durum literatürde diğer bitkilerle yapılan MD destekli damıtma çalışmalarında da benzer şekilde izlenmiştir (Marković ve ark., 2018). Damıtma süresi geleneksel

sistemde 100 dk alınırken, MD destekli sistemde 50 dk olarak alınmıştır. Literatürde defne bitkisiyle yapılan çalışmalarda 60 dk sonrasında uçucu yağ veriminde çok fazla bir değişim izlenmediği, dolayısıyla 120 dk'ya kadar beklemenin enerji tüketimi açısından olumsuz olduğu vurgulanmıştır. Testler sırasında da 70 dk'dan sonra BD sistemde kayda değer bir uçucu yağ akışı izlenmediğinden bu çalışmada geleneksel sistemle yapılan damıtmanın süresi 100 dk'da kesilmiştir (*Şekil 4*). *Şekil 4b*'de verilen verim-zaman grafiğini elde etmek için 5 dk aralıklarla mezür yardımıyla uçucu yağ miktarı ölçülmüştür. MD desteğiyle yapılan damıtma işleminin adımları kısaca şekilde özetlenebilir: İlk 10 dk'da sadece buhar desteği verilmiş sonra 10 dk MD uygulanmış ve 5 dk ara verilmiştir. Bu şekilde son MD gücü uygulandıktan sonra toplam 50 dk'da damıtma işlemi tamamlanmıştır. Damıtma sırasında defne bitkisinden ilk uçucu yağın florentine gelmesi diğer testlerde gerçekleştirilen kekik, adaçayı ve lavanta bitkilerine göre geç gelmektedir. Bunun sebebinin defne yapraklarının, bütün olarak kazana konulması olarak değerlendirilmektedir. Eğer yaprak ve ince dallar kıyılarak damıtma kazanına yerleştirilirse hücrelerdeki parçalanmaların daha hızlı olacağı ve daha erken sürede uçucu yağın florentine geleceği düşünülmektedir. Enerji tasarrufu açısından incelendiğinde BD sisteminde, suyun kaynatılıp 4 barlık basınca sahip buhar haline getirildiği damıtma öncesi durumda harcanan enerji miktarı da dikkate alındığında, toplamda 43.3 kWh'lık bir enerji tüketimi söz konusudur. Diğer taraftan MDD sisteminde ise 10 kWh'lık damıtma öncesi enerji tüketimine ilaveten 50 dk boyunca buhar desteği için harcanan ısıtma miktarı ve tüm magnetronların 30 dk boyunca farklı güçlerde çalıştırıldı harcadıkları güçlerin toplamı kadar bir enerji harcaması gerçekleşecektir. 12 magnetron aynı güçte devreye alındığı için enerji harcamasına dair veriler *Tablo 2*'de verilmiştir. Elde edilen bu sonuçlara göre, MD destekli sistemde yaklaşık %26-35 arasında bir enerji tasarrufunun söz konusu olduğu görülmektedir. En iyi verimin elde edildiği 450 W+ 30 dk'lık durumda bu oran yaklaşık %29.56 civarındadır.

Tablo 1. Geleneksel ve MD destekli damıtma işlemlerinde harcanan enerji miktarları

Table 1. Energy consumption in conventional and MW-assisted distillation processes

Testler	Damıtma Öncesi Buhar için (kWh)	Damıtma Süresi Buhar için (kWh)	Damıtma Süresi MD için (kWh)	Toplam Harcanan Enerji (kWh)	Enerji Tasarruf Yüzdesi (%)	Uçucu yağ verimi (ml)
BD	10	33.33	0	43.33	0	29
150 W + 30 dk	10	16.67	1.28	27.95	35.49	32
300 W+ 30 dk	10	16.67	2.57	29.24	32.52	34
450 W +30 dk	10	16.67	3.85	30.52	29.56	36
600 W +30 dk	10	16.67	5.14	31.81	26.59	33

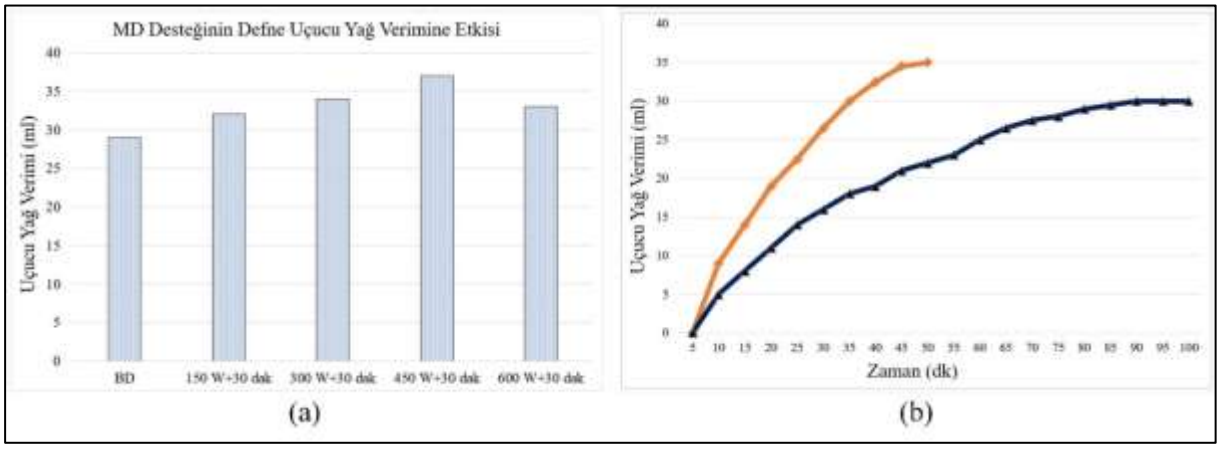

Figure 4. (a) Effect of some MW energy support on essential oil yield of laurel plant, (b) Comparison of yield-time values of SD and MWAD (for 450 W +30 min test) systems

Şekil 4. (a) Bazı MD enerji desteğinin defne bitkisinin uçucu yağ verimi üzerine etkisi, (b) BD ve MDD (450 W +30 dk testi için) sistemlerinin verim-zaman değerlerinin karşılaştırılması

3.2. Kimyasal Analiz Sonuçları

Tablo 2. Defne bitkisinden elde edilen uçucu yağ bileşenleri

Table 2. Essential oil components obtained from laurel plant

Rt	Kimyasal Bileşenler	Kimyasal Formülü	Grup Adı	BD	150 W+30 dk	300 W+30 dk	450 W+30 dk	600 W+30 dk
6.266	α-thujene			0.36	0.50	0.42	0.41	0.43
6.527	α-pinene			5.48	6.76	6.13	5.93	6.29
7.085	Camphene			0.57	0.76	0.66	0.65	0.64
7.926	Sabinene			12.01	13.97	13.23	13.12	12.85
8.116	β-pinene			4.48	5.46	5.10	4.98	5.16
8.542	β-myrcene	$C_{10}H_{16}$	Monoterpen-hidrokarbon	1.06	1.27	1.12	1.12	1.15
9.761	α-terpinene			0.32	0.47	0.43	0.41	0.47
10.114	P-cymene			1.15	1.36	1.31	1.32	1.30
10.435	Limonene			1.50	1.04	1.65	1.49	nd*
11.756	γ-terpinene			0.65	0.87	0.88	0.84	0.93
12.391	Sabinene hydrate <cis->			0.38	0.49	0.47	0.50	0.43
	Toplam (%)			**27.96**	**32.95**	**31.4**	**30.77**	**29.65**
10.673	1,8-cineole			36.53	40.77	42.08	43.41	41.13
14.090	Linalool			6.19	2.32	2.40	2.49	3.32
18.246	Borneol	$C_{10}H_{18}O$	Monoterpen-oksit	0.39	0.07	0.12	0.09	0.22
18.791	4-terpineol			1.43	1.68	1.72	1.73	1.52
19.737	β-fenchyl alcohol			1.35	1.92	1.90	1.98	1.69
23.443	Linalyl formate			9.79	0.66	1.81	0.96	4.15
	Toplam (%)			**55.68**	**47.42**	**50.03**	**50.66**	**52.03**
25.456	Bornyl acetate			0.46	0.58	0.55	0.57	0.53
25.629	Lavandulyl acetate	$C_{12}H_{20}O_2$	Monoterpen-ester	0.47	nd	0.07	nd	0.18
27.379	Ocimenyl acetate			0.51	0.81	0.75	0.79	0.71
29.615	β-terpinyl acetate			8.21	12.89	12.23	12.51	11.74
	Toplam (%)			**9.65**	**14.28**	**13.6**	**13.87**	**13.16**
29.906	Eugenol	$C_{10}H_{12}O_2$	Fenol	1.08	1.38	1.26	1.23	1.00
33.116	Methyleugenol	$C_{11}H_{14}O_2$		0.57	0.56	0.53	0.52	0.52
	Toplam (%)			**1.65**	**1.94**	**1.79**	**1.75**	**1.52**
34.014	Trans-caryophyllene			0.86	0.25	0.34	0.25	0.54
36.454	Farnesene <beta>	$C_{15}H_{24}$	Seskiterpen-hidrokarbon	0.42	nd	nd	nd	0.19
37.899	Germacrene-D			0.18	0.04	0.06	0.02	0.11
	Toplam (%)			**1.46**	**0.29**	**0.4**	**0.27**	**0.84**
43.735	Spathulenol	$C_{15}H_{24}O$	Seskiterpen-oksit	0.14	0.24	0.22	nd	0.23
43.963	Caryophyllene oxide			0.21	0.35	0.32	0.30	0.34
50.239	Cis-farnesol	$C_{15}H_{26}O$		0.21	nd	nd	nd	nd
	Toplam (%)			**0.56**	**0.59**	**0.54**	**0.3**	**0.57**
	Tüm bileşenlerin toplamı (%)			**96.96**	**97.47**	**97.76**	**97.62**	**97.77**

*nd: not detected

Yapılan kimyasal analiz sonucu defne bitkisinin uçucu yağında 64 adet bileşen bulunmuş ve bunlardan çoğu eser miktarda olduğu için *Tablo 1*'de sadece 29 adet bileşen verilmiştir. Bu sonuçlar incelendiğinde MD desteği

verilmesinin damıtma sonucu elde edilen bileşenler üzerinde etkisinin olduğu açıkça görülmektedir. Diğer literatür çalışmalarında olduğu gibi burada da en yüksek bileşen 1,8 cineole, sabinene, α-pinene gibi ana bileşenlerdir. MDD işlemi sonucunda bu 29 bileşenden 18'unda artma, 9'unda da azalma izlenir iken 2 bileşende ise kayda değer bir değişim izlenmemiştir. Özellikle linalool ve linalyl formate bileşenlerindeki radikal düşüşler dikkat çekicidir. Defne bitkisinin uçucu yağları monoterpen-oksitler, monoterpen-hidrokarbonlar, seskiterpen-hidrokarbonlar ve seskiterpen-oksitler olarak gruplandırılabilir. Grup bazında bakıldığında, bileşenlerin %55.68'inin monoterpen-oksitlerden, %27.96'sının monoterpen-hidrokarbonlardan, %0.56'sının seskiterpen-oksitlerden, %1.45'nin seskiterpen-hidrokarbonlardan oluştuğu görülebilir. Görece en büyük grubu oluşturan monoterpen-oksitlerin MD gücünden etkilenme biçimi; düşük MD güç uygulandığında yüzde oranı düşme, yüksek MD güç uygulandığında ise artma eğilimindedir. Diğer taraftan hidrokarbonlu bileşenlerin ise bunun tam tersi etkilendiği Tablo 2'den açıkça görülmektedir. Gruplar ve 6 ana bileşen bazında MD gücünün etkisi sırasıyla, *Şekil 5a* ve *5b*'de gösterilmiştir.

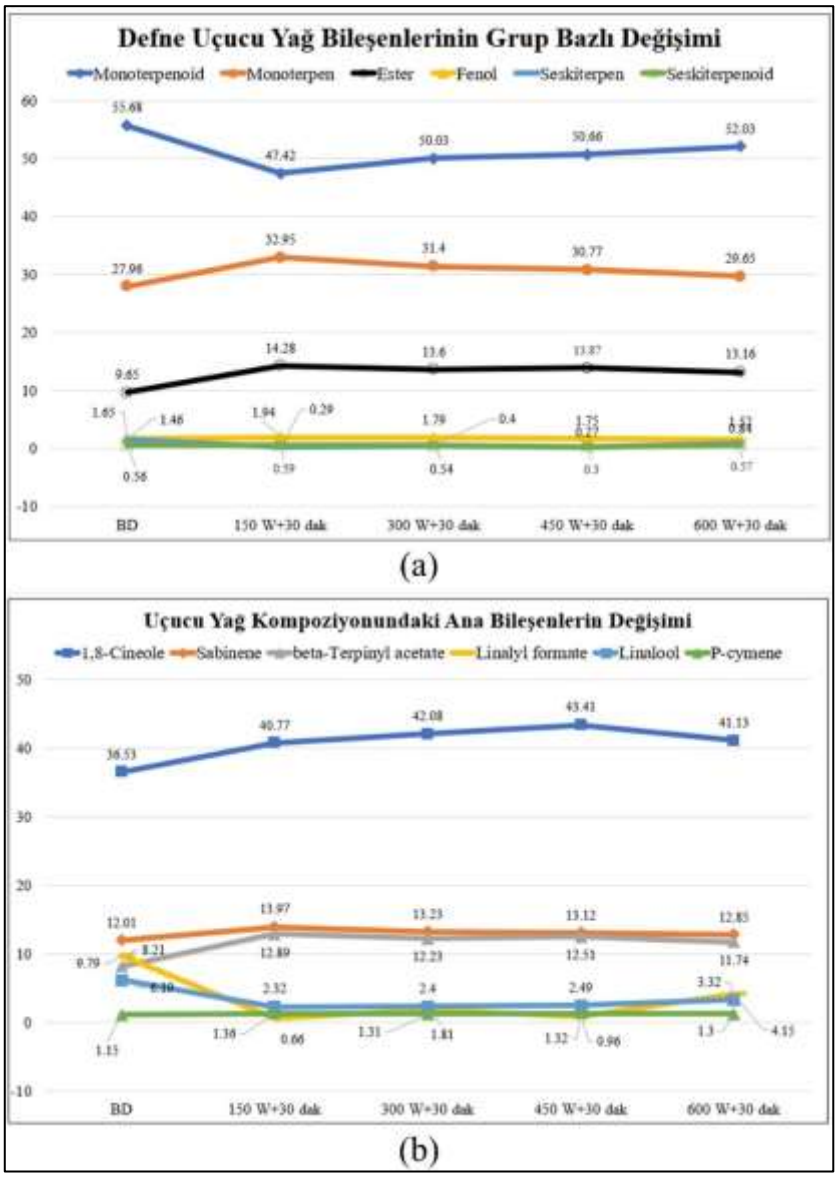

Figure 5. (a) Variation of essential oil components obtained from laurel plant according to groups (%), (b) Variation in 6 main components (%)

Şekil 5. (a) Defne bitkisinden elde edilen uçucu yağ bileşenlerinin gruplara göre değişimi (%), (b) 6 ana bileşendeki değişim (%)

4. Sonuç

Bu çalışmada, MD destekli bir damıtma sistemi endüstriyel boyutta tasarlanarak *L. nobilis* türünün uçucu yağları çıkarılmıştır. 12 adet magnetron damıtma kazanına homojen elektrik alan sağlayacak şekilde 4×3 olarak yerleştirilmiş ve defne bitkisi dal ve yapraklarıyla birlikte uçucu yağ amaçlı damıtma işlemine tabi tutulmuştur. Referans ölçüm olarak BD yöntemiyle 100 dk'lık bir damıtma işlemi gerçekleştirilmiş ve daha sonra farklı güçlerde (150, 300, 450 ve 600 W) MD desteği verilerek damıtma yapılmıştır. MDD işleminin süresi 50 dk olarak alınmıştır. MD desteği kesikli bir şekilde (belli aralıklarla) uygulanmıştır. Bunun nedeni magnetronların 4000 V gibi yüksek gerilimler altında çalışması ve yüksek gerilimi sağlayan transformatörlerin aşırı ısınmasının önlenmesidir. İleriki çalışmalarda önerilen bu MDD sisteminin soğutma sistemi üzerine çalışılması planlanmaktadır.

Gerçekleştirilen testler sonucunda elde edilen uçucu yağların yapılan kimyasal analizinde MD desteği uygulanmasının bileşenlerin bazılarında artmaya, bazılarında ise azalmaya yol açtığı görülmüştür. Özellikle monoterpen-oksitlerin uygulanan MD gücüyle azaldığı, monoterpen-hidrokarbonların ise arttığı dikkat çekmektedir. Monoterpen-oksitler içerisinde linalool ve linalyle acetate bileşenlerindeki değişim radikal boyutlardadır. Farklı sektörlerin farklı bileşenlere olan ihtiyaçları göz önüne alındığında MD desteğiyle bileşen bazlı farklılıklar oluşturmak için çalışmalar yapılabileceği değerlendirilmektedir. Öte yandan elde edilen uçucu yağ verimi maksimum %24 oranında artmış ve harcanan enerjide ise minimum %26.35 enerji tasarrufu söz konusudur.

Tüm bu sonuçlar dikkate alındığında, literatürde küçük ölçekli damıtma işlemleriyle çalışılmış ve ortaya konulmuş MD desteğine ilişkin verilerin endüstriyel bir boyutta da geçerli olduğu söylenebilir. Verimin artması, harcanan enerji miktarının azalması ve bazı bileşenlerdeki değişimlerin kayda değer oranda olması, MD destekli endüstriyel tip damıtma sistemlerinin optimize edilip sahada kullanılabilir hale getirilmesi açısından önemli bulgulardır.

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Kaynakça

Aktepe, B. P., Mertoğlu, K., Evrenosoğlu, Y. ve Aysan, Y. (2019). Farklı bitki uçucu yağların erwinia amylovora'ya karşı antibakteriyel etkisinin belirlenmesi. *Tekirdağ Ziraat Fakültesi Dergisi*, 16(1): 28-35. https://doi.org/10.33462/jotaf.516848

Anonim (2022). Defne Tarımı ve Endüstrisi Fizibilite Raporu (BAKA), https://baka.ka.gov.tr/assets/upload/dosyalar/defne-tarimi-ve-endustrisi-fizibilite-raporu.pdf (Accessed Date: 13.10.2023).

Allal, A., Bellifa, S., Benmansour, N., Selles, C., Semaoui, M., Hassaine, H. and Muselli, A. (2019). Essential oil and hydrosol extract chemical profile, antioxidant and antimicrobial potential of daphne gnidium l. From algeria. *Journal of Essential Oil Bearing Plants,* 22(5): 1277-1288. https://doi.org/10.1080/0972060X.2019.1673832

Ayhan, E. ve Erkan, N. (2023). Akdeniz Defnesi (Laurus nobilis L.) üretiminin kırsal ekonomiye potansiyel katkısının ve üretici profilinin, sorun ve beklentilerinin araştırılması (Bursa ili örneği). *Türkiye Ormancılık Dergisi*, 24(3): 262-271. https://doi.org/10.18182/tjf.1302497

Drinić, Z., Pljevljakušić, D., Živković, J., Bigović, D. and Šavikin, K. (2020). Microwave-assisted extraction of *O. vulgare* L. spp. *hirtum* essential oil: Comparison with conventional hydro-distillation. *Food and Bioproducts Processing*, 120: 158-165. https://doi.org/10.1016/j.fbp.2020.01.011

Ghorbani, L., Golkar, P., Jafari, R., Ahmadi, M. and Allafchian, A. (2023). Phytochemicals, essential oils composition and antioxidant activity of *astragalus* spp.. *Phlomis olivieri* and *daphne mucronata* in habitats of central iran. *Chemistry & Biodiversity*, 20(9): e202300811. https://doi.org/10.1002/cbdv.202300811

Gölükçü, M., Tokgöz, H. and Turgut, D. Y. (2018). Effect of distillation time on essential oil compositions of bay leaf (*Laurus nobilis* L.). *Food and Health*, 4(1): 37-42. https://doi.org/10.3153/JFHS18005

Irakli, M., Bouloumpasi, E., Christaki, S., Skendi, A. and Chatzopoulou, P. (2023). Modeling and optimization of phenolic compounds from sage (Salvia fruticosa L.) post-distillation residues: Ultrasound- versus microwave-assisted extraction. *Antioxidants*, 12(3): 549. https://doi.org/10.3390/antiox12030549

Jažo, Z., Glumac, M., Drventić, I., Žilić, L., Dujmović, T., Bajić, D., Vučemilo, M., Ivić, E., Bektić, S., Anačkov, G. T. and Radan, M. (2022). The essential oil composition of helichrysum italicum (Roth) g. Don: Influence of steam, hydro and microwave-assisted distillation. *Separations*, 9(10): 280. https://doi.org/10.3390/separations9100280

Kara, M., Soylu, S., Türkmen, M. and Kaya, A. (2020). Determination of chemical compositions and antifungal activities of laurel and fennel essential oils against fungal disease agents of cypress seedlings. *Journal of Tekirdag Agricultural Faculty*, 17(2): 264-275. https://doi.org/10.33462/jotaf.663452

Karık, Ü., Çiçek, F., Tutar, M. ve Fırat, A. Y. A. S. (2015). Türkiye defne (*Laurus nobilis* L.) populasyonlarının uçucu yağ bileşenleri. *Anadolu Ege Tarımsal Araştırma Enstitüsü Dergisi*, 25(1): 1-16.

Kavoura, D., Kyriakopoulou, K., Papaefstathiou, G., Spanidi, E., Gardikis, K., Louli, V., Aligiannis, N., Krokida, M. and Magoulas, K. (2019). Supercritical CO2 extraction of Salvia fruticosa. *The Journal of Supercritical Fluids*, 146: 159-164. https://doi.org/10.1016/j.supflu.2019.01.010

Marković, M. S., Radosavljević, D. B., Pavićević, V. P., Ristić, M. S., Milojević, S. Ž., Bošković-Vragolović, N. M. and Veljković, V. B. (2018). Influence of common juniper berries pretreatment on the essential oil yield, chemical composition and extraction kinetics of classical and microwave-assisted hydrodistillation. *Industrial Crops and Products*, 122: 402-413. https://doi.org/10.1016/j.indcrop.2018.06.018

Mohamed, T. A., Saleh, I., Ali, S., Hussien, T., Hegazi, N. M., Abdel-Halim, S., Abd El-Razek, M. H., El-Beih, A., Marzouk, M. M., Pare, P. W., Efferth, T. and Hegazy, M.-E. F. (2022). A comparative evaluation of the antimicrobial activities of the essential oils of three *salvia* species growing in egypt, obtained by hydrodistillation and microwave-assisted hydro-distillation. *Journal of Essential Oil Bearing Plants*, 25(5): 1109-1121. https://doi.org/10.1080/0972060X.2022.2135388

Mróz, M. and Kusznierewicz, B. (2023). Phytochemical screening and biological evaluation of Greek sage (Salvia fruticosa Mill.) extracts. *Scientific Reports*, 13(1): 22309. https://doi.org/10.1038/s41598-023-49695-w

Özer, T., Sert, F. Z. ve Öztürk, A. İ. (2019). Defne bitkisi ve yağı üzerine bir araştırma. *Gaziosmanpaşa Bilimsel Araştırma Dergisi*, 8(2): 25-34.

Özogul, Y., El Abed, N. and Özogul, F. (2022). Antimicrobial effect of laurel essential oil nanoemulsion on food-borne pathogens and fish spoilage bacteria. *Food Chemistry*, 368: 130831. https://doi.org/10.1016/j.foodchem.2021.130831

Suttiarporn, P., Wongkattiya, N., Buaban, K., Poolprasert, P. and Tanruean, K. (2020). Process optimization of microwave assisted simultaneous distillation and extraction from siam cardamom using response surface methodology. *Processes*, 8(4): 449. https://doi.org/10.3390/pr8040449

Şevik, R., Denizkara, A. J., Akarca, G., Atik, A. and Atik, İ. (2022). Physicochemical and microbiological properties of common carp (*cyprinus carpio*) fillets marinated with rosemary and laurel essential oils. *Journal of Aquatic Food Product Technology*, 31(9): 977-988. https://doi.org/10.1080/10498850.2022.2120790

Tomar, O., Akarca, G., Gök, V. and Ramadan, M. F. (2020). Composition and antibacterial effects of laurel (*laurus nobilis* l.) leaves essential oil. *Journal of Essential Oil-Bearing Plants*, 23(2): 414-421. https://doi.org/10.1080/0972060X.2020.1768903

Zhang, X., Huang, Y., Niu, Y., Liu, Z., Chen, M., An, Y. and Zhang, L. (2022). The preparation of the essential oil from pomelo (Citrus maxima 'shatian yu') peel using microwave-assisted distillation by pectinase soaking and its anti-fungal activity. *Separations*, 9(7): 161. https://doi.org/10.3390/separations9070161

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Konya ve Aydın İllerinde Süt Sığırı Ahırlarının Yapısal Durumlarının Değerlendirilmesi

Evaluation of Structural Conditions of Dairy Cattle Barns in Konya and Aydın Provinces

Onur ERZURUM[1*]

Öz

Çalışmada, Konya ve Aydın illerindeki süt sığırı işletmelerinden tesadüfi olarak seçilen toplam 220 işletmede, ahırların yapısal durumunun belirlenmesi amaçlanmıştır. Çalışmanın materyalini Konya ilinden 117 işletmeye, Aydın ilinden 103 işletmeye ait veriler oluşturmuştur. Verilerin elde edilmesi amacı ile 2024 yılı Ocak-Mart ayları arasında yetiştiricilerle görüşülerek yüz yüze anket uygulaması yapılmıştır. Çalışmanın yapıldığı işletmelere ait sonuçlarda ahırların %57.27'sinin yarı açık barınak tipine sahip olduğu, işletmelerin %76.21'inin beton zemini kullandığı, %71.82'sinde ayak hastalıkları ile karşılaşıldığı, %36.36'sının dışkı temizliği için mekanik yolları kullandığı ve %51.82'sinin 50 baş ve altı hayvan sayısına sahip olduğu bulunmuştur. Yapılan regresyon analizi sonucunda günlük sağım sayısının, barınak tipinin ve işletmede kaşağı varlığının günlük verim ortalaması üzerine etkisi önemli bulunurken ($p<0.05$), durak altlık materyali, havalandırma bacasının varlığı, dışkı temizleme şekli, tırnak bakım sıklığı, sağım şekli, suluk şekli ve havalandırma sisteminin günlük verim ortalaması üzerine etkisi önemsiz bulunmuştur ($p>0.05$). Yapılan ki-kare testine göre şehirler (Konya ve Aydın) ile yetiştirilen ırk, barınak tipi, barınak ve durak zemini, durak altlık materyali, duvar yapı malzemesi arasında ilişki tespit edilmiştir ($p <0.05$). Ahırların yapısal durumları doğrudan hayvan refahını etkilemektedir. Konya ve Aydın illerine bakıldığında her ikisinde de ahırların yapısal durumlarının iyileştirilmesi ve refah konusuna önem verilmesi gerekmektedir. Ahırların iyileştirilmesi için gerekli fizibilite çalışmaları, işletmelerin kurulum aşamasında yapılmalı ve fayda / zarar oranı değerlendirilmelidir. Bu değerlendirmeler yapılırken işletmenin bulunduğu bölge göz önünde bulundurulmalıdır. Ahırların yapısal durumlarının iyiliği hayvan refahıyla ilgili olduğundan hedef en iyiye ulaşmak olmalıdır. En iyiye ulaşılması için yetiştiricileri bilgilendirmek amacıyla eğitimlerin düzenlenmesi ve bu eğitimlerin: ihtiyacı karşılayan, gerektiğinde değişikliğe izin veren barınakların tasarlanması, hayvan davranışları, hayvan refahı ve ırka özgü özellikler gibi konuları içermesi önerilmektedir.

Anahtar Kelimeler: Süt sığırı yetiştiriciliği, Ahır yapısı, Konya, Aydın, Refah

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Abstract

It was aimed to determine the structural condition of the barns in 220 randomly selected dairy cattle enterprises in Konya and Aydın provinces. The material of the study consisted of data from 117 enterprises from Konya province and 103 enterprises from Aydın province. Between January and March 2024, a face-to-face questionnaire was applied to the breeders. It was found that 57.27% of the shelters were semi-open, 76.21% used concrete floors, 71.82% had foot diseases, 36.36% cleaned feces mechanically and 51.82% had less than 50 animals. As a result of regression analysis, while the effect of number of milkings, type of barn and the presence of a brusher on average daily yield was found to be significant ($p<0.05$), the effect of stall litter material, presence of ventilation chimney, stool cleaning method, hoof care frequency, milking method, drinker type and ventilation system was found to be insignificant ($p>0.05$). According to the chi-square test, there was a relationship between the cities (Konya and Aydın) and the breed, shelter type, barn and stall floor, stall litter material, wall construction material ($p<0.05$). Structural conditions of barns directly affect animal welfare. In Konya and Aydın provinces, the structural conditions of the barns should be improved, and welfare should be given importance. The necessary feasibility studies for the improvement of the barns should be carried out during the establishment phase of the enterprises and the benefit/loss ratio should be evaluated. Since the good structural condition of the barns is related to animal welfare, the goal should be to achieve the best. For this purpose, it is suggested that training should be organized to inform breeders and these trainings should include topics such as: designing shelters that meet the needs and allow for changes, animal behavior and welfare, and breed-specific characteristics.

Keywords: Dairy cattle breeding, Barn structure, Konya, Aydın, Welfare

1. Giriş

Elde edilecek hayvansal ürünlerin miktarını ve kalitesini arttırmak için sadece yüksek verimli hayvanların kullanılması yeterli değildir. Bunlara ek olarak doğru rasyon programının uygulanması ve çevre şartlarının iyileştirilerek hayvanlara konforlu bir alan sunulması gerekmektedir. Süt sığırlarına konforlu bir ortamın sunulmasını sağlayan ahırlar sabit yatırım maliyetlerinin yaklaşık %55'ini içermektedir (Alpan ve Aksoy, 2015).

Yetiştiricilikte ideal ortamın oluşturulabilmesi için, hayvanların biyolojik ihtiyaçları çevre tarafından karşılanmalıdır. Sürü yönetimi, bakım, besleme gibi çevre faktörleri genel olarak verim performansını ve sağlık durumlarını etkilerken; ahır içi çevre faktörlerinden olan sıcaklık, rüzgâr hızı ve bağıl nem ahır içindeki ortam kalitesine etki etmektedir. Bunlar aynı zamanda hayvanlar için stres oluşturan faktörlerdendir. Süt sığırı işletmelerindeki olumsuz çevre faktörleri verim parametrelerini güçlü bir şekilde etkilemektedir (Von Keyserlingk ve ark., 2009). Barınak yapısı (durak, zemin, havalandırma…), ahır yoğunluğu, iklim şartları gibi koşullar barındırma faktörlerinden olup, doğrudan ya da dolaylı olarak hayvan davranışları, refahı ve sağlığı ile ilişkilidir. Örneğin; havalandırması yetersiz olan bir işletmede solunum yolu hastalıkları daha çok görülebilir, aydınlatması yetersiz olan bir işletmede hayvanlarda agresiflik artabilir, durak ölçülerinin uygunsuz olması veya durakların sayıca az olması stres yaratabilir, dolayısıyla ahırlarda hayvanlara sunulan şartlar oldukça önemlidir (Alpan ve Aksoy, 2015; House ve Eng, 2016). Ahır tasarımları çevre şartlarının etkisini hem azaltabilecek hem de arttırabilecek bir konumda bulunduğundan oldukça önemlidir (House, 2011).

Hayvancılık işletmesinin planlaması yapılırken, barınak inşasına başlamadan önce kapsamlı bir fizibilite çalışmasına ihtiyaç vardır. Hayvan barınakları bulunduğu bölgenin coğrafi yapısına ve iklim şartlarına göre planlanmalı, yapı ve tesislerin ideal ölçülerde olmasına özen gösterilmelidir (Wathes ve Charles, 1994). Barınak inşası esnasında hayvanların doğal davranış özelliklerini (hareket etme, yatma, geviş getirme, yeme ve içme vb.) ve düşük maliyet-azami kâr prensibini dikkate almak önem arz eder. Kısaca barınaklar inşa edilirken barınak ölçüleri, iklim, hayvan refahı, hayvan davranışları ve biyogüvenlik kuralları gibi etkenler dikkate alınarak modern niteliklerde inşa edilmesi gerekmektedir (Uğur, 2014).

Bu araştırma, Konya ve Aydın illerindeki süt sığırı ahırlarının yapısal ve teknik özelliklerini incelemek, ahırların yapısal sorunları hakkında bilgi toplamak ve iller arasındaki farklılıkları ortaya koyabilmek amacıyla yapılmıştır.

2. Materyal ve Metot

Bu araştırmanın materyalini Konya (117 işletme) ve Aydın (103 işletme) illerinde bulunan süt sığırcılığı işletmelerinden rastgele seçilen toplam 220 işletme oluşturmuştur. İşletmelerle ilgili bilgilerin toplanmasında, yüz yüze anket uygulaması yapılmış, işletme sahiplerinin görüşlerine başvurulmuş, ahır ve işletme hakkında bilgiler toplanmıştır. Yüz yüze anket uygulaması 2024 yılının Ocak-Mart ayları arasında yapılmıştır. Anket formunda yer alan sorular EK1'de verilmiştir. Anket formunun oluşturulmasında Mundan ve ark. (2018)'dan yararlanılmıştır.

Bu çalışma Selçuk Üniversitesi Veteriner Fakültesi Deney Hayvanları Üretim ve Araştırma Merkezi (SÜVDAMEK) Etik Kurulu'ndan 02/11/23 tarih ve 2023/116 sayılı izin kapsamında hazırlanmıştır.

2.1. İstatistik analizler

Araştırmada elde edilen verilere ait tüm değişkenlerin normal dağılıma uygunluğu Shapiro-Wilk Testi kullanılarak Skewness ve Kurtosis değerleri hesaplanmıştır. Skewness değerinin -0.612 ile 0.957 arasında değiştiği, Kurtosis değerinin -0.959 ile 0.879 arasında değiştiği bulunmuştur. Skewness ve Kurtosis değerleri +1.5 ile -1.5 arasında olduğunda normal dağılım olarak kabul edilmektedir (Tabachnick ve Fidell, 2013). SPSS 26 paket programı kullanılarak bağımlı ve bağımsız değişkenlerin birbirleri ile ilgili ilişki düzeylerinin ortaya koyulabilmesi amacıyla Regresyon Analizi yapılmıştır. Bölge farklılıklarının ortaya koyulabilmesinde de ki-kare testinden faydalanılmıştır. İstatistiksel işlemlerin tamamında ilişki varlığının belirlenebilmesi için 0.05 düzeyi kullanılmıştır.

2.2. Örneklem sayısı belirlenmesi

Araştırmada örnekleme sayısının belirlenmesinde %95 güven aralığı kullanılmıştır. Örnek hacminin belirlenmesi için Eşitlik 1'de verilen basit tesadüfi örnekleme yöntemi formülü uygulanmıştır (Yamane, 1967). Yapılan hesaplamalar sonucunda Konya ilinde 117, Aydın ilinde 103 örnekleme sayısına ulaşılmıştır.

$$n = \frac{\mathrm{N} * t^2 * p * q}{d^2(\mathrm{N}-1) + t^2 * \mathrm{p} * \mathrm{q}} \quad \text{(Eş. 1)}$$

Formülde; n örnekleme büyüklüğü, p gerçekleşme olasılığı (0.5), q gerçekleşmeme olasılığı (0.5), t %95 güven sınırındaki t değerini (1.96), n evren büyüklüğü ve d kabul edilebilir hata payını temsil etmektedir.

Araştırmada örnekleme sayısının belirlenmesinde Konya ili için toplam işletme sayısını 46000, hata payını %9.05 temsil ederken Aydın ili için toplam işletme sayısını 17000, hata payını %9.63 temsil etmiştir. İki il için ise toplam işletme sayısını 63000, hata payını %6.6 temsil etmiştir.

3. Araştırma Sonuçları ve Tartışma

Araştırmanın yapıldığı işletmelerde ahırların %57.27'sini yarı açık (Konya %27.27 – Aydın %30), %29.55'ini kapalı (Konya %20.91 – Aydın %8.64) ve %13.18'ini de açık barınaklar (Konya %5 – Aydın %8.18) oluşturmuştur. Yarı açık işletmelerin diğerlerine göre sayıca fazla olması Mundan ve ark. (2018) ile Yener ve ark. (2013)'nın Şanlıurfa'da yapmış oldukları araştırma sonuçları ile benzerlik gösterirken, Demir ve ark. (2014)'nın Kars ilinde yaptığı çalışma ve Ankara ili Polatlı ilçesinde Koçak (2020)'ın yaptığı çalışma sonuçlarından farklı olmuştur. Bu durum farklı bölgelerdeki mevsimsel değişikliklerin etkisi ve işletme sahiplerinin kendi tercihleri olarak yorumlanabilir. Aydın gibi yazları sıcak ve nemli, kışları yumuşak geçen bir bölgede yetiştiriciler açık ve yarı açık işletmeleri daha fazla tercih etmiş, yazları daha kurak, kışları daha sert geçen Konya da ise yetiştiriciler kapalı işletmeleri daha fazla tercih etmişlerdir. Hava sıcaklığının inekler için kritik sıcaklık değeri olan -25ºC'nin altına düşmemesi Aydın'da yarı açık ve açık işletmelerin seçimini etkileyen başka bir faktör olabilir.

İşletmelerde kullanılan duvar yapı malzemelerinde işletmelerin %10'unun taş (Konya %7.28 – Aydın %2.72), %47.27'sinin briket (Konya %26.36 – Aydın %20.91), %29.55'inin tuğla (Konya %12.73 – Aydın %16.82), %13.18'inin ise kerpiç (Konya %6.36 – Aydın %6.82) kullandığı belirlenmiştir. Duvar yapı malzemeleri kullanımında Mundan ve ark. (2018) yaptıkları çalışmada çoğunlukla briket (%69.7) kullanıldığını, bunu tuğla (%18.4) ve taş (%11.9) kullanımının izlediğini belirtmiştir. Şeker ve ark. (2012) Muş ilinde ilk sırada taşın (%42.1), daha sonra briketin (%39.7) ve kerpicin (%18.2) kullanıldığını belirtmiştir. Erzurum ili için Erkmen ve ark. (2000) en çok kullanılan malzeme olarak taşın %66.97 oranında kullanıldığını, Güler ve ark. (2017) ise taş kullanımını %55.3 oranında bulduklarını ifade etmişlerdir. Yapılan çalışmada ise en fazla kullanılan malzeme %47.27 oranı ile briket olurken, taş kullanımı %10 olarak belirlenmiştir. Bu sonuçlara göre Mundan ve ark. (2018) yaptıkları çalışma ile benzerlik gösterirken diğerleri ile benzerlik göstermemektedir. Bu durum yine bölgelerin mevsimsel şartlarına bağlı olarak değişiklik göstermiş olabilir. Kerpiç boşluklu bir yapıya sahip olup nem almaya müsait olduğundan, briket ve tuğlanın aksine kışları sıcak, yazları serin bir ortam sunmasına rağmen (Tiryaki, 2022) işletmeler tarafından fazla tercih edilmemiştir. Bu durum çevredeki diğer işletmelerden görülen bölgesel bir alışkanlık ve maliyet etkisi olarak yorumlanabilir. Ek olarak, yapı malzemesi seçiminde biyogüvenlik için uygunluk, kolay temin edilebilirlik ve maliyet hesabı da göz ardı edilmemelidir.

Barınak ve durak zemini seçimi için Konya'da bulunan işletmelerin %33.64'ünün beton, %3.18'inin tuğla, %0.91'inin kiremit, %9.09'unun bunların dışında bir malzeme kullandığı; Aydın'da bulunan işletmelerin ise %43.18'inin beton, %4.54'ünün tuğla, %2.27'sinin kiremit ve %3.18'inin bunların dışında bir malzeme kullandığı belirlenmiştir. Barınak ve durak zemini için araştırmada elde edilen genel oranlar ise *Şekil 1*'de verilmiştir. Barınak ve durak zemini tercihinde en yüksek oranla (%76.21) beton kullanıldığı belirlenmiştir. Diğer çalışmalarda bulunan beton kullanım oranları; Tutkun (1999) %48.5, Köseman ve Şeker (2016) %97.4, Güler ve ark. (2017) %43.8, Alkan ve Güney (2019) %60.93 olarak tespit edilmiştir. Bu çalışmalarda da beton en yüksek kullanım oranına sahiptir ve yapılan çalışma ile benzerlik göstermektedir. Diğerlerine göre temizlenmesi daha kolay olan ve ek bir maliyet gerektirmeyen betonun hala sıklıkla kullanıldığı görülmektedir. Genel olarak barınak ve durak zemini seçimi için aşınmaya karşı dayanıklı, kısmen yumuşak, hayvanların kaymasına engel olacak şekilde pürüzlü, kolay temizlenebilir ve temizlik için kullanılabilecek kimyasallara dayanıklı malzemeler tercih edilmelidir.

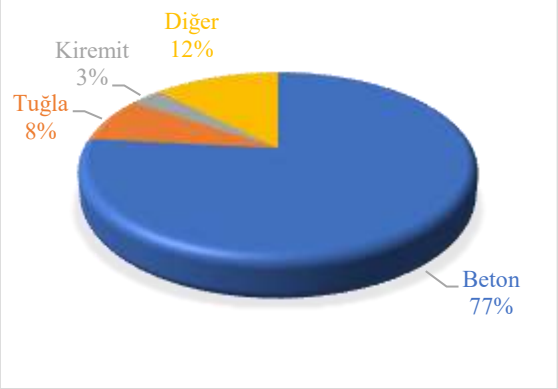

Figure 1. Shelter and stall floor preference (%)

Şekil 1. Barınak ve durak zemini tercihi (%)

Durak altlık materyali kullanımında işletmelerin %20.91'i kauçuk paspas (Konya %13.18 – Aydın %7.28), %10.9'u kum (Konya %4.54 - %6.37), %50'si beton (Konya %29.54 – Aydın %20.46), %10'u sap-saman (Konya %3.63 – Aydın %6.37), %5'i talaş (Konya %0.92 – Aydın %4.09), %3.18'i diğer (Konya %1.37 – Aydın %1.83) seçeneğini işaretlemiştir. Durak altlık materyalleri süt ineklerinin rahat etmesini ve konforlu bir alanda dinlemelerini sağlayan (saman, talaş, kum, kauçuk paspas, mattress vb…) maddelerdir. Duraklarda daha fazla yatarak vakit geçiren ineklerin süt verimlerinde artış gözlendiği çalışmalarda belirtilmiştir (Munksgaard ve Simonsen 1996; Bewley ve ark., 2010). Yatma sürelerini etkileyen en önemli faktörlerden birisi durağın rahatlığıdır. İnekler, kuru ve yumuşak bir alan sunan durakları diğerlerine göre daha fazla tercih ederler (Boone ve ark., 2010; Camiloti ve ark., 2012, Erzurum ve Yılmaz, 2020). Bazı işletmeler altlık malzemelerini kullanmayı tercih ederlerken bazıları ise altlık malzemesi kullanmayarak beton zemini kullanmaktadırlar. Köseman ve Şeker (2016) yaptıkları çalışmada işletmelerin çoğunun (%77.3) altlık malzemesi kullanmadığını, Yayar ve Karkacier (1996) ise işletmelerin %48.94'ünün saman kullandığını, %22.40'ının ise bir şey kullanmadığını belirtmiştir. Yenice ve Savaş (2016) tarafından Rize ilinde yapılan çalışmada da işletmelerin %87.9'unun altlık kullanmadığı belirtilmiştir. Yapılan çalışmada ise işletmelerin %50'si beton kullandığını (beton kullanımı aslında işletmelerin hiçbir şey kullanmadığı olarak da yorumlanabilir), %20.91'inin kauçuk paspas kullandığını belirtmiştir. İşletmeler durak başı maliyet hesabı yaptıkları için barınak kurulumunda altlık malzemesini ek bir yük olarak görmektedirler. Bu nedenle beton zemini kullanmaya devam etmektedirler. Ayrıca barınak inşası sırasında verilen hibelerin kullanılabilmesi için işletmelerin tamamen beton zemini kullanmak istemeleri de etkili olabilir (Yener ve ark., 2013). Ancak uzun süreli düşünüldüğünde, durakların rahatlığının inekleri yatmaya teşvik edeceği ve yatma süresinin uzamasının ineklerin süt verimlerinde %30 oranında bir artış sağlayabileceği de unutulmamalıdır.

Bir yıl içinde görülen ayak hastalıklarının değerlendirilmesinde işletmelere; ayak hastalığı görülmeyenler (sıfır) ile 26 ve üzerinde ayak hastalığı görülenler arasında değişen seçenekler için tercih yaptırılmıştır. Bu tercihlere göre; ayak hastalığı görülmeyen işletme oranı %28.18 (Konya %16.36 – Aydın %11.82), 1-5 arası ayak hastalığı görülen işletme oranı %54.54 (Konya %27.27 – Aydın %27.27), 6-10 arası %13.64 (Konya %7.73 – Aydın %5.91), 11-15 arası %1.37 (Konya %0.46 – Aydın %0.91), 16-20 arası %0.46 (Aydın %0.46), 26 ve üzerinde ayak hastalığı görülen işletme oranı %1.82 (Konya %1.36 – Aydın %0.46) olarak belirlenmiştir. 21-25 arası ayak hastalığı görülen işletme ise yoktur. Tüm işletmeler değerlendirildiğinde ayak hastalığı görülen işletmelerin oranı ise %71.82 olarak bulunmuştur. İncelenen işletmelerde tırnak bakımını düzenli olarak yaptıranlar ile herhangi bir sorun ile karşılaşıldığında ihtiyaç halinde tırnak bakımı yaptıranlar hemen hemen aynı oranda bulunmuştur. *Tablo 1*'de işletmelerin hayvanlar için tırnak bakımlarını ne kadar sıklıkta yaptırdıkları verilmiştir. Tırnak bakımı ayak sağlığı için oldukça önemlidir. Düzenli olarak tırnak bakımı yapılmadığı durumlarda ayak hastalıkları görülmektedir. Ayak hastalığı görülen hayvanlar ayağa kalkmak ve yürümek istemedikleri için beslenme alanına gitmek istemezler. Böylece yem tüketiminde azalma ve dolaylı olarak verimlerde düşüş yaşanır. Tırnak bakımının düzenli olarak yılda 2 defa yapılması gereklidir. Kıyıcı ve Çınar (2020) ayak hastalığı bulunan işletme oranını %31.9 olarak belirtmiştir. Tatar ve Esenbuğa (2022) çalışmasında tırnak bakımı yaptıranların oranını %75 olarak vermiştir. Çalışmanın yapıldığı işletmelerde yılda 2 defa tırnak bakımı yapan işletme oranı %27.27 bulunurken ihtiyaç olduğunda tırnak bakımı yaptıranların oranı ise %46.82 olarak bulunmuştur. Genellikle

işletmeler tarafından ek bir maliyet ve iş gücü olarak görülen tırnak bakımları aslında verim için oldukça önemli bir faktördür. Sürüden çıkarma nedenlerine bakıldığında da ayak hastalıkları ilk sıralarda yer almaktadır.

Tablo 1. Tırnak bakım sıklığı tercihleri (işletme sayısı)

Table 1. Hoof care frequency preferences (number of dairy cattle farms)

	45 günde 1	3 ayda 1	6 ayda 1	Yılda 1	İhtiyaç olduğunda
Konya	7	15	32	9	54
Aydın	4	8	28	14	49
Toplam	11	23	60	23	103

İşletmelerin tırnak bakımı yaptırılmasında tercih ettikleri sıklık dilimleri.

Dışkı temizleme ile ilgili verilen cevaplarda Konya'daki işletmelerin %38.46'sının mekanik olarak yaptığı, %46.15'inin kürek kullandığı, %15.39'unun diğer yollara başvurduğu, basınçlı su kullanımının ise tercih edilmediği; Aydın'daki işletmelerin %33.98'inin mekanik olarak yaptığı, %43.69'unun kürek kullandığı, %3.88'inin basınçlı su kullandığı ve %18.45'inin diğer yollara başvurduğu belirlenmiştir. Dışkı temizleme ilgili genel bulgular *Şekil 2*'de verilmiştir. Düzenli olarak dışkı temizliği yapılmaması tırnak yapısının nemli kalmasına, tırnakta yumuşamaya, yabancı cisimlerin canlı tırnak dokusuna geçmesine ve patojen etkenlerin faaliyete başlamasına neden olarak ayak hastalıklarını oluşturabilir.

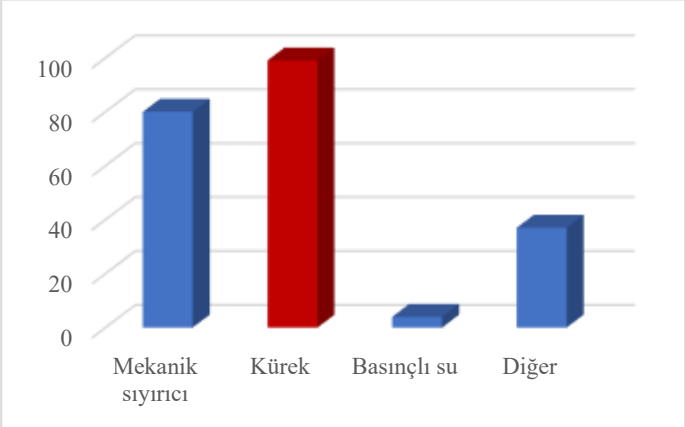

Figure 2. Types of fecal cleaning in dairy cattle farms

Şekil 2. Dışkı temizleme tipleri

Çalışmanın yapıldığı işletmelerin büyük kısmındaki (%51.82) hayvan sayısı 50 baş ve altındadır. Bu işletmelerin %28.64'ü Konya ilinde, %23.18'i ise Aydın ilindedir. İşletme büyüklüğüne dair diğer sayısal veriler *Şekil 3*'te verilmiştir.

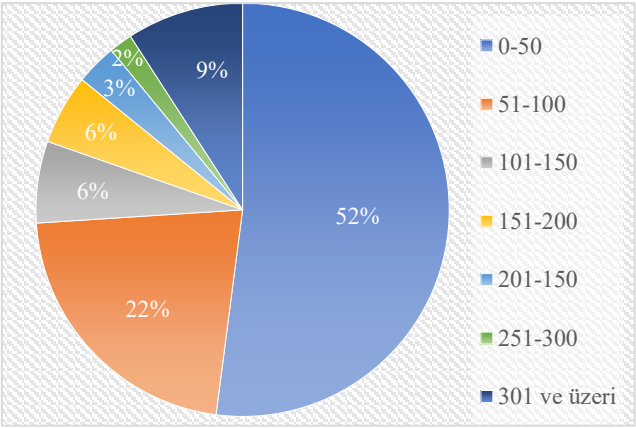

Figure 3. Number of animals in dairy farms (head)

Şekil 3. Süt sığırı işletmelerindeki hayvan sayısı (baş)

Barınak içi konforu, stresi ve hayvan sağlığını etkileyen en önemli faktörlerden birisi de havalandırmadır. Havalandırma ahır içindeki gazların (karbondioksit, metan, hidrojen sülfür), ısınan havanın ve istenmeyen kokuların uzaklaştırılması için önemlidir. İnceleme yapılan işletmelerin %53.18'inde havalandırma bacası bulunmaktayken %46.82'inde bulunmamaktadır. Sığırlar için otomatik kaşağılar bir rahatlama aracı olarak kullanılır. Ahır içi refah oranını artırmakla kalmayıp kan dolaşımını hızlandırması ve iştahı artırması ile verimler üzerine etki edebilir (Uğur, 2014). İşletmelerdeki havalandırma bacası ve otomatik kaşağı kullanım oranları *Tablo 2*'de verilmiştir. Havalandırma yöntemi olarak baca kullanan işletmelerin oranını Yenice ve Savaş (2016) %4.7, pencere kullananların oranını ise %12.1, Alkan ve Güney (2019) baca kullananları %43.91, kullanmayanları ise %55.71 olarak vermiştir. Yapılan çalışmada havalandırma bacası kullananların oranı %53.18 olurken kullanmayanların oranı ise %46.82 olmuştur. Dolayısı ile havalandırma için başka yöntemlerin (pencere, kapı, fan vb.) kullanıldığı düşünülebilir ya da havalandırmaya gereken önemin verilmediği ve hayvanların refah açısından rahatsız bir ortamda bulundurulduğu söylenebilir.

Tablo 2. Havalandırma bacası ve otomatik kaşağı kullanımı (%)

Table 2. Use of ventilation shafts and automatic brush (%)

	Var		Yok	
	Konya	**Aydın**	**Konya**	**Aydın**
Havalandırma Bacası	56	61	61	42
Otomatik Kaşağı	60	49	57	54

İşletmelerdeki havalandırma bacası ile kaşağı varlığının belirlenmesi

Verim ortalamaları; 0-20 litre, 21-30 litre, 31-40 litre, 41-50 litre, 51 ve üzeri şeklinde gruplandırılmıştır. Buna göre işletmelerin %32.28'i 0-20 lt (Konya %20.46 – Aydın %11.82), %42.27'si 21-30 lt (Konya %20.46 – Aydın %21.81), %20.91'i 31-40 lt (Konya %10.91 – Aydın %10), %3.18'i 41-50 lt (Konya %1.36 – Aydın %1.82), %1.36'sı ise 51 lt ve üzeri (Aydın %1.36) süt verimine sahiptir.

Elde edilen verilerin SPSS paket programı ile yapılan regresyon analizinde sağım sayısının, barınak tipinin ve işletmede kaşağı varlığının günlük verim ortalaması üzerine etkisi önemli bulunmuştur ($p<0.05$) (*Tablo 3*). Sağım sayısındaki bir birimlik artış günlük süt verimi üzerine 0.756 değerinde pozitif yönlü bir değişim göstermiştir. Barınak tipindeki bir birimlik artış günlük süt verimi üzerine -0.187 değerinde negatif yönlü bir değişim göstermiştir. Kaşağı varlığındaki bir birimlik artış günlük süt verimi üzerine -0.284 değerinde negatif yönlü bir değişim göstermektedir.

Tablo 3. Değişkenlerin günlük verim ortalamasına ilişkin regresyon analizleri sonuçları

Table 3. Results of regression analysis of variables on average daily yield

Faktörler[a]					
Model		**Standardize Edilmemiş Katsayılar b**	**t**	**Önem**	**Standart Hata**
	(Sabit)	1.749	2.976	0.003	0.588
	Sağım sayısı	0.756	4.868	0.000	0.155
	Barınak tipi	-0.187	-2.414	0.017	0.078
	Durak altlık materyali	-0.016	-0.365	0.715	0.043
	Havalandırma bacası	-0.113	-0.957	0.340	0.118
	Dışkı temizleme şekli	-0.028	-0.520	0.604	0.054
	Kaşağı	-0.284	-2.552	0.011	0.111
	Tırnak bakımı sıklığı	-0.018	-0.435	0.664	0.041
	Sağım şekli	-0.130	-0.591	0.555	0.220
	Suluk şekli	-0.079	-0.634	0.527	0.124
	Havalandırma sistemi	0.006	0.161	0.872	0.039

$R=.692$ $R^2=.479$ $F_{(11\text{-}220)}=11.672$ P:0.00 a: Bağımlı değişken: Günlük verim ortalaması

Anketlerden elde edilen veriler için uygulanan ki-kare testine göre şehirler (Konya ve Aydın) ile yetiştirilen ırk, barınak tipi, barınak ve durak zemini, durak altlık materyali, duvar yapı malzemesi arasında ilişki tespit edilirken; hayvan sayısı, sağılan hayvan sayısı, günlük verim ortalaması, günlük sağım sayısı, bir yıl içinde ayak hastalığı görülen hayvan sayısı, havalandırma bacası varlığı, dışkı temizleme şekli, kaşağı varlığı, tırnak bakım sıklığı, sağım şekli, suluk şekli, havalandırma sistemi arasında ilişki tespit edilmemiştir (*Tablo 4*).

Tablo 4. Şehirlere göre verilerin ki-kare analizi sonuçları

Table 4. Chi-Square analysis results of data by city

Değerler	Konya (117)	Aydın (103)	p
Hayvan sayısı (baş)			
0-50	63	51	
51-100	21	28	
101-150	8	6	0.482
151-200	8	4	
201-250	5	2	
251-300	1	3	
301 ve üstü	11	9	
Sağılan hayvan sayısı (baş)			
0-50	87	70	
51-100	16	15	
101-150	6	4	0.461
151-200	2	3	
201-250	1	0	
251-300	1	5	
301 ve üstü	4	6	
Yetiştirilen ırk			
Holstein	56	43	0.020
Simental	27	13	
İkiside	34	47	
Günlük verim ortalaması (lt)			
0-20	45	26	
21-30	45	48	0.109
31-40	24	22	
41-50	3	4	
51 ve üstü	0	3	
Sağım sayısı			
1	3	4	0.248
2	100	79	
3	14	20	
Barınak tipi			
Açık	11	18	0.002
Yarı açık	60	66	
Kapalı	46	19	
Barınak ve Durak zemini			
Beton	95	74	
Tuğla	9	7	0.038
Kiremit	5	2	
Diğer	8	20	
Durak altlık materyali			
Kauçuk paspas	29	17	
Kum	10	14	
Beton	65	45	0.025
Sap-saman	8	14	
Talaş	2	9	
Diğer	3	4	

Tablo 4. (devamı) Şehirlere göre verilerin ki-kare analizi sonuçları

Table 4.(continued) Chi-Square analysis results of data by city

Değerler	Konya (117)	Aydın (103)	p
Ayak hastalığı görülenler (baş)			
Yok (sıfır)	36	26	
1-5	60	60	
6-10	17	13	
11-15	1	2	0.608
16-20	0	1	
21-25	0	0	
25 ve üstü	3	1	
Havalandırma bacası			
Var	56	61	
Yok	61	42	
Dışkı temizleme şekli			0.092
Mekanik	45	35	0.156
Kürek	54	45	
Basınçlı su	0	4	
Diğer	18	19	
Kaşağı			
Var	60	49	
Yok	57	54	
Tırnak bakımı sıklığı			0.583
45 günde 1	7	4	0.453
3 ayda 1	15	8	
6 ayda 1	32	28	
Yılda 1	9	14	
İhtiyaç olduğunda	54	49	
Duvar yapı malzemesi			0.020
Taş	17	5	0.039
Briket	58	48	
Tuğla	28	37	
Kerpiç	14	15	
Sağım şekli			0.109
Makine	110	99	0.476
El ile	7	4	0.791
Suluk şekli			
Otomatik suluk	81	73	
Yalak/Tekne	36	30	0.248
Havalandırma sistemi			0.974
Pencere	16	12	
Baca	14	14	0.002
Pencere + baca	30	24	
Şerit	28	26	
Diğer	29	27	

Ki-kare testi ile şehirler ile değişkenlerin ilişkisinin belirlenmesi

4. Sonuç

Konya ve Aydın illeri bulundukları bölge itibarı ile farklı coğrafi ve iklimsel şartlar altındadır. Bu bölgelerde bulunan süt sığırı işletmelerinin barınak yapıları değişiklik göstermektedir. Çalışmada elde edilen sonuçlar da barınak yapılarının ve donanımlarının farklılığını ortaya koymaktadır. Şehirler ile arasında ilişki bulunan barınak tipi, barınak ve durak zemini, durak altlık materyali, duvar yapı malzemesi tercihleri bölgelerin coğrafi ve iklimsel farklılıkları sonucu olabileceği gibi bölgede yapılan geleneksel hayvancılık tekniklerinden de kaynaklanabilmektedir. Dolayısıyla süt hayvancılığı için tek bir doğru bulunmamaktadır. Bölgenin ihtiyaçları ve çevresel faktörlerine bağlı olarak barınak yapıları ve donanımları yapılacak olan hayvancılık tipine yön vermektedir.

Barınak yapı ve donanımları ile şehirler arasında görülen farklılıkları bölgelerin iklim şartları etkileyebilmektedir. Bu şartların hayvanlar üzerindeki olumsuz etkilerinin azaltılması ideal çevre şartlarında barındırılmalarına bağlıdır. Bu amaçla; bölgenin iklim şartlarının detaylı bir şekilde incelenerek hayvan sağlığı ve verimi üzerindeki olumsuz etkileri giderebilecek barınak tipleri üzerinde durulmalıdır. Bulunulan bölge Konya gibi yazları kuru ve sıcak, kışları ise soğuk ve kar yağışlı karasal iklime sahip; Aydın gibi yazları sıcak ve nemli kışları ılık ve yağışlı akdeniz iklimine sahip ise açık, yarı açık barınak tipleri seçilebilir. İki il içinde aynı barınak tipi seçilebilmesine rağmen çalışma da Aydın bölgesinde muhtemelen nemin etkisinden dolayı açık ve yarı açık işletme sayısı, Konya ilinde ise kış aylarının daha sert geçmesinden dolayı kapalı barınak tipi daha fazla bulunmuştur. Kış aylarının daha sert geçtiği doğu bölgelerinde de kapalı barınak tipi seçilebilir. Barınak konumlandırılmasında kuzey rüzgârlarına hâkim olacak şekilde giriş yönünün güneye veya doğuya yönelik olması tercih edilmelidir (Moran, 1989; Uğur, 2014; Alpan ve Aksoy, 2015). Barınak tasarımında pahalı ve tamamen kapalı yapılar yerine, daha ekonomik ve açık sistem barınaklar tercih edilmektedir (Arıcı, 1982). Türkiye'de süt sığırı barınakları inşa edilirken her yörenin iklim şartlarına, yapısal ve teknik özelliklerine göre yeni modellerin geliştirilmesine, daha geniş ölçekli ve hayvan refahını gözeten çalışmaların yapılmasına ihtiyaç bulunmaktadır.

Sonuç olarak Aydın ve Konya illerindeki işletmelerin yapısal olarak durumları incelenmiş olup modern süt sığırı işletmesi bakımından değerlendirilmesi yapılmıştır. Yaklaşık olarak işletmelerin yarısı hayvan yoğunluğu açısından büyük kapasiteye sahipken diğerlerinin daha küçük yapılı işletmeler ya da aile işletmeleri olarak devam ettiği söylenebilir. Hayvan refahının arttırılması için kullanılan ekipmanların arttırılması gerektiği ve özellikle otomatik kaşağılar ile durak altlıkları kullanımının üzerinde durulması gerekmektedir. Hayvancılığın geliştirilmesi amacıyla bu konularda ilgili yerlerde yetiştiricilere eğitim verilmesi planlanabilir. Ahırların planlama ve kurulum aşamasındaki maliyet hesaplarında büyük miktarda ekonomik yük oluşturan teknolojik ve yeni nesil ekipmanların kullanımının ilerleyen zamanlarda kendi maliyetlerini karşılayabileceği ve hatta işletme karlılığını arttıracağı konusunda bilgilendirmeler yapılmalıdır. Daha sonraki çalışmalarda bu ve benzeri illerdeki ahır yapılarının detaylı olarak karşılaştırılması bölge ve ülke hayvancılığının daha planlı olmasına katkı sağlayacaktır.

Teşekkür

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Çıkar Çatışması Beyanı

Makale yazarı olarak herhangi bir çıkar çatışması olmadığını beyan ederim.

Yazarlık Katkı Beyanı

Planlama: OE; Materyal ve Metot: OE; Veri toplama ve İşleme: OE; İstatistiki Analiz; OE; Literatür Tarama: OE; Makale Yazımı, İnceleme ve Düzenleme: OE.

Kaynakça

Alkan, S. ve Güney, Z. (2019). Ordu ili sığırcılık işletmelerinin yapısal özelliklerinin belirlenmesi. *Mediterranean Agricultural Sciences,* 32(3): 447-452.

Alpan, O. ve Aksoy, A. R. (2015). Sığır Yetiştiriciliği ve Besiciliği. 7.baskı, Favori Basım, İstanbul.

Arıcı, İ. (1982). Kırsal toplu yerleşim ve işletme avlularının düzenlenmesi. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi,* 13: 3-4.

Bewley J. M., Boyce, R. E., Hockin, J., Munksgaard, L., Eicher, S. D., Einstein, M. E. and Schutz, M. M. (2010). Influence of milk yield, stage of lactation, and body condition on dairy cattle lying behaviour measured using an automated activity monitoring sensor. *Journal of Dairy Research,* 77(1): 1-6.

Boone, R. E., Bucklin, R. A. and Bray, D. R. (2010). Comparison of free stall bedding materials and their effect on cow behavior and cow health. *Applied Engineering in Agriculture,* 26(6): 1051-60.

Camiloti, T., Fregonesi, J., Von Keyserlingk, M. and Weary, D. (2012). Effects of bedding quality on the lying behavior of dairy calves. *Journal of Dairy Science.* 95(6): 3380-3.

Demir, P., Adıgüzel, S. I., Sarı, M. ve Ayvazoğlu, C. (2014). Kars merkez ilçedeki süt sığırcılık işletmelerinin genel yapısı ve ekonomik boyutu. *FÜ Sağlık Bilimleri Dergisi,* 28(1): 9-13.

Erkmen, Y., Çelik, A. ve Yıldız, C. (2000). Erzurum İli Süt Sığırcılığı İşletmelerinin Yapısal Durumu ve Ahır İçi Mekanizasyon Özellikleri Üzerine Bir Araştırma. *Tarımsal Mekanizasyon 19. Ulusal Kongresi.* 01-02 Haziran, S. 468-474, Erzurum, Türkiye.

Erzurum, O. and Yılmaz, A. (2020). The effect of different quality bedding materials used in dairy cows on milk yield. *Eurasian Journal of Veterinary Sciences,* 36(4): 347-354.

Güler, O., Aydın, R., Diler, A., Yanar, M., Koçyiğit, R. ve Maraşlı, A. (2017). Sığırcılık işletmelerinin barınak özellikleri üzerine bir araştırma; Erzurum ili Narman ilçesi örneği. *YYÜ Tarım Bilimleri Dergisi,* 27: 396- 405.

House, H. K. and Eng, P. (2016). Dairy Housing - Ventilation Options for Free Stall Barns, Ontario.

House, J. (2011). A Guide to Dairy Herd Management. Meat & Livestock Australia Limited.

Koçak, D. (2020). *Ankara ili Polatlı ilçesi küçük ve büyükbaş hayvancılık işletmelerinin barındırma sistemlerinin hayvan refahı bakımından değerlendirilmesi.* (Yüksek Lisans Tezi) Kırıkkale Üniversitesi, Sağlık Bilimleri Enstitüsü, Kırıkkale.

Kösemen, A. ve Şeker, İ. (2016). Malatya ilinde sığırcılık işletmelerinin mevcut durumu: I. yapısal özellikler. *FÜ Sağlık Bilimleri Veteriner Dergisi,* 30(1): 5-12.

Kıyıcı, J. M. ve Çınar, M. U. (2020). Türkiye'de süt sığırı yetiştiriciliği uygulamaları üzerine bir araştırma. *Hayvan Bilimi ve Ürünleri Dergisi,* 3(2): 165-175.

Moran, J. (1989). The influence of season and management system on intake and productivity of confined dairy cows in a Mediterranean climate. *Animal Production,* 49(3): 339-344.

Mundan, D., Atalar, B., Meral, B. A. ve Yakışan, M. M. (2018). Modern süt sığırı işletmelerinin yapısal ve teknik özelliklerinin belirlenmesi üzerine bir araştırma. *Atatürk Üniversitesi Veteriner Bilimleri Dergisi,* 13(2): 201-210.

Munksgaard, L. and Simonsen, H. B. (1996). Behavioral and pituitary adrenal-axis responses of dairy cows to social isolation and deprivation of lying down. *Journal of Animal Science.,* 74(4): 769-78.

Şeker, İ., Tasalı, H., ve Güler, H. (2012). Muş İlinde sığır yetiştiriciliği yapılan işletmelerin yapısal özellikleri. *FÜ Sağlık Bilimleri Veteriner Dergisi, 26*(1), 9-16.

Tabachnick, B. G. and Fidell, L. S. (2013). Using Multivariate Statistics. Boston, Pearson.

Tatar, Y. E. ve Esenbuğa, N. (2022). İzmir ili Ödemiş ilçesi sığırcılık işletmelerinin sürü yönetim tekniklerinin incelenmesi. *Palandöken Journal of Animal Sciences Technology and Economics,* 1(1): 16-23.

Tiryaki, O. (2022). *Koyun yünü katkılı kerpicin bazı fiziksel ve mekanik özellikleri.* (Yüksek Lisans Tezi) Konya Teknik Üniversitesi, Lisansüstü Eğitim Enstitüsü, Konya.

Tutkun, M. (1999). *Diyarbakır ili merkez ilçeye bağlı köylerdeki süt sığırcılığının yapısı.* (Yüksek Lisans Tezi) Ankara Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

Uğur, F. (2014). Sığır Yetiştirme (Ders Kitabı). Çanakkale Onsekiz Mart Üniversitesi Yayınları No: 117. Birinci baskı. Pozitif Matbaa, Türkiye.

Von Keyserlingk, M., Rushen, J., de Passillé, A. M. and Weary, D. M. (2009). Invited review: The welfare of dairy cattle—Key concepts and the role of science. *Journal of Dairy Science,* 92(9): 4101-11.

Wathes, C. M. and Charles, D. R. (1994). Livestock Housing. CAB International, Wallingford Oxon, OX10 8DE, UK.

Yamane, T. (1967). Elementary Sampling Theory. Englewood Cliffs, New Jersey: Prentice- Hall, Inc., 405 pp. USA.

Yayar, R. ve Karkacier, O. (1996). Tokat ili Pazar ilçesi süt sığırcılığı işletmelerinin ekonomik ve teknik özellikleri üzerinde bir araştırma. *Gazi Osman Paşa Üniversitesi Ziraat Fakültesi Dergisi,* 13(1): 269-288.

Yener, H., Atalar, B. ve Mundan, D. (2013). Şanlıurfa ilindeki sığırcılık işletmelerinin biyogüvenlik ve hayvan refahı açısından değerlendirilmesi. *Harran Üniversitesi Veteriner Fakültesi Dergisi,* 2(2): 87-93.

Yenice, G. ve Savaş, S. (2016). Rize ilinde yapılan süt sığırcılığının mevcut durumunun araştırılması. *Atatürk Üniversitesi Veteriner Bilimleri Dergisi,* 11(1): 74-83.

Ek1: Anket formu

Süt Sığırı İşletmelerinin Barınak Özelliklerinin Değerlendirilmesi

Vereceğiniz cevaplar için lütfen kutucuğu işaretleyiniz.

İşletmenin bulunduğu il	
Konya	Aydın

İşletmedeki hayvan sayısı (baş)						
0-50	51-100	101-150	151-200	201-250	251-300	300 ve üstü

İşletmedeki sağılan hayvan sayısı (baş)						
0-50	51-100	101-150	151-200	201-250	251-300	300 ve üstü

Günlük hayvan başına süt verim ortalaması (litre)				
0-20	21-30	31-40	41-50	50 ve üstü

Yetiştiriciliği yapılan ırk		
Holstein	Simental	İkiside

Günlük sağım sayısı		
1	2	3

Barınak tipi		
Açık	Yarı açık	Kapalı

Barınak ve Durak Zemini			
Beton	Tuğla	Kiremit	Diğer

Durak Altlık Materyali					
Kauçuk paspas	Kum	Beton	Sap-saman	Talaş	Diğer

Bir yıl içinde ayak hastalığı görülen hayvan sayısı (baş)						
Yok (sıfır)	1-5	6-10	11-15	16-20	21-25	26 ve üstü

İşletmede havalandırma bacası var mı?	
Evet	Hayır

Dışkı temizleme şekli			
Mekanik sıyırıcı	Kürek	Basınçlı su	Diğer

Barınakta otomatik kaşıyıcı var mı?	
Evet	Hayır

Tırnak bakım sıklığı				
45 günde 1	3 ayda 1	6 ayda 1	Yılda 1	İhtiyaç olduğunda

Barınak yapımında kullanılan duvar yapı malzemesi				
Taş	Briket	Tuğla	Kerpiç	Diğer

Sağım şekli	
Makineli sağım	Elle sağım

Suluk	
Otomatik suluk	Yalak / Tekne

Barınaktaki havalandırma sistemi		
Pencere	Havalandırma bacası	Pencere + baca

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

The Influence of Nitrogen Rates on Yield and Some Quality Parameters of Sweet Corn (*Zea mays saccharata* Sturt.) Growing in Diyarbakır Districts of Türkiye

Diyarbakır İlinde Yetiştirilen Tatlı Mısırda (*Zea mays saccharata* Sturt.) Farklı Azot Seviyelerinin Verim ve Bazı Kalite Parametreleri Üzerine Etkisi

Özlem AVŞAR[1*], Betül KOLAY[2], Uğur BİLGE[3]

Abstract

Sweet corn (*Zea mays saccharata* Sturt), is a maize subspecies with rapidly increasing consumption in the world and in Türkiye both in terms of its nutritional content and various uses in fresh, frozen and canned form. Nitrogen plays a crucial role in promoting most of plants growth and productivity. Plant nutrient recommendations are important to maximise profit and productivity in sugar maize production. The influences of nitrogen (N) fertigation on yield and some quality parameters of sweet corn under South Eastern Anatolia Region (Diyarbakır) conditions of Türkiye were investigated in that trial. Fertigation applications were executed under regional conditions of Diyarbakır on the experimental land of GAPUTAEM (GAP International Agricultural Research and Training Center). "BATEM Tatlı" variety of sweet corn was utilized as the plant material. The trial was arranged as randomized complete block design with 4 replications and five different N applications (0-75-150-225-300 kg ha^{-1}) were implemented to trial plots through a fertigation system. During the 2015 and 2016 growing season that the trial was carried out a total of 520 mm and 476 mm of irrigation water were applied, respectively. According to the study results N levels had a significant effect on fresh grain yield, crude protein ($p < 0.01$) and crude oil ($p < 0.05$). Furthermore, increased N levels had no effect on brix (dissolved solids in a liquid), L* (brightness) and a*/b* (redness/yellowness) values. Fresh grain yield (11000 kg ha^{-1}) of sweet corn under the effect of 150 kg ha^{-1} nitrogen treatment was the highest. The maximum crude protein (12.60) was recorded from 300 kg ha^{-1} N and crude oil (5.56) under the effect of 225 kg ha^{-1} nitrogen treatment was the highest. This study provides guidance for nitrogen management in sweet corn production in arid regions, such as the Southeast Region of Türkiye. Implementing 150 kg N ha^{-1} with a fertigation system is a sustainable method for sweet corn production.

Keywords: Nitrogen, Fertigation, Sweet corn

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Öz

Tatlı mısır gerek besin içeriği gerekse taze, dondurulmuş ve konserve şeklindeki değişik kullanımı ile dünyada ve Türkiye'de hızla tüketimi artan bir mısır alttürüdür. Azot, birçok bitkinin büyümesinde ve verimliliğinde önemli bir rol oynamaktadır. Tatlı mısır üretiminde kârı ve verimliliği en üst seviyeye çıkarmak için gerekli bitki besin elementi tavsiyeleri önem taşımaktadır. Bu çalışma da Türkiye'nin Güneydoğu Anadolu Bölgesi (Diyarbakır) koşullarında farklı azot (N) gübreleme seviyelerinin mısırda (*Zea mays saccharata* Sturt.) verim ve bazı kalite parametreleri üzerine etkileri araştırılmıştır. Çalışma Diyarbakır ili koşullarında GAPUTAEM (GAP Uluslararası Tarımsal Araştırma ve Eğitim Merkezi) deneme arazisinde yürütülmüş ve bitki materyali olarak BATEM tatlı tatlı mısır çeşidi kullanılmıştır. Araştırma tesadüf blokları deneme desenine göre 4 tekerrürlü olarak düzenlenmiş ve fertigasyon sistemi ile beş farklı N uygulaması (0-75-150-225-300 kg ha^{-1}) yapılmıştır. Denemenin yürütüldüğü 2015 ve 2016 yetiştirme sezonu boyunca sırasıyla toplam 520 mm ve 476 mm sulama suyu uygulanmıştır. Çalışma sonuçlarına göre, N seviyelerinin taze dane verimi, ham protein ($p < 0.01$) ve ham yağ ($p < 0.05$) üzerinde istatistiki olarak önemli bir etkiye sahip olduğu görülmüştür. Ayrıca artan N seviyelerinin brix (sıvıdaki çözünmüş katı madde), L* (parlaklık) ve a*/b* (kırmızılık/sarılık) değerleri üzerinde herhangi bir etkisi olmamıştır. Tatlı mısırın en yüksek taze dane verimi (11000 kg ha^{-1}) 150 kg ha^{-1} azot uygulamasından elde edilmiştir. En yüksek ham protein değeri (12.60) 300 kg ha^{-1} N'den elde edilirken, ham yağ ise (5.56) 225 kg ha^{-1} azot uygulamasında en yüksek değere sahip olmuştur. Bu çalışma, Türkiye'nin Güneydoğu Bölgesi gibi kurak bölgelerde tatlı mısır üretiminde fertigasyon yöntemiyle uygulanması gereken optimum azot uygulaması konusunda yol göstermekle birlikte 150 kg N ha^{-1} uygulaması sürdürülebilir bir yöntem olarak öne çıkmıştır.

Anahtar Kelimeler: Azot, Fertigasyon, Tatlı mısır

1. Introduction

Cereals are major products which cover a wide area of the world. Among cereals, corn is crucial for both human nutrition and animal feed. As a result of the development of high-yield regular, breeding different varieties and its extensive adaptation to environmental conditions, corn took a part as a leader, beating rice and wheat. In terms of grain production per hectare, it is the highest-grading cereal. For a large number of industrial output and biofuels, corn is essential and has a great economic importance not only for human consumption but also for animal nutrition (Shyam et al., 2021). Sweet corn (*Zea mays* L.) may be distinguished from other types of corn consumed before the physiologic ripening period with a short shelf life due to a higher respiration rate, which remains fresh and before all sugar's conversion towards starch (Okumura et al., 2013). Furthermore, compared to field corn, sweet corn offers higher prices for kg ha^{-1} but yields are low. Lack of systematic research and the absence of better varieties are major reasons for this low yield (Khan et al., 2017). The sweetness taste of sweet corn is owing to a genetic mutation in the field corn's su ("sugary") gene, which affects the conversion of sugar to starch in the grain's endosperm. Standardized practices for cultivating and managing the process of sweet corn after harvest have been widely prevalent (Singh et al., 2014). Consuming sweet corn, which is present in various dishes as an ingredient, has become popular in Türkiye due to its numerous health benefits.

Among the essential nutrients for proper plant cultivation including sweet corn, nitrogen (N) has a significant role as it is required for chlorophyll production and protein synthesis (Basal and Szabo, 2020). Supplementing nitrogen fertilizer is necessary to meet the demand of plants, as the naturally present N in soil is usually insufficient for achieving high yields (Sainju and Singh, 2008). During the vegetative growth period, leaves require a large quantity of nitrogen, and healthy leaf growing is crucial for both fruit production and retention (Oosterhuis et al., 1983). When plants experience a shortage of nitrogen, they tend to display stunted growth and smaller leaves. Due to the high mobility of nitrogen through phloem, older leaves demonstrate chlorosis at the beginning of nitrogen absence. The lack of N causes the chloroplast disruption and if the nitrogen deficiency is not compensated, the plant may die (Alimohammadi et al., 2011).

Sweet corn responds differently to nitrogen fertilizer application, which depends on soil properties, irrigation methods, N application time and frequency. However, the relationship between nitrogen application and its effect on the yield of sweet corn is not well-understood, especially when excessive nitrogen is applied via drip fertigation. Based on the different climatic conditions, plant varieties as well as sowing time, researchers suggest a varying rate of application of N for sweet corn. The most effective N application rate for sweet corn was reported as 110.8 kg ha^{-1} N (Okumura et al., 2014), 240 kg ha^{-1} N (Bhatt, 2012), and 120 kg ha^{-1} N (Masood et al., 2003) whereas some other researchers (Khazaei et al., 2010) revealed that the grain yield was not affected by the difference in nitrogen rate. Developing optimum nitrogen management implementations for plants can enhance grain yield, efficiency, quality and profitability for producers while reducing soil nitrate accumulation and minimizing leaching to groundwater (Schlegel and Havlin, 1995). As a notable crop, sweet corn requires large amount of nitrogen, which can be supplemented by applying fertilizer to the soil.

Freshwater is crucial for agricultural activities as it is used to irrigate cultivated area and provide water for plants (Jeet et al., 2022). Meteorological forecasts predict that water scarcity will be a critical factor affecting food security and environmental safety. Improving the water and N use efficiency is crucial for sustainable agriculture, rural development, and environmental protection (Šútor and Gomboš, 2006).

To provide the required nutrients and irrigation water of the plant, it is important to consider the amount, method, and frequency of application. From this point of view drip irrigation is a proven method that offers agronomic, economic, and agro-technical benefits for efficient water and fertilizer use. It can replace surface irrigation, with 90% water use efficiency (Allen, 1998). Drip fertigation is an efficient farming technique that involves the application of liquid fertilizer through irrigation. One of the most significant advantage of drip fertigation is providing crop nutrients on an as-needed basis by delivering water and nutrients directly to the crop root zone, which helps to reduce the possibility of environmental contamination. This technique is also known as "spoon-feeding" and helps in precise delivery of water and nutrients to the crops. One previous study suggested that drip fertigation can improve sweet corn yield in open fields, producing up to four ears per stalk (Takeshita et al., 2019).

Prevalent embracement of drip irrigation corn yields and irrigation water efficiency have improved over the last few years in Türkiye unfortunately water use efficiency in South East Anatolia Region included Diyarbakır province is still far lower because of applying surface irrigation systems in corn cultivation. Additionally, local farmers are generally tended to apply high rates of N-fertilizers to obtain high yields. However, excessive use of N leads to serious environmental risks through its loss into the environment rather than better absorption. Regarding the findings of the study conducted in the Southeast Anatolia Region, an increase in the yield of sweet corn and grain protein content with an increase in N rates and the highest fresh ear yields were obtained at 240 kg N ha^{-1} through furrow irrigation system (Öktem, 2007). In the meantime, reported that further studies are necessary to assess the impact of NPK fertilizer applications on maize production in a moderate semi-arid environment.

As a consequence, further improvements related to increasing water use efficiency and optimum N management strategies remain a significant requirement for the region as mentioned by (Nasseri, 2021). Although several studies have been conducted on corn production via drip fertigation, utilize various nitrogen levels, limited research has been carried out on sweet corn, applying different rates of nitrogen in Türkiye and also in Southeast Anatolia Region.

Based on the above discussion, the main goals of this study were to assess how sweet corn production responds to varying levels of nitrogen, and to increase the farmer's income by improving the yield while optimizing N rates.

2. Material and Method

A field study was performed at GAP International Agricultural Research and Training Center (GAPUTAEM) Diyarbakır, Türkiye, in 2015-2016 years, to investigate the reaction of sweet corn to nitrogen levels on the yield and some soil properties. Deep cracks (up to 80-90 cm) arises on the soil surface in summer as a consequence of clay-based feature of soil (Gürsoy et al., 2006).

The soil was sampled from 0-30 cm depth through a drill and analysed at GAPUTAEM laboratory and the findings is given in *Table 1*. The soil of experimental area was clay-loam, low in organic matter, high in obtainable potassium and low in phosphorus with no salinity problems. The mean bulk density of the soil in 2015 and 2016 growing season is 1.33 and 1.25 g cm^{-3} is respectively. The field had not been planted any plant about 2 years before this experiment was conducted. With the assistance of a pressure plate, field capacity (FC) and permanent wilting point (PWP) values were determined, and the available water capacity (AWC) was calculated as subtraction from FC to PWP values (Tüzüner, 1990).

Table 1. Some soil features of experimental site

Years	2015	2016
Texture	Clay-Loam (C-L)	Clay-Loam (C-L)
EC (dS m^{-1})	1.65	0.90
pH	8.10	8.25
CaC03 (%)	9.97	11.00
P2O5 (kg ha^{-1})	3.21	4.02
K2O (kg ha^{-1})	243	243
Organic Matter (%)	“0.95	1.10
Bulk Density (g/cm^3)	1.33	1.25
Field Capacity (%)	44.05	44.03
Permanent Wilting Point (%)	30.04	30.08

Diyarbakır is one of the provinces in the Southeastern Anatolia Region where continental climate prevails.

Table 2 shows the climatic data for the years in which the study was conducted (2015-2016) and for long years. In the light of this information, it is observed that the average temperature values of 2016 (15.7 °C) are above the average temperature values of 2015 and long years. *Table 2* shows that the average maximum temperature value (40 °C) determined in July 2015 is above the average maximum temperature values of long years and 2016 and the average monthly precipitation values for long years (68.2 mm) are higher than the average precipitation values in 2015 and 2016 years.

Table 2. Monthly data of the climate in Diyarbakır for long period and during the 2015-2016 growing season of sweet corn

Meteorological data	Years	April	May	June	July	August
Average temperature (°C)	Long Years	13.8	19.2	26.3	31.1	30.4
	2015	12.4	18.8	26.1	31.7	30.9
	2016	15.7	19.9	26.8	31.6	31.9
Average maximum temperature (°C)	Long Years	20.4	26.5	33.6	38.4	38.2
	2015	19.2	27.1	34.4	40	39.3
	2016	23.7	27.5	34.7	39.2	40.5
Average minimum temperature (°C)	Long Years	7.2	11.3	16.9	21.8	21.1
	2015	5.5	10.3	15.9	21.4	21.2
	2016	7.1	11.6	17.3	22.5	22.1
Monthly average rainfall (mm)	Long Years	68.2	42.9	8.1	0.7	0.4
	2015	48.6	48.2	7.4	0	0
	2016	29	41.4	18.4	0	0.2

Reference: Diyarbakir meteorological directorate https://www.mgm.gov.tr/ ; *among 1950-2014 years

2.1. Characteristics of the plant material

Türkiye's first local sweet corn variety developed by the Directorate of Western Mediterranean Agricultural Research Institute was registered in 2013. The variety was developed within the scope of Sugar Maize Variety Development studies, which is a sub-project of the Mediterranean Region Maize Breeding Research project supported by the General Directorate of Agricultural Research and Policies (TAGEM). BATEM TATLI is a standard type of sweet corn variety with an average fresh cob yield of 1 513 kg ha^{-1} and grain yield of 589 kg ha^{-1} with crude protein (10.7%), crude fat (6.7%), starch (53.3%) and sugar (4.8%) contents. Sweet corn, which is a hot climate plant, requires at least eight hours of direct sunlight per day. Planting should occur after the last frost of spring, and when the soil's temperature at a depth of 7-8 cm is at least 10-12.7 °C. Low soil temperature causes low germination rate and negatively affects cultivation. Harvesting fresh corn varies depending on the region and climate, but typically takes 70-80 days (Anonymous, 2014).

2.2. Irrigation system and nitrogen treatments

The experiment was organized as a randomized complete block design, which included four replications. The trial area was tillaged and levelled before planting. Sweet corn seeds were planted by hand with a row spacing of 70 cm and 20 cm (intra-row spacing) with a sowing depth of 5-6 cm and 71400 seeds per hectare on April 20 and 25, 2015 and 2016 respectively. The experiment consisted of 20 plots in total, with 5 plots in each block and a distance of 3 meter was maintained between blocks and 2-meter between plots. The experiment comprised of 20 plots in total, with 5 plots in each block.

All observations were attained from two rows in each plot and all treatments were harvested at the milk stage, based on the thumbnail method (Çetinkol, 1989). During both years, the initial irrigation was implemented using sprinkler irrigation for uniform emergence. For the remaining irrigations, drip irrigation method was implemented twice a week and the amount of irrigation water was determined by measuring the amount of evaporation from Clas A Pan adjusting the wetting area ratio accordingly. The soil water content was monitored by gravimetric method at 15-day intervals during the drip irrigation treatment to a depth of 90 cm every week and irrigation water was applied to reach the field capacity, from a depth of 30 cm on each plot. The drip irrigation and fertigation were scheduled once in five days and ten days respectively as required the treatments. As a result of the analyses, irrigation water electrical conductivity value (EC): 0.60 dS/m, pH: 7.6 were determined. Required irrigation water has been calculated depend on the Class A pan evaporation, utilizing the given equation.

$$I = A.Ep.Kp.Pc \quad \text{(Eq. 1)}$$

Where I equals required irrigation water (I), A equals irrigated plot area (m^2), Ep equals cumulative evaporation quantity for 5 day intervals (mm), Kp equals coefficient (including pan coefficient kp, crop coefficient kc), and Pc equals canopy cover area (%). The canopy cover percentage was initially set at 30% for the first irrigation, and the subsequent irrigations performed via measured values.

Utilizing the water balance equation and soil water measurements, plant water consumption was estimated. The formula for calculating plant water consumption includes irrigation, precipitation, water leakage, and soil

water content changes during the season. The formula for calculating plant water consumption includes irrigation, precipitation, water leakage, and soil water content changes during the season as shown:

$$ET = I + P \pm DS - D \quad \text{(Eq. 2)}$$

Where: ET is evapotranspiration (mm), I irrigation (mm), P precipitation (mm), D deep percolation (mm) and DS is change of soil water storage. Assuming negligible deep percolation losses below the root zone, the study implemented irrigation based on field capacity. Soil water content was measured every 15 days at 0-90 cm soil layer during both growing seasons using the gravimetric method (oven dry basis). During the cultivation periods of 2015 and 2016, 520 mm and 476 mm of irrigation water were respectively implemented. Chemical pesticides were applied and weed control applications were implemented during the entire plant growth season. The crop evapotranspiration for 2015 and 2016 was calculated as 554 mm and 495 mm, respectively. Five pure nitrogen dosses (0, 75, 150, 225 and 300 kg ha^{-1}) were performed in the trial. Nitrogen doses were determined as the lower and upper values of the nitrogen levels applied by the farmers cultivating maize. Triple Super Phosphate (42% P_2O_5) and Ammonium Sulphate (21% N) were utilized as the base fertilizer, and Ammonium Nitrate (33% N) was applied as the top fertilizer. The reason for selecting these fertilizers is that they can be used for fertilizing through the fertigation system. Based on the soil analysis conducted in both years of the experiment, an equal amount of 100 kg ha^{-1} phosphorus and 1/5 of the designated nitrogen was added to each parcel as a base fertilizer. The remaining 4/5 of the nitrogen was applied equally once every two irrigations using the fertigation method till one week before the harvest. With this fertilization schedule, the sweet corn plant's nitrogen demand is adequately met during the necessary periods (Çetin and Tolay, 2009).

Due to the sufficient potassium content of soil potassium fertilization was not implemented during both growing seasons. The plants were harvested on August 1 and August 3, 2015 and 2016 respectively, during the milk stage.

In the trial, fresh grain yield, brix value, crude protein content, crude oil content, brightness (L*) and yellowness/redness (a*)/(b*) values were explored. In the middle of two rows for each parcel, observations on brix, crude protein content, crude oil content, brightness (L*) and yellowness/redness (a*)/(b*) values have been made from 10 random chosen plants while the fresh grain yield were attained from every plant in the middle of a pair of rows. The calculations of the properties investigated in the study were performed according to the methods of the Ministry of Agriculture and Forestry, Agricultural Values Measurement Trials Technical Instruction (Anonymous, 2015). The data obtained in the study were evaluated via JMP 5.1 statistical package. Analysis of variance (ANOVA) and Least Significant Difference (LSD 0.05) test was attained by combination of two years.

3. Results and Discussion

Perusal of the data revealed that different N level applications had a significant ($P \leq 0.01$) effect on fresh grain yield (FGY) of sweet corn. Maximum FGY values (11000.7 kg ha^{-1}) was reported when N was applied at the rate of 150 kg ha^{-1}, but further increase in N rate for both years has negative significant effect on FGY (*Table 3*). These results in line with Kara and Kırtok (2006), Yılmaz (2005) who emphasized that FGY increased with increasing nitrogen level. Turgut (1998), stated that the highest yield of sweet corn fresh ear yield was attained at 280 kg ha^{-1} of nitrogen level based on regression analyses via surface irrigation method. The effects of the years on FGY were defined to be significant ($P \leq 0.01$) in the study. In comparison to 2016, the average value of FGY increased in 2015. Average maximum temperature values of 2015 (39.3 °C) were higher than 2016 (40.5 °C). High temperature values occurred hourly especially during the flowering period in July affected the yield values. The high yield values in 2015 can be associated with climate data. Upon examining *Table 2*, it becomes apparent that average monthly precipitation values for 2016 were lower than those of 2015. This indicates that the growing season in 2016 was drier than in 2015, and the higher yields in the latter year can also be attributed to the study being conducted on a fallow field.

Table 3. Influence of different nitrogen rates on some properties of sweet corn in the 2015-2016 growing seasons

		N levels					
		0 kg ha^{-1}	**75 kg ha^{-1}**	**150 kg ha^{-1}**	**225 kg ha^{-1}**	**300 kg ha^{-1}**	**Mean**
Fresh grain yield (kg ha-^{1}) **	2015	7 920.5	10 330.7	14 040.2	12 500.7	8 660.7	10 690.6 a
	2016	5 070.7	6 650.7	7 970.2	6 410.5	6 310.5	6 480.7 b
	Mean	6 500.1 d	8 490.7 bc	11 000.7 a	9 460.13 ab	7 490.1 cd	
	CV (%)	18	LSD (0.01): Nitrogen Levels:165			LSD (0.01): Years:215	
Brix **	2015	23.00	24.13	22.38	21.75	23.00	22.90 b
	2016	27.13	25.88	25.13	26.25	24.75	25.82 a
	Mean	25.19	25.00	23.75	24.00	23.88	
	CV (%)	8.2	LSD (0.01): Years:1.9				
Crude protein (%) **	2015	10.60	11.33	11.45	11.70	11.73	11.36
	2016	10.80	11.00	11.65	11.90	12.40	11.55
	Mean	10.70 d	11.16 c	11.55 bc	11.80 ab	12.60 a	
	CV (%)	3.4	LSD (0.01): Nitrogen Levels:0.4				
Crude oil (%) *, **	2015	5.18	5.28	5.30	5.33	5.20	5.25 b
	2016	5.45	5.60	5.73	5.80	5.73	5.66 a
	Mean	5.31 b	5.44 ab	5.51 a	5.56 a	5.46 ab	
	CV (%)	16	LSD (0.05): Nitrogen Levels:0.16			LSD (0.01): Years:0.07	
L(Brightness) *	2015	68.45	65.80	71.07	66.89	67.87	67.87 b
	2016	69.00	69.25	71.88	69.00	70.20	70.20 a
	Mean	68.70	67.53	71.47	69.52	67.94	
	CV (%)	8.9	LSD (0.05): Years:2.26				
Yellowness/redness (a*/b*)	2015	0.280	0.283	0.243	0.270	0.330	0.280
	2016	0.270	0.285	0.288	0.278	0.288	0.280
	Mean	0.275	0.284	0.265	0.274	0.309	
	CV (%)	14					

** significant at the level of 0.01; * significant at the 0.05 level

Based on regression analysis between nitrogen levels (X) and FGY (Y). FGY increased in a quadratic way for N rates (*Figure 1*). The relation among N levels and FGY was formed by y: 538.51 + 2.82 X – 0.467 X^2 (R^2: 0.15) equation. Increase N levels up to 150 kg ha^{-1} leads to increase in FGY. Lower FGY values were attained from 225 and 300 kg ha^{-1} N rates. A previous study, in which the recommended N level for sweet corn was 300 kg ha^{-1} under surface irrigation conditions was performed in the same field that this study was conducted (Kılınç et al., 2023). However, in the mentioned study, it has been detected that applying only 150 kg ha^{-1} of nitrogen using a fertigation system can result in the highest sweet corn yield, which is only half of the recommended nitrogen level. This finding not only helps reduce the production cost for producers, but also helps prevent soil and water pollution, which is vital for sustainable agriculture.

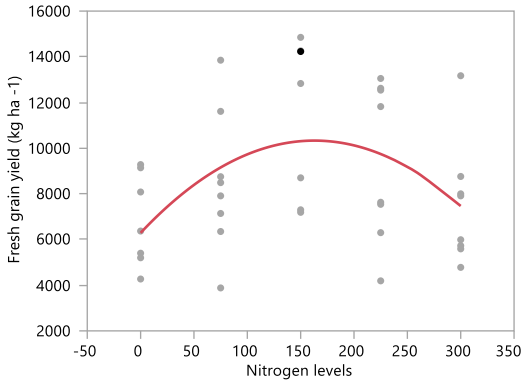

Figure 1. Influence of nitrogen levels on fresh grain yield

Starch and oil are crucial components of corn grain. Sweet corn quality can be assessed based on its protein, oil content, and brix (total soluble solids). Brix represents the percentage of solids present in the kernel juice and is directly related to the overall plant quality. In fact, it encompasses a blend of sucrose, fructose, vitamins, minerals, amino acids, proteins, hormones, and other solid components. A higher brix level indicates superior taste and

nutritional value (Harrill, 1998). At milk maturity, about l0 g of grains from the mid-section of each of 10 ears were cut and squeezed by hand and the milky endosperm fluid was poured onto a refractometer and measured in °Brix, which is an estimated expression of total sugar. The utilize of different N rates did not lead to a significant difference in brix values, although there was an increase by 25.82% during 2016 growing season (*Table 3*). According to White et al. (2007), the composition of grain is affected by environment factors such as temperature, soil type, planting date, year and location leading to changes in quality.

Regression analysis was performed to determine association between nitrogen levels (X) and brix values (Y) The relationship between them viewed as Brix = 22.694286 – 0.0216667 X+ 0.0023175 X^2 (R^2: 0.007211) the equation. No significant difference in brix was observed for any of N levels (*Figure 2*).

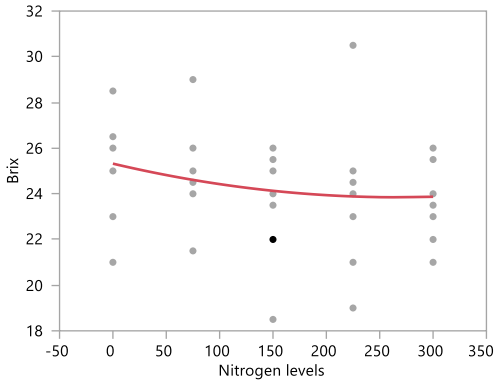

Figure 2. Influence of nitrogen levels on brix value

Applying different rates of nitrogen fertilization affected both the crude protein and oil contents of sweet corn grains, as illustrated in *Table 3*. The grains were dried in an oven following harvest. Four replicates of each sample from each N rate were examined. Ten subsamples for the protein and oil contents of each plot were gathered using near-infrared (NIR) technology. The values of crude protein ranged from 10.70% to 12.06%. The application of 300 kg ha^{-1} N level resulted in the highest and 0 kg ha^{-1} eventuated the lowest (10.70%) crude protein content. Goldberg (2003) reported that cereals contain 6-15% protein and that most corn protein (75%) comes from the endosperm (Shewry, 2007), which is consistent with these findings. One of the reasons for the rise in protein in grain could be due to the presence of N, which is part of protein (Haque et al., 2001). One possible explanation for the rise in protein content is that nitrogen is a building block of amino acids, and amino acids build up nitrogen over time. The oil content of sweet corn grains ranged from 5.31% to 5.56%. The highest oil content values were achieved from 2016 growing season (5.66%) and 225 kg ha^{-1} N application (5.56%) while the lowest ones obtained from 0 kg ha^{-1} (5.31) and 2015 growing season (5.25). No interaction existed between the effect of the year and different N applications. Similarly, according to Patil et al. (1996) the application of N increased oil content. This could be due to fact that synthesis of fat requires N. In contrast, Holou and Kindomihou (2011), reported no interaction (P = 0.14) existed between the effect of the year and that of the N rate and N fertilization did not significantly affect the average oil content of the grain.

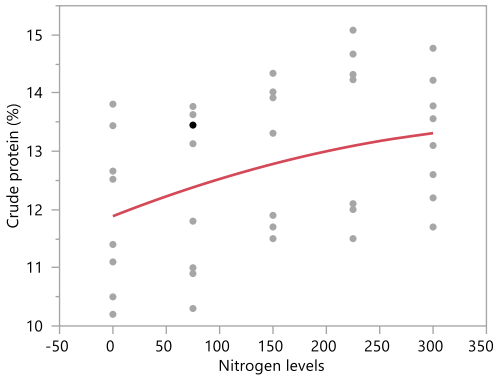

Figure 3. Influence of nitrogen levels on crude protein

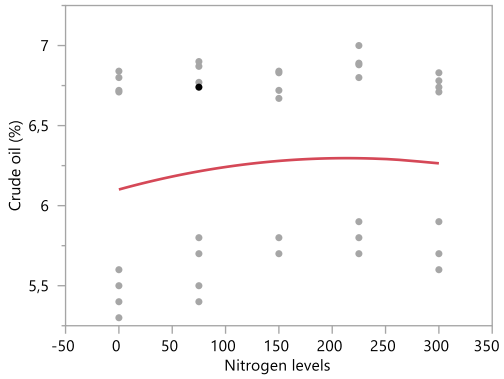

Figure 4. Influence of nitrogen levels on crude oil

A significant correlation between the crude protein content and the different N concentrations was observed in the regression analysis and the relationship was interpreted according to y:12.069536 + 0.0475333 X – 0.0008159 X^2 (R^2: 0.147289) the equation. The crude protein content was increased as N application levels increased.

Regression analysis was performed to determine association between nitrogen levels (X) and oil content (Y) and the relationship between N levels and oil content based on y: 6.1976429 + 0.00545 X – 0.0004302 X^2 (R^2: 0.014544) the equation (*Figure 4*).

Grain colour was determined by calculating L, a* and b* parameters obtained by spectrophotometer (model: CM-3220d, Minolta, Japan) according to CIELAB colour system and reported in terms of L*, a*/b* values at three different points on the cobs, including the tip, middle and bottom of the cob. The L* value symbolizes the brightness, the* value redness (positive value) and greenness (negative value), and the b* value is the yellowness (positive value) and the blueness (negative value).

Colour properties of fresh grains were shown in *Table 3*. Grain brightness values were not significantly influenced by N rates in both years. The mean values were between 67.53 and 71.47. The second year of the experiment has signified a significant increase ($P \leq 0.05$) in bright quality. This indicates that the grains grown in 2016 (70.20) were brighter in colour than those grown in 2015 (67.87). Regression analysis was performed to determine association between nitrogen levels (X) and L * values (Y) and the relationship between them viewed as y: 72.955036 + 0.0232 X – 0.0110825 X^2 (R^2: 0.099892) the equation (*Figure 5*).

The results in *Table 2* indicated that a*/b* colour parameters were not significantly affected by different nitrogen rates and also no difference between years was reported. Regression analysis was executed to investigate the relationship between nitrogen levels (X) and a*/b* colour parameters (Y) with Y:2646429 + 0.0001667 X + 0.0000254 X^2 (R^2: 0.008666) the equation (*Figure 6*).

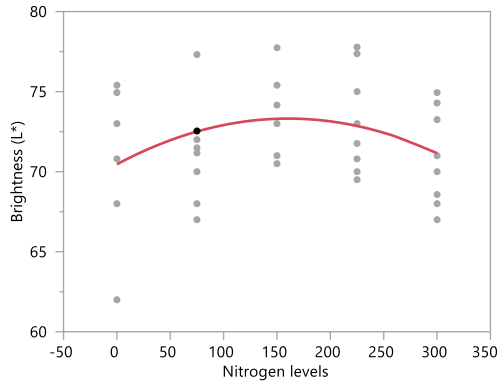

Figure 5. Influence of nitrogen levels on brightness (L*)

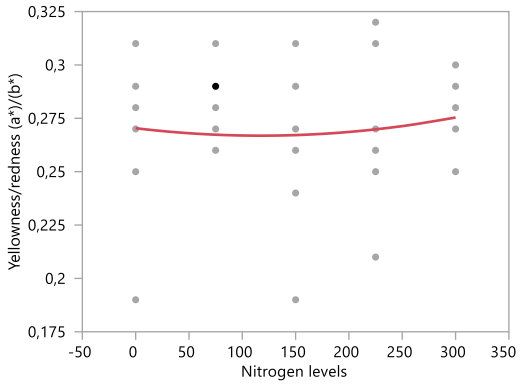

Figure 6. Influence of nitrogen levels on yellowness/redness (a*)/(b*)

4. Conclusions

This experiment targeted to evaluate the appropriate nitrogen level for sweet corn using the fertigation system, relying on two years of data. Increasing nitrogen application rates caused an increase in fresh grain yield of BATEM TATLI sweet corn variety up to 150 kg ha^{-1} N level while higher N applications (225 and 300 kg ha^{-1}) cause a decrease. The highest crude oil (5.56) was obtained under the treatment of 225 kg ha^{-1} nitrogen, while the maximum crude protein (12.60) was recorded under the treatment of 300 kg ha^{-1} N. However, nitrogen levels had no marked effects on brix, L* and a*/b* values. The impact of different climatic conditions on FGY, brix, crude oil, and L properties showed significant differences between years.

According to the results of the study 150 kg ha^{-1} of nitrogen was acquired to be the optimum level for sweet corn production. Farmers in the South-eastern Anatolia region who produce corn performing surface irrigation methods tend to apply around 250-300 kg ha^{-1} N of nitrogen. Nevertheless, the study presented that almost half of this nitrogen amount is overused, resulting in inefficiencies and potential environmental impacts. However, further research is required to examine the effects of different nitrogen levels on various sweet corn varieties under field conditions.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Author Contributions

The authors of the manuscript declare that they have contributed equally to the study.

References

Alimohammadi, M., Yousefi, M. and Zandi, P. (2011). Impact of nitrogen rates on growth and yield attributes of sweet corn grown under different Phosphorus levels, *Journal of American Science,* 7(10): 201-206.

Allen, R. G. (1998). Crop Evapotranspiration-Guideline for computing crop water requirements. *Irrigation and Drain,* 56: 300.

Anonymous (2014). Features of BATEM TATLI variety. https://arastirma.tarim.gov.tr/batem (Accessed Date: 01.03.2015).

Anonymous (2015). Ministry of Agriculture and Forestry. "Measuring Agricultural Values Technical Instructions". https://www.tarim.gov.tr

(Accessed Date: 10.08.2015).

Basal, O. and Szabó, A. (2020). Yield and quality of two soybean cultivars in response to drought and N fertilization. *Journal of Tekirdag Agricultural Faculty,* 17(2): 203-210.

Bhatt, P. S. (2012). Response of sweet corn hybrid to varying plant densities and nitrogen levels. *African Journal of Agricultural Research,* 7(46): 6158-6166. https://doi.org/10.5897/AJAR12.557

Çetin, Ö. and Tolay, I. (2009). Fertigation: Fertilisation combined with irrigation. *Hasad Publishers*, 160 (In Turkish).

Çetinkol, M. (1989). Sweet corn production. *Hasad Monthly Agriculture and Livestock Journal,* 4(46), 20-23 (In Turkish).

Goldberg, G. (2003). Recommendations of The Task Force. Plants: diet and health. The report of a British Nutrition Foundation Task Force, 282-285.

Gürsoy, S., Kılıç, H. and Sessiz, A. (2006*). Determination of the most suitable seedbed preparation and sowing method after cotton harvest in cotton-wheat crop rotation system in Southeastern Anatolia Region*. Final Report of Research Project. Republic of Turkey Ministry of Agriculture and Rural Affairs, General Directorate of Agricultural Research, Southeastern Anatolia Agricultural Research Institute (In Turkish).

Haque, M. M., Hamid, A. and Bhuiyan, N. I. (2001). Nutrient uptake and productivity as affected by nitrogen and potassium application levels in maize/sweet potato intercropping system. *Korean Journal of Crop Science*, 46(1), 1-5.

Harrill, R. (1998). Using a Refractometer to Test The Quality of Fruits and Vegetables. Pineknoll Publishing, U.S.A.

Holou, R. A. Y. and Kindomihou, V. (2011). Impact of nitrogen fertilization on the oil, protein, starch, and ethanol yield of corn (*Zea mays* L.) grown for biofuel production. *Journal of Life Sciences,* 5: 1013-1021.

Jeet, P., Singh, D. K., Sarangi, A., Mali, S. S. and Singh, A. K. (2022). Delineation of potential water harvesting site for agriculture water planning in Betwa basin of India using geospatial and analytical hierarchical process technique. *Geocarto International*, 37(25): 8315-8335.

Kara, B. and Kırtok, Y. (2006) Determination of the yield, nitrogen uptake and use efficiency of corn on the different plant density and nitrogen doses in the Çukurova conditions. *Çukurova University Journal of Agriculture Faculty*, 21: 23–32.

Khan, Z. H., Khalil, S. K., Iqbal, A., Ullah, I., Ali, M., Shah, T. and Shah, F. (2017). Nitrogen doses and plant density affect phenology and yield of sweet corn. *Fresenius Environmental Bulletin, 2*6(6): 3809-3815.

Khazaei, F., Alikhani, M. A., Yari, L. and Khandan, A. (2010). Study the correlation, regression and path coefficient analysis in sweet corn (*Zea mays var. saccharata*) under different levels of plant density and nitrogen rate. *Journal of Agricultural and Biological Science*, 5(6): 14-19.

Kılınç, S., Atakul, Ş., Kahraman, Ş., Aktaş, H., Erdemci, İ. and Gül, İ. (2023). The effect of sowing times on some yield and quality characteristics of sweet corn (*Zea mays sacchararata* Sturt.) varieties. *Kahramanmaraş Sütçü İmam University Journal of Agriculture and Nature.,* 26(2): 282-292. https://doi.org/10.18016/ksutarimdoga.vi.1049530

Masood, M., Shamsi, I. H., Hussain, N. and Shah, W. A. (2003). Performance of various maize varieties as affected by different NP levels, *Asian Journal of plant Science,* 2(7): 535-538.

Nasseri, A. (2021). Long-term water productivity of maize (*Zea mays* L.) from limited irrigation conditions under moderate semi-arid environment. *Journal of Tekirdag Agricultural Faculty*, 18(3): 400-410.

Oktem, A. (2007). Effect of nitrogen on fresh ear yield, protein content and micronutrient concentration of sweet corn. *Philippine Agricultural Scientist*, 90(4): 289-294.

Okumura, R. S., de Cinque Mariano, D., Franco, A. A. N., Zaccheo, P. V. C. and Zorzenoni, T. O. (2013). Sweet corn: Genetic aspects, agronomic and nutritional traits. *Applied Research & Agrotechnology,* 6(1)*:* 105-114.

Okumura, R. S., Vidigal Filho, P. S., Scapim, C. A., Marques, O. J., Franco, A. A. N., Souza, R. S. and Reche, D. L. (2014). Effects of nitrogen rates and timing of nitrogen topdressing applications on the nutritional and agronomic traits of sweet corn. *Journal of Food, Agriculture and Environment,* 12(2): 391-398.

Oosterhuis, D. M., Chipamaunga, J. and Bate, G. C. (1983). Nitrogen uptake of field-grown cotton. I. Distribution in plant components in relation to fertilization and yield. *Experimental Agriculture,* 19(1): 91-101. https://doi.org/10.1017/S0014479700010553

Patil, D. B., Lakkineni K. C. and Bhargawa, S. C. (1996). Seed yield and yield contributing characteristics as influenced by N supply in rapeseed-mustard. *Journal of Agronomy and Crop Science,* 177: 197–205.

Sainju, U. M. and Singh, B. P. (2008). Nitrogen storage with cover crops and nitrogen fertilization in tilled and nontilled soils. *Agronomy Journal,* 100(3): 619-627. https://doi.org/10.2134/agronj2007.0236

Schlegel, A. J. and Havlin, J. L. (1995). Corn response to long-term nitrogen and phosphorus fertilization. *Journal of Production Agriculture*, 8(2): 181-185.

Shewry, P. R. (2007). Improving the protein content and composition of cereal grain. *Journal of cereal science,* 46(3): 239-250. https://doi.org/10.1016/j.jcs.2007.06.006

Shyam, C. S., Rathore, S. S., Shekhawat, K., Singh, R. K., Padhan, S. R. and Singh, V. K. (2021). Precision nutrient management in maize (*Zea mays*) for higher productivity and profitability. *The Indian Journal of Agricultural Sciences*, 91(6): 933-935.

Singh, I., Langyan, S. and Yadava, P. (2014). Sweet corn and corn-based sweeteners. *Sugar Tech,* 16: 144-149. https://doi.org/10.1007/s12355-014-0305-6

Šútor, J. and Gomboš, M. (2006). Volume changes of heavy soils of east Slovakian lowland. *Cereal Research Communications*, 34(1): 299-302.

Takeshita, M., Nakanishi, K., Takahashi, T., Minohara, T., Maeyama, T., Hibi, T. and Goto, H. (2019). Effects of drip irrigation and fertigation on yield and production of multiple ears of sweet corn in Japan. *Japanese Journal of Farm Work Research*, 54(3): 151-161.

Turgut, İ. (1998). Effect of plant density and nitrogen doses on fresh ear yield and yield components of sweet corn grown under Bursa conditions. *Turkish Journal of Agriculture and Forestry,* 24(2000): 341- 347.

Tüzüner, A. (1990). Soil and Water Analysis Laboratory Manual. Ministry of Agriculture, Forestry and Rural Affairs, General Directorate of Rural Services, Ankara,. Türkiye.

White, P. J., Pollak, L. M. and Duvick, S. (2007). Improving the fatty acid composition of corn oil by using germplasm introgression. *Lipid Technology*, 19(2): 35-38. https://doi.org/10.1002/lite.200600009

Yılmaz, M. F. (2005). *The effect of different row spacing and nitrogen doses on yield, yield components and seed quality of second crop maize (Zea mays L.) under Kahramanmaraş conditions.* (MSc. Thesis). Department of Field Crops, Kahramanmaraş Sütçü İmam University, Institute of Science and Technology, Kahramanmaraş, Türkiye.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluating the Nutritive Value and Quality of Fodder Pea (*Pisum arvense* L.) Silage Added with Varying Rates of Barley (*Hordeum vulgare* L.) and Wheat (*Triticum aestivum* L. Em Thell) Cracks

Farklı Oranlarda Arpa (*Hordeum vulgare* L.) ve Buğday (*Triticum aestivum* L. Em Thell) Kırığı Eklenen Yem Bezelyesi (*Pisum arvense* L.) Silajının Besleme Değeri ve Kalitesinin Değerlendirilmesi

Ertan ATEŞ[1*], Hazım Serkan TENİKECİER[2]

Abstract

Silage represents the most effective solution for addressing the deficit in quality, abundance and cost-effectiveness of roughage. The main purpose of silage production is to store fresh herbage material with high nutritional value with minimum nutrient loss. For fodder and silage production, fodder pea is grown in mixtures with cereals in different ratios, but also for the silage from the pure fodder pea using additives. Molasses and crashed cereal grains or cereal can be added to silage material in order to increase its carbohydrate content. The research was conducted to determine nutritive value and silage quality of barley and wheat cracks added at different ratios to fodder pea silage in complete randomized split-plot design with four replications. 100 g withered fodder pea sample without additives and 100 g withered fodder pea sample with 3 g, 6 g, 9 g and 12 g cracked barley were vacuumed in to the 20x26 cm plastic bags and were stored in a dark environment for a period of 45 days to facilitate fermentation at ambient temperatures ranging from 15 to 28°C. Crude protein (%), crude ash (%), dry matter (%), digestible dry matter (DDM, %), dry matter intake (DMI, %), ADF (%), NDF (%), P (%), K (%), Ca (%), Mg (%), total digestible nutrients (TDN), Nel, NEm, Neg, pH, Fleig Score and RFV of pure fodder pea and cracked barley and wheat added silages were determined. According to results, fodder peas, which have a high protein and low carbohydrate content, be ensiled by the addition of high-carbohydrate wheat and barley cracks in order to obtain a quality silage. For this purpose, it is suggested to add at least 6% wheat cracks or 9% barley cracks to fodder pea silage.

Keywords: Cereal cracks, Fleig score, Fodder pea, Mineral content, Silage

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Öz

Silaj, kaba yemlerin yetersizliğini, kalitesizliğini ve kaba yem üretiminin maliyet etkinliğinin karşılanması açısından en etkili çözümü temsil eder. Silaj üretiminin ana amacı, yüksek besin değerine sahip taze kaba yem materyalinin minimum besin kaybıyla depolanmasıdır. Yem bezelyesi kuru-yeşil ot ve silaj üretimi için farklı oranlarda tahıllarla karışımlar halinde yetiştiriciliği yapılırken, ayrıca katkı maddeleri kullanılarak saf yem bezelyesi silajı da elde edilmektedir. Melas ve tahıl veya kırılmış tahıl taneleri, silaj materyaline karbonhidrat içeriğini artırmak amacıyla eklenebilir. Bu araştırma, yem bezelyesi silajına farklı oranlarda eklenen arpa ve buğday kırıklarının, silajın besin değerini ve kalitesine etkisini belirlemek için tesadüf parselleri deneme desenine göre dört tekrarlamalı olarak yürütülmüştür. 100 g katkısız soldurulmuş yem bezelyesi ile 100 g katkısız soldurulmuş yem bezelyesine 3 g, 6 g, 9 g ve 12 g arpa ve buğday eklenmiş yem bezelyesi örnekleri 20x26 cm plastik torbalara vakumlanmış ve karanlık bir ortamda 15 ila 28°C arasında değişen ortam sıcaklıklarında 45 gün boyunca fermantasyonun kolaylaştırılması için depolanmıştır. Saf yem bezelyesi ile arpa ve buğday kırıkları eklenmiş silajların ham protein (%), ham kül (%), kuru madde (%), sindirilebilir kuru madde (DDM, %), kuru madde tüketimi (DMI, %), ADF (%), NDF (%), P (%), K (%), Ca (%), Mg (%), toplam sindirilebilir besin elementi içeriği (TDN), Nel, NEm, Neg, pH, Fleig Skoru ve nispi yem değeri (RFV) belirlenmiştir. Sonuçlara göre, yüksek protein ve düşük karbonhidrat içeriğine sahip olan yem bezelyesinden kaliteli bir silaj elde etmek için yüksek karbonhidratlı buğday ve arpa kırıklarının eklenmesiyle silolanabileceği belirlenmiştir. Bu amaçla, yem bezelyesi silajına en az %6 buğday kırığı veya %9 arpa kırığı eklenmesi önerilmektedir.

Anahtar Kelimeler: Tahıl kırığı, Fleig skoru, Yem bezelyesi, Mineral içeriği, Silaj

1. Introduction

It is documented that in ancient Egypt, water-rich feeds were stored in containers with no contact with air. In Europe, the silage production has started to develop in the 18. century. The introduction of silage in Turkey has a history of approximately 80-90 years, with the first silage production taking place at Atatürk Forest Farm. In the 1970s, the technology began to be recognised by animal breeders, with promotional projects being carried out and silage machines being provided to some enterprises. These endeavours have made a considerable contribution to the enhancement of feed management and animal nutrition. In recent years, with the growing importance and incentives given to animal husbandry, there has been an increasing need for high-quality, abundant, and cheap roughages for the feeding of cultivated and hybrid animals, the number of which has reached significant dimensions, albeit insufficient. Consequently, silage represent the most effective solution for addressing the deficit in quality, abundance and cost-effectiveness of roughage.

The main purpose of silage production is to store fresh herbage material with high nutritional value with minimum nutrient loss (Burgu and Mut, 2023). It is possible to produce silage from a variety of plants. The most prevalent silage crops currently in use are maize, sorghum, Sudan grass, sorghum-Sudan grass hybrid varieties, other grasses, legumes and legume-grasses mixtures. Furthermore, vegetable residues, canned sugar, waste products from fruit juice production, as well as some tree leaves and fruits, are also utilised in the process (Yıldırım, 2015; Özdemir and Okumuş, 2021). Nevertheless, it's essential that the plant intended for ensiling possesses suitable dry matter content and readily soluble carbohydrates for effective ensiling. The low dry matter content of forage legumes, such as fodder peas, the low water-soluble carbohydrates and high buffer capacity of legumes cause them to be difficult to ensilage (Yücel et al., 2013). In their respective studies, Jones et al. (1990) and Jacobs et al. (1995) demonstrated that the incorporation of cereal grains or beet pulp into green fodders with low dry matter content enhances the fermentation properties of silage.

For fodder and silage production, fodder pea is grown in mixtures with cereals in different ratios, but also for the silage from the pure fodder pea using additives. Due to the ready availability of molasses and crashed cereal grains or cereal cracks in the market, these are added to silage material in order to increase its carbohydrate content (Gülümser et al., 2019). Besides, many livestock breeders also ask whether wheat (*Triticum* sp.) or barley (*Hordeum vulgare* L.) grains can be added to fodder pea silage and in what quantity. In order to answer this question, this study was carried out to determine the effect of barley and wheat cracks on the quality of pure fodder pea silage.

2. Materials and Methods

The fodder pea (variety 'Töre') for the research were sown on 15 November 2022, with a row spacing of 25 cm and a seeding rate of 120 kg per hectare (Ates et al., 2020) on a 5-hectare farmer's field located in Gazioğlu, Süleymanpaşa-Tekirdağ, Türkiye. A basal fertilizer containing nitrogen (N) and phosphorus (P) at a rate of 50 kg per hectare was incorporated into the soil during land preparation. Fresh samples were taken at the full-bloom stage at a height of 3 cm above the ground (Tenikecier and Ates, 2021). The samples were left to wither for 2 hours and then approximately 1.5-2 cm chopped by mechanically (Er and Mut, 2023). Grains of barley variety 'Kristal' and wheat variety 'LG-59 'were subjected to a mechanical cracking process. 100 g withered fodder pea sample without additives and 100 g withered fodder pea samples with 3 g, 6 g, 9 g and 12 g cracked barley and wheat (separately for both species) were vacuumed (İleri et al., 2022; Tenikecier and Ateş, 2024) in to the 20x26 cm plastic bags and were stored in a dark environment for a period of 45 days to facilitate fermentation at ambient temperatures ranging from 15 to 28°C (Jia et al., 2021). After 45 days, the pH of the silages was measured using a pH meter. The research was conducted in complete randomized split-plot design with four replications.

It is well-documented that oven drying feed samples at temperatures exceeding 60°C can result in heat-damaged protein and increased values of fiber and lignin. Furthermore, oven drying feedstuffs containing proanthocyanidins, even at temperatures below 60°C, has been shown to increase neutral detergent fiber (NDF), fiber-bound nitrogen, and lignin content (Reed and Van Soest, 1984). To determine the dry matter content, the matured silage samples were dried to a constant weight in an air oven at 60°C for 48 hours, followed by a subsequent day of storage at ambient temperature (Tenikecier and Ateş, 2024). The samples were then ground to small pieces (≤1 mm) and utilized for analysis. The N content was analyzed following the procedures outlined by the Association of Official Analytical Chemists (AOAC, 2019). The crude protein content (%) was calculated by multiplying the nitrogen content by a factor of 6.25. The

samples were wet-digested with a nitric-perchloric acid mixture, and P (%) content was determined spectrophotometrically. The potassium (K, %), calcium (Ca, %), and magnesium (Mg, %) contents were quantified using an inductively coupled plasma-optical emission spectrometer (ICP-OES) (Isaac and Johnson JR, 1998). Crude ash (%), acid detergent fiber (ADF, %), and NDF (%) contents were determined using Weende and Van Soest methodologies (AOAC, 2019; Van Soest et al., 1991). All analyses were conducted in duplicate. The digestible dry matter (%), dry matter intake (%), relative feed value (%), total digestible nutrients (TDN), net energy for lactation (NEl), net energy for maintenance (NEm), and net energy for gain (NEg) were calculated using established equations for forage evaluation (Schroeder, 1994). Fleig score was calculated using the formula suggested by Kılıç (1986).

Statistical analysis of all data was performed using analysis of variance (ANOVA) with TARIST software (Açıkgöz et al., 1994), and treatment means were compared using the least significant difference (LSD) test, implemented with MSTAT-C software.

3. Results and Discussion

The results are given in *Tables 1* to *3*. There were no statistically significant difference between means of DMI, NEl, Neg (P>0.05).

Table 1. The crude protein, crude ash, dry matter, digestible dry matter, dry matter intake, acid detergent fiber and neutral detergent fiber of ensiled fodder pea, cracked wheat and barley grains added fodder pea silage

	Crude Protein (%)	Crude Ash (%)	Dry Matter (%)	DDM (%)	DMI (%)	ADF (%)	NDF (%)
Fodder Pea	19.78a	3.52f	38.30bc	67.83c	3.15	27.05f	38.05bc
Fodder Pea+3% cracked barley	17.17g	3.90e	38.51abc	67.66f	3.14	27.26d	38.26abc
Fodder Pea+3% cracked wheat	17.52f	4.08d	37.90c	67.98a	3.19	26.85h	37.65c
Fodder Pea+6% cracked barley	17.54f	4.11d	38.58abc	67.61f	3.20	27.33c	38.33abc
Fodder Pea+6% cracked wheat	17.71de	4.21c	38.98ab	67.91b	3.10	26.94g	38.73ab
Fodder Pea+9% cracked barley	17.64ef	4.22bc	38.86ab	67.53h	3.11	27.43b	38.61ab
Fodder Pea+9% cracked wheat	17.88c	4.31b	39.05ab	67.83c	3.09	27.05f	38.80ab
Fodder Pea+12% cracked barley	17.80cd	4.64a	38.99ab	67.44ı	3.10	27.55a	38.74ab
Fodder Pea+12% cracked wheat	18.24b	4.56a	39.31a	67.78d	3.07	27.12e	39.06a
Mean	*17.92*	*4.17*	*38.72*	*67.73*	*3.13*	*27.18*	*38.47*
LSD	0.160**	0.094**	0.932**	0.041**	ns	0.051**	0.932**

The highest crude protein (19.78%) and lowest crude ash (3.52%) ratios were found in pure fodder pea silage. While the highest DDM (67.98%) was determined in fodder pea+3% cracked wheat silage, the lowest dry matter (37.90%), ADF (26.85%) and NDF (37.65%) contents were recorded in the same treatment (P<0.01). The DMI values varied between 3.07 to 3.20% (*Table 1*). The addition of cereal cracks to silage has resulted in decreases in the crude protein content of the silage. This situation arises from the lower crude protein content of the additives compared to pure fodder pea. Indeed, in a study, the crude protein content in barley grains was determined to be 5.5% (Acar and Bostan, 2016). These researchers reported that the inclusion of barley cracks, molasses, and whey additives in various ratios resulted in alfalfa (*Medicago sativa* L.) silages with ADF and NDF contents ranging from 30.85% to 32.59% and from 39.69% to 41.20%, respectively. Turgut et al. (2005) reported that the significant relations between silage and silage material in terms of NDF and ADF contents. Yavuz et al. (2009) recommended that the ADF content of feeds used in the nutrition of high-yielding dairy cattle should be 30% or less, while the NDF content should be 40% or less. Heuze et al. (2017) reported that the crude protein and digestibility ratios decrease when the dry matter ratio increase. Gülümser et al. (2019) found that the silages with ADF and NDF contents ranging from 24.60% to 42.75% and from 35.97% to 55.07%, respectively. İleri et al. (2022) also indicated that silage fermentation is delayed and quality is reduced under low carbohydrate conditions. The results of our analysis of NDF and ADF contents were found to be consistent with those of previous studies (Geren, 2001; Heuze et al., 2017).

While the highest P ratio (0.38%) was found in fodder pea+3% cracked wheat silage, the lowest K (1.65%) in and Ca (0.98%) contents were determined in fodder pea+12% cracked wheat and fodder pea+12% cracked barley silages respectivcely (*Table 2*). The highest Mg content (0.39%) was identified in fodder pea silage with 3%

cracked barley, while the lowest TDN value (64.67) was calculated in fodder pea silage with 12% cracked barley. Tekeli and Ates (2005) asserted that the K content in roughage should be between 0.6% and 0.8%, the P content between 0.18% and 0.39%, the Ca content between 0.18% and 0.44%, and the Mg content between 0.04% and 0.10% in order to meet the nutritional requirements of dairy and beef cattle. The skeletal system holds a significant portion of Mg, comprising approximately 68-73% of the total Mg content in an animal's body. Additionally, the presence of P in the rumen is vital, as higher levels of P promote Mg absorption. In instances where animals graze on phosphorus-deficient pastures, the rumen may have low concentrations of P, further hindering Mg absorption. Moreover, the Ca levels in the blood also influence these processes (Ates, 2017). It is observed that the mineral contents in silages are at levels sufficient to meet the needs of animals.

Table 2. The mineral contents of ensiled fodder pea, cracked wheat and barley grains added fodder pea silage

	P (%)	K (%)	Ca (%)	Mg (%)	TDN
Fodder Pea	0.31f	1.99b	1.19b	0.36c	65.24b
Fodder Pea+3% cracked barley	0.36c	2.02a	1.22a	0.39a	65.00d
Fodder Pea+3% cracked wheat	0.38a	1.96c	1.21a	0.38b	65.47a
Fodder Pea+6% cracked barley	0.33d	1.96c	1.17c	0.38b	64.93d
Fodder Pea+6% cracked wheat	0.37b	1.86d	1.11d	0.36c	65.40a
Fodder Pea+9% cracked barley	0.32e	1.87d	1.09e	0.35d	64.80e
Fodder Pea+9% cracked wheat	0.36c	1.75e	1.11d	0.34e	65.24b
Fodder Pea+12% cracked barley	0.30g	1.75e	0.98g	0.31f	64.67f
Fodder Pea+12% cracked wheat	0.33d	1.65f	1.06f	0.31f	65.17c
Mean	*0,34*	*1.87*	*1.13*	*0.35*	*65.10*
LSD	0.005**	0.024**	0.014**	0.007**	0.071**

Table 3. The Fleig score, NEI, Nem, NEg, pH and RFV of ensiled fodder pea, cracked wheat and barley grains added fodder pea silage

	NEl	NEm	NEg	pH	Fleig Score	RFV
Fodder Pea	0.67	0.73	0.40	4.50a	101.47c	165.84ab
Fodder Pea+3% cracked barley	0.67	0.72	0.40	4.40ab	106.15bc	164.51abc
Fodder Pea+3% cracked wheat	0.68	0.73	0.40	4.37abc	106.13bc	168.15a
Fodder Pea+6% cracked barley	0.67	0.72	0.40	4.41ab	105.76bc	164.09abc
Fodder Pea+6% cracked wheat	0.67	0.73	0.40	4.19de	115.35a	163.13bc
Fodder Pea+9% cracked barley	0.67	0.72	0.40	4.25cde	112.86a	162.68bc
Fodder Pea+9% cracked wheat	0.67	0.73	0.40	4.19de	115.24a	162.60bc
Fodder Pea+12% cracked barley	0.67	0.72	0.39	4.16e	116.58a	161.94bc
Fodder Pea+12% cracked wheat	0.67	0.73	0.40	4.31bcd	111.35ab	161.43c
Mean	*0.67*	*0,73*	*0.40*	*4.31*	*110.10*	*163.82*
LSD	ns	ns	ns	0.133**	5.620**	4.278**

The Nel, NEg and NEm values varied between 0.67-0.68, 0.39-0.40 and 0.72-0.73, respectively (P>0.05). The applications of barley and wheat cracks were lowered the pH of the silage (*Table 3*). The lowest pH were measured in fodder pea+12% cracked barley (4.16), fodder pea+6% cracked wheat (4.19), fodder pea+9% cracked wheat (4.19) and fodder pea+9% cracked barley (4.25) silages (P<0.01). One of the most important factors in determining the quality of silage is a low pH. The low pH is of significant importance in terms of proteolysis, which is the process that leads to the deterioration of silage. Consequently, in order for proteolysis to cease completely, the pH of the silage must be reduced to below 4 (Virtanen, 1993; Gülümser et al., 2019). In a good silage, there is a close relationship between pH value and Flieg score of silage (Kılıç, 2010; Er and Mut, 2023). The lowest Fleig scores were calculated in fodder pea (101.47), fodder pea+6% cracked barley (105.76), fodder pea+3% cracked wheat (106.13) and fodder pea+3% cracked barley (106.15) silages (P<0.01). Karaevli and Baytekin (2018) added barley cracks and inoculant to silages made from wheat, barley, triticale, oats, and rapeseed herbages in varying proportions. The researchers reported that the positive improvements in silage characteristics as the amount of barley cracks and inoculant increased. Gülümser et al. (2019) demonstrated that the incorporation of molasses or barley cracks at varying proportions into cowpea (*Vigna unguiculata* L.) and soybean (*Glycine max* L.) crops

enhanced silage quality. Among the tested silages, those containing soybean and 5% barley cracks exhibited superior performance. The relative feed value index is a measure of the quality of a given fodder. As the RFV of a given fodder decreases, its quality also decreases (Önal Aşçı and Acar, 2018). The relative feed values were varied between 161.43-168.15 (*Table 3*). The relative feed values were opposite to the reports of Canbolat et al. (2019), who reported that the values increased when molasses was added to the fodder pea silage. Tenikecier and Ateş (2024) suggested adding 12% cracked oat grains to fodder peas during ensiling to achieve high-quality silage based on Fleig scores.

4. Conclusions

In conclusion, it is recommended that fodder peas, which have a high protein and low carbohydrate content, be ensiled by the addition of high-carbohydrate wheat and barley cracks in order to obtain a quality silage. For this purpose, it is suggested to add at least 6% wheat cracks or 9% barley cracks to fodder pea silage.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Ateş, E., Tenikecier, H. S.; Design: Ateş, E., Tenikecier, H. S.; Data Collection or Processing: Ateş, E., Tenikecier, H. S.; Statistical Analyses: Ateş, E., Tenikecier, H. S.; Literature Search: Ateş, E., Tenikecier, H. S.; Writing, Review and Editing: Ateş, E., Tenikecier, H. S.

References

Acar, Z. and Bostan, M. (2016). The effects of some natural additives on quality of alfalfa silage. *Anadolu Journal of Agricultural Sciences*, 31(3): 433-440. https://doi.org/10.7161/omuanajas.269998

Açıkgöz, N., Akbaş, M. E., Moghaddam, A. and Özcan, K. (1994). Database-Based Turkish Statistics Program for PCs: TARIST. *Turkey 1st Field Crops Congress*, 25-29, April, p: 264–267, İzmir, Türkiye.

AOAC (2019). Official Methods of Analysis of AOAC International. 21st Ed, Association of Official Analytical Chemists, USA.

Ates, E. (2017). Slope aspect has effects on vegetation and forage traits of anthropogenic pasture under two grazing treatments. *Revista de la Facultad de Agronomía de la Universidad del Zulia*, 34: 236-252.

Ates, E., Tenikecier, H. S. and Ozkan, U. (2020). The dry matter yield, -tocopherol, -carotene and some mineral contents in fodder pea (*Pisum arvense* L.) varieties at different growth stages. *Comptes Rendus de l'Academie Bulgare des Sciences*, 73(4): 579-586. https://doi.org/10.7546/CRABS.2020.04.18

Burgu L. and Mut, H. (2023). Silage yield and some quality traits of silage maize varieties growing as second crop. *Journal of Tekirdag Agricultural Faculty*, 20 (1): 12-24. https://doi.org/10.33642/jotaf.1039381

Canbolat, Ö., Akbay, K. C. and Kamalak, A. (2019). Possibilities of use of molasses as carbohydrate source in pea silages. *Journal of Agriculture and Nature*, 22(1): 122-130. https://doi.org/10.18016/ksutarimdoga.vi.455713

Er, E. and Mut, H. (2023). Determination of silage quality of mixtures of berseem clover (*Trifolium resupinatum* L.) and annual ryegrass (*Lolium multiflorum* Lam.) under Bilecik conditions. *ISPEC Journal of Agricultural Sciences*, 7(4): 730-738. https://doi.org/10.5281/zenodo.10207729

Geren, H. (2001). Effect of sowing dates on silage characteristics of different maize cultivars grown as second crop under Bornova conditions. *Journal of Agriculture Faculty of Ege University*, 38: 47-54.

Gülümser, E., Mut, H., Başaran, U. and Çopur Doğrusöz, M. (2019). Effects of molasses or crushed barley addition on the quality of cowpea and soybean silages. *BSEU Journal of Science*, 6: 161-167. https://doi.org/10.35193/bseufbd.589388

Heuze, V., Tran, G., Edouard, N. and Lebas, F. (2017). Maize Silage. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. https://feedipedia.org/node/13883 (Accessed Date: 01.06. 2024).

İleri, O., Kara, E., Erkovan, Ş., Sürmen, M., Erkovan, H. İ. and Koç, A. (2022). Silage quality of corn grown at different weed densities. *Turkish Journal of Range and Forage Science*, 3(2): 36-40. https://doi.org/10.51801/turkjrfs.1092563

Isaac, R. A. and Johson JR, W. C. (1998). Handbook of Reference Methods for Plant Analysis. (Ed: Kalra, Y.P.). Elemental Determination by Inductively Coupled Plasma Atomic Emission Spectrometry. CRC Press, Washington DC, USA, 165-170.

Jacobs, J. L., Morris, R. J. and Zorrilla-Rios, J. (1995). Effect of ensiling whole barley grain with pasture on silage quality and effluent production, and the performance of growing cattle. *Australian Journal of Experimental Agriculture*, 35: 731-738.

Jia, T., Wang, B., Yu, Z. and Wu, Z. (2021). The effects of stage of maturity and lactic acid bacteria inoculants on the ensiling characteristics, aerobic stability and in vitro digestibility of whole-crop oat silages. *Grassland Science*, 67: 55–62. https://doi.org/10.1111/grs.12285

Jones, D. I. H., Jones, R. and Moseley. G. (1990). Effect of incorporating rolled barley in autumn cut ryegrass silage on effluent production, silage fermentation and cattle performance. *Journal of Agricultural Science*, 115: 399-408.

Karaevli, M. E. and Baytekin, H. (2018). Investigation of the Possibilities of Using Some Winter Annual Field Crops in Silage Production in Trakya Region. *COMU Journal of Agricultural Faculty*, 6: 249-254. https://doi.org/10.33202/comuagri.504361

Kılıç, A., 1986. Silo Feed (Production, Learning and Application Recommendations) [Silo Yemi (Üretim, Öğrenim ve Uygulama Önerileri)]. Bilgehan Basımevi, İzmir, Türkiye. (In Turkish)

Kılıç, A., 2010. Silo Feed [Silo Yemi]. Hasad Yayıncılık, İstanbul, Türkiye. (In Turkish)

Önal Aşçı, Ö. and Acar, Z. (2018). Quality in Forages [Kaba Yemlerde Kalite]. TMMOB Chamber of Agricultural Engineers, Ankara, Türkiye. (In Turkish)

Özdemir, M. and Okumuş, O. (2021). Some silage studies made in Turkey in the last five years. *Erciyes Tarım ve Hayvan Bilimleri Dergisi*, 4(2): 30-39.

Reed, J. D. and Van Soest, P. J. (1984). Estimating the nutritive value of crop residue and agro-industrial by-products by chemical methods. *Proceedings of the FAO/ILCA Expert Consultation*, 5–9 March, Addis Ababa, Ethiopia.

Schroeder, J. W. (1994). Interpreting Forage Analysis. Extension Dairy Specialist (NDSU), AS-1080, North Dakota State University.

Tekeli, A. S. and Ates, E. (2005). Yield potential and mineral composition of white clover (*Trifolium repens* L.)-tall fescue (*Festuca arundinacea* Schreb.) mixtures. *Journal of Central European Agriculture*, 6: 27-34.

Tenikecier, H. S. and Ates, E. (2021). Yield, some cell wall components and mineral content of fodder pea (*Pisum arvense* L.) forage as influenced by cultivar, growth stages and phosphorus application. *Journal of Elementology*, 26(2): 319-332. https://doi.org/10.5601/jelem.2021.26.1.2118

Tenikecier, H. S. and Ateş, E. (2024). Effect of adding different ratios of oat (*Avena sativa* L.) cracks on the silage quality of fodder pea (*Pisum arvense* L.). *ISPEC Journal of Agricultural Sciences*, 8: 638-646.

Turgut, I., Duman, A., Bilgili, U. and Acikgoz, E. (2005). Alternate row spacing and plant density effects on forage and dry matter yield of corn hybrids (*Zea mays* L.). *Journal of Agronomy and Crop Science*, 191: 146-151.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. (1991). Methods for dietary fibre, neutral detergent fibre, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, 74: 3583–3597.

Virtanen, A. I. (1993). The A. I. V. method of preserving fresh fodder. *Empire Journal of Experimental Agriculture*, 1: 143-155.

Yavuz, M., İptaş, S., Ayhan, V. and Karadağ, Y. (2009). Quality of Forages and Nutritional Disorders Caused by Forages [Yem bitkilerinde Kalite ve Yem bitkilerinden Kaynaklanan Beslenme Bozuklukları]. Republic of Türkiye, Ministry of Agriculture and Forestry, Ankara, Türkiye, 163-186. (In Turkish)

Yıldırım, B. (2015). Silage studies in Turkey: 2005-2014. *Iğdır Universtiy Journal of Institiuon of Science & Technology*, 5(2): 79-88.

Yücel, C., Avcı, M., Kılıçalp, N. and Akkaya, M. R. (2013). The silage characteristics of legume, grasses and mixtures of siled with *Lactobacillus buchneri*. *Journal of Tekirdag Agricultural Faculty*, 10(3): 11-18.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Chemical Composition and Methane Production Potential of Agricultural Residues: Olive Pomace, Cottonseed Meal and Red Pepper Processing Waste

Tarımsal Artıkların Kimyasal Komposizyonları ve Metan Üretim Potansiyeli: Zeytin Prinası, Pamuk Tohumu Küspesi ve Kırmızı Biber İşleme Atıkları

Serdar ÜÇOK[1*], Xufei YANG[2]

Abstract

Biogas is a renewable energy source produced through the anaerobic digestion of organic materials such as agricultural residues, manure, sewage, and food waste. This process involves the breakdown of these materials by microorganisms in the absence of oxygen, resulting in the production of a mixture of gases, primarily methane (CH_4) and carbon dioxide (CO_2), along with trace amounts of other gases like hydrogen sulfide (H_2S) and ammonia (NH_3). Biogas production from agricultural residues like olive pomace (OLV), cottonseed meal (CTM), and red pepper processing (RPP) waste holds promise for sustainable energy generation and waste management. This study investigates the chemical composition and methane production potential of these residues, emphasizing their protein, fat content, and Acid Detergent Fiber (ADF)/Neutral Detergent Fiber (NDF) ratios. Chemical analyses revealed significant variations among the materials, with cotton waste exhibiting the highest dry matter, organic matter, protein, and fat content, while pepper waste showed the highest ash content, and olive waste had the highest fiber (ADF and NDF) content. Methane production ranged from 0.34 to 0.45 m^3 kg^{-1} of organic dry matter (ODM), with cotton displaying the highest methane yield. Biogas production ranged from 0.61 to 0.78 m^3 kg^{-1} ODM, with cotton again yielding the highest biogas production. Methane content in biogas varied between 54.64% and 57.72%, with cotton also showing the highest methane content. At the end of the study, the dry matter (DM) and organic dry matter (ODM), ash, protein, fat, ADF, and NDF ratios of the materials were determined to be 85.51%-94.09%, 87.91%-92.92%, 7.08%-12.09%, 7.49%-15.93%, 3.76%-8.01%, 52.16%-71.07%, and 34.49%-55.58%, respectively. The materials showed chemical differences. Research highlights include the significant bioenergy potential of olive waste and cottonseed meals, alongside the environmental benefits of utilizing olive pomace for biogas production. Experimental findings reveal varying methane and biogas yields across materials, influenced by their nutrient compositions. The study underscores the viability of integrating these agricultural residues into biogas production systems, contributing to renewable energy initiatives and sustainable agricultural waste management practices.

Keys Words: Biogas, Methane, Agricultural organic wastes

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Öz

Biyogaz, tarımsal artıklar, gübre, kanalizasyon ve gıda atıkları gibi organik materyallerin anaerobik olarak çürütülmesi yoluyla üretilen yenilenebilir bir enerji kaynağıdır. Bu işlem, oksijen yokluğunda bu malzemelerin mikroorganizmalar tarafından parçalanmasını içerir ve bunun sonucunda başta metan (CH_4) ve karbon dioksit (CO_2) olmak üzere bir gaz karışımının yanı sıra eser miktarda hidrojen sülfür (H_2S) ve amonyak (NH_3) gibi diğer gazların üretilmesi sağlanır. Zeytin posası (OLV), pamuk tohumu küspesi (CTM) ve kırmızı biber işleme (RPP) atıkları gibi tarımsal atıklardan biyogaz üretimi, sürdürülebilir enerji üretimi ve atık yönetimi için umut vaat etmektedir. Bu çalışma, bu atıkların kimyasal bileşimini ve metan üretim potansiyelini, protein, yağ içeriği ve Asit Deterjan Sellülozu (ADF)/(Nötral Deterjan Sellülozu) NDF oranlarına vurgu yaparak araştırmaktadır. Kimyasal analizler, organik materyaller arasında önemli farklılıklar olduğunu ortaya koymuş; pamuk atığı en yüksek kuru madde, organik madde, protein ve yağ içeriğini gösterirken, biber atığı en yüksek kül içeriğini, zeytin atığı ise en yüksek lif (ADF ve NDF) içeriğini göstermiştir. Metan üretimi, organik kuru madde (ODM) başına 0.34 ile 0.45 m^3 kg^{-1} arasında değişmiş ve en yüksek metan verimi pamukta gözlemlenmiştir. Biyogaz üretimi, ODM başına 0.61 ile 0.78 m^3 kg^{-1} arasında değişmiş ve en yüksek biyogaz üretimi yine pamuk atıklarında ortaya çıkmıştır. Biyogazdaki metan içeriği %54.64 ile %57.72 arasında değişmiş ve pamuk en yüksek metan içeriğini göstermiştir. Çalışma sonucunda materyallerin kuru madde (KM) ve organik kuru madde (OKM), kül, protein, yağ, ADF (Asit Detergent Fibre) ve NDF (Neutral Detergent Fibre) oranları yapılan analizler sonucunda sırasıyla; %85.51-%94.09, %87.91-%92.92, %7.08-%12.09, %7.49-%15.93, %3.76-%8.01, %52.16-%71.07 ve %34.49-%55.58 olarak belirlenmiştir. Materyaller arasında kimyasal farklılıklar meydana gelmiştir. Araştırma, zeytin atığı ve pamuk tohumu küspesinin önemli biyoyakıt potansiyelini ve zeytin posasının biyogaz üretimi için kullanılmasının çevresel faydalarını vurgulamaktadır. Deneysel bulgular, besin bileşimleri farklı organik atıkların metan ve biyogaz verimlerini ortaya koymaktadır. Çalışma, bu tarımsal atıkların biyogaz üretim sistemlerine entegre edilmesinin yenilenebilir enerji girişimlerine ve sürdürülebilir tarımsal atık yönetimi uygulamalarına katkıda bulunma olasılığını vurgulamaktadır.

Anahtar Kelimeler: Biyogaz, Metan, Tarımsal organik atıklar

1. Introduction

Biogas production from agricultural by-products such as olive pomace (OLV), cottonseed meal (CTM), and red pepper processing (RPP) waste represents a promising strategy for both sustainable energy generation and effective waste management. These by-products, typically considered agricultural waste, can be repurposed through anaerobic digestion to produce valuable bioenergy, reducing environmental pollution and offering a renewable energy source.

Research has shown that anaerobic digestion of olive mill solid waste can result in substantial bioenergy production, significantly mitigating the environmental impacts commonly associated with olive oil production. For instance, Uddin et al. (2021) demonstrated that this process not only diverts waste from landfills but also creates an opportunity to harness energy in a sustainable manner. Moreover, Messineo et al. (2020) have investigated the anaerobic digestibility of both raw and pretreated olive pulp, underscoring the potential for hydrogen and biogas production under various conditions. This highlights the adaptability of olive by-products as feedstock for bioenergy generation under different treatment processes, further enhancing the feasibility of their use on a commercial scale.

Similarly, cottonseed hulls have been identified as an excellent substrate for biogas production. When combined with cow dung in anaerobic digestion processes, the biogas yield is notably enhanced (Venkateshkumar et al., 2021). This synergistic effect between different organic materials improves the efficiency and economic viability of the biogas production process. Investigations into other agricultural by-products, such as citrus pulp and olive pomace, have also demonstrated the feasibility of these materials for biogas production (Valenti et al., 2017). These findings support the notion that agricultural residues, which are often available in large quantities, can be effectively used as feedstocks for bioenergy production, promoting a circular economy in agricultural practices.

The potential for co-digestion processes, which involve the simultaneous digestion of multiple organic wastes, has been explored to enhance biomethane production further. Al-Addous et al. (2017) recommended co-digestion of olive and date waste as a means to optimize biomethane yields. This approach not only improves the overall efficiency of biogas production but also allows for the processing of a wider range of waste materials, thereby reducing waste disposal issues. In addition, other studies have explored the use of diverse feedstocks, such as coffee pulp, chicken feathers, and sugar beet pulp, in biogas production. These studies showcase the versatility and adaptability of anaerobic digestion processes to a variety of organic wastes, expanding the potential feedstock base for biogas plants (Sumardiono et al., 2021; Ziemiński and Kowalska-Wentel, 2016; Sumardiono et al., 2016).

Biogas production from olive mill waste offers significant environmental benefits. For example, Alonso-Fariñas et al. (2020) highlighted the potential for heat and electricity cogeneration through anaerobic digestion, followed by the composting of the digestate. This not only contributes to renewable energy production but also results in valuable by-products, such as compost, that can be used to enrich soil, thereby closing the loop in agricultural waste management. Moreover, the integration of biogas production into circular economy concepts, such as converting cassava pulp and wastewater into biogas, illustrates the potential for sustainable energy generation across various industries (Lerdlattaporn et al., 2020). This approach emphasizes the need for innovative solutions that can transform waste into resources, aligning with global sustainability goals.

Overall, research consistently indicates that biogas production from various agricultural by-products is a viable and sustainable approach. It can significantly contribute to renewable energy generation, reduce agricultural waste, and protect the environment by lowering greenhouse gas emissions and minimizing reliance on fossil fuels (Aybek et al., 2015; Develi et al., 2021). By converting waste materials into valuable energy resources, biogas production supports a more sustainable and resilient energy future.

In Turkey, cotton production is substantial, resulting in a significant amount of cottonseed pomace, also known as cottonseed meal or cake. The country produces approximately 800.000 to 900.000 tons of cotton fiber annually, leading to a considerable quantity of cottonseed by-products. Based on the proportion of cottonseeds to the overall cotton output and the processing methods employed, pomace production is estimated to be in the range of several hundred thousand tons per year (Semerci and Çelik, 2018; Tokel et al., 2022). This large volume of cottonseed by-

products presents an opportunity for biogas production, turning what would otherwise be agricultural waste into a valuable energy source.

Similarly, the olive oil industry in Turkey generates a significant amount of waste. Out of the total 1.700,000 tons of olives grown in the country, 1.300.000 tons of oily olives were processed, resulting in the production of around 175.000 tons of olive oil. This processing results in the generation of approximately 1.774,800 tons of waste annually, which includes 515.000 tons of pomace and 1.259.800 tons of wastewater (Kaya, 2024). From a biogas generation perspective, this represents a substantial quantity of raw material that can be harnessed for energy production, turning a potential environmental liability into a renewable energy asset.

The annual biomass residues produced from greenhouse crops, such as tomatoes, peppers, and eggplants, further contribute to the potential feedstock for biogas production. These residues amount to approximately 1.690.000 tons on a wet basis and 253.000 tons on a dry basis, with pepper crop residue alone accounting for 205.000 tons (wet) and 35.000 tons (dry) (Bilgin et al., 2015). Given the high production potential of these wastes, they can be effectively used as additives in biogas production, enhancing the overall biogas yield.

In this study, the chemical composition, methane production, and biogas yields of cottonseed meal, olive pomace, and pepper processing residues were determined. The findings underscore the viability of using these agricultural by-products as valuable resources for biogas production, supporting sustainable energy initiatives and contributing to the circular economy by transforming waste into renewable energy sources.

2. Materials and Methods

2.1. Procurement of olive pomace (OLV), cottonseed meal (CTM), and red pepper processing (RPP) waste.

The materials used were cottonseed meal, red pepper processing waste, and olive pomace from the olive oil processing plant (*Figure 1*). The materials were first sun-dried naturally and then ground to a size of 1 mm using an industrial grinder. A Kern precision balance was used to weigh the raw materials and the materials obtained in the experiments. A Microtest ash furnace was used to determine the ash and organic matter content. A Nüve oven was used to determine moisture content, a Velp UDK 139 protein meter to determine protein content, an Ankom XT10 fat meter to determine fat content, and an ANKOM NDF/ADF fiber analyzer to determine NDF and ADF content. The inoculum, with a solids content of approximately 2 %, was obtained from the mesophilic environment of the Kahramanmaraş Water and Sewerage Administration (KASKİ) Central Wastewater Treatment Plant and from biogas reactors with a pH of 6.8.

Figure 1. OLV (a), CTM (b), and RPP(c) waste

The Hohenheim Batch Test (HBT) method uses 100 mL glass syringes (*Figure 2*). The patented HBT syringe is shown in *Figure 2*. The syringe consists of the following components: (1) lubricant and seal, (2) 1 mL compartment, (3) gas chamber, (4) gas analysis port, (5) clamp, (6) glass syringe, (7) fermentation materials, (8) plunger, and (9) thin tube. A sealed tube and clamp are attached to the tip of the syringe to prevent gas leakage.

HBT syringes are placed in a hot water bath (*Figure 3*), which has 128 chambers and a heater to heat the water inside.

To determine the methane content in the biogas, an infrared-spectrometric methane-sensor "Advanced Gasmitter" D-AGM Plus 1010 device with a precision of 20 mL was used.

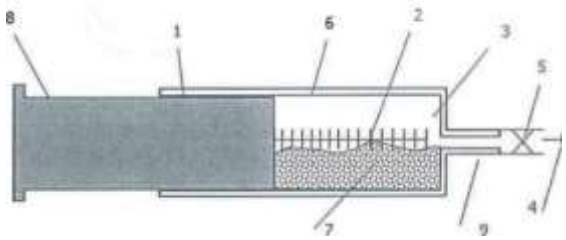

Figure 2. HBT Syringe

Figure 3. Water Bath

2.2. Method

Olive pomace (OLP), cottonseed meal (CTM) and red pepper processing waste (RPP) were dried and ground to pass through a 1 mm sieve. The dry matter, crude ash, organic matter, crude protein (by Kjeldahl method) and crude fat (by Soxhlet extractor method) contents of the prepared materials were determined according to AOAC, (1990). ADF and NDF contents were determined according to Van Soest et al. (1991). For the determination of the methane potential, all samples were weighed to 0.2 g on dry basis and filled into 100 mL test syringes in triplicate (VDI 4630, 2006). The net biogas (Net_{biogas}) was calculated by subtracting the inoculum ($T_{inoculum}$) from the total gas (T_{gas}).

$$Netbiogas = Tgas - Tinoculum \quad \text{(Eq. 1)}$$

2.3. Evaluation of Data

The chemical properties of the materials prepared according to the standard requirements were determined in the laboratory of the Department of Biosystems Engineering of Kahramanmaraş Sütçü İmam University, Faculty of Agriculture. These characteristics included crude protein (CP (%)), crude fat (CF (%)), % dry matter (DM), % organic dry matter (ODM), ADF (%), NDF (%), biogas and methane production, and methane content in biogas. Measurements, performed in triplicate, included mean and standard deviation values, statistical differences and analysis of variance (SPSS one-way ANOVA). Data were interpreted in tables and figures.

3. Results and Discussion

At the end of the study, the dry matter (DM) and organic dry matter (ODM), ash, protein, fat, ADF, and NDF ratios of the materials were determined to be 85.51%-94.09%, 87.91%-92.92%, 7.08%-12.09%, 7.49%-15.93%, 3.76%-8.01%, 54.47%-71.07%, and 35.24%-55.58%, respectively. The materials differed chemically. The highest DM (94.09%), ODM (92.92%), protein (15.93%), and fat (8.01%) were found in cotton waste, while the highest ash (12.09%) was found in pepper waste, and the highest NDF (71.07%) and ADF (55.58%) were found in olive waste. The lowest DM (85.51%), ODM (87.91%), were found in RPP, the lowest ash (7.08%), CP and the lowest protein (7.49%) and fat (3.76%) in OLV waste and the lowest NDF (54.47%) and ADF (35.24%) in CTM waste (*Table 1*).

Table 1. Chemical Properties of the Materials

M	DM	ODM	Ash	CP	Fat	NDF	ADF
OLV	87.06±0.57b	92.05±0.15b	7.95±0.16b	7.49±0.35c	3.76±0.04c	71.07±0.64a	55.58±0.43a
RPP	85.51±0.62c	87.91±0.33c	12.09±0.34a	8.61±0.23b	6.74±0.16b	55.76±0.30c	36.49±0.47b
CTM	94.09±0.65a	92.92±0.08a	7.08±0.09c	15.93±0.17a	8.01±0.16a	54.47±0.30b	35.24±0.47c

P≤0.05; a,b,c,d, differences between the averages shown with different letters in the same column are important

3.1. Examination of the Average Methane Production of All Samples

The time-dependent methane production graph of all materials studied is presented in a figure, while the average cumulative specific methane, biogas values, and methane ratios in the biogas of the materials are presented in a table. In addition, the changes in the average cumulative specific methane and biogas production of the materials are shown in a *Table 2.*

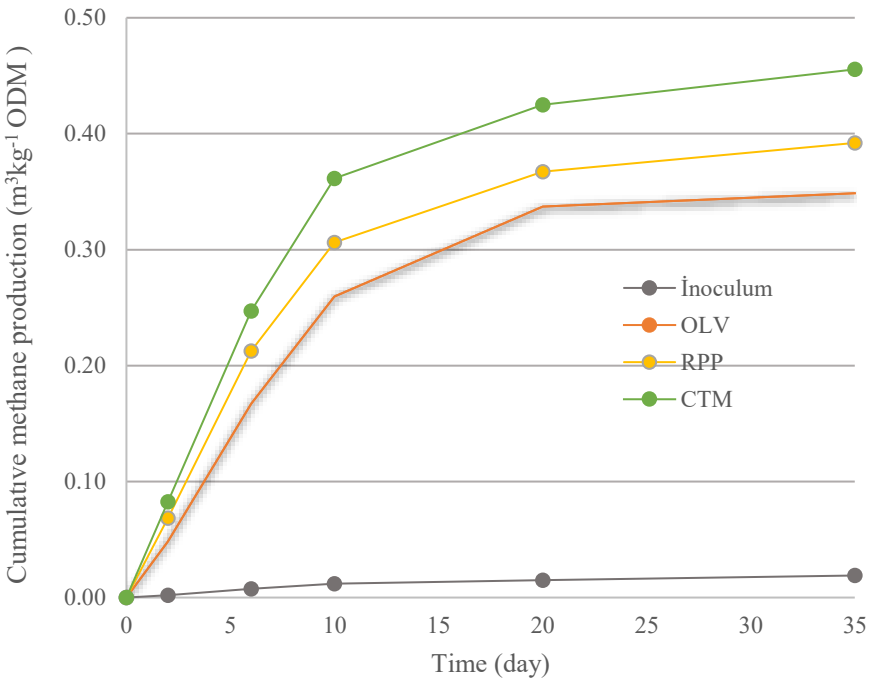

Figure 4. Time-Dependent Methane Production Graph

As a result of the measurements, the cumulative methane production of the inoculum (starter) from anaerobic (oxygen-free) decomposition was approximately 0.02 45 m^3kg^{-1} ODM. The average cumulative methane production values of all materials were between 0.34-0.45 m^3kg^{-1} ODM. The cumulative methane production was 0.42 m^3kg^{-1} ODM for cotton, 0.39 m^3kg^{-1} ODM for pepper and 0.34 m^3kg^{-1} ODM for olive. The average cumulative biogas production values of all materials ranged between 0.61-0.78 m^3kg^{-1} ODM, with the highest cumulative biogas production occurring in cotton (0.78 m^3kg^{-1} ODM) and the lowest in olive (0.61 m^3kg^{-1} ODM) (*Figure 4*, *Table 2*). The methane ratios in the biogas varied between 54.64%-57.72%, with the maximum methane ratio in cotton and the minimum in pepper (*Table 2*, *Figure 5*). Statistical comparison showed that the cumulative specific methane, biogas values and methane ratios in biogas of all materials were not significantly different (P≤0.05) (*Table 2*).

In the study, the average cumulative specific methane and biogas yields were highest for cotton, pepper, and olive residues, respectively. Chemical analyses indicated that higher protein and fat content, along with lower ADF and NDF ratios, led to higher cumulative methane and biogas production (*Table 1*, *Table 2*). NDF (cellulose+lignin+hemicellulose) and ADF (cellulose+lignin) consist primarily of cell wall components such as cellulose, lignin, and insoluble proteins. An increase in ADF and NDF ratios indicates a higher fibrous structure, which reduces digestibility and potentially reduces gas production. Amino acids from protein hydrolysis are fermented via reactions such as the Strickland reaction without the formation of hydrogen, while long-chain fatty acids (LCFA) from lipid hydrolysis can be converted to acetate and hydrogen at very low hydrogen partial

pressures, which are consumed only by methanogenic or sulfate-reducing bacteria (Dong et al., 2009; Hallenbeck, 2009). Proteins provide nutrients for biological degradation processes and thus create a buffering capacity during anaerobic digestion. However, high concentrations of ammonium nitrogen (NH_4+) from proteins and LCFAs from lipids can create inhibitory conditions (Ariunbaatar et al., 2015; Chen et al., 2014) and affect hydrogen production during fermentation. Nitrogen is essential for the growth and activity of anaerobic microorganisms. Proteins and amino acids in feedstocks can serve as nitrogen sources to support microbial activity and enhance biogas production. Oils have a high energy content and can produce more biogas per unit weight compared to carbohydrates and proteins because they are composed of long-chain fatty acids, which produce significant amounts of methane when degraded (Chen et al., 2014).

Table 2. Average Cumulative Specific Methane, Biogas Values, and Methane Ratios in Biogas of the Materials

	Methane				Biogas				Metan rate (%)
	Measurements			Avr. ±Std error	Measurements			Avr. ±Std error	
Materials	1	2	3	(m^3kg^{-1})	1	2	3	(m^3kg^{-1})	
OLV	0.33	0.34	0.35	0.34±0.009c	0.59	0.61	0.62	0.61±0.020c	56.91a
RPP	0.40	0.37	0.38	0.39±0.019b	0.74	0.69	0.71	0.71±0.009b	54.64b
CTM	0.46	0.45	0.45	0.45±0.004a	0.80	0.78	0.77	0.78±0.013a	57.72a

P≤0.05; Differences indicated by different letters (a, b, c, d) in the same column for cumulative specific methane, biogas production, and methane ratios in biogas averages are significant.

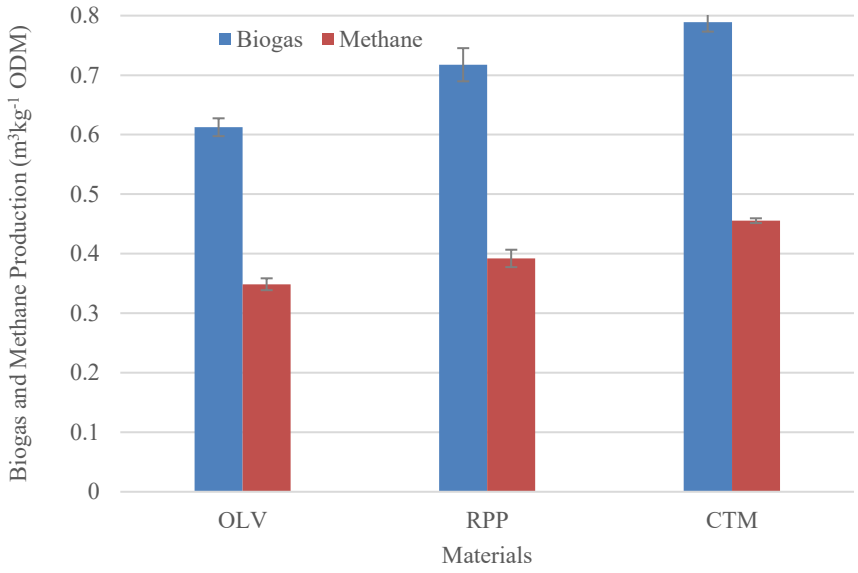

Figure 5. Changes in Average Cumulative Specific Methane and Biogas Production of Materials

In this study, an increase in protein and fat content correlated with increased methane and biogas production. Juanga et al. (2021) reported maximum methane production of 0.32 and 0.37 m^3kg^{-1} from processed and unprocessed cotton residues, Li et al. (2011) the daily average gas production achieved 508.57 mL/d, Borja et al. (2003) found methane production from olive pomace of 0.25 m^3kg^{-1}, Zupancic et al. (2024) in their study of pepper processing waste found biogas production of 0.68 m^3kg^{-1} and methane production of 0.4 m^3kg^{-1}. In this study, biogas production was found to average 0.71 m^3kg^{-1} and methane production was found to average 0.39 m^3kg^{-1}, Tufaner (2020), in its study of olive pomace, found a methane content of 62.6%. Zhang et al. (2018), obtained around 60% methane content in biogas. If we compare it with this study, the methane content was found to be slightly high. It can be said that the reason for this is due to the oil and persistent biodegradable content of olive pomace, which varies according to the variety.

Compared to the literature, methane and biogas production from olive and cotton residues were higher, while methane and biogas production from processed pepper residues were approximately similar. Variations in methane

and biogas production may be due to product diversity and associated differences in chemical and elemental composition.

4. Conclusions and Recommendations

The study determined dry matter (DM) and organic dry matter (ODM) content, ash, protein, fat, ADF, and NDF ratios, average cumulative specific methane and biogas yields, and methane content in biogas for CTM, RPP, and OLV.

- There were chemical differences among the materials.
- Average cumulative methane production ranged from 0.34 to 0.45 m^3kg^{-1}ODM, cumulative biogas production ranged from 0.61 to 0.78 m^3kg^{-1}, and methane content in biogas ranged from 54.64% to 57.72%.
- Statistical comparisons revealed no significant differences ($P \leq 0.05$) in cumulative specific methane and biogas yields or methane content in biogas among the materials studied.
- Chemical analyses showed that higher protein and fat content and lower ADF and NDF ratios correlated with increased cumulative methane and biogas production.
- Cotton, pepper, and olive waste have the potential to multiply as additives in biogas plants. Utilization of these components could be an important resource for sustainable energy production.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authorship Contribution Statement

Concept: Üçok, S., Yang, X.; Design: Üçok, S., Yang, X; Data Collection or Processing: Üçok, S., Yang, X; Statistical Analyses: Üçok, S.; Literature Search: Üçok, S., Yang, X; Writing, Review and Editing: Üçok, S., Yang, X.

References

Al-Addous, M., Alnaief, M., Class, C. B., Nsair, A., Kuchta, K. and Alkasrawi, M. (2017). Technical possibilities of biogas production from olive and date waste in jordan. *BioResources*, 12(4): 9383-9395.

Alonso-Fariñas, B., Oliva, A., Rodríguez-Galán, M., Esposito, G., García-Martín, J. F., Rodríguez-Gutiérrez, G. and Fermoso, F. G. (2020). Environmental assessment of olive mill solid waste valorization via anaerobic digestion versus olive pomace oil extraction. *Processes*, 8(5): 626.

AOAC (1990). Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Washington, DC, U.S.A.

Ariunbaatar, J., Di Perta, E. S., Panico, A., Frunzo, L., Esposito, G., Lens, P. N. and Pirozzi, F. (2015). Effect of ammoniacal nitrogen on one-stage and two-stage anaerobic digestion of food waste. *Waste Management,* 38(2015): 388-398.

Aybek, A., Üçok S., Bilgili M. E. and İspir M. A. (2015) Digital mapping and determination of biogas energy potential of usable animal manure and cereal straw wastes in Turkey. *Journal of Tekirdag Agricultural Faculty,* 12(3): 109-120.

Bilgin, S., Yılmaz, H. and Koçer, A. (2015). Briquetting of greenhouse pepper crop residues. *Agricultural Engineering International: CIGR Journal*, (Special Issue: 18th World Congress of CIGR): 185–192.

Borja, R., Martín, A., Rincón, B. and Raposo, F. (2003). Kinetics for substrate utilization and methane production during the mesophilic anaerobic digestion of two phases olive pomace (TPOP). *Journal of Agricultural and Food Chemistry,* 51(11): 3390-3395.

Chen, J. L., Ortiz, R., Steele, T. W. J. and Stuckey, D. C. (2014). Toxicants inhibiting anaerobicdigestion: a review. *Biotechnology Advances,* 32: 1523–1534.

Develi, H. C., Aybek, A. and Üçok, S. (2021). Pellet production from pistachio shell and olive cake for biofuels. *Journal of Tekirdag Agricultural Faculty*, 18(4): 689-701.

Dong, L., Zhenhong, Y., Yongming, S., Xiaoying, K. and Yu, Z. (2009). Hydrogen production characteristics of the organic fraction of municipal solid wastes by anaerobic mixed culture fermentation. *International Journal of Hydrogen Energy*, 34(2): 812-820.

Hallenbeck, P. C. (2009). Fermentative hydrogen production: principles, progress, and prognosis. *International Journal of Hydrogen Energy,* 34(17): 7379-7389.

Juanga-Labayen, J., Yanac, K. and Yuan, Q. (2021). Effect of substrate-to-inoculum ratio on anaerobic digestion of treated and untreated cotton textile waste. *International Journal of Environmental Science and Technology,* 18(2021): 287-296.

Kaya, G. (2024*). Evaluation of bioenergy recovery from olive mill waste and cotton stalks in Turkey: Case study for biogas production* (MSc. Thesis) Studiengang University of Applied Sciences/Fachbereich Bioengineering, Wien, Austria.

Lerdlattaporn, R., Phalakornkule, C., Trakulvichean, S and Songkasiri, W. (2020). Implementing circular economy concept by converting cassava pulp and wastewater to biogas for sustainable production in starch industry. *Sustainable Environment Research*, 31(1): 20.

Li, Y., Zhang, Q., Li, W. and Yu, L. (2011). Effects of different pretreatment conditions on biogas production by anaerobic fermentation of cotton stalk. *Transactions of the Chinese Society of Agricultural Engineering*, 27(2): 287-292.

Messineo, A., Manfredi, P. M. and Roberto Volpe. (2020). Biomethane recovery from olive mill residues through anaerobic digestion: A review of the state of the art technology. *Science of The Total Environment*, 703(10): 135508.

Semerci, A. and Çelik, A. D. (2018). Functional analysis of cotton production in Hatay Province. *Journal of Tekirdag Agricultural Faculty,* 15(2): 78-86.

Sumardiono, S., Jos, B., Dewanti, A. A. E., Mahendra, I. N. B, and Cahyono, H. (2021). Biogas production from coffee pulp and chicken feathers using liquid- and solid-state anaerobic digestions. *Energies,* 14(15): 4664.

Sumardiono, S., Riyanta, A. B., Matin, H. H. A., Kusworo, T. D., Jos, B. and Budiyono, B. (2016). Increasing biogas production from sugar cane baggase by anaerobic co-digestion with animal manure. *Sriwijaya International Conference on Engineering, Science and Technology (SICEST 2016),* 9-10 November, P. 183-189, Bangka Island, Indonesia.

Tokel, D., Dogan, I., Hocaoglu O. A. and Ozyigit, I. I. (2022). Cotton agriculture in Turkey and worldwide economic impacts of Turkish cotton. *Journal of Natural Fibers*, 19(15): 10648-10667.

Tufaner, F. (2020). Biogas Productıon From Olive Pomace (Prina) Wastes. *V. Internatıonal Battalgazi Scıentıfic Studıes Congress,* 18-20 December, P. 511-519, Malatya, Turkey.

Uddin, M. A., Siddiki, S. Y. A., Ahmed, S. F., Rony, Z. I., Chowdhury, M. A. K. and Mofijur, M. (2021). Estimation of sustainable bioenergy production from olive mill solid waste. *Energies*, 14(22): 7654.

Valenti, F., Cascone, G. and Arcidiacono, C. (2017). Potential biogas production from agricultural by-products in sicily: a case study of citrus pulp and olive pomace. *Journal of Agricultural Engineering,* 48(4): 196-202.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. (1991). Methods for dietary fiber, neutraldetergent fiber, and nonstarchpolysaccharides in relationtoanimalnutrition. *Journal of Dairy Science,* 74: 3583–3597.

VDI 4630 (2006). Fermentation of Organic Material, Characterization of Substrate, Collection of Material Data, Fermentation Tests, *VDI Society Energy Technology*, Stuttgart, Germany.

Venkateshkumar, R., Shanmugam, S. and Veerappan, A. (2021). Evaluation of biogas through chemically treated cottonseed hull in anaerobic digestion with/without cow dung: an experimental study. *BioEnergy Research,* 16(1): 660-672.

Ziemiński, K. and Kowalska W. M. (2016). Effect of different sugar beet pulp pretreatments on biogas production efficiency. *Applied Biochemistry and Biotechnology,* 181(3): 1211-1227.

Zupančič, G. D., Lončar, A., Ranilović, J., Šubarić, D and Panjičko, M. (2024). The influence of polyphenolic compounds on anaerobic digestion of pepper processing waste during biogas and biomethane production. *Processes*, 12(5): 913.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Swimming Behavior Characteristics in Horses and Their Impact On Pregnancy Rates

Atlarda Yüzme Davranışı Özellikleri ve Gebelik Oranları Üzerindeki Etkileri

Yavuzkan PAKSOY[1*], Nazan KOLUMAN[2], Serap GÖNCÜ[3]

Abstract

In this study, the swimming behaviors of 20 Thoroughbred mares living in a private horse farm in Ulukışla district of Niğde and the effect of swimming on pregnancy rate were investigated. 20 English breed horses between the ages of 4-18 and without any health problems that would prevent them from getting pregnant were included in the study. The horses included in the study had no previous swimming experience. A veterinarian specialized in equine medicine collected the data by examining the observations and camera recordings. The behaviors of the horses around and inside the pool were observed. The pregnancy rate was determined by dividing the number of pregnant horses for each group by the total number of horses. The necessary graphs and tables were created with Microsoft Excel and SPSS statistical package programs to explain and analyze the statistical descriptive characteristics of the camera recordings and observation results. In the presented study, the analysis of pregnancy rates in the swimming group and the control group was performed using the Chi-square method with the SPSS statistical program. 19 of the 20 horses (95%) that were made to swim in the pool and 7 of the 12 horses (58.33%) that were made to swim in the pool became pregnant. The results revealed a range of behaviours including initial reactions to the pool, swimming techniques and post-swim activities. In particular, horses displayed a mixture of curiosity, attention and exploration when first introduced to the water, with the majority taking a measured and cautious approach during pool entry. Swimming behaviours were characterised by alertness, directional tendencies and vocalisations reflecting natural instincts and adaptability. Post-swim activities such as tail wagging, shaking and nose touching provided information on physical adaptation, moving away from the water and potential social or self-comforting behaviours. These findings contribute to the understanding of the behaviour of horses in aquatic environments and highlight the importance of welfare considerations in water-based activities for horses. Furthermore, addressing their natural behaviours and needs improves reproductive performance by an average of 37%. Further research may explore the specific triggers behind the observed behaviours, improve our understanding of equine behaviour in aquatic environments and encourage optimal care practices.

Keywords: Behavior, Horse, Pregnancy rate, Performance, Swimming patterns

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Öz

Bu çalışmada, Niğde'nin Ulukışla ilçesindeki özel bir at çiftliğinde yaşayan 20 Safkan kısrağın yüzme davranışları ve yüzmenin gebelik oranı üzerine etkisi incelenmiştir. Yaşları 4-18 aralığında olan ve gebe kalmaları için herhangi bir sağlık problemi bulunmayan 20 baş İngiliz ırkı at çalışmaya dahil edilmiştir. Çalışmaya dahil edilen atların daha önce yüzme deneyimi olmamıştır. At hekimliği konusunda uzman veteriner hekim gözlem ve kamera kayıtlarını inceleyerek verileri toplamıştır. Atların havuzun çevresinde ve içerisinde sergiledikleri davranışları gözlemlenmiştir. Gebelik oranı, her grup için gebe at sayısının toplam at sayısına bölünmesiyle belirlendi. Kamera kayıtlarının ve gözlem sonuçlarının istatistiksel tanımlayıcı özelliklerini açıklamak ve analiz etmek için gerekli grafik ve tablolar Microsoft Excel ve SPSS istatistik paket programları ile oluşturulmuştur. Sunulan çalışmada, yüzme grubu ve kontrol grubundaki gebelik oranlarının analizi SPSS istatistik programı ile Ki-kare yöntemi kullanılarak yapılmıştır. Havuzda yüzdürülen 20 atın 19'u (%95), kontrol grubunu oluşturan 12 atın 7'si (%58.33) gebe kalmıştır. Sonuçlar, havuza ilk tepkiler, yüzme teknikleri ve yüzme sonrası aktiviteler de dahil olmak üzere bir dizi davranışı ortaya koymuştur. Özellikle, atlar suyla ilk kez karşılaştıklarında merak, dikkat ve keşfin bir karışımını göstermiş, çoğunluğu havuza giriş sırasında ölçülü ve temkinli bir yaklaşım sergilemiştir. Yüzme davranışları, doğal içgüdüleri ve uyum kabiliyetini yansıtan uyanıklık, yön eğilimleri ve vokallerle karakterize edildi. Kuyruk sallama, silkinme ve buruna dokunma gibi yüzme sonrası aktiviteler fiziksel uyum, sudan uzaklaşma ve potansiyel sosyal veya kendini rahatlatma davranışları hakkında bilgi sağlamıştır. Bu bulgular, atların su ortamlarındaki davranışlarının anlaşılmasına katkıda bulunmakta ve atlar için su temelli faaliyetlerde refah hususlarının önemini vurgulamaktadır. Ayrıca, doğal davranışlarını ve ihtiyaçlarını ele alarak üreme performansını ortalama %37 oranında artırmaktadır. Daha fazla araştırma, gözlemlenen davranışların ardındaki belirli tetikleyicileri keşfedebilir, su ortamlarındaki at davranışlarına ilişkin anlayışımızı geliştirebilir ve en uygun bakım uygulamalarını teşvik edebilir.

Anahtar Kelimeler: Davranış, At, Gebelik oranı, Performans, Yüzme modelleri

1. Introduction

To achieve sufficient perfomances from horses in horse breeding, it is crucial to establish optimal environmental conditions (Gücüyener Hacan and Akçapınar, 2013). Adequate care and nutrition for horses are possible through understanding their behaviors. Behavior encompasses the responses of organisms to stimuli from their environments (Akçapınar and Özbeyaz, 1999; Gill et al., 2005), guided by their senses (Gill et al., 2005). Horses utilize senses such as touch, sight, hearing, smell, and taste to interact with their surroundings. Horses exhibit both normal and abnormal behaviors. Examples of normal behaviors in horses include feeding, mimicking, swimming, exploring, establishing dominance, mothering and forming friendships (Gücüyener Hacan and Akçapınar, 2013). Abnormal behaviors in horses include kicking, biting, wind sucking, wood chewing and spinning (Gücüyener Hacan and Akçapınar, 2013).

Horses were domesticated around 5000 BCE (Kelly et al., 2021). While horses were historically bred for agriculture, transportation, military purposes and food, they are now bred for sporting purposes due to advancements in industry and technology (Danışan et al, 2014). For horses to perform well in sporting competitions, their physiological, anatomical and psychological health must be optimal. In addition to conventional exercise and treatment methods, alternative methods are gaining popularity. Swimming horses in pools or in the sea is a prime example. Swimming strengthens muscles, develops cardiovascular and respiratory systems, activates reproductive activities, reduces stress and aids in mental rehabilitation (Taşdemir, 2023).

Swimming is a sport that actively engages the arms, legs and core muscles, requiring the use of many muscles in the body. Swimming reduces pressure on joints, prevents injuries during training, balances heart rate, increases fat burning, promotes muscle mass development and maintains a healthy metabolism (Jackson et al., 2022). Endorphin release during swimming reduces pain and stress (Jackson et al., 2022). While swimming, horses traditionally relied on natural bodies of water, today, the number of horse pools and underwater treadmills in specialized farms or rehabilitation centers is increasing. Pool depth, width, length and water temperature are scientifically adjusted. Scientific recommendations also guide the selection of auxiliary materials.

When incorporating swimming training into horse training and rehabilitation programs, several factors must be considered. Horses should be adequately prepared for the program, accustomed to the equipment and water and gradually exposed to increasing depths. Both horses and trainers should be prepared for various scenarios. Age, gender, breed, performance status, health, swimming experience and breeding and rehabilitation goals should be considered when designing appropriate training programs (Tranquille et al., 2017).

Horses are born with an instinctive swimming behavior, believed to be inherited from their ancestors due to the need to navigate deep waters to escape danger or reach different grazing areas in the wild (Robinson, 2021). The strong muscles, long legs and flexible spines of horses contribute to their swimming abilities. A horse that may be hesitant to walk in water can often swim confidently once it ventures into deeper areas. While swimming, horses keep their heads above water, allowing them to maintain the proper position and have a clear field of vision. They make movements similar to paddling, akin to the trotting behavior they exhibit on land (Robinson, 2021). Their front legs propel them forward in the water, while the hind legs provide balance and control. The hind legs move more than the front legs during swimming, providing stability and propulsion. Horses are not as fast in water as they are on land. While a galloping horse can reach speeds of 40-70 km/h, a swimming horse can reach speeds of 4-10 km/h. Horses cannot hold their breath underwater for extended periods. They can swim with a rider, but many horses are not fond of this situation. When riding a horse in water, the rider should sit on the horse's back slowly, avoid sudden movements, and allow the horse freedom of movement (Dewsbury, 2023). Horses can comfortably stay on the water's surface due to their large lungs. Horses propel themselves forward in water by moving their front legs, while their hind legs are used for balance and control. The hind legs move more than the front legs during swimming, providing stability and propulsion. Horses are not as fast in water as they are on land, so they move more slowly while swimming. It is crucial for horses to have large lungs to stay comfortably on the water's surface.

Several important considerations should be taken into account when introducing horses to swimming. These include acclimating the horse to water, ensuring the water's temperature and cleanliness, gradually increasing the depth, monitoring the horse's behavior and rinsing them clean after exiting the water.

Considerations for introducing horses to swimming

Several considerations must be taken into account when introducing horses to swimming:

• Horses should be accustomed to water by washing their feet.

• They can be introduced to water by walking them around small puddles.

• The swimming pool, sea, water treadmill, or river should be explored, allowing the horse to become familiar with it using its sensory organs.

• Horses should not be forced to enter the water; small encouragements can be given.

• The depth should gradually increase once the horse is in the water.

• Inexperienced horses should be guided by one or two trainers using a long rope, holding them from one or both sides, and directing them from the pool edge.

• The behavior of horses inside and outside the water should be well understood before and after entering the water to prevent any abnormal behavior or modify the training program.

• The water should be at an appropriate temperature, clean, free from harmful elements and the horse should be rinsed with clean water after exiting.

• Horses should be given rest periods of 5-10 minutes between swimming sessions (Dewsbury, 2023; Smith et al., 2012).

It is believed that horses are born with the instinctive ability to swim due to the need to navigate deep waters to escape danger or reach different grazing areas in the wild. Their swimming abilities are supported by their strong muscle structure, long legs, and flexible spines. A horse that may be hesitant to walk in water can often swim confidently once it ventures into deeper areas. During swimming, horses keep their heads above water, allowing them to maintain the proper position and have a clear field of vision.

Swimming in horses has been frequently recommended in recent years in terms of muscle development, heart health and welfare issues. Many horses can swim in shallow water. There is no need to specially teach these animals to swim, it is an instinct that is inherent in nature. However, the first swimming experience is important and should not be forced. Due to limited literature on this topic, the aim is to contribute to colleagues and breeders in this field. Therefore, the aim of this study was to investigate the swimming behaviour and experience of horses in detail.

2. Materials and Methods

2.1. Ethical Approval

In this study, routine breeding in stud farms practices have not been deviated from. Data obtained in these study within the scope of these applications for Experimental and Other Scientific Purposes Concerning the Welfare and Protection of Animals Used Regulation (Official No. 28141 dated 13.12.2011, Gazette) article 2, second paragraph: “This Regulation, non-experimental agricultural and clinical veterinarian In accordance with the provision does not cover applications’, the scope since it is outside the Ministry (T.R. Adana Governorship Provincial Directorate of Agriculture and Forestry, Number: E-74530962-325.99-13486280.) is not subject to permission.

This study utilized a total of 20 Thoroughbred mares (4-18 years old) from a private horse farm located in Ulukışla, Niğde, Turkey. Ulukışla, where the study was conducted, has a continental climate and is located at an altitude of 1427 m. The district is located between 34°30"16' East longitude and 36°58"5' North latitude.

The average annual temperature of the district is 9.8 °C. The lowest average temperature was found in January with -2.1 and the highest in July with 21.9 °C. The district experiences four seasons distinctly, with spring and autumn seasons showing a transitional feature. The climate is a Mediterranean-Central Anatolian transition climate. Summers are cool and dry, winters are cold and snowy. Precipitation intensity shifts to spring and winter seasons. Average annual rainfall: 513 mm.

Figure 1. Ulukışla location

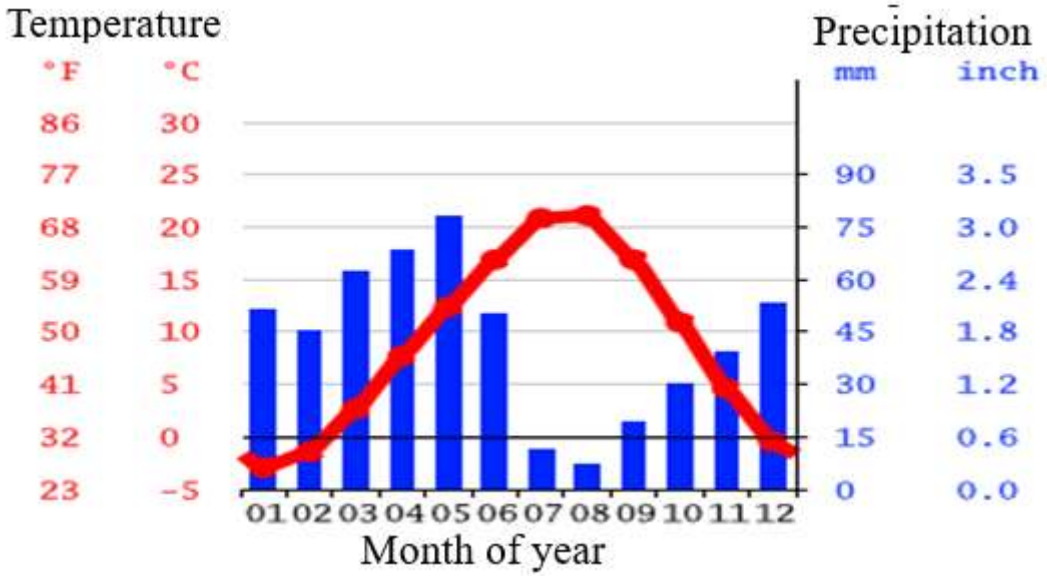

Figure 2. Ulukışla climate

The study was conducted in a privately owned Horse Farm in Ulukışla. The horses were floated in February, the average air temperature was 2°C and the average humidity was 72%. The horses that were swam and included in the control group were mated in March-April-May and the average air temperature was 11°C and the average humidity was 57%. In the trial, a pool was designed for a business to float horses. This pool is 40 m long, 3 m wide and 2.5 m deep. The sole is covered with a non-slip material. There is a 25% inclined ramp at the entrance and exit of the pool so that 1 m horses can enter and exit easily (*Figure 3-5*). The water temperature of the pool was maintained at 25°C room temperature and the pool was cleaned daily throughout the duration of the trial.

Animal material of the study, were selected from among 60 Thoroughbred mares on the farm based on their age and being previously healthy animals that had never swum before. Throughout the trial period, the horses were left unshod. The horses were allowed to roam freely around the pool for two hours the day before without any research conducted to familiarize them with the pool.

The control group of the study consisted of 12 Thoroughbred healthy mares between the ages of 5-18, kept on the same farm. A similar care and feeding program was applied to the mares included in the control group, and they were mated without swimming.

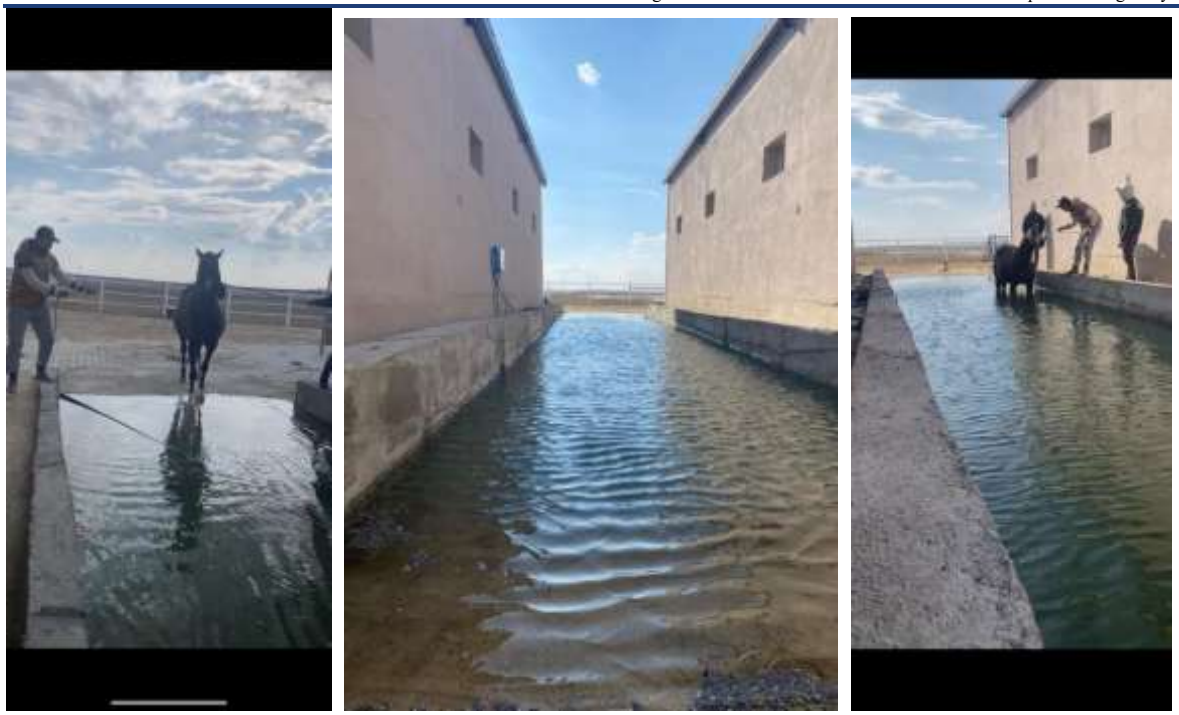

Figure 3-4-5. Pool where horses are swum

Within the scope of the research, the behavior of 20 horses regarding entering and staying in the pool and all their pool experiences were recorded with a camera. Research data was obtained by researchers by examining camera recordings and continuous observation method. During the research, observations were made by the subject expert and the data was recorded on camera and then the data was extracted by watching these records. The leg movements of the horses in the pool were also examined with the help of a wide-angle camera covering the entire pool. The data were measured with a stopwatch and the times were recorded.

Each horse was swum from one end of the pool to the other 5 repetitions a day during the trial period. After exiting the pool, they were kept on concrete for the first 5 min and then on soil for another 5 min. They were then washed with clean water, dried and taken back to their shelter.

The focus was on the behavioral characteristics of horses, such as the number of days it takes to enter the pool, smelling and drinking the pool water, the way they enter the pool, and the feet they prefer for entering and exiting the pool. All horses entered the pool at varying durations between 0-15 min through these trials.

When entering the pool, the horses were gently encouraged by caretakers on both sides to enter the pool on their own for 5 min. Horses that did not enter were encouraged to do so with carrots and green grass for 5 min. However, horses that still did not want to enter the pool had their eyes covered and were gently guided into the pool, and their eyes were uncovered after all four legs entered the water. An adaptation period of 7 days was implemented, followed by observations within the next 5 days.

During the trial period, horses are individually housed, having access to clean water through automatic troughs in the stables and water containers in the paddock whenever they desire. They are fed three meals a day, totaling 5 kg of oats, 3 kg of barley, 3 carrots, 3 apples and 8 kg of hay daily. Each horse is fed in the same manner. It is known that care, feeding and season affect the productivity ability of animals. Therefore, all animals included in the study were housed under similar environmental conditions (Karadağ and Soysal, 2018). No food or drink was given to the horses 1 h before and 1 h after swimming.

In this study, data on 26 characteristics of 20 horses of similar breed and characteristics, different ages (4-18 years old), kept under the same conditions and raised in a private horse care enterprise, were evaluated. The horses' approach to the pool, their behavior when entering and exiting and their behavior while in the pool constituted the basic data of the study. Behavioral frequency and percentage rates were used as descriptive statistics. To see the effect of cooling in the enterprise on the pregnancy rate in horses, horses in the same enterprise and not subject to any treatment were evaluated as a control group. The pregnancy rate was determined by dividing the number of

pregnant horses by the total number of horses for each group. The graphs and tables necessary to describe and analyze the statistical descriptive features of camera recordings and observation results were created with Microsoft Excel and SPSS statistical package programs (Gül and Oflaz, 2021). In the study presented, the analysis of pregnancy rates in swimming group and control group was conducted using the Chi-square method with the SPSS statistical program. Statistical significance was set at $p \leq 0.05$.

3. Results and Discussion

In this study, the swimming experience behaviors of 20 sample horses of the same breed and conditions, which were cared for in a private enterprise, were observed. According to the data, 70% of the horses are 4-7; 30% are 8-18 years old. This distribution shows that the majority of horses (70%) are in the young and middle-aged group.

The behavior of animals is a mixture of instincts and behaviors based on intellectual intelligence. Living beings learn, remember, know and apply. Many horses can swim and there is no need to specially teach these animals to swim, it is an instinct that is inherent in nature. The first experience is effective in improving the animals' later behaviors, abilities and reflexes. Despite it being their first time swimming in the deep part of the water, all horses were able to swim without any hesitation.

When horses first encounter the pool step back, neigh, hit the water with front foot, smelling water and rearing behavior has been observed (*Figure 6*)

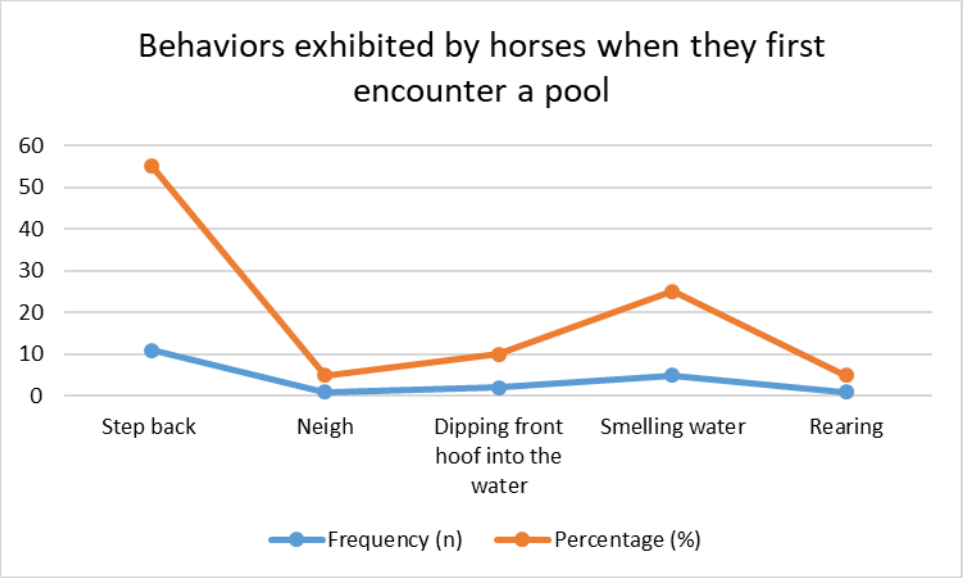

Figure 6. Behaviors exhibited by horses when they first encounter a pool

According to the figure, the behaviors exhibited by horses when they first encounter a pool are as follows. Step back behavior is observed at the highest frequency (55%). This behavior is the initial reaction of horses when approaching water. The step back behavior appears to be the most common response as horses' approach water. This reaction may stem from a natural caution toward water or indicate a bit of apprehension during their initial contact with water. Neigh behavior is observed in only 5% of the total behaviors. This seems to be a rare response during horses' initial contact with water. This suggests that horses generally remain silent or exhibit less vocal reactions when encountering water. Dipping front hoof into the water (10%) and smelling water (25%) behaviors indicate horses' interest and curiosity about water. These behaviors play an important role in horses' exploration and familiarization with water. "Rearing" behavior is less common compared to other behaviors (5%). This may suggest that horses can show a more anxious or cautious response to water. Overall, the behaviors exhibited by horses when they first encounter a pool reflect various emotional responses such as curiosity, anxiety and exploration. Horse owners and caretakers can better understand how horses behave in such environments by observing their reactions to water and taking necessary precautions.

In *Table 1*, an array of behavioral patterns observed during the initial entry of horses into the pool is presented. The predominant mode of entry, evident in a substantial majority (85%) of cases, involves walking into the pool.

This behavior signifies a measured and cautious approach, indicating that horses exhibit a level of comfort and familiarity with the aquatic environment. Conversely, a smaller fraction (15%) of horses opted for a more energetic response by running into the pool, suggestive of a heightened sense of eagerness or confidence. This interplay between caution and boldness underscores the diverse behavioral repertoire exhibited by horses in novel aquatic contexts.

Table 1. Horses' behavior upon entering the pool

Behaviour	Description	Frequency (n)	Percentage (%)
Manner of entering the pool	Running	3	15
	Walking	17	85
First foot entering the pool	Right	20	100
	Left	0	0
First foot leaving the pool	Right	20	100
	Left	0	0
Time taken to accept entering the pool (days)	1	17	85
	2	3	15
Behavior of drinking pool water	Yes	4	20
	No	16	80
Behavior of smelling pool water	Yes	20	100
	No	0	0

The consistent preference for using both right and left foot during both the entry into and exit from the pool, observed in all instances (100%), may indicate either a naturally ingrained tendency or a learned behavior among horses. This inconsequential attitude in limb selection could be influenced by factors such as limb dominance or the cumulative experiences horses have had with water-related activities, contributing to a predictable pattern of behavior.

Furthermore, the rapid acclimatization of the majority of horses (85%) to pool entry within a single day suggests a remarkable capacity for environmental adaptation. However, it is noteworthy that a minority (15%) required an extended period of two days to fully accept this behavior, highlighting the inherent variability in adaptation rates across individual horses.

The behavior of drinking pool water, exhibited by a minority (20%) of horses, may reflect either a natural curiosity or a physiological need for hydration. Conversely, the majority (80%) abstaining from this behavior could be attributed to factors such as perception of water quality or access to alternative water sources. The ubiquitous behavior of smelling pool water (100%) serves as a common exploratory strategy employed by horses to gather crucial information about water properties, temperature and potential hazards, contributing significantly to their overall assessment and navigation of the pool environment.

Collectively, these behavioral observations underscore the diverse range of responses displayed by horses upon encountering a pool, encompassing elements of cautiousness, adaptability, exploratory tendencies and individual variability. A nuanced understanding of these behavioral nuances is pivotal in designing and maintaining optimal aquatic environments for horses, thereby ensuring their welfare and well-being in aquatic settings.

The behavioral aspects of the horses in the pool is given in *Table 2*. The absence of head submersion (0%) among the observed horses indicates a behavioral tendency of keeping the head above water during swimming. This behavior aligns with the natural instinct of horses to maintain a clear airway and visibility of their surroundings while in the water. It suggests that the horses in this study did not engage in diving or fully submerging behaviors typical of some aquatic species. The prevalence of "Pricked" ears (85%) while swimming signifies an alert and focused state among the horses. Pricked ears are associated with heightened attention and

awareness, indicating that the horses were actively monitoring their environment and responding to stimuli while in the pool. Conversely, the presence of "Normal" ear positions (15%) may indicate moments of relaxation or less intense engagement with the swimming activity. The consistent use of back legs for propulsion by all horses (100%) during swimming is in line with biomechanical expectations.

Table 2. The behaviors of horses in the pool

Behaviour	Description	Frequency (n)	Percentage (%)
Does it submerge its head while swimming?	Yes	0	0
	No	20	100
Position of the ears while swimming	Pricked	17	85
	Normal	3	15
Moving legs while swimming	Front	0	0
	Back	20	100
Directional inclination	Middle of pool	17	85
	Left side	1	5
	Right side	2	10
Neighing in the pool	Yes	20	100
	No	0	0

Horses primarily rely on their powerful hind limbs for forward movement in water, leveraging the strength and coordination of these muscles to navigate effectively. The majority of horses (85%) displaying a "Middle of pool" directional inclination suggests a tendency to swim towards the central area of the pool. This behavior could indicate a preference for open water or a neutral swimming trajectory without distinct directional biases. The smaller percentages of horses favoring the "Left side" (5%) or "Right side" (10%) of the pool may reflect individual variations or environmental factors influencing their swimming paths. The universal occurrence of neighing behavior (100%) while in the pool indicates a vocalization pattern associated with various emotions and communication among horses. Neighing could signify excitement, social interaction with other horses, or responses to the pool environment such as unfamiliar stimuli or changes in water conditions.

Swimming is a sport renowned for its holistic engagement of various muscle groups, including the arms, legs and core muscles, fostering overall muscular development and cardiovascular health (Jackson et al., 2022). The activity's low-impact nature reduces strain on joints, mitigating the risk of injuries during training and promoting joint longevity. Moreover, swimming is known to regulate heart rate, boost fat metabolism, stimulate muscle growth and sustain a healthy metabolic rate (Jackson et al., 2022). The release of endorphins during swimming contributes to pain relief and stress reduction, enhancing the overall well-being of swimmers (Jackson et al., 2022).

In parallel, the behavioral aspects of horses in swimming environments unveil intriguing parallels and distinctions. *Table 3* delineates these observations, notably the absence of head submersion (0%), aligning with horses' innate instinct to maintain clear airways and visibility while in water, thus deviating from fully submerging behaviors seen in some aquatic species. The prevalence of "Pricked" ears (85%) underscores horses' heightened alertness and environmental monitoring during swimming, akin to humans' focused engagement in the sport. Conversely, "Normal" ear positions (15%) among horses may denote relaxation or reduced attention during specific swimming phases, akin to human swimmers experiencing varied levels of intensity in their workouts.

Overall, these detailed behavioral observations provide valuable insights into how horses adapt and behave in aquatic environments. The maintenance of an alert and focused state, coupled with strategic limb usage and directional tendencies, reflects the natural swimming behaviors of horses and their ability to navigate and interact within pool settings.

Analysis of the behaviors observed in *Table 3* regarding horses' post-swimming activities are as follows; All horses (100%) exited the pool by walking, which is indicative of a deliberate and composed approach after the

swimming session. Walking as the exclusive exit behavior suggests that horses may have developed a routine and comfortable method for leaving the water. The first tail swinging times of horses post-exit the pool varied. Notably, 10% of horses immediately swung their tails upon exiting the pool, possibly indicating an immediate response to the water. However, the majority (90%) had first tail swinging times ranging from 0.5 to 1.5 minutes. This tail swinging period could signify a post-swimming relaxation process, where horses adjust physically and mentally to their environment. Horses exhibited diverse first shake-off durations after leaving the pool. The highest proportion (45%) had first shaken-off durations between 0.80 to 1.5 minutes, indicating a relatively quick adjustment phase. However, 35% of horses had shaken-off later between 2.00 to 3.00 minutes, suggesting a more prolonged recovery or water clearance process. Additionally, 15% of horses had started shaking off between 3.00 to 4.50 minutes for shaking off, reflecting further individual variations in post-swimming physical recovery.

Table 3. Horses' behavior upon exiting the pool

Behaviour	Description	Frequency (n)	Percentage (%)
Exiting the pool manner	Walking	20	100
	Running	0	0
Tail swinging duration (mins.)	0	2	10
	0.5-1.5	18	90
Shake-off duration (mins.)	0.80-1.5	9	45
	2.00-3.00	7	35
	3.00-4.50	3	15
First behavior observed after exiting the pool	Head shaking	13	65
	Shaking off	2	10
	Tail swinging	5	25

Upon exiting the pool, horses displayed a range of initial behaviors. The most prevalent behavior was head shaking (65%), which could be associated with clearing water from ears or expressing relief post-swimming. Tail swinging was observed in 25% of horses, potentially aiding in water removal from the body. Additionally, 10% of horses engaged in a general shake-off motion, contributing to the drying process and physical comfort.

These observations provide valuable insights into horses' post-swimming behaviors and their physiological and psychological responses upon exiting the pool. Tail swinging and shake-off durations suggest a period of physical adjustment and water clearance, while head shaking and neighing behaviors may reflect emotional states or communication signals among the horses. The consistency in walking exits and the prevalence of specific post-exit behaviors highlight the importance of considering horses' comfort and well-being during and after swimming activities, contributing to a comprehensive understanding of equine behavior in aquatic settings.

Scientific interpretation of the data provided regarding behaviors observed in horses after exiting a pool were given in *Table 4*.

Table 4. Behaviors observed in horses after exiting the pool

Behaviour	Description	Frequency (n)	Percentage (%)
Rolling on the ground	Yes	12	60
	No	8	40
Time spent nose touching upon exiting the pool (mins)	0	2	10
	0.5-1.5	18	90

The observed behavior of horses rolling on the ground post-pool exit is a common phenomenon in equine behavior studies. Rolling behavior in horses is associated with various factors, including thermoregulation, alleviation of discomfort or irritation, social communication and muscular relaxation. In this study, 60% of the observed horses engaged in rolling behavior, indicating a significant prevalence of this post-pool activity among the studied population.

Rolling on the ground is often linked to thermoregulation, where horses use rolling as a means to redistribute their wet coat and regulate body temperature. Additionally, rolling can serve as a way for horses to alleviate any potential discomfort or irritation caused by pool water, harnesses, or other equipment used during aquatic activities. This behavior may also have social implications, as rolling can leave scent marks on the ground, contributing to olfactory communication among herd members.

The data also includes observations of horses spending time snorting upon exiting the pool. While this behavior was less prevalent, with 2 horses (10% of the observed behaviors) engaging in snorting at 2 minutes, it still represents a notable aspect of post-pool behavior.

Snorting behavior in horses can indicate various states, such as relief and nose cleaning. It can also be a self-comforting behavior which horses may remove the harmful subtances in their respiratory systems.

Overall, the combination of rolling on the ground and snorting behaviors observed in this study reflects the diverse range of post-pool activities exhibited by horses. Further research could delve into the specific triggers and motivations behind these behaviors, contributing to a deeper understanding of equine behavior in aquatic environments and enhancing welfare considerations for horses engaged in water-based activities.

Pregnancy status of the treatment and control groups horses is given in *Table 5* and *6*. While 7 (58.33%) of 12 horses in the non-floated control group became pregnant, 19 (95%) of 20 horses that were floated became pregnant. This shows that swimming behavior has a greater effect on pregnancy rate than expected. In horse breeding, the birth season of the foal (January-June) is as important as obtaining a foal per year. For this, the horse must become pregnant on time and with the least number of vaccinations. In this way, breeding stallions are used more effectively and breeding costs are reduced. In addition, the risk of problems such as uterine inflammation due to repeated overmating is reduced. Heat stress is also an important factor in pregnancy rate (Kang et al., 2023).

Table 5. Reproduction performances of Horses

Pregnancy	Total number horse	Pregnant horse number	Ratio (%)
Control group	12	7	58.33
Pool group	20	19	95.00
X^2			.018

Table 6. Swimming * Pregnancy Crosstabulation

			.00	1.00	Total
Swim	1.00	Count	5	7	12
		Expected count	2.3	9.8	12.0
	2.00	Count	1	19	20
		Expected count	3.8	16.3	20.0
Total		Count	6	26	32
		Expected count	6.0	26.0	32.0

As a result of the chi-square analysis (*Table 7*), it was understood that pool application increased the pregnancy rate of horses at a very significant level (p=0.018).

Factors that create stress in horses, lack of socialization and inadequate training have a negative effect on pregnancy rates (Malschitzky et al., 2015). In line with this view, it has been observed that horses that are made to swim are psychologically relaxed and increase their muscle mass by swimming. It has been stated that increasing horse welfare and improving environmental conditions will have positive effects on birth rate and pregnancy rate (Paksoy and Güngör, 2024). In our study, the welfare levels of horses that were regularly swam were increased, necessary environmental arrangements were made and as a result, it was observed that the pregnancy rate increased.

Table 7. Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided
Pearson Chi-Square	6.619[a]	1	.010		
Continuity Correction[b]	4.431	1	.035		
Likelihood Ratio	6.644	1	.010		
Fisher's Exact Test				.018	.018
Linear-by-Linear Association	6.412	1	.011		
N of Valid Cases	32				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.25.
b. Computed only for a 2x2 table

Heat stress is an important welfare issue, there is not a clear definition of heat stress in horses, and there is little data available regarding this condition. In relation to welfare in horses, heat stress can be defined as the inability of the horse to maintain body temperature within a prescribed temperature range (Caulfield et al., 2014).

Hot and humid climatic conditions may exacerbate heat accumulation in the body by restricting heat dissipation (Brownlow et al., 2016; Brownlow and Smith, 2021). It has been documented that body temperature can significantly increase as ambient temperature increases (Aujard and Vasseur, 2001; Minka and Ayo, 2016; Soroko et al., 2017). Humidity will also influence body temperature. As aforementioned, water has high conductivity, so it helps heat dissipation when it is used as a conductive heat transfer but during, and immediately after exercise, the body temperature of horses is significantly higher when humidity is higher, under the same ambient temperature (Kohn et al., 1999). Although horses are non-panting animals and they can only breathe through the nostrils, an increase in respiratory rate during periods of heat load has been reported (Kohn and Hinchcliff, 1995) that indicate it has a primary role in thermoregulation that can contribute to brain cooling (Lekeux et al., 2014; Robertshaw, 2006). Effective and practical intervention methods include using a fan to supply airflow or pouring cool water on the skin can be applied to minimize the prolonged heat stress (Brownlow, 2018; Jeffcott et al., 2009; Marlin et al., 1998; Takahashi et al., 2020; Williamson et al., 1995).

Acute heat stress can affect reproductive functions in both the stallion and the mare. When the body temperature of a stallion is elevated, the scrotal temperature can also be elevated, which may result in poor spermatogenesis or mutations in gamete DNA, as well as decreasing testosterone levels for a few weeks after heat shock exposure (Hansen, 2009; Love and Kenney, 1999; Setchell, 2006). It has also been reported that semen concentration, number of spermatozoa and motile sperm per ejaculation in bulls were lower during summer than in winter and spring (Bernabucci et al., 2010). However, mild heat stress may not result in diminished breeding ability due to the thermoregulation function of the scrotum where there is heat exchange between highly coiled arteries and veins around the testis (Amann, 2011; Gordon et al., 2014). In a study of mammalian females, acute heat stress decreased maternal blood flow to the placenta (Alexander et al., 1987) and reduced follicular volume (Wolfenson et al., 1997), which can cause poorer reproductive results.

If environmental heat stress is prolonged by seasonal or geographical location, various physical factors can change, such as normal body temperature range, fat deposition, coat thickness, or hair density, as an adaptation to mitigate the effects of long-term heat stress conditions (Bernabucci et al., 2010; Collier et al., 2019). Furthermore, the sensitivity and population of the receptors for homeostatic signals can be changed, such as by decreasing catecholamines and glucocorticoids (Bernabucci et al., 2010; Collier et al., 2019). When heat stress is prolonged, following changes have been reported such as damage to oocyte quality (Al-Katanani et al., 2002), suppression of gonadotropin-releasing hormone (Satué et al., 2021), reduced numbers of gonadotropin receptors (Hansen, 2009; Shimizu et al., 2005) and medium-sized follicles (Roth et al., 2000), impaired embryonic development (Bernabucci

et al., 2010; Ealy et al., 1993) and abnormal foetal development (Mortensen et al., 2009; Smith et al., 2012; Yu et al., 2022). In various studies, the heat stress is also recognized as a teratogen (Barrier et al., 2009; Graham and Marshall, 2005; Ouellet et al., 2021). Adaptation to heat stress changes the sensitivity of the onset of sweating, as well as the number of active sweat glands and its volume (McCutcheon and Geor, 2000; Sawka et al., 2001; Sneddon et al., 2008). It was reported that repeated exercise initiates the onset of sweating at lower body temperature (McCutcheon and Geor, 2000) and the sweat gland volume in Thoroughbreds was significantly increased during the summer season when compared to the winter season (Sneddon et al., 2008). Adaptation to the prolonged heat stress can be fixed in gene expressions such as changes in morphological traits, behaviour, metabolism, and productivity over generations to decrease metabolic heat production and increase heat dissipation efficiency (Bernabucci et al., 2010; Geor et al., 1996); (Sejian et al., 2018).

4. Conclusions

In conclusion, this detailed behavioral analysis sheds light on the complex interaction of horses' natural instincts, their adaptability and their responses to new stimuli in their aquatic environment. Swimming behavior in horses is particularly beneficial for post-operative recovery, inadequate muscle mass, endurance in competitions and problems experienced due to psychological disorders. This study showed that swimming behavior in horses provided a 37% positive effect on pregnancy rate and provided significant material and spiritual gains in terms of breeding.

It was determined that swimming behavior is innate in horses and that they are born with this behavior in their repertoire. It was observed that horses generally exhibited a mixture of curiosity, attention and exploration such as stepping back, sniffing the water and dipping their hooves when they first encountered a pool. This study shows horse owners, horse caretakers and colleagues that aquatic environments increase horse welfare and positively affect their reproductive performance.

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Ethical Statement

In this study, routine breeding in stud farms practices have not been deviated from. Data obtained in these study within the scope of these applications for Experimental and Other Scientific Purposes Concerning the Welfare and Protection of Animals Used Regulation (Official No. 28141 dated 13.12.2011, Gazette) article 2, second paragraph: “This Regulation, non-experimental agricultural and clinical veterinarian In accordance with the provision does not cover applications’, the scope since it is outside the Ministry (T.R. Adana Governorship Provincial Directorate of Agriculture and Forestry, Number: E-74530962-325.99-13486280) is not subject to permission.

Conflicts of Interest

The authors declared that there is no conflict of interest.

Authorship Contribution Statement

Conceptualization, N.K.; writing-original draft preparation, N.K. and Y.P.; writing-review and editing, N.K.; Y.P. and S.G. All authors reviewed and approved the final version of the manuscript.

References

Akçapınar, H. and Özbeyaz, C. (1999). *Basic information on animal breeding.* Career Printing Limited Company Ankara, Türkiye. ISBN: 975-96978-0-7.

Alexander, G., Hales, J. R., Stevens, D. and Donnelly, J. B. (1987). Effects of acute and prolonged exposure to heat on regional blood flows in pregnant sheep. *Journal of Developmental Physiology,* 9(1): 1–15.

Al-Katanani, Y. M., Paula-Lopes, F. F. and Hansen, P. J. (2002). Effect of season and exposure to heat stress on oocyte competence in Holstein Cows1. *Journal of Dairy Science,* 85(2): 390–396. https://doi.org.10.3168/jds.S0022-0302(02)74086-1

Amann, R. P. (2011). Physiology and endocrinology. In: McKinnon AO, Squires EL, Vaala WE, Varner DD (eds) Equine reproduction, vol 1. 2nd edn. Wiley-Blackwell, Oxford, pp 881-908.

Aujard, F. and Vasseur, F. (2001). Effect of ambient temperature on the body temperature rhythm of male gray mouse lemurs (Microcebus murinus). *International Journal of Primatology,* 22(1):43–56.

Barrier, M., Dix, D. J. and Mirkes, P. E. (2009). Inducible 70 kDa heat shock proteins protect embryos from teratogen-induced exencephaly: analysis using Hspa1a/a1b knockout mice. *Birth Defects Research Part A.,* 66(8):732–740. https://doi.org.10.1002/bdra.20610

Bernabucci, U., Lacetera, N., Baumgard, L. H., Rhoads, R. P., Ronchi, B. and Nardone, A. (2010). Metabolic and hormonal acclimation to heat stress in domesticated ruminants. *Animal,* 4(7):1167–1183. https://doi.org.10.1017/S175173111000090X

Brownlow, M. A. (2018). Cooling interventions for thoroughbred racehorses: An overview of physical heat transfer mechanisms & practical considerations. *Control and Therapy Series*, 137(1): 43–52.

Brownlow, M. A. and Smith, T. (2021). The use of the hand-held infrared thermometer as an early detection tool for exertional heat illness in Thoroughbred racehorses: a study at racetracks in eastern Australia. *Equine Veterinary Education,* 33(6):296–305.

Brownlow, M. A., Dart, A. J. and Jeffcott, L. B. (2016). Exertional heat illness: a review of the syndrome affecting racing Thoroughbreds in hot and humid climates. *Austrailian Veterinary Journal, 94*(7):240–247. https://doi.org.10.1111/avj.12454

Caulfield, M. P., Cambridge, H., Foster, S. F. and McGreevy, P. D. (2014). Heat stress: a major contributor to poor animal welfare associated with long-haul live export voyages. *Veterinary Journal,* 199(2):223–228.

Collier, R. J., Baumgard, L. H., Zimbelman, R. B. and Xiao, Y. (2019). Heat stress: physiology of acclimation and adaptation. *Animal Frontiers,* 9(1): 12–19. https://doi.org.10.1093/af/vfy031

Danışan, S., Çalışkan, H. and Özbeyaz, C. (2014). Learning and training abilities of horses. *Lalahan Journal of Livestock Research Institute,* 54(2): 77-84.

Dewsbury, N. (2023). Can Horses Swim: Uncovering the Aquatic Abilities of Equines. https://allabouthorses.org/basics/can-horse-swim/ (Accessed Date: 29.10.2023)

Ealy, A. D., Drost, M. and Hansen, P. J. (1993). Developmental changes in embryonic resistance to adverse effects of maternal heat stress in cows 1. *Journal of Dairy Science,* 76(10):2899–2905. https://doi.org.10.3168/jds.S0022-0302(93)77629-8

Geor, R. J., McCutcheon, L. J. and Lindinger, M. I. (1996). Adaptations to daily exercise in hot and humid ambient conditions in trained Thoroughbred horses. *Equine Veterinary Journal,* 28(S22):63–68. https://doi.org.10.1111/j.2042-3306.1996.tb05033.x

Gill, W., Meadows, D. G. and Neel, V. B. (2005). Understanding Horse Behaviour. Institute of Agriculture, Agricultural Extension Service. https://horses.extension.org/wp-content/uploads/2019/07/understanding_horse_behavior.pdf

Gordon, R. K., Mawyer, J. D., Cavinder, C. A., Sigler, D. H., Blanchard, T. L., Love, C. C., Brinsko, S. P., Arnold, C. E., Teague, S. and Vogelsang, M. M. (2014). Effects of moderate exercise on semen parameters and serum LH and cortisol concentrations in stallions. *Journal of Equine Veterinary Science,* 34(1):65–65. https://doi.org.10.1016/j.jevs.2013.10.040

Graham, J. M. and Marshall, J. (2005). Edwards: Discoverer of maternal hyperthermia as a human teratogen. *Birth Defects Research Part A: Clinical and Molecular Teratology,* 66(11):857–864. https://doi.org.10.1002/bdra.20185

Gücüyener Hacan, Ö. and Akçapınar, H. (2013). Behaviour in horses. *Lalahan Journal of Livestock Research Institute,* 53(1): 47-57.

Gül, S. and Oflaz, N. Z. (2021). Comparison of some morphological and physiological characteristics of awassi sheep grown in Gaziantep and Kilis Provinces. *Journal of Tekirdag Agricultural Faculty*, 18(1): 146-156.

Hansen, P. J. (2009). Effects of heat stress on mammalian reproduction. *Philosophical Transactions of the Royal Society B,* 364(1534): 3341–3350. https://doi.org.10.1098/rstb.2009.0131

Jackson, M., Kang, M., Furness, J. and Kemp-Smith, K. (2022). Aquatic exercise and mental health: A scoping review. *Complementary Therapies in Medicine:* 66: 102820.

Jeffcott, L., Leung, W. M. and Riggs, C. (2009). Managing the effects of the weather on the Equestrian Events of the 2008 Beijing Olympic Games. Vet J., 182(3): 412–429. https://doi.org.10.1016/j.tvjl.2009.07.037

Kang, H., Zsoldos, R. R., Sole-Guitart, A., Narayan, E., Cawdell-Smith, A. J. and Gaughan, J. B. (2023). Heat stress in horses: a literature review. *International Journal of Biometeorology,* 67(6):957-973. https://doi.org.10.1007/s00484-023-02467-7

Karadağ, O. and Soysal, M. İ. (2018). Determination of some fertility, growth and morphological characteristics of honamli goats. *Journal of Tekirdag Agricultural Faculty*, 15(1): 135–142.

Kelly, K. J., McDuffee, L. A. and Mears, K. (2021). The effect of human-horse ınteractions on equine behaviour, physiology and welfare: A scoping review. *Animals (Basel),* 11(10): 2782.

Kohn, C. W. and Hinchcliff, K. W. (1995). Physiological responses to the endurance test of a 3-day-event during hot and cool weather. *Equine Veterinary Journal,* 27(S20): 31–36. https://doi.org.10.1111/j.2042-3306.1995.tb05005.x

Kohn, C. W., Hinchcliff, K. W. and McKeever, K. H. (1999). Effect of ambient temperature and humidity on pulmonary artery temperature of exercising horses. *Equine Veterinary Journal,* 31(S30): 404–411. https://doi.org.10.1111/j.2042-3306.1999.tb05256.x

Lekeux, P., Art, T. and Hodgson, D. R. (2014). The Respiratory System: Anatomy, Physiology, and Adaptations to Exercise and Training. In: Hodgson DR, McKeever KH, McGowan CM (eds) The Athletic Horse: Principles and Practice of Equine Sports Medicine: Second Edition. 2nd edition edn. Elsevier Inc., pp 125–154. https://doi.org.10.1016/B978-0-7216-0075-8.00018-6

Love, C. C. and Kenney, R. M. (1999). Scrotal heat stress induces altered sperm chromatin structure associated with a decrease in protamine disulfide bonding in the stallion. *Biology of Reproduction,* 60(3):615–620. https://doi.org.10.1095/biolreprod60.3.615

Malschitzky, E., Pimentel, A. M., Garbade, P., Jobim, M. I. M., Gregory, R. M. and Mattos, R. C. (2015). Management strategies aiming to improve horse welfare reduce embryonic death rates in mares. *Reproduction in Domestic Animals,* 50(4): 632-6. https://doi.org.10.1111/rda.12540

Marlin, D. J., Scott, C. M., Roberts, C. A., Casas, I., Holah, G. and Schroter, R. C. (1998). Post exercise changes in compartimental body temperature accompanying intermittent cold water cooling in the hyperthermic horse. *Equine Veterinary Journal,* 30(1): 28–34. https://doi.org.10.1111/j.2042-3306.1998.tb04085.x

McCutcheon, L. J. and Geor, R. J. (2000). Influence of training on sweating responses during submaximal exercise in horses. *Journal of Applied Physiology,* 89(6):2463–2471. https://doi.org.10.1152/jappl.2000.89.6.2463

Minka, N. S. and Ayo, J. O. (2016). Effects of cold-dry (Harmattan) and hot-dry seasons on daily rhythms of rectal and body surface temperatures in sheep and goats in a natural tropical environment. *Journal of Circadian Rhythms.* 14(1): 8. https://doi.org.10.5334/jcr.143

Mortensen, C. J., Choi, Y. H., Hinrichs, K., Ing, N. H., Kraemer, D. C., Vogelsang, S. G. and Vogelsang, M. M. (2009). Embryo recovery from exercised mares. *Animal Reproduction Science,* 110(3–4):237–244. https://doi.org.10.1016/j.anireprosci.2008.01.015

Ouellet, V., Boucher, A., Dahl, G. E. and Laporta, J. (2021). Consequences of maternal heat stress at different stages of embryonic and fetal development on dairy cows' progeny. *Animal Frontiers,* 11(6):48–56. https://doi.org.10.1093/af/vfab059

Paksoy, Y. and Güngör, Ö. F. (2024). Birthing behaviors and birth-related measurements in thoroughbred horses. *Kahramanmaras Sutcu Imam University Journal of Agricultural and Nature, 27*(3): 727-734.

Robertshaw, D. (2006). Mechanisms for the control of respiratory evaporative heat loss in panting animals. *Journal of Applied Physiology,* 101(2): 664–668. https://doi.org.10.1152/japplphysiol.01380.2005

Robinson, L. (2021). Can Horses Swim? All You Need To Know About Swimming With Your Horse. https://www.horsefactbook.com/fun/can-horses-swim/7 (Accessed Date: 02.10.2021)

Roth, Z., Meidan, R., Braw-Tal, R. and Wolfenson, D. (2000). Immediate and delayed effects of heat stress on follicular development and its association with plasma FSH and inhibin concentration in cows. *Journal of Reproduction Fertility,* 120(1):83-9010. https://doi.org.1530/jrf.0.1200083

Satué, K., Fazio, E., Muñoz, A. and Medica, P. (2021). Endocrine and electrolyte balances during periovulatory period in cycling mares. *Animals,* 11(2): 1–12. https://doi.org.10.3390/ani11020520

Sawka, M. N., Montain, S. J. and Latzka, W. A. (2001). Hydration effects on thermoregulation and performance in the heat. *Comparative Biochemistry and Physiology Part A Molekuler and Integrative Physiology,* 128(4):679–690. https://doi.org.10.1016/S1095-6433(01)00274-4

Sejian, V., Bhatta, R., Gaughan, J. B., Dunshea, F. R. and Lacetera, N. (2018). Review: Adaptation of animals to heat stress. *Animal,* 12(s2): 431–s444. https://doi.org.10.1017/S1751731118001945

Setchell, B. P. (2006). The effect of heat on the testes of mammals. *Animal Reproduction,* 3(2):81–91.

Shimizu, T., Ohshima, I., Ozawa, M., Takahashi, S., Tajima, A., Shiota, M., Miyazaki, H. and Kanai, Y. (2005). Heat stress diminishes gonadotropin receptor expression and enhances susceptibility to apoptosis of rat granulosa cells. *Reproduction*, 129(4): 463–472. https://doi.org.10.1530/rep.1.00502

Smith, R. L., Vernon, K. L., Kelley, D. E., Gibbons, J. R. and Mortensen, C. J. (2012). Impact of moderate exercise on ovarian blood flow and early embryonic outcomes in mares. *Journal of Animal Science,* 90(11): 3770–3777. https://doi.org.10.2527/jas.2011-4713

Sneddon, J. C., Ritruechai, P., de Yanés, G. S. and Howard, C. V. (2008). Seasonal influences on quantitative changes in sweat-associated anatomy in native and thoroughbred horses. *Veterinary Dermatology,* 19(3):163–173. https://doi.org.10.1111/j.1365-3164.2008.00671.x

Soroko, M., Howell, K., Dudek, K., Henklewski, R. and Zielińska, P. (2017). The influence of breed, age, gender, training level and ambient temperature on forelimb and back temperature in racehorses. *Animal Science Journal,* 88(2): 347–355.

Takahashi, Y., Ohmura, H., Mukai, K., Shiose, T. and Takahashi, T. A. (2020). Comparison of five cooling methods in hot and humid environments in Thoroughbred horses. *Journal of Equine Veterinary Science,* 91: 103130–103130. https://doi.org.10.1016/j.jevs.2020.103130

Taşdemir, Ü. (2023). Horse Swimming. *Journal of Equine Sciences*. https://www.atbilimleridergisi.com.tr/author/unaltasdemir/ (Accessed Date: 29.03.2023)

Tranquille, C. A., Nankervis, K. J., Walker, V. A., Tacey, J. B. and Murray, R. C. (2017). Current Knowledge of Equine Water Treadmill Exercise: What Can We Learn From Human and Canine Studies? *Journal of Veterinary Science,* 50: 76-83. https://doi.org/10.3390/ani11061508

Williamson, L., White, S., Maykuth, P., Andrews, F., Sommerdahl, C. and Green, E. (1995). Comparison between two post exercise cooling methods. *Equine Veterinary Journal,* 27(S18): 337–340. https://doi.org.10.1111/j.2042-3306.1995.tb04948.x

Wolfenson, D., Lew, B. J., Thatcher, W. W., Graber, Y. and Meidan, R. (1997). Seasonal and acute heat stress effects on steroid production by dominant follicles in cows. *Animal Reproduction Science,* 47(1):9–19. https://doi.org.10.1016/S0378-4320(96)01638-7

Yu, K., Pfeiffer, C., Burden, C., Krekeler, N. and Marth, C. (2022). High ambient temperature and humidity associated with early embryonic loss after embryo transfer in mares. *Theriogenology,* 188: 37–42. https://doi.org.10.1016/j.theriogenology.2022.05.014

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Effect of Melatonin Treatment on Reproductive Hormones and Sexual Behaviors in Sheep*

Koyunlarda Melatonin Uygulamasının Üreme Hormonları ve Eşeysel Davranışlara Etkisi

Nesrin ÖZTÜRK[1], Cemil TÖLÜ[2*]

Abstract

In seasonal oestrus animals such as sheep, out-off-season lambing practices and synchronization of oestrus are important in terms of herd management and farm economics. The present study aimed to determine the effects of melatonin implants administered before the breeding season on melatonin, estrogen, progesterone hormone concentrations, and sexual behavior in Tahirova sheep. The study was conducted on 60 Tahirova dairy ewes, aged 1-4 years, and 6 head rams, aged 1-2 years. On June 26, melatonin implants were administered to half of the ewes (18 mg dose/ewe) and rams (54 mg dose/ram). Fifteen days after the implantation of melatonin, all the ewes (530 g/ewe) and rams (660 g/ram) were given supplemental feeding (flushing) with grain feed for a period of 60 days. On August 1, the ewes exhibiting signs of estrus following the introduction of a ram were relocated to individual paddocks, where mating was conducted using the hand-mating method. The frequency of sniffing, touching the ram's scrotum, turning the ram, head-turning, and tail wagging was recorded during the hand-mating procedure. Additionally, the sexual behaviors exhibited by the ram were documented. Furthermore, an investigation was conducted to ascertain whether an interaction occurred within the first minute. The intervals, sexual interaction rate of the ewe, total frequency of sexual interaction, time per sexual interaction, and total sexual interaction time were observed. Blood samples were collected regularly on the initial day, the 21st day, the 42nd day, the 63rd day, the 94th day, and the 129th day for subsequent hormone analysis. Hormonal analyses were conducted using the ELISA method on blood serum samples. The melatonin hormone concentration was observed to be higher in the treatment (MT) group than in the control (C) group on the 63rd day (P=0.0476). The sexual interaction rate of the MT group was found to increase significantly in comparison to the C group (P=0.0045). Additionally, the gestation rate was shorter in the MT group than in the C group (P≤0.05). It can thus be concluded that the melatonin implant, when applied before the breeding season, significantly increases melatonin hormone concentrations on the 63rd day and significantly shortens the periods of gestation in Tahirova dairy sheep.

Keywords: Tahirova sheep, Melatonin, Estrogen, Progesterone, Sexual interaction rate, Gestation, Ewe age.

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*This study was summarized from the Nesrin ÖZTÜRK MSc thesis.

Öz

Koyun gibi mevsime bağlı kızgınlık gösteren hayvanlarda, mevsim dışı kuzulatma uygulamaları ve östrusların senkronizasyonu sürü yönetimi ve işletme ekonomisi açısından önem taşımaktadır. Bu çalışmada, aşım sezonu öncesi uygulanan melatonin implantının Tahirova koyunlarında melatonin, östrojen ve progesteron hormon seviyeleri ve eşeysel davranışlara etkisi belirlenmiştir. Çalışmada 1-4 yaşları arasında 60 baş Tahirova ırkı koyun ve 1-2 yaşlı 6 baş koç kullanılmıştır. 26 Haziran'da koyun (18 mg doz/koyun) ve koçların (54 mg doz/koç) yarısına melatonin implantı uygulanmıştır. Melatonin implantından 15 gün sonra koyun (530 g/koyun) ve koçların (660 g/koç) tamamına klasik yöntemle dane yemle ek yemleme (flushing) uygulaması 60 gün süreyle gerçekleştirilmiştir. 1 Ağustos'ta koç katımı ile kızgınlıkları tespit edilen koyunlar bireysel bölmelere alınarak elde aşım yöntemiyle çiftleştirmeleri gerçekleştirilmiştir. Elde aşım sırasında koyunlarda koklama, koçun skrotumuna dokunma, koçun etrafında dönme, koça dönüp bakma ve kuyruk sallama davranış sıklığı alınırken, koça ait olan eşeysel davranışlarda kaydedilmiştir. Ayrıca gözlemlerde 1 dakikalık aralıklarla etkileşimin olup olmadığı, koyunların eşeysel etkileşim oranı, toplam eşeysel etkileşim sıklığı, eşeysel etkileşim başına düşen süre ve toplam eşeysel etkileşim süresi belirlenmiştir. Çalışmada başlangıç, 21., 42., 63., 94. ve 129. günlerde kan alımı yapılmıştır. Kan serum örneklerinde Elisa yöntemi ile hormon analizleri ile yapılmıştır. Çalışmada 63. günde melatonin hormon konsantrasyonu uygulama (MT) grubunda kontrol (C) grubundan daha yüksek olmuştur ($P=0,0476$). Koyun eşeysel etkileşim oranı kontrol grubuna göre uygulama grubunda önemli ölçüde artırmıştır ($P=0,0045$). Koç katımı ile gebe kalma oranı uygulama grubunda kontrol grubundan daha kısa gerçekleşmiştir ($P\leq0,05$). Sonuçta, Tahirova süt koyunlarında aşım sezonu öncesi melatonin implantı uygulaması 63. günde melatonin hormon konsantrasyonunda önemli ölçüde artış sağlamış ve gebe kalma süresini ise önemli düzeyde kısaltmıştır.

Anahtar Kelimeler: Tahirova koyunu, Melatonin, Östrojen, Progesteron, Eşeysel etkileşim oranı, Gebe kalma, Koyun yaşı

1. Introduction

Fertility is the most sustainable income on a livestock farm. In seasonal oestrus animals such as sheep, out-off-season lambing practices and synchronization of oestrus are important in terms of herd management and farm economics. Although the use of hormone-impregnated sponges in small ruminants is common, due to difficulties in application, ear root implants that secrete melatonin hormone for 3-4 months have recently become common (Sasa et al., 2016; Öziş Altınçekiç and Koyuncu, 2017; Elhadi et al., 2022; Tölü et al., 2022). Melatonin hormone is used for out-off-season lambing. Melatonin hormone is not a hormone used for synchronization of oestrus. Melatonin synthesis, secreted from the pineal gland in the brain, is under the control of neural, hormonal, and enzymatic systems through photoperiodic interaction (Zarazaga et al., 2009). The main purpose of light management is to increase melatonin release by increasing the dark period during the circadian cycle. The use of exogenous melatonin administration is based on imitation of melatonin release over short days. It is known that melatonin levels in sheep vary depending on the time of day (Carcangiu et al., 2013). The values determined during the day are lower than those determined at night (Carcangiu et al., 2013; Sasa et al., 2016). However, an increase in melatonin hormone levels can be observed during the daytime with the effect of the melatonin implant (Lincoln and Ebling, 1985; Sasa et al., 2016; Elhadi et al., 2022). Kisspeptin neurons appear to play a fundamental role in determining reproductive status, as anoestrus is characterized by increased negative feedback from estrogen on GnRH secretion. Kisspeptin cells provide direct synaptic input to GnRH cells, and kisspeptin is a potent stimulator of GnRH secretion (Clarke et al., 2009). It has been determined that melatonin implant in sheep has a positive effect on oestrus period, pregnancy, birth, and offspring productivity (Tölü et al., 2022).

The oestrous cycle in sheep is approximately 16-17 days. The oestrous cycle consists of proestrus, oestrus, metestrus, and diestrus periods and the anoestrus period outside the breeding season. In sheep, the corpus luteum begins to secrete progesterone on the 2nd and 3rd day of the cycle. Progesterone hormone secretion reaches its highest level on the 8th day and continues at this level until the 12th and 14th day. If there is no pregnancy, $PGF2_{\alpha}$ secreted from the uterus regresses the corpus luteum. Progesterone concentration begins to increase from the third day of this period and reaches its peak level on the 8th day. Progesterone concentration, which remains at its peak level until approximately the 11th day, decreases rapidly after this day and decreases again to <1 ng/mL in the last two days of dioestrus (Kalkan and Horoz, 1997).

The changes observed in domestic sheep breeds mating in short photoperiods in terms of gonadal function and the seasonal release of the hormones that control it (GnRH, FSH, and LH) show gender dependency and the direct effect of lighting is lower in males than in females. While sexual activity in females usually stops during long days, it can continue throughout the year in males. In Hu sheep that received subcutaneous injections of melatonin 5 and 10 mg/sheep during the oestrus period, higher levels of melatonin and progesterone hormones were determined in the application groups compared to the control group (Song et al., 2019). Koca and Özbeyaz (2019) reported that estrogen levels varied between 38.66-97.57 pg/mL during the test days, low progesterone levels were necessary to increase ovulation rates, and low oestrus levels and low progesterone levels were necessary to increase the number of lambs. Tahirova sheep genotype, which is crossbred between East Friesian and Kıvırcık sheep, is an important genotype for Türkiye dairy sheep breeding. Tahirova genotype lambs once a year, have a lactation period of 7-8 months and an average lamb yield of 1.6-1.8 lambs per ewe (Sönmez et al., 2009; Tölü et al., 2022). Determining the effect of melatonin application on the reproductive hormone profile of female animals of Tahirova sheep and its relationship with breeding behavior is important in terms of obtaining offspring out of season. In this study, the effect of melatonin implants applied before the breeding season on melatonin, estrogen, and progesterone hormone levels and sexual behavior in Tahirova sheep was investigated.

2. Materials and Methods

The study was conducted at Çanakkale Onsekiz Mart University Faculty of Agriculture Farm Animal Production Application and Research Unit. The unit is in the center of Çanakkale (40°07'41.9"N 26°26'19.3"E).

2.1. Animals and management

In the study, 30 females of melatonin treatment (MT) and 30 females of control (C) group Tahirova sheep were used, which received melatonin implants (18 mg 1 pellet) on June 26. In addition, hand-mating behavior data of 6 rams (3 heads with melatonin treatment, 3 pellets; and 3 heads with control) were also used in the study. Melatonin

subcutaneous implants were applied to the back of the ear. The study was conducted on two groups (MT and C). Ewes were distributed to the groups randomly, considering age, lactation order, milk yield, live weight, and body condition score. While the ages of ewes varied between 1-4 years, the ages of rams varied between 1-2 years. In the MT group, 11 ewes were 4 years old, 8 ewes were 2, 3 and 1 years old, while in the C group, 11 ewes were 4 years old, 7 ewes were 3 years old, 8 ewes were 2 years old, and 9 ewes were 1 year old. Rams with and without melatonin implants were homogeneously distributed and mated according to the MT and C groups of the females.

The ewes included in the experiment were in the 5th month of lactation. Milk yield was 552 mL/day in the MT group and 556 mL/day in the C group, average live weight was 54 kg and average body condition score was 2.70 in both groups. Milking was done in a 2 x 12 automatic parallel milking unit between 7:30-9:00 in the morning and 16:30-18:00 in the evening. Fifteen days after the melatonin implant, supplementary feeding (flushing) of ewes and rams with whole grain feed was carried out for 60 days. The ewes were fed at a level of 1.6 times the living energy need, and rams were fed at a level of 1.2 times the living energy need during the mating period (NRC, 2007). Alfalfa hay (90.32% DM, 18.48% HP), oat straw (92.37% DM, 9.78% HP), and corn silage (90.64% DM, 10.16% HP) concentrated feed in pellet form (90.53% DM, 18.36% HP) was used in the nutrition of ewes and rams. Ewes were given 530 g/ram barley during evening milking, and 660 g/ewe grain barley (90.35% DM, 10.67% HP) was given to the rams in group conditions. The ewes and rams were housed under open shelter conditions in different paddocks with trees providing shade during the daytime.

2.2. Hormone analyses

Blood serum from day 0 before the melatonin implant, and day 21, day 42, day 63, day 94, and day 129 after the melatonin implant was used. The commercial melatonin implant product (Regulin®) contains 18 mg of melatonin hormone and is stated to release melatonin hormone for 3-4 months. In the study, which introduced the aproned ram 36 days after the melatonin implant, hormone levels were determined for a total of 6 periods before the application and for 4 months. The blood samples taken were centrifuged at 3500 rpm for 10 min. and the serum was separated from the blood cells. Blood serums were stored in a deep freezer at -20 ºC until hormone analysis was performed. Hormone analyses were performed by the Enzyme-linked immunosorbent assay (ELISA) method at the department of Animal Science Laboratory of Çanakkale Onsekiz Mart University, Thermo Scientific Multiskan FC Microplate Reader was used in the analyses. Hormone analyses of melatonin (MEL), estrogen (ES), and progesterone (Pg) were performed with sheep-specific commercial hormone kits. The kit (Shanghai Sunred Biological Technology Co.) uses a double-antibody sandwich enzyme-linked immunosorbent assay.

2.3. Mating observation and measurement

In the study, ewes mating took place between the 38th and 74th days after the melatonin implant. Ewes, whose oestrus was detected with aproned rams in the morning and evening hours, were mated homogeneously with rams with and without melatonin implant by hand-mating method (*Figure 1*). Ewes who were detected to be in heat were mated with the assigned ram 8-12 hours later (Tölü and Savaş, 2010). The oestrus search was done with the rams used for mating. However, the rams that were going to mate were not used in the oestrus search during that period. Gestation rates were determined from lambing status at birth. The mating behavior dataset of each ewe was obtained from direct observation and camera recordings. The protocol for testing sexual behavior was carried out in an area separated by iron bars 3 m wide and 4 m long. For direct observations, one observer counted the behaviors and the other recorded them. The behaviors of ewes sniffing (SNF), touching of ram's scrotum (TSC), turning the ram (TR), looking back at the ram (LBR), and tail wagging (TW) were recorded during mating (Tölü and Savaş, 2010; Konyalı et al., 2011). The ram courtship index was calculated from the sum of the frequency of ano-genital sniffing, foreleg kicks, tongue flicks, vocalizations, and lateral approaches (Tölü et al., 2024). Bilateral sexual interaction rate (BSIR) and ewe sexual interaction rate (ESIR) were determined at 1-min. intervals during the 10-min mating period. Total sexual interaction frequency (TSIF), times per sexual interaction (PSI), and total sexual interaction time (TSIT) were determined from camera recordings. Behavioral observations in camera recordings were made by the same person via computer.

Figure 1. Ewes and rams in group C (left; behavior of touching of ram's scrotum) and group MT (right; behavior of head-turning to ram) during hand-mating in Tahirova sheep

2.4. Statistical Analyses

Repeated measures analysis of variance was used to analyze reproductive hormone concentrations. Logarithmic transformation was applied to hormone values before statistical analysis. Group (MT, C), ewe age (1,…4), and group x age interaction were fixed factors, and the hormone value of the individual per experiment was included in the model as a covariate. While the analysis of mating behaviors was performed with the same model (for fixed factors), the ram courtship index (ano-genital sniffing + foreleg kicks + tongue flicks + vocalizations + lateral approaches) was included in the model as a covariate. A square root ($\sqrt{y+10}$) transformation was applied to each of the behaviors. In the analysis of BSIR, ESIR, TSIF, PSI, and TSIT properties measured in hand-mating observations (no transformation was applied), group (MT, C), sheep age (1,…4), group x age interaction were included with fixed factors in the model. In the analysis of the gestation rate and gestation length analyzed on the hormone measurement days, group (MT, C), ewe age (1,…4), group x ewe age interaction were fixed factors, and the body condition score of the ewe at mating was included as covariates. Tukey test was used in post hoc analyses. The animal was included as random effect in all statistical models. All analyses were performed using the SAS (2021) statistical package program.

3. Results

3.1. Hormone analyses

Melatonin (MEL) hormone concentrations of Tahirova sheep, determined according to the group and ewe ages according to the days of melatonin implant, showed significant differences between the groups on the 63rd day after the implant (*Table 1*). The hormone level of the MT group was higher than that of the C group on the 63rd day after implant (P≤0.05). MEL concentrations at the initial, 21st, and 94th days differed significantly according to their ewe age (P≤0.05). The 4-year-old ewe differed significantly from other ewe ages with its low melatonin value in the initial measurement. In the measurement made on the 21st day, 1- and 2-year-old ewes are lower than 3- and 4-year-old ewes. On the 94th day, 1 and 2-year-old ewes and 3- and 4-year-old ewes had higher values (P≤0.05).

The highest MEL level occurred on the 129th day after the implant, while the lowest level occurred on the 42nd day in the MT group (*Figure 2*). The MEL level was high at the beginning and on the 129th day, while it was at the lowest levels on the 21st day and 42nd day in group C.

Estrogen (ES) concentrations were at similar levels across groups (*Table 2*). Estrogen concentrations differed significantly on the 42nd day and the 94th day according to ewe age (P≤0.05). 1 and 2-year-old ewes had lower ES concentrations in the measurements made on the 42nd day and 3- and 4-year-old ewes ES concentrations were higher on the 94th day (P≤0.05).

After the melatonin hormone implant, ES hormone concentrations in groups MT and C were highest on the 63rd day and lowest on the 129th day (*Figure 3*). In the MT group, the values on the 94th day and the 129th day were similar.

Table 1. Least squares mean ± standard error and P values* of MEL hormone concentrations (ng/L) on melatonin implant days in Tahirova sheep according to group (C, MT) and ewe ages

Melatonin, ng/L		Initial	21st day	42nd day	63rd day	94th day	129th day
Group (G)	C	228.5±25.56	136.0±23.84	104.4±23.34	139.9±27.67^{x}	189.5±34.96	258.4±34.01
	MT	196.1±18.55	134.3±21.89	158.6±35.44	172.5±33.65^{y}	154.3±18.88	211.8±28.14
	P	0.7534	0.1119	0.1132	0.0476	0.4337	0.7847
Ewe age (A)	1	224.1±33.95^{a}	64.7±18.59^{a}	147.9±59.22	210.4±51.05	211.8±47.13^{a}	270.6±53.70
	2	215.3±24.16^{a}	70.8±25.30^{a}	89.7±30.90	123.3±26.87	201.5±30.51^{a}	213.8±26.85
	3	267.5±38.02^{a}	215.7±34.99^{b}	151.2±48.60	181.9±44.01	163.2±42.57^{b}	265.7±46.73
	4	145.2±19.35^{b}	163.1±22.28^{b}	137.9±37.55	100.9±40.29	116.7±28.58^{b}	179.8±41.36
	P	0.0305	<0.0001	0.2865	0.5967	0.0093	0.9502
G x A	P	0.1214	0.8405	0.3370	0.0539	0.0067	0.7917
Initial	P	-	<0.0001	<0.0001	<0.0001	<0.0001	0.0001

*Statistical analyses were performed on transformed (log n+30) values. The difference between the means shown with different letters within each group (x-y) and ewe age (a-b) in the same column is statistically significant (P≤0.05).

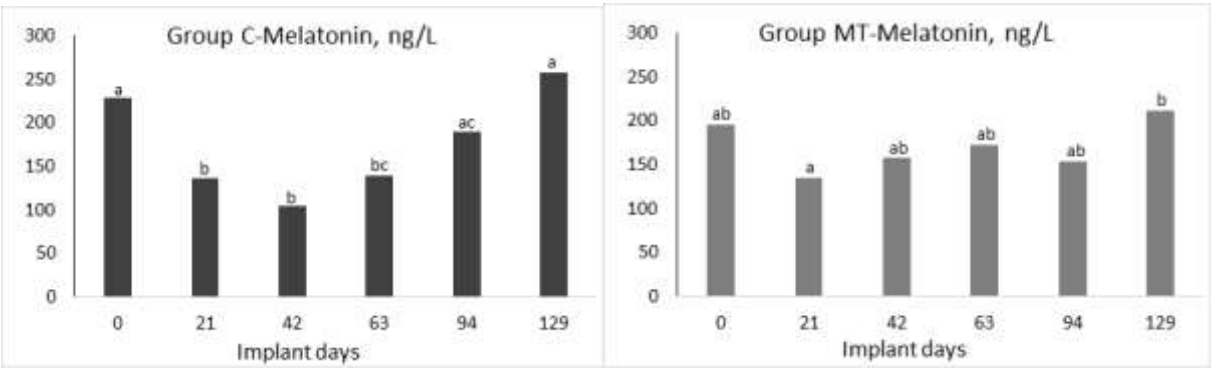

Figure 2. Means of MEL hormone concentrations (ng/L) on melatonin implant days and significance levels between days in Tahirova sheep according to groups (C, MT), (The difference between the means shown with different letters within each group is statistically significant, P≤0.05)

Table 2. Least squares mean ± standard error and P values of ES hormone concentrations (pg/L) on melatonin implant days in Tahirova sheep according to group (C, MT) and ewe ages

Estrogen, pg/L		Initial	21st day	42nd day	63rd day	94th day	129th day
Group (G)	C	12.3±2.50	12.3±1.96	17.1±2.27	24.1±2.09	14.4±2.80	9.5±1.05
	MT	14.7±3.12	15.5±2.55	16.4±2.11	22.5±1.50	11.5±1.49	8.4±1.04
	P	0.1741	0.0835	0.1728	0.9719	0.9335	0.5331
Ewe age (A)	1	17.1±4.92	13.9±4.06	11.5±2.11^{a}	24.8±2.53	17.3±3.11^{a}	10.6±2.06
	2	9.2±2.16	12.7±2.78	11.2±2.72^{a}	23.8±1.82	15.5±2.49^{a}	7.8±0.85
	3	16.2±4.09	16.0±4.00	25.7±2.92^{b}	26.2±3.06	12.0±3.70^{b}	9.4±1.31
	4	10.4±3.64	13.0±2.52	16.7±2.66^{b}	18.5±2.33	7.6±2.16^{b}	7.6±1.45
	P	0.9565	0.1839	<0.0001	0.0660	0.0011	0.9974
G x A	P	0.0520	0.1675	0.3221	0.0982	0.3174	0.4907
Initial	P	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Statistical analyses were performed on transformed (log n+5) values. The difference between the means shown with different letters within and ewe age (a-b) in the same column is statistically significant (P≤0.05).

Progesterone (Pg) hormone concentrations in Tahirova sheep were at similar levels according to groups as in ES hormone (*Table 3*). Pg levels on the 42nd day and 63rd day were slightly higher in the MT group than in the C group (P≤0.10). Pg hormone levels on the 21st day and the 129th day differed according to the age of ewe (P≤0.05). While 1 and 2-year-old ewe had lower values than 3- and 4-year-old ewe in the measurements made on the 21st day, 4-year-old ewe differed from other ewe age groups with its lower values on the 129th day (P≤0.05).

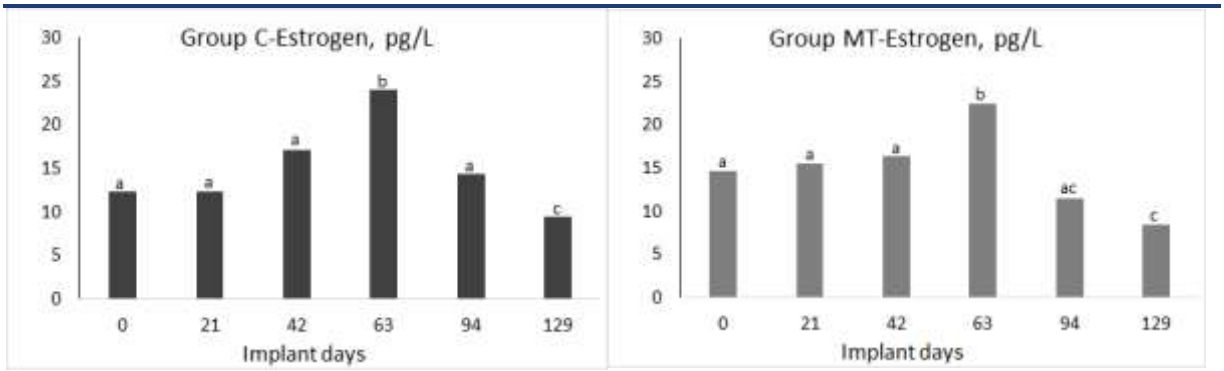

Figure 3. Means of ES hormone concentrations (pg/L) on melatonin hormone implant days and significance levels between days in Tahirova sheep according to groups (C, MT), (The difference between the means shown with different letters within each group is statistically significant, P≤0.05)

Tablo 3. Least squares mean ± standard error and P values* of Pg hormone concentrations (ng/mL) on melatonin implant days in Tahirova sheep according to group (C, MT) and ewe ages

Progesterone, ng/mL		Initial	21st day	42nd day	63rd day	94th day	129th day
Group (G)	C	2.4±0.51	3.8±0.59	3.9±0.46	5.0±0.53	5.0±0.43	5.4±0.41
	MT	2.2±0.51	2.9±0.39	4.2±0.53	5.4±0.61	4.7±0.44	4.7±0.35
	P	0.3297	0.5615	0.0814	0.0715	0.3945	0.2966
Ewe age (A)	1	3.4±0.97	2.3±0.89[a]	4.6±0.88	5.6±1.01	4.3±0.35	5.5±0.50[a]
	2	1.6±0.39	2.6±0.45[a]	4.7±0.52	5.2±0.44	4.5±0.46	5.3±0.43[a]
	3	2.6±0.75	4.7±0.76[b]	5.4±0.70	5.9±0.69	5.9±0.72	5.7±0.66[a]
	4	1.5±0.54	3.3±0.45[b]	2.7±0.53	4.0±0.86	4.5±0.67	3.8±0.45[b]
	P	0.5381	<0.0001	0.0691	0.6923	0.0613	0.0393
G x A	P	0.6352	0.9483	0.5547	0.1887	0.3288	0.0571
Initial	P	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

*Statistical analyses were performed on transformed (log n+3) values. The difference between the means shown with different letters within each group and ewe age (a-b) in the same column is statistically significant (P≤0.05).

The means of Pg hormone concentrations on melatonin implant days and significance levels between days in Tahirova sheep by groups are shown in *Figure 4*. Pg hormone concentrations in the groups followed an increasing course as the days progressed. While Pg levels differ between the initial day (0 days), the 21st day, and the 42nd, 63rd, 94th, and 129th day, the values between the other days were similar in the MT group. While the initial Pg hormone concentration in group C differed significantly from the other days with its low value, there was a significant difference between the values on the 129th day and the values on the 21st and 42nd days (P≤0.05).

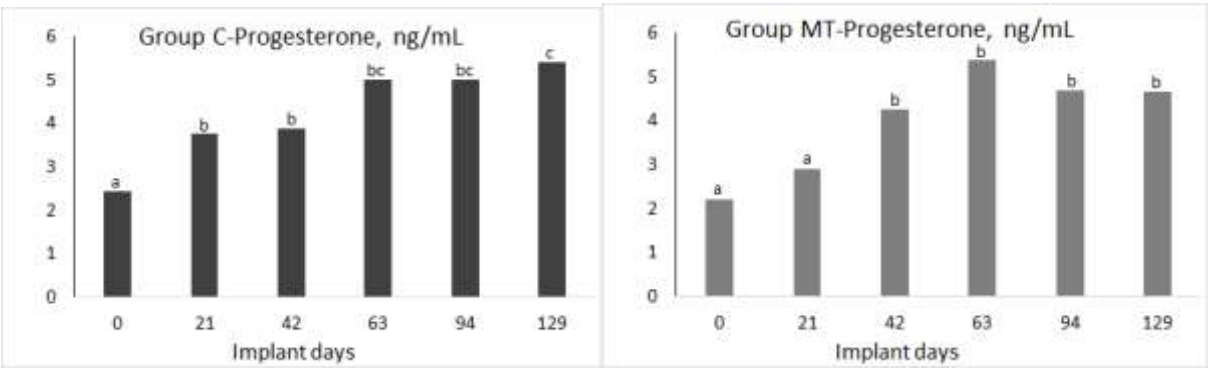

Figure 4. Means of Pg hormone concentrations (ng/mL) on melatonin implant days and significance levels between days in Tahirova sheep according to groups (C, MT), (The difference between the means shown with different letters within each group is statistically significant, P≤0.05)

3.2. Mating observation and measurement

The sexual behaviors obtained in the ewe in the MT and C groups during the hand-mating observations that took place for 10 min. in the study are presented in *Table 4*. Sexual behaviors were similar according to group and ewe age (P>0.05). The behaviors of ewes sniffing (SNF), touching of ram's scrotum (TSC), and tail wagging (TW) behaviors were numerically slightly higher in the MT group. Turn of the ram (TR) and head-turning (HT) behaviors were slightly higher in the control group. Similarly, 1-year-old ewe had slightly higher behavioral frequencies other than TR behavior (P>0.05). It is noteworthy that a lower frequency of TR behavior in 3- and 4-year-old ewes than in 1- and 2-year-old ewes (P>0.05). The ram courtship index (RCI) value, which is included as a covariate in the model, did not have a significant effect on the behaviors considered (P>0.05).

Table 4. Mean ± standard error and P values* of sexual behavior during hand-mating on melatonin implant days in Tahirova sheep according to group (C, MT) and ewe ages

Behavior, times / ewe /10 min.		SNF	TSC	TR	HT	TW
Group (G)	C	2.6±0.56	5.0±0.64	1.4±0.80	7.6±1.15	36.4±5.14
	MT	2.9±0.58	5.7±0.88	0.9±0.31	7.5±1.13	41.8±5.27
	P	0.7912	0.4912	0.4393	0.8268	0.4328
Ewe age (A)	1	3.4±0.94	7.3±1.43	2.0±0.61	5.5±1.18	42.1±7.06
	2	2.9±0.83	5.4±0.63	2.25±1.73	5.3±1.20	41.8±9.32
	3	2.9±0.98	5.1±1.15	0.5±0.40	9.1±2.05	41.3±6.82
	4	2.0±0.56	4.1±0.87	0.3±0.09	9.7±1.65	33.4±5.86
	P	0.7564	0.4074	0.2824	0.3301	0.8446
G x A	P	0.2894	0.3938	0.2868	0.6675	0.9968
RCI	P	0.3868	0.9919	0.5158	0.3974	0.5935

SNF: Sniffing, TSC: Touching of ram's scrotum, TR: Turn of ram, HT: Head-turning, TW: Tail wagging; RCI (ram courtship index): Ano-genital sniffing + foreleg kicks + tongue flicks + vocalizations + lateral approaches. *Square Root (√y+10) transformation was applied to the data.

In the hand-mating observations made for 10 min. in Tahirova sheep, ewe sexual interaction rate (ESIR) differed significantly (P = 0.0045) according to the groups, while other measurements were similar according to the groups (*Table 5*). Ewes in the MT group had a higher rate of ESIR than ewes in the control group (P≤0.05). While total sexual interaction frequency (TSIF) and times per sexual interaction (PSI) differed significantly according to ewe ages, other observations were similar according to ewe ages. While TSIF differed from 3- and 4-year-old ewe with its lower frequency in 2-year-old ewe, a significant difference was observed in PSI between 1- and 4-year-old ewe (P≤0.05).

Table 5. Mean ± standard error and P values of mating measurements during hand-mating on melatonin implant days in Tahirova sheep according to group (C, MT) and ewe ages

Behavior, ewe /10 min.		BSIR, %	ESIR, %	TSIF, times	PSI, sec.	TSIT, min.
Group (G)	C	90.2±2.89	30.5±3.15^{x}	12.6±0.70	25.8±1.50	5.3±0.32
	MT	87.4±3.10	44.2±3.38^{y}	13.1±0.75	27.2±1.61	5.7±0.34
	P	0.5139	0.0045	0.6123	0.5070	0.3080
Ewe age (A)	1	88.9±4.12	35.3±4.49	11.9±1.00^{ab}	30.9±2.14^{a}	6.1±0.46
	2	84.6±4.58	35.8±4.99	10.8±1.12^{a}	28.8±2.37^{ab}	5.3±0.51
	3	94.6±4.58	38.3±4.99	15.0±1.12^{b}	24.0±2.37^{bc}	5.9±0.51
	4	87.3±3.62	40.0±3.94	13.8±0.88^{b}	22.4±1.87^{c}	4.8±0.40
	P	0.4621	0.8564	0.0374	0.0165	0.1901
G x A	P	0.7876	0.1389	0.9823	0.4100	0.4262

BSIR: Bilateral sexual interaction rate, ESIR: Ewe sexual interaction rate, TSIF: Total sexual interaction frequency, PSI: Times per sexual interaction, TSIT: Total sexual interaction time. The difference between the means shown with different letters within each group (x-y) and ewe age (a-c) and ewe age in the same column is statistically significant (P≤0.05).

While no pregnancy was observed in group C on the 42nd day after the implant, pregnancy was observed in 1 ewe in the MT group. On the 63rd day after the implant, an average pregnancy rate of 65.38% and an average

gestation period of 6.00 days were determined in the C group, and an 88.00% pregnancy rate and an average gestation period of 10.72 days were determined in the MT group (P≤0.05; Data not shown).

4. Discussion

In Tahirova sheep that received a melatonin implant before the breeding season, it was determined that the melatonin implant significantly increased the MEL hormone concentration on the 63rd day (*Table 1*). At 63 days post-implant, 172.5±33.65 ng/L MEL hormone concentration was determined in the MT group, while 139.9±27.67 ng/L MEL hormone concentration was determined in the C group. The MEL hormone level, which decreased to the lowest levels in the C group on the 42nd day, remained at similar values in the MT group (*Figure 2*). Group C started to increase on the 63rd day after the introduction of ram on the 36th day. In a study conducted with different sheep breeds, higher levels of melatonin hormone were determined in the application group than in the control group in measurements made on the 43rd day after the implant (Sasa et al., 2016). Elhadi et al. (2022) determined that melatonin implants in early lactation Lacaune and Manchega sheep increased the melatonin hormone concentration in both breeds. In the study in which subcutaneous melatonin injections of 0, 5, and 10 mg/ewe were applied to Hu sheep during the oestrus period; Melatonin hormone level was reported as 458.69 ± 48.40 pg/mL in ewe administered 5 mg melatonin, 458.09 ± 60.60 pg/mL in ewe administered 10 mg, and 393.37 ± 51.53 pg/mL in the control group (Song et al., 2019).

It is known that melatonin, whose daily release increases as the days shorten, stimulates GnRH release in sheep showing seasonal oestrus (Lincoln and Clarke, 1997; Casao et al., 2008). With the increase in GnRH secretion, gonads are stimulated, and oestrus develops in animals. In this study, ewes with melatonin implants came into oestrus in a shorter time and became pregnant earlier than ewes without melatonin implants. This situation seems to occur in the MT group with the effect of the MEL hormone. It is stated that the MEL hormone is used to reduce heat in sheep out of season or to an early period and that it also has a positive effect on embryo development (Tamarkin et al., 1985; Çevik and Yurdaydın, 1998). In the present study, the melatonin hormone, which varies depending on the age of the ewe, differed from each other in 1- and 2-year-olds and 3- and 4-year-olds, although it changed from day to day. Carcangiu et al. (2013) determined that the melatonin level, which varies significantly depending on the age of the ewe, is lower in 3–4-year-old ewes than in 16–18-month-old ewes. Significant interactions between group and age were observed for MEL concentration at days 63 and 94, respectively (*Table 1*). The MEL trends of the groups were different on different days (*Figure 1*). The age of the ewe seemed to affect MEL hormone levels on days 63rd and 94th.

While no significant change in the ES hormone was observed in the study in the days after the melatonin implant, the ES level on the 63rd day was significantly higher than the other days in both groups (*Table 2*; *Figure 3*). In Awassi sheep, higher estrogen hormone levels were determined in the melatonin-implanted group than in the control group (Al-Tai et al., 2021). The estrogen hormone was between 3.50 and 8.42 pg/mL, and the lowest estrogen level was measured on the 15th day in the measurements made between 0 and 18 days in Akkaraman sheep (Arsoy and Sağmanlıgil, 2018). The fact that ES values on the 63rd day of the study were determined to be higher than the other days may be since the ewes' oestrus periods and pregnancy periods occur within this date range. So, estrogen hormone levels in sheep can reach their highest levels during the oestrus period (Hafez, 1993; Goodman and Inskeep, 2015).

While Pg concentrations were similar between groups in the study, the MT group had slightly higher Pg concentrations than group C on the 42nd and 63rd days (*Table 3*). In addition, while the Pg level tended to increase continuously until the 42nd day, it continued at similar values within the group after today (*Figure 4*). It can be said that progesterone concentrations were slightly high in the study in which there was no pregnancy until the 63rd day (except for 1 pregnant ewe on the 42nd day in the MT group). In sheep, it was determined as 0.17 ng/mL during oestrus, 6.50 ng/mL in dioestrus, 0.04 ng/mL in anoestrus, 7.32 ng/mL in early pregnancy, and 11.34 ng/mL in mid-term pregnancy (Alaçam, 2007). Uyanık et al. (2009) determined a progesterone level of 2.02 ng/mL before pregnancy in Morkaraman breed sheep, and they determined a progesterone level between 2.41 ng/mL and 15.92 ng/mL, increasing every week between the 5th and 21st weeks, respectively. In the study, Pg hormone levels were above 2 ng/mL even on the days when mating had not yet started. This situation suggests the possibility that some ewes in Tahirova sheep are in an oestrus cycle. It can be said that out-of-season oestrus monitoring and oestrus

synchronization studies are needed to clarify this situation in the Tahirova sheep genotype obtained by the crossbred method.

In the present study, Pg hormone levels may have been higher in the MT group because the ewes in the MT group came into oestrus and became pregnant in a shorter time than the ewes in the C group. Studies have shown that melatonin implantation can affect pregnancy status when rams are introduced. Therefore, the conception and oestrus of the animals can affect the levels of progesterone hormone. In the measurements made on the 7th and 20th day after melatonin implantation (18 mg/ewe), it was found that the progesterone hormone administration group was higher than the control group in Kıvırcık sheep (Yılmazer et al., 2018). In Border Leicester x Scottish Blackface sheep, it was reported that melatonin-implanted sheep had slightly higher progesterone hormone levels than the control group, and the difference between groups was significant when measured at the 8th week of pregnancy (McEvoy et al., 1998). In Rasa Aragonesa sheep, on the 5th and 8th days after the 18 mg melatonin implant, significantly higher progesterone hormone levels were measured in the treatment group than in the control group sheep (Abecia et al., 2006).

The frequencies of behaviors were similar between groups in hand-mating observations made for 10 min. in Tahirova sheep. However, the ewe sexual interaction rate (ESIR) was higher in the MT group than in the C group (*Tables 4*, *5*). Total sexual interaction frequency (TSIF) and time per sexual interaction (PSI) differed significantly according to ewe age (*Table 5*). In the study, it can be said that the melatonin implant causes an increase in reproductive hormones as well as an increase in the frequency of mating behavior. Studies examining the effects of exogenous melatonin applications on sexual behavior were examined on rams rather than ewes (Rekik et al., 2015; Abecia et al., 2018; Kleemann et al., 2021; Tölü et al., 2024). No study has been found examining the effect of exogenous melatonin application on sexual behavior in females. It can be said that the melatonin implant, which has been found to contribute positively to the increase in sexual activity in male sheep, also increases sexual activity in female sheep in a similar way.

5. Conclusions

Ear subcutaneous melatonin implant application, which is applied just before the breeding season and is expected to increase hormone secretion to higher levels during the breeding season; It significantly increased the melatonin hormone level in Tahirova sheep, especially within the expected date ranges (for 3-4 months). Melatonin implant, which causes an increase in reproductive hormones in ewes during mating intervals, also causes sexual behaviors to occur at a slightly higher frequency and rate during mating. In other words, the melatonin implant seems to increase sexual activity in ewes. So, ewes in the melatonin treatment group had a significantly higher rate of sexual interaction than ewes without melatonin implant treatment.

Melatonin implant applied just before the breeding season (June) increased sexual activity and resulted in oestrus and pregnancy in ewes in the treatment group in a shorter time than in the control group. However, it would be more useful to test the melatonin implant used to provide off-season oestrus in Tahirova sheep in different seasons other than the breeding season.

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Ethical Statement

All animal handling and experimental procedures were performed by the Committee on Animal Research and Ethics of Çanakkale Onsekiz Mart University (Turkey) on animal use (no. 2018/05-11).

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Cemil, T.; Design: Nesrin, Ö., Cemil, T.; Data Collection or Processing: Nesrin, Ö., Cemil, T.; Statistical Analyses: Cemil, T.; Literature Search Nesrin, Ö., Cemil, T.; Writing, Review and Editing: Nesrin, Ö., Cemil, T.

References

Abecia, J. A., Araya J., Chemineau, P., Palacios, C., Keller, M. and Delgadillo, J. A. (2018). Photoperiod-melatonin-induced, sexually-activated rams increase pregnancy rate and number of lambs per ewe in a ram effect. *Large Animal Review,* 24: 31-35.

Abecia, J. A., Palacin, I., Forcada, F. and Valares, J. A. (2006). The effect of melatonin treatment on the ovarian response of ewes to the ram effect. *Domestic Animal Endocrinology,* 31: 52-62.

Alaçam, E. (2007). *Production of a radioimmunoassay kit for blood progesterone hormone measurements in cows, sheep and dogs and its use in various physio-pathological cases.* Ankara Üniversitesi Bilimsel Araştırma Projesi (2005-08-10-070) Project Report, Ankara (In Turkish).

Al-Tai, S. N. N., Alkalby, J. M. A. and Al-Shwilly, H. A. J. (2021). Profile Of reproductive hormones secretion during estrus and pregnancy associated with different estrus synchronization methods in Awassi ewes in non-breeding season. *Natural Volatiles & Essential Oils,* 8(6): 1934-1947.

Arsoy, D. and Sağmanlıgil, V. (2018). Reproductive cycles in white Karaman ewes: comparison of ovarian hormone secretion and reproductive behavior in non-pregnant and pregnant ewes in semi-intensive conditions. *Acta Scientiarum. Animal Sciences,* 40: e39908.

Carcangiu, V., Mura, M.C., Parmeggiani, A., Piccione, G., Bini, P. P., Cosso, G. and Luridina, S. (2013). Daily rhythm of blood melatonin concentrations in sheep of different ages. *Biological Rhythm Research,* 44(6): 908-915.

Casao, A., Vega, S., Palacin, I., Perez-Pe, R., Lavina, A., Quintin, F. J., Sevilla, E., Abecia, J. A., Cebrian-Perez, J. A., Forcada, F. and Muino-Blanco, T. (2008). Effects of melatonin implants during non-breeding season on sperm motility and reproductive parameters in Rasa Aragonesa Rams. *Reproduction in Domestic Animals,* 45: 425-432. https://doi.org/10.1111/j.1439-0531.2008.01215.x

Clarke, I. J., Smith, J. T., Caraty, A., Goodman, R. L. and Lehman, M. N. (2009). Kisspeptin and seasonality in sheep. *Peptides,* 30(1):154-63. https://doi.org/10.1016/j.peptides.2008.08.022

Çevik, M. and Yurdaydın, N. (1998). Effect of photoperiodism on fertility in domestic animals. *Lalahan Hayvancılık Araştırma Enstitüsü. Dergisi,* 38(1): 69-78. (In Turkish).

Elhadi, A., Salama, A. A. K., Such, X. and Caja, G. (2022). Responses to melatonin of 2 breeds of dairy ewes in early lactation under autumn photoperiod conditions. *Journal of Dairy Science,* 105: 2587-2596.

Goodman, R. L. and Inskeep, E. K. (2015). Control of the Ovarian Cycle of the Sheep. In: Knobil and Neill's Physiology of Reproduction 4th Edition Volume 2. Eds: Plant T. M. and Zelenik, A. J., Elsevier, London, U.K.

Hafez, E. S. E. (1993). Reproduction in Farm Animals. 6th Edition. Lea & Feibeger., Philadelphia, USA.

Kalkan, C. and Horoz, H. (1997). Pubertal and Sexual Cycles. In: Parturition and Infertility In Domestic Animals. Eds: Alaçam, E., Medisan, Ankara, Türkiye. (In Turkish).

Kleemann, D. O., Kelly, J. M., Arney, L. J., Len, J., Tilbrook, A. J. and Walker, S. K. (2021). Sexual behaviour, semen quality and fertility of young Border Leicester rams administered melatonin during spring. *Animal Reproduction Science,* 231: 106804 https://doi.org/10.1016/j.anireprosci.2021.106804

Koca, A. and Özbeyaz, C. (2019). The effects of progesterone and estrogen hormone levels on some reproductive characteristics of the Akkaraman sheep. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi,* 22(Suppl 2): 424-430.

Konyalı, A., Tölü, C., Ayağ, B. S. and Akbağ, H. I. (2011). Observations on hand-mating behaviors, several physiological and hematological parameters in Turkish dairy goats. *Animal Science Journal,* 82: 251-258.

Lincoln, G. A. and Clarke, I. J. (1997). Refractoriness to a static melatonin signal develops in the pituitary gland for the control of prolactin secretion in the ram. *Biology of Reproduction,* 57: 460-467.

Lincoln, G. A. and Ebling, F. J. P. (1985). Effect of constant-release implants of melatonin on seasonal cycles in reproduction, prolactin secretion and moulting in rams. *Journal of Reproduction & Fertility,* 73: 241-253.

McEvoy, T. G., Robinson, J. J., Aitken, R. P. and Robertson, I. S. (1998). Melatonin treatment of embryo donor and recipient ewes during anestrus affects their endocrine status, but not ovulation rate, embryo survival. *Theriogenoiogy,* 49: 943-955.

NRC (2007). Nutrient Requirements of Small Ruminants, National Research Council of the National Academies, Washington, DC., U.S.A.

Rekik, M., Taboubi, R., Ben Salem, I., Fehri, Y., Sakly, C., Lassoued, N. and Hilali M. E. (2015). Melatonin administration enhances the reproductive capacity of young rams under a southern Mediterranean environment. *Animal Science Journal,* 86: 666-672. https://doi.org/10.1111/asj.12350

Öziş Altınçekiç, Ş. and Koyuncu, M. (2017). Comparison of effects of CIDR and prostaglandin applications on the reproductive performance of Kıvırcık ewes in anestrous. *Journal of Tekirdag Agricultural Faculty,* 14(01): 9-15 (In Turkish).

SAS (2021). Statistical Analysis System, SAS/STAT® 9.3 User's Guide. Cary, NC.

Sasa, A., Rodrigues, P. A., Nonaka, K. O., Balieiro, J. C. de C. and Coelho, L. A. (2016). Plasma melatonin and progesterone profiles of Suffolk and Romney Marsh ewes implanted with melatonin during anoestrus season at lower latitudes in Southern Hemisphere. *Acta Scientiae Veterinariae,* 44(1): 1378.

Song, Y., Wu, H., Wang, X., Haire, A., Zhang, X., Zhang, J., Wu, Y., Lian, Z., Fu, J., Liu, G. and Wusiman, A. (2019). Melatonin improves the efficiency of super-ovulation and timed artificial insemination in sheep. *Peer J,* 7: e6750. https://doi.org/10.7717/peerj.6750

Sönmez, R., Kaymakçı, M., Eliçin, A., Tuncel, E., Wassmuth, R. and Taşkın, T. (2009). Sheep breeding studies in Turkey. *Türkiye Koyunculuk Kongresi,* 12-13 February, p. 7-24, İzmir, Türkiye (In Turkish).

Tamarkin, L., Baird, C. J. and Almedia, O. F. (1985). Melatonin: A coordinating signal for mammalian reproduction? *Science,* 227: 714-720.

Tölü, C. and Savaş, T. (2010). Comparison of Gökçeada, Maltese and Turkish Saanen goat genotypes for reproduction traits. Journal of *Tekirdağ Agricultural Faculty,* 7(2): 113-121 (In Turkish).

Tölü, C., Yazgan, N., Akbağ, H. I. and Savaş, T. (2024). Effects of melatonin implant on hormone profile and mating behaviour in rams. *Hayvansal Üretim,* 65(1): 29-36. https://doi.org/10.29185/hayuretim.1473580

Tölü, C., Yazgan, N., Akbağ, H. I., Yurtman, İ. Y. and Savaş T. (2022). Effects of melatonin implants on reproductive performance of dairy sheep and dairy goats. *Reproduction in Domestic Animals,* 57: 665–672. https://doi.org/10.1111/rda.14107

Uyanık, F., Güvenç, K., Gültekin, M. and Gürbulak, K. (2009). Serum leptin and progesterone levels during gestation in ewes. *Journal of The Faculty of Veterinary Medicine Erciyes University,* 6(1): 31-36 (In Turkish).

Yılmazer, C., Çevik, M. and Koçyiğit, A. (2018). Effects of subcutaneous melatonin implants and short-term intravaginal progestagen treatments on estrus induction and fertility of Kıvırcık ewes on seasonal anestrus. *Polish Journal of Veterinary Sciences,* 21(2): 353-359.

Zarazaga, L. A., Gatica, M. C., Celi, I., Guzman, J. L. and Malpaux, B. (2009). Effect of melatonin implants on sexual activity in Mediterranean goat females without separation from males. *Theriogenology,* 72: 910-918.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Desalinated Sea Water Usage Possibilities in *Muscari armeniacum* (Grape Hyacinth) Cultivation

Muscari armeniacum (Üzüm Sümbülü) Yetiştiriciliğinde Tuzdan Arındırılmış Deniz Suyu Kullanım Olanaklarının Belirlenmesi

Necmettin GÜR[1], Özgür KAHRAMAN[2*]

Abstract

In the current period of time, many environmental problems have occurred in the world with the population increase, industrialization and construction, along with migration from rural areas to urban areas. Among the environmental problems that occur due to all these developments; the decrease in potable and usable freshwater resources, global warming, climate change and drought are the leading environmental problems. This study was carried out in the open field of a private apartment building in Izmir, Turkey to determine the possibility of using desalinated seawater in the cultivation of *Muscari armeniacum* Leichtlin ex Baker. Depending on the purpose of the study, *Muscari armeniacum* Leichtlin ex Baker was grown using desalinated seawater and tap water (control). To determine the effect of desalinated seawater on plant growth, leaf length, leaf width, root length, underground part weight, number of bulblets and upper part weight were measured. It was observed that *Muscari armeniacum* Leichtlin ex Baker plants showed normal growth when desalinated seawater was used throughout the experiment. According to the statistical analysis, the difference between desalinated sea water and tap water was significant only in leaf length and leaf width parameters. While the average leaf length was 54.47 cm and leaf width were 5.71 mm in tap water (control), the average leaf length was 53.47 cm and leaf width were 5.19 mm in desalinated sea water treatment. The effect of irrigation water sources on other parameters was statistically insignificant. As a result of the study, desalinated seawater can be used for the cultivation of *Muscari armeniacum* Leichtlin ex Baker. It is recommended that studies evaluating the possibilities of using desalinated sea water in the cultivation of different ornamental plant species will contribute to the literature.

Keywords: Desalination, *Muscari armeniacum*, Ornamental plant cultivation, Irrigation

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Öz

İçinde bulunduğumuz zaman diliminde kırsal alanlardan kentsel alanlara doğru yapılan göçler ile birlikte gerçekleşen nüfus artışı, sanayileşme ve yapılaşma ile birlikte dünya üzerinde birçok çevre sorunu meydana gelmiştir. Tüm bu gelişmelere bağlı olarak meydana gelen çevre sorunları içerisinde; içilebilir ve kullanılabilir tatlı su kaynaklarındaki azalma, küresel ısınma, iklim değişikliği ve kuraklık bu çevre sorunlarının başında gelmektedir. Bu çalışma, *Muscari armeniacum* Leichtlin ex Baker yetiştiriciliğinde tuzdan arındırılmış deniz suyunun kullanım olasılığını belirlemek amacıyla Türkiye'nin İzmir ilinde özel bir apartman dairesine ait açık alanda gerçekleştirilmiştir. Çalışmanın amacına bağlı olarak *Muscari armeniacum* Leichtlin ex Baker, tuzdan arındırılmış deniz suyu ve musluk suyu (kontrol) kullanılarak yetiştirilmiştir. Tuzdan arındırılmış deniz suyunun bitki gelişimi üzerindeki etkisini belirlemek için yaprak uzunluğu, yaprak genişliği, kök uzunluğu, toprak altı kısım ağırlığı, yavru soğan sayısı ve üst aksam ağırlığı parametreleri ölçülmüştür. *Muscari armeniacum* Leichtlin ex Baker bitkileri, deneme süreci boyunca tuzdan arındırılmış deniz suyu kullanımında normal büyüme gösterdiği gözlemlenmiştir. Yapılan istatistiksel analizlere göre, tuzdan arındırılmış deniz suyu ve musluk suyu kullanımlarının bitkiler üzerinde sadece yaprak uzunluğu ve yaprak genişliği parametrelerinde gösterdiği farklılık önemli olarak görülmüştür. Musluk suyu (kontrol) kullanımında ortalama yaprak uzunluğu 54.47 cm, yaprak genişliği 5.71 mm olurken, tuzdan arındırılmış deniz suyu arıtımında ortalama yaprak uzunluğu 53.47 cm, yaprak genişliği ise 5.19 mm olarak gerçekleşmiştir. Sulama suyu kaynaklarının diğer parametrelere etkisi istatiksel olarak önemsiz bulunmuştur. Çalışmanın sonucu olarak *Muscari armeniacum* Leichtlin ex Baker bitkisi yetiştiriciliğinde tuzdan arındırılmış deniz suyu kullanılabilir olduğu görülmüştür. Tuzdan arındırılmış deniz suyunun farklı süs bitkisi türlerinin yetiştiriciliğinde kullanım olanaklarının değerlendirildiği çalışmaların yapılmasının literatüre katkı sağlayacağı yönünde tavsiyelerde bulunulmuştur.

Anahtar Kelimeler: Tuzdan arındırma, *Muscari armeniacum*, Süs bitkisi yetiştiriciliği, Sulama

1. Introduction

The excessive increase in population, construction and industrialization in the world causes many environmental problems. Global warming and climate change, increase in urban heat island effect, decrease in natural resources due to high use and drought are the most important of these problems (Beyaz, 2023). Especially the decrease in freshwater resources and unconscious-high water consumption is the factor that affects the present and the future most deeply. Water is the most valuable natural resource and is very important for all living life on earth (Bakanoğulları et al., 2022). Water is the most common compound in the world as a resource and covers most of the planet. Unfortunately, only a very small portion of this resource is available. 97.4% of the world's water resources are salt water and 2.6% are fresh water. Only 0.8 per cent of freshwater resources are potable and usable. The remaining part of fresh water that is potable and usable is glaciers, snow-covered areas and unusable (Polat, 2013). In this case, different practices are carried out to protect freshwater resources. For example, in countries such as the USA, Saudi Arabia, Australia and China, treated wastewater is used for reuse in urban open-green areas for irrigation, ornamental plant cultivation and agricultural irrigation (Laurenson et al., 2012; Zhang and Shen, 2019; Singh, 2021). In addition, arid landscape approaches to minimize water use in urban areas also appear as a different application in this regard (Kavuran and Yılmaz, 2022). In addition to all these, the transformation of salty water, i.e. seawater, which constitutes the majority of the world's water amount, into potable and usable fresh water stands out as an unlimited potential in terms of creating water supply (Nasar, 2014).

For seawater to be used for drinking water or domestic use, many countries carry out studies for desalination processes, establish facilities and make them available to their citizens. Saudi Arabia, United Arab Emirates, USA, Libya, Libya, Japan, and Spain are examples of these countries (Alabdula'aly, 1997; Polat Bulut, 2021). In addition to the potability of seawater, there are many studies in the literature on its use in agricultural production. Martinez-Mate et al. (2018), in their study, focused on the use of desalinated seawater (DSW) in hydroponic systems in regions experiencing water scarcity and lettuce production with this system in Southeast Spain. They stated that lettuce production in hydroponic systems is more efficient than traditional methods in terms of water efficiency and greenhouse gas emissions. They also found that although DSW increased energy use by 17% in hydroponic systems, greenhouse gas emissions were low. In the study, they stated that the energy dependence required for DSW can be met with renewable systems. Therefore, they suggested that the use of hydroponic systems with DSW in regions where freshwater resources are scarce may be a highly efficient strategy in terms of production. Aznar-Sánchez et al. (2021), in their study, examined farmer profiles and behaviours of farmers in Southeast Spain towards the use of DSW for irrigation purposes. They determined that although the use of DSW as an alternative water use is planned in Southeastern Spain, the demand of farmers is low at this point. They suggested that necessary programmes should be carried out to increase the use of DSW by farmers. At this point, a survey was conducted in the study area. As a result of the survey, they determined that there are different farmer typologies in the region and that farmers have different attitudes and preferences towards DSW. As the main finding of the study, they have determined that the pricing of the use of DSW is mainly effective on farmers. As a result, they made recommendations to encourage the use of DSW by farmers. Martínez-Alvarez et al. (2023), in their study, examined the supply of DSW for agricultural uses in Southeast Spain from a multidisciplinary perspective. In the study, they stated that DSW has been used steadily in the region in the last 10 years and has given successful results in agricultural production. On the other hand, they also examined the energy consumption and cost related to the supply of DSW. At this point, they suggested that if the energy need is met by using renewable energy sources, the costs can be reduced considerably. However, from different perspectives, they also stated that the use of traditional freshwater resources and DSW will provide maximum benefit.

Among the studies conducted on the production of agricultural plants from desalinated seawater, Maestre-Valero et al. (2020) investigated the usability of desalinated sea water in irrigation in the young stages of plants for citrus production. In the study they carried out during two crop periods, they irrigated with only tap water (Control), a mixture of 50% tap water and 50% desalinated sea water, and only desalinated sea water. Although they did not observe any statistical difference in the development parameters of the plants in their results, they determined concentrations that could increase element-based toxicity in the leaves of some plants. On the other hand, they stated that the use of desalinated sea water as irrigation water in the young stages of plants would not pose a problem. Antolinos et al. (2020) mentioned that both soilless plant cultivation and alternative water sources

are very important in arid and semi-arid climates. They grew two different types of tomatoes in hydroponic systems using only desalinated sea water, only tap water, and a mixture of the two. Although the dry matter content, colour and acidity values showed differences because of the trial, they stated that these differences were at a tolerable level and acceptable to the consumer. As a result, they showed that desalinated seawater can be used in hydroponic systems and that it can be more cost-effective.

This study was carried out to determine the possibility of using desalinated sea water (DSW) as irrigation water in the cultivation of *Muscari armeniacum* Leichtlin ex Baker for the conservation and sustainable use of freshwater resources.

2. Material and Method

The study was conducted between March 2023 and June 2023, when Muscari armeniacum has the highest utilization criteria for landscape architecture (Kılıçaslan and Dönmez, 2016), in the open area of a private apartment building in the Buca district of Izmir. *Muscari armeniacum* Leichtlin ex Baker (Grape Hyacinth) with bulb circumference of 5-6 cm was used as plant material in the study. Grape Hyacinth bulbs were obtained from Asya Tulip company, which produces and trades bulbous plants in Karatay district of Konya.

Grape Hyacinth bulbs were grown in 6-litre plastic pots measuring 31x19x17 cm. A mixture of peat and perlite (v/v) was prepared as growing medium and this mixture was filled into the growing pots. The analysis of peat and perlite used in the mixture are given in *Tables 1* and *2*.

Table 1. Analysis values of the peat used in the growing medium.

Parameters	Analysis Values
pH	5.5-6.8
EC (µS/cm)	220
Organic Matter (%)	54-60
Humidity (%)	53.43
Purity (%)	95

Table 2. Analysis values of perlite used in the growing medium.

Parameters	Analysis Values
Density	70-80 kg/m^3 (±%10)
Grain Diameter	0-6 mm
Thermal Conduction Coefficient	0.040-0.045 Kcal/mhC
Chemical Composition	SiO_2 (%74)
	Al_2O_3 (%14)
	Na_2O (%3)
	K_2O (%5)
	MgO (%0.5)
	CaO (%0.5)
	Fe_2O_3 (%1)
pH	7
Melting Point	1200 °C

In the study, only tap water (control) and only desalinated sea water were applied to grape hyacinth bulbs. Sea water was obtained from Ilıca Public Beach in Çeşme district of İzmir, where 38°18'31.08" north parallel and 26°22'29.33" east meridian intersect. The seawater was boiled in a 5 litre aluminium teapot and the steam from the jug was directed to the condensation vessel through a hose. The water vapour was condensed by cooling the condensation vessel with ice moulds and desalinated sea water (DSW) was obtained. The pH (Joytech pH Meter) and EC (Zauss TDS and EC Meter) values of tap water and desalinated seawater were measured before and after desalination (*Table 3*). Tap water and desalinated seawater were added to the growing medium with the help of a nosed flower watering can until water came out of the drainage holes of the plastic containers.

Table 3. pH and EC values of tap water and seawater before and after desalination

	pH	EC (µS/cm)
Before Desalination of Sea Water	7.5	19990
After Desalination of Sea Water	7.6	860
Tap Water	7.8	464

The study was established according to the random plots experimental design with three replications. Grape hyacinth bulbs were planted in the growing medium at a depth of 4 cm and planting distance of 7x6 cm on 4 March 2023. In each replicate (in pots), 12 grape hyacinth bulbs were used. Plants were grown for 12 weeks with only desalinated seawater and tap water.

Leaf length and leaf width parameters were measured every 4 weeks to determine plant growth. On 4 June 2023, root length, root weight, number of bulbs and top weight were measured after uprooting. The measurements were made as follows.

•Leaf length: It is the measurement made with the help of a ruler from the exit point to the tip of the leaves of the plant.

•Leaf width: It is the measurement made with callipers from the widest part of the leaf.

• Root length: It is the measurement made with the help of a ruler from the base of the onion to the end point.

•Underground part weight: It is the measurement obtained by weighing the onions, bulbs, bulblets and roots on a precision balance.

•Upper part weight: It was obtained by weighing the leaves, flower stems and flowers cut from the onion nose on a precision balance.

•Number of bulblets: It was obtained by counting the number of daughter bulbs formed by the mother bulb after harvesting.

Normality test was performed on the monthly measurement data obtained from each parameter. In normality test, skewness/ kurtosis values of all data were divided by standard deviation values. All the results obtained were between -1.96 and 1.96 and it was determined that all of the data showed normal distribution (Büyüköztürk, 2011). Independent Groups T test was applied to the data using SPSS 27 (IBM SPSS Statistics, Chicago, USA) statistical programme and the differences of irrigation methods on the measurement parameters were determined (p=0.05).

3. Results and Discussion

As a result of the statistical analyses, it was determined that tap water (control) and desalinated sea water treatments caused a significant difference between the treatments on leaf length at the end of the 4^{th}, 8^{th} and 12^{th} week at 95% confidence interval. In all three periods, leaf length values of tap water treatment were greater than desalinated sea water treatment (*Figure 1*).

The results of the Independent Groups T test on the averages of leaf length values are given in *Table 4*.

Table 4. Independent Groups T test results for the effect of treatments on the mean values of leaf length in the measurement periods of the experiment

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Week 4 Leaf Length	0.986792	0.376755	12.555845	4.00	0.000232*	4.333333	0.345125
Week 8 Leaf Length	1.475032	0.291347	10.925935	4.00	0.000399*	1.250000	0.114407
Week 12 Leaf Length	0.491371	0.521951	3.355151	4.00	0.028433*	1.000000	0.298049
Significance:	p<0.05: There is a significant difference (*). / p>0.05: No significant difference						

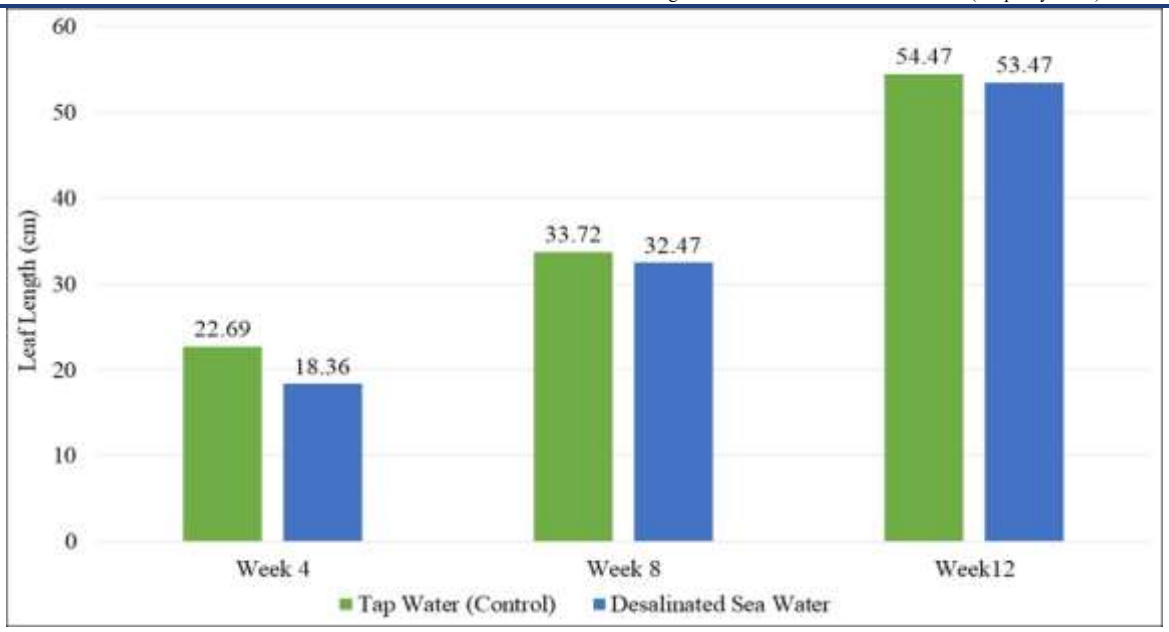

Figure 1. Effect of irrigation treatments on leaf length at different periods

Tanrıverdi (2019), in his study listing geophyte plants found in the flora of Yalova province, determined that the leaf length values of the *Muscari armeniacum* plant varied between 10-40 cm. In this study, similar leaf length results were obtained at the end of the 4th and 8th weeks, but greater values were obtained at the end of the 12th week than in this study.

Leaf width values varied between 5 mm and 7 mm in tap water (control) treatments and between 4 mm and 6 mm in desalinated sea water treatments. The results of Independent Groups T test on the averages of leaf width values are shown in *Table 5*.

Table 5. Independent Groups T test results for the effect of the treatments on the mean leaf width values in the measurement periods of the experiment

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Week 4 Leaf Width	0.235294	0.652994	5.728716	4.00	0.004597*	0.063333	0.110554
Week 8 Leaf Width	0.000000	1.000000	5.656854	4.00	0.004813*	0.053333	0.094281
Week 12 Leaf Width	0.000000	1.000000	5.656854	4.00	0.004813*	0.053333	0.094281
Significance:	p<0.05: There is a significant difference (*). / p>0.05: No significant difference						

At the end of the 4th, 8th and 12th week, the leaf length of plants treated with tap water was found to be higher than that of desalinated sea water (*Figure 2*).

Gürsoy (2009) conducted biological studies on *Muscari armeniacum* and *Muscari neglectum* plants naturally distributed in Western Anatolia and investigated morphological, anatomical, palynological, seed germination and growing media of the plants. The leaf width values of *Muscari armeniacum* plant was between 1 and 5 mm on the studies. The leaf width values were obtained from this study coincide with Gürsoy (2009)'s study.

Root length values varied between 11 and 14 cm in tap water (control) treatments and between 11 and 14 cm in desalinated sea water treatments. The results of Independent Groups T test on the averages of root length values are shown in *Table 6*.

Table 6. Independent Groups T-test results for the effect of treatments on the mean root length values measured at the uprooting period of the experiment.

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Root Length	3.287564	0.144017	1.244223	4.00	0.281346	0.193333	0.155385
Significance:	p<0.05: There is a significant difference (*). / p>0.05: No significant difference						

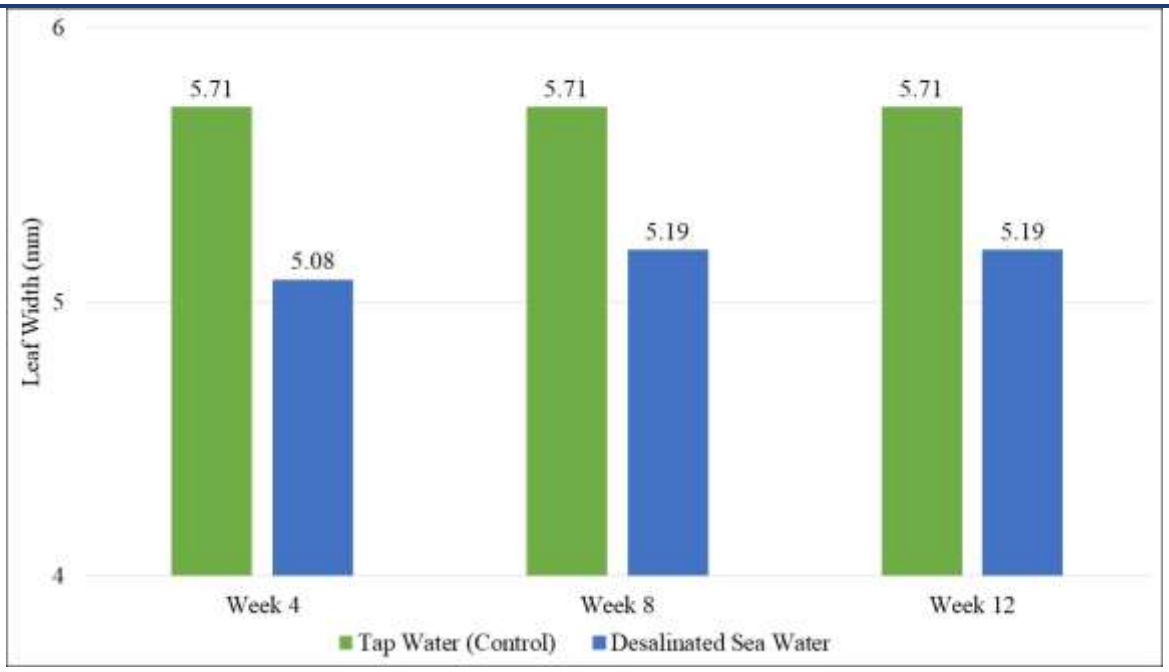

Figure 2. Effect of irrigation treatments on leaf width at different periods

The mean values of the measurement values of the root length parameter after uprooting in the experiment are shown in *Figure 3*.

Kahraman (2020) investigated the effect of 1 cm deep shallow planting, 4 cm deep medium depth planting and 7 cm deep planting depths on the growth and development of *Muscari armeniacum* plants. The lowest root length value was determined at 8.56 cm deep planting depth and the highest root length value was determined at 11.50 cm medium depth planting depth. In this study, similar root length values were found.

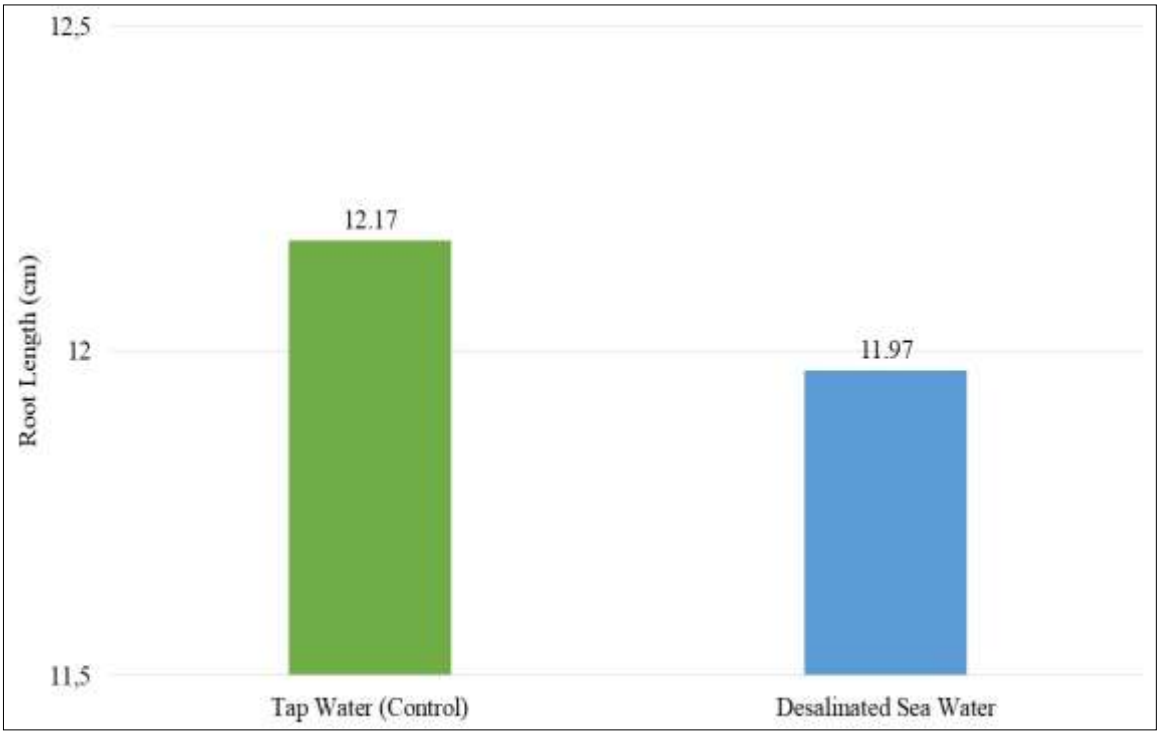

Figure 3. Effect of irrigation treatments on root length

Underground part weight values ranged between 12.18 g and 13.33 g in tap water (control) treatments and between 12.08 g and 12.66 g in desalinated seawater treatments (*Figure 4*). As a result of the statistical comparison analyses performed on the averages of the measurement values, it was observed that there was no significant difference between the two different treatments at 95% confidence interval values in the post-removal measurements of tap water (control) and desalinated sea water treatments. The results of the Independent Groups T test on the averages of the weight values of the underground part are shown in *Table 7*.

Navarro et al. (2023) used desalinated seawater in the cultivation of *Citrus macrophylla* and sour orange plants in two different irrigation methods as continuous and open irrigation. As a result of their 140-day experiment, they stated that although toxicity differences were observed in plant leaves, the use of desalinated seawater did not statistically differ in root development in plant growth parameters.

Table 7. Independent Groups T test results for the effect of treatments on the mean underground part weight values measured at the uprooting period of the experiment

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Underground Part Weight	0.425847	0.549637	0.719475	4.00	0.511642	0.280000	0.389173
Significance:	p<0.05: There is a significant difference (*). / p>0.05: No significant difference						

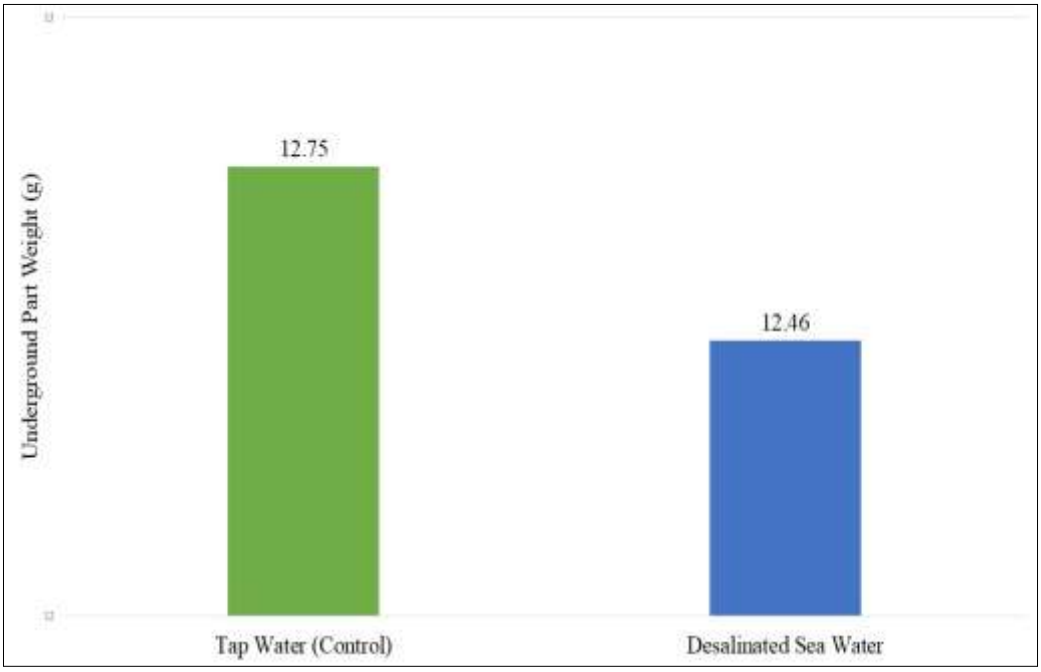

Figure 4. Effect of irrigation treatments on underground part weight

The values of the weight of the upper part varied between 10 and 17 g in tap water (control) treatments and between 10 and 16 g in desalinated sea water treatments. According to the statistical analyses, it was observed that there was no significant difference between the two different treatments at 95% confidence interval values in the measurements of tap water (control) and desalinated sea water treatments after uprooting. The results of the Independent Groups T test on the averages of the upper part weight values are shown in *Table 8*.

Table 8. Results of Independent Groups T-test for the effect of treatments on the mean upper part weight values measured during the uprooting period of the experiment

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Upper Part Weight	2.037905	0.226598	1.879645	4.00	0.133336	0.690000	0.367091
Significance:	p<0.05: There is a significant difference (*). / p>0.05: No significant difference						

The averages of the measurement values of the upper part weight parameter after dismantling in the experiment are shown in *Figure 5*.

Kahraman (2019) investigated the effects of taking flower buds at different developmental stages on onion and plant growth of *Muscari armeniacum* plant and found that the effect of taking flower buds at different developmental stages on the weight of the upper part of the plant was statistically insignificant. In this study, it was observed that desalinated sea water as a different irrigation application did not cause a significant difference on the weight of *Muscari armeniacum* plant tops.

The number of bulblets varied between 1 and 5 in tap water (control) treatments and between 0 and 6 in desalinated sea water treatments. As a result of the statistical comparison analyses performed on the averages of the measurement values, it was observed that there was no significant difference between the two different treatments at 95% confidence interval values in the measurements of tap water (control) and desalinated sea water treatments after disassembly. The results of the Independent Groups T-test on the number of bulbs are shown in *Table 9*.

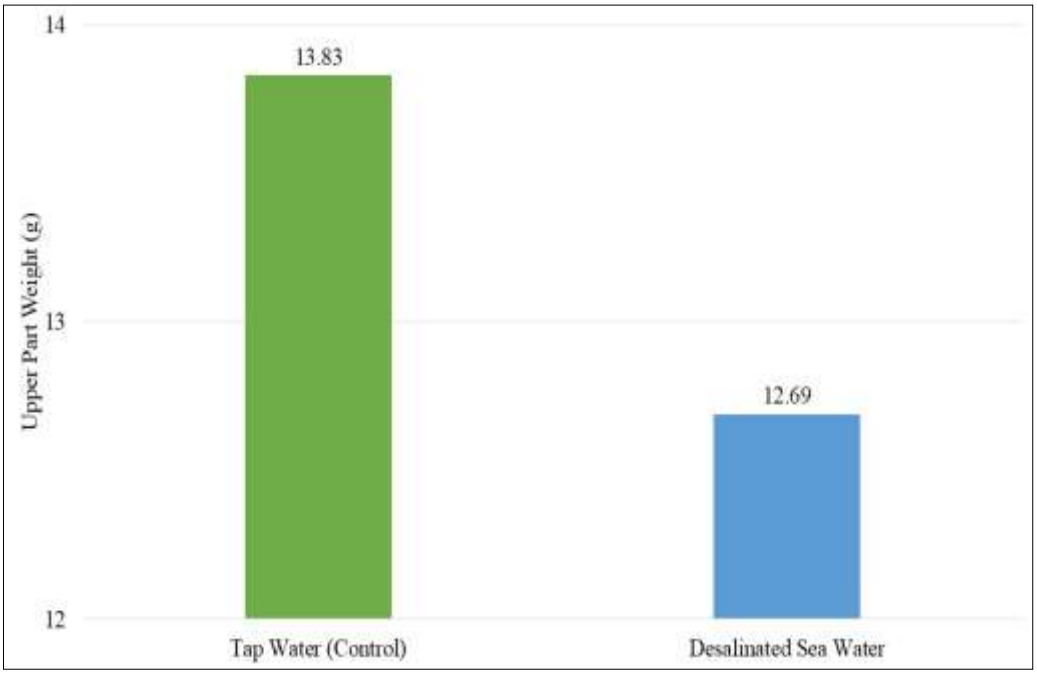

Figure 5. Effect of irrigation treatments on upper part weight

Table 9. Independent Groups T-test results for the effect of treatments on the mean number of bulblets measured at the disembarkation period of the experiment.

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Number of Bulblets	2.117727	0.219300	0.840169	4.00	0.448100	0.166667	0.198373
Significance:	p<0.05: There is a significant difference (*). / p>0.05: No significant difference						

The averages of the measurement values of the parameter of the number of bulblets after disassembly in the experiment are shown in *Figure 6*.

Jeon et al. (2011), investigated the effect of different growth regulators on direct shoot and bulblets formation of *Muscari armeniacum*. They used MS media supplemented with NAA, DA and TDZ in tissue culture. After the completion of the experimental period, they reported that they did not observe phenotypic variations in the plants and that 1-1.5 bulblets were formed per plant on average. Plant growth regulators had insignificant effect on the number of bulblets. In this study, it was determined that irrigation treatments did not have a significant difference on the number of bulblets.

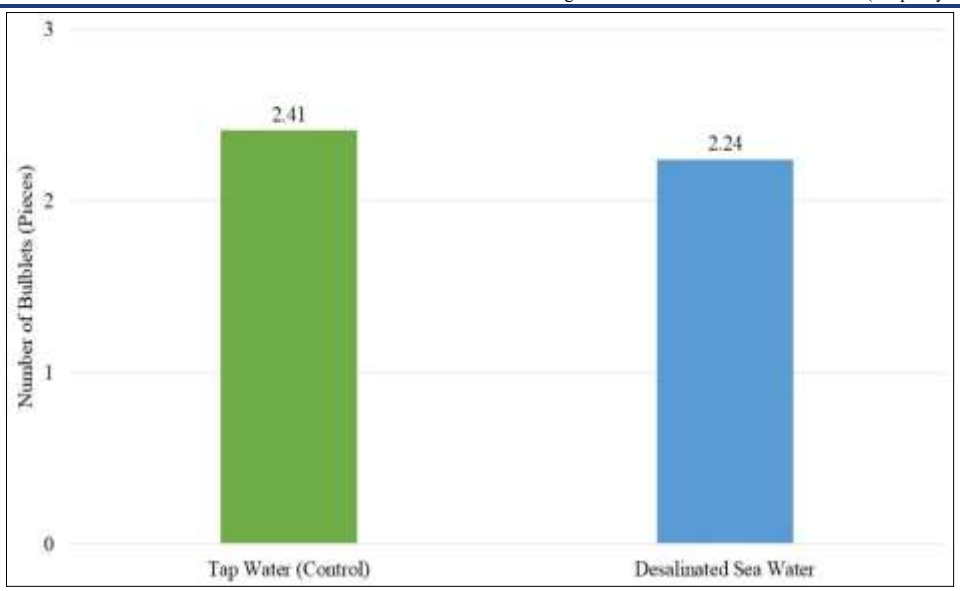

Figure 6. Effect of irrigation treatments on number of bulblets

4. Conclusions

In this study, DSW did not inhibit the growth and development of *Muscari armeniacum* Leichtlin ex Baker. As seen in the measurement parameters, the values when DSW was used were mostly below the values when the plant reached its optimum form in the control irrigation. However, the measured values obtained using DSW were tolerable, although lower than the values of the control plants. The use of DSW may have different physiological effects in different plant species. The use of DSW in ornamental plant cultivation and urban areas will contribute to the protection and sustainability of freshwater resources. For this purpose, the effects of DSW use in the cultivation of different ornamental plant species and irrigation of urban areas on plant species and the environment should be investigated.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Gür, N.; Kahraman, Ö., Design: Gür, N.; Data Collection and Processing: Gür, N.; Statistical Analyses: Gür, N.; Kahraman, Ö., Literature Search: Gür, N., Writing, Review and Editing: Gür, N.; Kahraman, Ö.

References

Alabdula'aly, A. I. (1997). Fluoride content in drinking water supplies of Riyadh, Saudi Arabia. *Environmental Monitoring and Assessment*, 48: 261-272. https://doi.org/10.1023/A:1005795820508

Antolinos, V., Sanchez-Martinez, M. J., Maestre-Valero, J. F., Lopez-Gomez, A. and Martinez-Hernandez, G. B. (2020). Effects of irrigation with desalinated seawater and hydroponic system on tomato quality. *Water*, 12(2): 518. https://doi.org/10.3390/w12020518

Aznar-Sanchez, J. A., Belmonte-Urena, L. J., Velasco-Munoz, J. F. and Valera, D. L. (2021). Farmers' profiles and behaviours toward desalinated seawater for irrigation: Insights from South-east Spain. *Journal of Cleaner Production*, 296: 126568. https://doi.org/10.1016/j.jclepro.2021.126568

Bakanoğulları, F., Bahar, E., Kıvrak, C. and Gür, M. (2022). Assessment of meteorological and agricultural drought analysis in Kırklareli province. *Journal of Tekirdag Agricultural Faculty*, 19(4): 756-768. https://doi.org/10.33462/jotaf.1060752

Beyaz, R. (2023). Germination and seedling properties of *Lotus corniculat*us L. under simulated drought stress. *Journal of Tekirdag Agricultural Faculty*, 20(4): 879-889. https://doi.org/10.33462/jotaf.1226444

Büyüköztürk, Ş., Çokluk, Ö. and Köklü, N. (2011). Normalization Test. In: Statistics for Social Sciences. Pegem Akademi Publications, Turkey.

Gürsoy, M. (2009). *Biological studies on some muscari miller species (Muscari armeniacum Leichtlin Ex Baker, Muscari neglectum Guss.) distributed in Western Anatolia*. (Master's Thesis). Celal Bayar University, Institute of Science and Technology, Manisa, Türkiye.

Jeon, S. M., Chung, M. Y. and Kim, C. K. (2011). Effect of plant regulators on direct shoot formation and bulblet formation from flower stalk culture of *Muscari armeniacum* 'Early Giant'. *Current Research on Agriculture and Life Sciences*, 29: 21-27. (In Korean)

Kahraman, Ö. (2019). Effects of taking flower buds at different developmental periods on bulb and plant development of *Muscari armeniacum* Leichtlin ex Baker. *Anadolu Journal of Agricultural Sciences*, 34(1): 12-17. https://doi.org/10.7161/omuanajas.444180

Kahraman, Ö. (2020). Growing of *Muscari armeniacum* (Grape Hyacinth) at different planting depths. *Journal of Agriculture and Nature*, 23(6): 1441-1448. https://doi.org/10.18016/ksutarimdoga.vi.707845

Kavuran, D. and Yılmaz, R. (2022). Selection of appropriate plant species in xeriscape studies: Süleymanpaşa, Tekirdağ example. *Landscape*, 4(2): 69-91. https://doi.org/10.53784/peyzaj.1167964

Kılıçaslan, N. and Dönmez, Ş. (2016). The use of bulbous plants growing naturally in the lake's region in landscape architecture. *Turkish Journal of Forestry*, 17(1): 73-82.

Laurenson, S., Bolan, N. S., Smith, E. and McCarthy, M. (2012). Use of recycled wastewater for irrigating grapevines. *Australian Journal of Grape and Wine Research*, 18(1): 1-10. https://doi.org/10.1111/j.1755-0238.2011.00170.x

Maestre-Valero, J. F., Martínez-Alvarez, V., Jódar-Conesa, F. J., Acosta, J. A., Martin-Gorriz, B., Robles, J. M., ... and Navarro, J. M. (2020). Short-term response of young mandarin trees to desalinated seawater irrigation. *Water*, 12(1): 159. https://doi.org/10.3390/w12010159

Martínez-Alvarez, V., Imbernón-Mulero, A., Gallego-Elvira, B., Soto-García, M. and Maestre-Valero, J. F. (2023). Multidisciplinary assessment of the agricultural supply of desalinated seawater in south-eastern Spain. *Desalination*, 548: 116252. https://doi.org/10.1016/j.desal.2022.116252

Martinez-Mate, M. A., Martin-Gorriz, B., Martínez-Alvarez, V., Soto-García, M. and Maestre-Valero, J. F. (2018). Hydroponic system and desalinated seawater as an alternative farm-productive proposal in water scarcity areas: Energy and greenhouse gas emissions analysis of lettuce production in southeast Spain. *Journal of Cleaner Production*, 172: 1298-1310. https://doi.org/10.1016/j.jclepro.2017.10.275

Nasar, M. (2014). Exploitation survey of sea water in agriculture of coastal deserts in Libya. *Proceedings of the International Academy of Ecology and Environmental Sciences*, 4(2): 72.

Navarro, J. M., Antolinos, V., Botía, P. and Robles, J. M. (2023). Deficit Irrigation applied to lemon trees grafted on two rootstocks and irrigated with desalinated seawater. *Plants*, 12(12): 2300. https://doi.org/10.3390/plants12122300

Polat, A. (2013). Reuse of treated wastewater for the sustainability of water resources. *Turkish Journal of Scientific Reviews*, (1): 58-62.

Polat Bulut, A. (2021). Seawater use and purification technologies for increasing water needs. *Turkish Journal of Scientific Reviews*, 14(2): 124-137.

Singh, A. (2021). A review of wastewater irrigation: Environmental implications. *Resources, Conservation and Recycling*, 168: 105454. https://doi.org/10.1016/j.resconrec.2021.105454

Tanrıverdi O, D. (2019). *Geophytes of Yalova Province and their use possibilities in landscape.* (Master's Thesis). Bursa Uludağ University, Institute of Science and Technology, Bursa, Türkiye.

Zhang, Y. and Shen, Y. (2019). Wastewater irrigation: past, present, and future. *Wiley Interdisciplinary Reviews: Water*, 6(3): 1234. https://doi.org/10.1002/wat2.1234

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluating the Impacts of the Land Consolidation Project Implemented in Tekirdağ Province on Agricultural Enterprises

Tekirdağ İlinde Uygulanan Arazi Toplulaştırma Projesinin Tarımsal İşletmeler Üzerindeki Etkilerinin Değerlendirilmesi

Derya İlkay YILMAZ[1*], Fuat YILMAZ[2]

Abstract

This study aims to evaluate the structural, economic, and social impacts of the land consolidation project implemented in Tekirdağ province on agricultural enterprises. The research utilizes data from surveys conducted with farmers in villages designated as consolidation areas, along with records from the General Directorate of State Hydraulic Works. To determine the impacts of land consolidation, descriptive statistics, the Januszewski Index (JI), the Simmons Index (SI), and other consolidation indicators were employed. Following land consolidation, the average parcel size of enterprises increased by 30.54%, reaching an average of 34.79 decares, while the number of parcels decreased by 42.37%, resulting in an average of 9.29 parcels. The increase in the JI value from 0.344 to 0.419 and the SI value from 0.197 to 0.254 suggests that land fragmentation has decreased. However, these values also indicate that it could be further reduced with improved planning. From an economic perspective, fuel consumption decreased by 11.96%, averaging 4.71 liters, and travel time loss reduced by 12.50%, averaging 0.77 hours, indicating that land consolidation has enhanced the efficiency of enterprises. The social impacts of the project were less positive than anticipated, with many farmers expressing dissatisfaction due to insufficient information during the planning phase, delays in project completion, and perceived discrepancies between promised and actual outcomes. Regarding social impacts, the percentage of farmers who believed that land consolidation would be beneficial was 93.07% before the process, which fell to 41.58% afterward. Additionally, 84.16% of farmers raised objections about the process. This suggests that the land consolidation project may not have achieved the expected positive impacts. To improve the effectiveness of land consolidation projects and increase farmer satisfaction, several key enhancements are needed. Project planning should be more comprehensive and grounded in up-to-date data, with a commitment to transparency throughout all stages. Encouraging farmer participation in the consolidation process and increasing their awareness and understanding are essential. It is also important to create avenues for farmers to voice their concerns and actively contribute to the process. Furthermore, accelerating project timelines and ensuring the complete delivery of promised services would help build farmers' trust. Implementing these strategies could lead to more positive social and economic outcomes for land consolidation projects.

Keywords: Consolidation indicators, Economic impacts, Farmer satisfaction, Rural development, Land arrangement

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Öz

Bu çalışma, Tekirdağ ilinde uygulanan arazi toplulaştırma projesinin tarımsal işletmeler üzerindeki yapısal, ekonomik ve sosyal etkilerini değerlendirmeyi amaçlamaktadır. Araştırma kapsamında toplulaştırma ilan edilen köylerdeki çiftçilerden anket yoluyla elde edilen veriler ve Devlet Su İşleri Genel Müdürlüğü'nün kayıtları kullanılmıştır. Arazi toplulaştırmanın etkilerini belirlemek için betimleyici istatistikler, Januszewski İndeksi (JI), Simmons İndeksi (SI) ve diğer toplulaştırma göstergeleri kullanılmıştır. Arazi toplulaştırma sonrasında işletmelerin ortalama parsel büyüklüğü %30.54 artarak ortalama 34.79 dekara çıkarken, parsel sayısı %42,37 azalarak ortalama 9.29 parsel olmuştur. Arazi parçalılığı göstergelerinden olan JI değerinin 0,344'ten 0,419'a ve SI değerinin 0.197'den 0,254'e yükselmesi, arazi parçalanmasının azaldığını ancak daha iyi planlamayla daha da azaltılabileceğini ortaya koymaktadır. Ekonomik açıdan, yakıt tüketiminin %11.96 azalarak ortalama 4.71 l ve yol zaman kaybının %12.50 oranında azalarak ortalama 0.77 saat olduğu belirlenmiştir. Bu durum arazi toplulaştırmanın işletmelerin verimliliğini artırdığını göstermektedir. Projenin sosyal etkilerinin beklenenden daha olumsuz olduğu belirlenmiştir. Pek çok çiftçi, planlama aşamasında yetersiz bilgi verilmesi, projenin tamamlanmasındaki gecikmeler ve vaat edilen ile gerçekleşen sonuçlar arasındaki tutarsızlıklar nedeniyle memnuniyetsizliklerini dile getirmişlerdir. Sosyal etkiler incelendiğinde, arazi toplulaştırmanın faydalı olacağını düşünen çiftçilerin oranı %93.07 iken arazi toplulaştırma sonrası bu oran %41.58'e düşmüştür. Ayrıca çiftçilerin %84.16'sının süreçle ilgili itirazlarda bulunduğu belirlenmiştir. Bu durum, arazi toplulaştırma projesinin beklenen pozitif etkileri tam olarak sağlamamış olabileceğini göstermektedir. Arazi toplulaştırma projelerinin etkinliğini artırmak ve çiftçi memnuniyetini sağlamak için çeşitli iyileştirmeler gerekmektedir. Proje planlaması daha kapsamlı ve güncel verilere dayanmalı, tüm aşamalarda şeffaflık sağlanmalıdır. Çiftçilerin toplulaştırma sürecine katılımını teşvik etmek ve farkındalıklarını artırmak esastır. Ayrıca, çiftçilerin endişelerini dile getirebilecekleri ve sürece aktif olarak katkıda bulunabilecekleri mekanizmalar oluşturulmalıdır. Bunun yanı sıra, projelerin sürelerini hızlandırmak ve vaat edilen hizmetlerin eksiksiz olarak yerine getirilmesi, çiftçilerin güvenini artıracaktır. Bu stratejilerin uygulanması, arazi toplulaştırma projelerinin daha olumlu sosyal ve ekonomik sonuçlara ulaşmasına katkıda bulunabilir.

Anahtar Kelimeler: Toplulaştırma göstergeleri, Ekonomik Etkiler, Çiftçi memnuniyeti, Kırsal kalkınma, Arazi düzenlemesi

1. Introduction

The majority of agricultural enterprises in Türkiye are small in area and consist of many separate and distant parts (Sağlam, 2022). This situation leads to deterioration in the agricultural structure, makes it difficult to take measures to increase productivity, and increases production costs (Ekinci and Sayılı, 2010; Küsek, 2014). Land consolidation is an important tool to increase agricultural productivity by merging scattered and small parcels into sufficient size and regulating their shapes (Aktaş et al., 2006; Takka, 1993). Land consolidation is defined as the merging of scattered and small parcels into sufficient size and the regulation of their shapes (Takka, 1993). These efforts not only unite parcels but also contribute to saving labor and fuel, and increasing the income of agricultural enterprises by providing agricultural infrastructure systems (roads, irrigation and drainage) (Akçay and Angın, 1989; Kuzu and Değirmenci, 2020).

Land consolidation projects start with the identification of the area to be consolidated and end with the distribution of new title deeds. These processes include the determination of the request for consolidation, information meetings, notation in the land registry, grading and preparation of new parceling plans (Official Gazette, 2019). Land consolidation is considered an important solution in cases where fragmented and scattered land ownership reduces agricultural productivity and makes mechanization difficult (Kumbasaroğlu and Dağdemir, 2007; Kır, 2012). Reducing the number of parcels, increasing their size, and improving their shape enhances agricultural efficiency and reduces costs (Polat and Manavbaşı, 2012; Arslan and Tunca, 2013). Land consolidation also contributes to environmental quality by reducing fuel consumption and CO2 emissions (Ayten and Çay, 2017; Kirmikil and Aydus, 2018). Studies conducted in the Trakya Region show that land consolidation has positive results in terms of agricultural productivity, irrigation, road access, and agricultural tool use (Bilgin, 2014; Gözener et al., 2016). Land consolidation projects have a positive impact on the economic and social status of farmers (İkikat Tümer et al., 2016).

Land consolidation is considered as an important tool to support rural development. These initiatives aim to organize rural lands, increase productivity and ensure the sustainability of agriculture. This study, conducted in Tekirdağ province, aimed to evaluate the structural and economic impacts of the land consolidation project on agricultural enterprises. Additionally, it aims to increase the effectiveness of future projects by examining the problems encountered in the consolidation process and farmer opinions.

The hypotheses of the study are as follows:

Hypothesis 1: The land consolidation project implemented in Tekirdağ province has structurally positive impacts on enterprises.

Hypothesis 2: The land consolidation project implemented in Tekirdağ province has economically positive impacts on enterprises.

Hypothesis 3: The land consolidation project implemented in Tekirdağ province has socially positive impacts on enterprises.

2. Materials and Methods

2.1. Material

In Tekirdağ province, a total of 36 villages, including 17 in Hayrabolu, 7 in Malkara, and 12 in Süleymanpaşa districts, were declared as consolidation areas within the scope of the soil protection and land use law numbered 5403, with the decision published in the Official Gazette dated 11.03.2017 and numbered 30004 (Official Gazette, 2017).

The survey data obtained from farmers in the villages designated as consolidation areas constitute the primary data and main material of the study. The records of the State Hydraulic Works were used as secondary data. The questionnaires of the study are administered between July and October 2023.

This study was prepared within the scope of permission from the Tekirdağ Namık Kemal University Social and Human Sciences Scientific Research and Publication Ethics Committee dated 05/01/23 and numbered 254168.

2.2. Method

2.2.1. Sampling Method

The stratified random sampling formula (Equation 1) of the Neyman Method is used to determine the sample size

(Yamane, 2001). The value of D^2 in the formula is calculated using Equation 2.

$$n = \frac{(\sum N_h * S_h)^2}{N^2 * D^2 + \sum(N_h * S_h^2)} \quad \text{(Eq.1)}$$

$$D^2 = \frac{d^2}{Z^2} \quad \text{(Eq.2)}$$

$$n_i = \frac{N_h * S_h}{\sum N_h * S_h} * n \quad \text{(Eq.3)}$$

N_h : Number of enterprises in strata
S_h : Standard deviation of strata
N : Population size
d : A percentage deviation from the mean
Z : Table value according to degrees of freedom
S_h^2 : Variance of strata
n_i : Number of samples in a stratum
n : Sample size

Enterprises are divided into three strata based on their land size: 0-140 da, 141-400 da, and 401 da or more. Using a 95% confidence interval and allowing a 10% deviation from the mean, the total number of enterprises to be surveyed was determined as 101. The sample size was distributed among these strata according to the optimum distribution criterion (Equation 3), resulting in 32 enterprises in the 0-140 da range, 21 enterprises in the 141-400 da range, and 48 enterprises in the 401 da or more range. Additionally, the number of enterprises to be surveyed was set at 49 in Hayrabolu district, 12 in Malkara district, and 40 in Süleymanpaşa district.

2.2.2. Determining Structural Impacts

The structural characteristics of the enterprise (enterprise size, number and size of parcels), land fragmentation indicators (Januszewski Index [JI] and Simmons Index [SI]), distance of parcels to the enterprise and field road length values were examined for differences before and after land consolidation. Since the data were found to be non-normally distributed, the differences are analyzed using the Wilcoxon test. JI and SI indices, which are widely used globally, reveal land fragmentation by analyzing the parcels owned by the enterprise (Platonova et al., 2011; Demetriou et al., 2013; Popov, 2017).

Januszewski Index (JI): This index (Equation 4), used to define land fragmentation, is a numerical indicator of the total parcel area (TPA) and the area of each fragmented parcel (PA) (Januszewski, 1968; McGarigal and Marks, 1995).

$$JI = \frac{\sqrt{TPA}}{\sum_i^n \sqrt{PA_i}} \quad \text{(Eq.4)}$$

Simmons Index (SI): This index determines a numerical measure of land fragmentation (Equation 5). The value is equal to 1 when the enterprise has a single parcel (Simmons, 1964).

$$SI = \frac{\sum_i^n PA_i^2}{TPA^2} \quad \text{(Eq.5)}$$

JI and SI values approaching 1 indicate a decrease in fragmentation, while values approaching 0 indicate an increase.

In addition, the parameters used include the consolidation rate over the number of parcels (CR, Equation 6), the total distance of parcels to the enterprise (TDP), the area-road length suitability (ARLS, Equation 7), the average number of parcels per farmer (ANPPF), and the average number of shares per farmer (ANSPF) (Akdeniz and Temizel, 2018).

$$CR = \frac{Number\ of\ old\ parcels\ (units) - Number\ of\ new\ parcels\ (units)}{Number\ of\ old\ parcels\ (units)} x100 \quad \text{(Eq.6)}$$

$$ARLS = \frac{Length\ of\ road\ between\ enterprise\ and\ parcel\ (km)}{0{,}043\ \sqrt{Parcel\ area(ha)}} \quad \text{(Eq.7)}$$

ARLS value closer to 1 indicates a better road network for the enterprise (Kuzu and Değirmenci, 2020).

2.2.3. Determining Economic Impacts

To determine the economic impacts of land consolidation, the inputs used by the enterprises before and after consolidation are analyzed. This analysis includes changes in the amount of inputs due to road and time, resulting from the change in the distances of the parcels to the enterprise. The assumption is made that farmers used an average of 0.407 liters of fuel per kilometer (Polat and Manavbaşı, 2012; Kuzu and Değirmenci, 2020; Gürgenç Irmaklı and Aydın, 2022). While calculating the time spent by the farmers to reach their parcels, it is assumed that their average speed is 15 km h^{-1} (Boztoprak et al., 2015; Kuzu and Değirmenci, 2020; Gürgenç Irmaklı and Aydın, 2022).

2.2.4. Determining Social Impacts

In order to determine the social impacts of land consolidation, farmers are asked about their level of knowledge and their opinions on the consolidation process, and the data are evaluated using frequency tables.

3. Results and Discussion

3.1. General information on farmers and enterprises

In this section, the demographic characteristics of the farmers and the characteristics of the farms are analyzed. Information about the farmers surveyed in the study is given in *Table 1*. All surveyed farmers were male. Their average age was 59.7 years. 1.98% of the farmers were younger than 35 years, 17.82% were between 35-50 years and 80.20% were older than 50 years. 63.37% of the farmers were primary school graduates, 14.85% were middle school graduates, 14.85% were high school graduates and 6.93% were university graduates. Farmers' agricultural experience ranged from 2 years to 63 years, with an average agricultural production experience of 43.44 years. 54.46% of the farmers reported earning non-agricultural income. The average family size was 3.52 persons.

Table 1. Information about farmers

		Frequency	%			Frequency	%
Age	<35	2	1.98	Family size	1 - 3	60	59.41
	35-50	18	17.82		4 - 6	34	33.66
	50 <	81	80.20		7 and above	7	6.93
Education	Primary School	64	63.37	Non-agricultural income	Pension	50	49.50
	Middle School	15	14.85		None	46	45.54
	High School	15	14.85		Trade	3	2.97
	University	7	6.93		Village headman	2	1.98

The average land size of 360.98 da before consolidation decreased by 4.35% to 345.26 da after consolidation (*Table 2*). Previous studies found that farm sizes decreased by between 2.90% and 45.84% after consolidation (Boztoprak et al., 2015; Mesci and Karlı, 2018; Kesici Bahar, 2019; Lök and Değirmenci, 2019; Durduran et al., 2018; Kirmikil and Aydus, 2018). The irrigated land size of the enterprises decreased by 8.96% and the dry land size decreased by 3.98%. The average number of parcels decreased by 42.37% from 16.12 to 9.29. The number of whole parcels decreased by 44.79% and the number of parcels with shares decreased by 43.62%. While the total size of whole parcels increased by 4.97%, the total size of shared parcels decreased by 63.54%. The average rate of decrease in the number of all parcels in studies conducted throughout Türkiye can be stated as 39.56%. The rate of decrease in the number of all parcels in Tekirdağ province was found to be close to the average for Türkiye (Eser and Uçan, 2012; Kır, 2012; Arslan and Tunca, 2013; Boztoprak et al., 2015; Şişman and Bilgin, 2016; Dağdelen et al, 2017; Akdeniz and Temizel, 2018; Akkaya Aslan, 2018; Durduran et al., 2018, Kirmikil and Aydus, 2018; Kuzu et al., 2018; Mesci and Karlı, 2018; Tunalı and Dağdelen, 2018; Kesici Bahar, 2019; Kuşlu and Ertem, 2019; Lök and Değirmenci, 2019; Kuzu and

Değirmenci, 2020; Gürgenç Irmaklı and Aydın, 2022)

While the average parcel size per enterprise was 26.65 da before the land consolidation project, this value increased to 34.79 da after the consolidation project. In previous studies, the rates of change in parcel size after consolidation vary between 27.33% and 75.23% (Eser and Uçan, 2012; Kır, 2012; Dağdelen et al., 2017; Akkaya Aslan, 2018; Durduran et al., 2018; Tunalı and Dağdelen, 2018; Kesici Bahar, 2019; Lök and Değirmenci, 2019). According to the Wilcoxon test results, the difference was significant for all structural characteristics of the enterprises before and after the consolidation project.

Table 2. Structural characteristics of the enterprises (before and after consolidation)

	Before consolidation			**After consolidation**		
	Min.	Max.	Average	Min.	Max.	Average
Land size (da)	23.00	2250.00	360.98	20.00	2140.00	345.26
Irrigated land size (da)	0.00	455.00	27.22	0.00	398.00	24.78
Dry land size (da)	3.00	2115.00	333.76	2.00	2021.00	320.48
Number of parcels	3.00	63.00	16.12	2.00	37.00	9.29
Number of whole parcels	0.00	56.00	13.53	2.00	36.00	7.47
Number of shared parcels	0.00	12.00	2.82	1.00	7.00	1.59
Size of whole parcels (da)	0.00	2150.00	312.38	0.00	2140.00	327.89
Size of shared parcels (da)	0.00	364.00	47.70	0.00	70.00	17.39
Average parcel size (da)	2.30	189.00	26.65	4.60	225.00	34.79

3.2. Indicators of fragmentation and consolidation of enterprises

3.2.1. Januszewski Index (JI) and Simmons Index (SI)

When JI and SI values approach 1, it indicates that fragmentation has decreased, whereas values approaching 0 indicate that fragmentation has increased. After consolidation, the JI value increased from 0.344 to 0.419, and the SI value increased from 0.197 to 0.254 (*Table 3*). The increase in these index values can be interpreted as a decrease in fragmentation. However, the current index values remain relatively low compared to the ideal value of 1, suggesting that there is significant room for improvement in reducing fragmentation. These results show that the land consolidation project successfully reduced land fragmentation. However, better planning could lead to even greater improvements.

Table 3. JI and SI values of enterprises

	Before consolidation	**After consolidation**
JI	0.344	0.419
SI	0.197	0.254

In studies conducted in Niğde and Denizli provinces, JI and SI values increased after consolidation (Akkaya Aslan, 2018; Lök and Değirmenci, 2019).

According to the Wilcoxon test results, the difference between the JI values ($\bar{x}$=0.344, SD:0.143) and SI values ($\bar{x}$=0.197, SD:0.16678) before consolidation and JI values ($\bar{x}$=0.419, SD:0.145) and SI values ($\bar{x}$=0.254, SD:0.17088) after consolidation are significant (Z=-5.539 for JI; p=0.000<0.05, Z=-5.067 for SI; p=0.000<0.05). According to these results, the consolidation project reduced land fragmentation.

3.2.2. Consolidation Indicators

The consolidation rate (CR) of the enterprises based on the number of parcels was calculated as 35.40%. In studies conducted on land consolidation in Türkiye, the consolidation rate was observed to vary between 27.11% and 77%, with an average consolidation rate of 43.91% (Kır, 2012; Arslan and Tunca, 2013; Boztoprak et al., 2015; Şişman and Bilgin, 2016; Dağdelen et al., 2017; Kuzu et al., 2018; Tunalı and Dağdelen, 2018; Lök and Değirmenci, 2019). The consolidation rate in Tekirdağ province was found to be lower than the average.

In the study, the total distance of the parcels to the enterprise (TDP) was 13.145 km on average before consolidation, while it became 11.584 km as a result of consolidation. An average decrease of 11.88% in the total distance of the parcels to the enterprise was observed after consolidation. The decrease rate is similar to previous studies (Kuzu et al.,

2018; Kuşlu and Ertem, 2019). While the area-road length suitability (ARLS) was 70.326 on average before consolidation, it decreased by 8.71% as a result of consolidation and became 64.199 (*Table 4*). The Average Number of Parcels Per Farmer (ANPPF) decreased by 44.57% before consolidation and became 9.06. The Average Number of Shares Per Farmer (ANSPF) decreased by 36.08% after consolidation and became 2.02.

Table 4. Consolidation Indicators

	Before consolidation	After consolidation	Change (%)
TDP	13.145	11.584	11.88
ARLS	70.326	64.199	8.71
ANPPF	16.350	9.060	44.57
ANSPF	3.160	2.020	36.08

According to the Wilcoxon test results, the difference between before consolidation TDP ($\bar{x}$=13.145, SD:11.32129) and ARLS ($\bar{x}$=70.326, SD:68.54491) and the after consolidation TDP ($\bar{x}$=11.584, SD:10.44998) and ARLS ($\bar{x}$=64.199, SD:64.52481) is significant (Z=-4.587 for TDP; p=0.000<0.05; for ARLS (Z=-3.755; p=0.000<0.05). These results indicate that the consolidation project reduced the total distance of the parcels to the enterprise and the area-road length suitability values.

3.3. Change in fuel consumption and travel time loss due to shortened distance

As a result of the consolidation, the distance of parcels to the enterprise has decreased. Consequently, changes in fuel consumption and travel time loss due to the shortened total distance have been examined.

The change in fuel consumption and travel time loss due to distance was calculated after the consolidation. Farmers make an average of 12 trips to the fields for wheat production and 9 trips for sunflower production. Before consolidation, the average fuel consumption per round trip was 5.35 liters, which decreased by 11.96% to 4.71 liters after consolidation (*Table 5*). This difference was found to be statistically significant (p=0.01<0.05). These results demonstrate that the land consolidation project reduced fuel consumption and associated costs.

Before consolidation, the average travel time loss per round trip for enterprises was 0.88 hours, which decreased by 12.50% to 0.77 hours after consolidation. Considering the wheat and sunflower production processes, the travel time loss per enterprise decreased by 6.93 to 9.24 hours after consolidation. This difference was also statistically significant (p=0.01<0.05). Other studies have shown that travel time loss decreased by 50% to 82% (Ayten and Çay, 2017; Kuzu and Değirmenci, 2020; Gürgenç Irmaklı and Aydın, 2022).

Table 5. Changes in fuel consumption and travel time loss of enterprises due to distance

	Before consolidation	After consolidation	Change (%)
Average fuel consumption (l)	5.35	4.71	11.96
Average road time loss (h)	0.88	0.77	12.50

3.4. Opinions and experiences of farmers about consolidation

95.05% of the farmers reported attending the informational meetings held prior to the consolidation, and 94.79% stated that they were provided with sufficient information. The farmers who felt they were not adequately informed indicated that the implementation differed significantly from the plans presented during the informational meetings.

The rate of farmers who objected to the new parceling plans and/or ownership lists was 84.16%. The most common objection, accounting for 50.59%, was the change in parcel locations (*Table* 6). Other objections included parcel size (21.18%), the desire to remain in the same location (17.65%), the desire for consolidation (11.76%), parcel geometry (8.24%), land value (5.88%), geographical structure (5.88%), neighbor relations (3.53%), individual title deeds (1.18%), fixed facilities (1.18%), and soil structure (1.18%). These complaints suggest that the expectations set during the project planning phase were not adequately met. The research findings are similar to those of a study conducted by Sayın Kaya and Şişman (2020) in the province of Aksaray.

45.88% of the farmers stated that their objections did not yield any results, 35.29% said their objections were accepted, and 18.82% reported partial success. The proportion of farmers who indicated that the consolidation took longer than planned was 84.16%, while 24.75% reported experiencing income loss.

Table 6. Issues that farmers object to

Subject of objection	Frequency	%*
Change in parcel locations	43	50.59
Parcel size	18	21.18
Desire to remain in the same location	15	17.65
Desire for consolidation	10	11.76
Parcel geometry	7	8.24
Land value	5	5.88
Geographical structure (slope, cracks etc.)	5	5.88
Neighbor relations	3	3.53
Individual title deeds	1	1.18
Fixed facilities	1	1.18
Soil structure	1	1.18

* More than one answer is given by the farmers

Before consolidation, 93.07% of the farmers believed that the consolidation would be beneficial, but this percentage dropped to 41.58% after consolidation. Among the farmers who expressed negative views about the consolidation project, 48.08% stated that the outcomes did not match what was promised before the project, and 32.69% indicated that the implementation was flawed (*Table 7*). This shift in perception is largely attributed to the lack of transparency and communication throughout the project.

Table 7. Reasons for negative views after consolidation

Reasons for negative change	Frequency	%*
The outcomes did not match what was promised	25	48.08
The implementation was flawed	17	32.69
There was biased behavior	16	30.77
The personnel conducting the consolidation were inadequate	9	17.31
My new lands are less productive	7	13.46
No soil classification was conducted	4	7.69
I had to leave ancestral land	3	5.77
My lands became more dispersed (distance between parcels increased)	3	5.77

* More than one answer is given by the farmers

Tablo 8. Reasons for positive views after consolidation

Reason for positive change	Frequency	%*
Every parcel became accessible by road	32	76.19
My scattered parcels were consolidated	22	52.38
The number of shared titles decreased	14	33.33
The land was leveled, making agricultural operations easier	3	7.14
Public lands were distributed	2	4.76
Infrastructure (roads, irrigation, and drainage) facilities were established	1	2.38
Gathering the land parcels reduced my production costs	1	2.38

* More than one answer is given by the farmers

The aspects that farmers with positive views on the land consolidation project found favorable are presented in *Table 8*. 76.19% of the farmers reported that every parcel became accessible by road, 52.38% stated that their scattered parcels were consolidated, and 33.33% noted that the number of shared titles decreased, leading them to view the consolidation projects positively.

92.68% of the farmers reported incurring additional expenses due to land consolidation. Of these expenses, 62.50% were for leveling operations, 31.25% for boundary adjustment, and 6.25% for boundary delineation. The average cost per enterprise was calculated to be 34.307.89 TL.

4. Conclusions

In Tekirdağ province, the average land size of enterprises decreased by 4.35% following land consolidation. The higher reduction rate compared to the deductions recorded by the General Directorate of State Hydraulic Works (DSI) may be attributed to farmers working on lands with unclear ownership or on treasury lands.

The study found that the number of parcels per enterprise decreased by 42.37% after land consolidation. The reduction in the average number of parcels indicates that one of the objectives of the consolidation has been achieved.

After consolidation, the number of whole parcels decreased by 44.79%, and the number of shared parcels decreased by 43.62%. The decrease in whole parcels can be explained by the merging of adjacent whole parcels under a single title deed. The average parcel size per enterprise increased by 30.54%, reaching 34.79 da. The increase in average parcel sizes can be considered an indication of the effectiveness of land consolidation projects in enhancing the efficiency of tools and machinery.

The reduction in the number of parcels, coupled with the increase in the number of whole parcels and parcel area, is a structurally desirable situation for enterprises. This suggests that the land consolidation project has had a structurally positive impact on the enterprises.

According to the calculated JI and SI index values, the land consolidation reduced land fragmentation. However, the land consolidation project in Tekirdağ province has reduced land fragmentation less compared to other provinces. These results indicate that while the land consolidation project has decreased land fragmentation, better planning could further reduce fragmentation.

The consolidation rate (CR) based on the number of parcels per enterprise was calculated to be 35.40%. By consolidating the arable lands of enterprises, assessing the boundary losses due to fragmented lands, and saving time, labor, fuel, and depreciation costs associated with accessing the land. These changes are expected to contribute to increased income for enterprises, thereby benefiting the national economy.

Following the land consolidation project, the increase in average parcel size and the decrease in both the number of parcels and land fragmentation indicate that enterprises have achieved a more efficient structure. These findings support the first hypothesis of the study and demonstrate the positive structural impacts of land consolidation projects on enterprises.

The total distance of parcels from the enterprise (TDP) decreased by 11.88%, from 13.145 km to 11.584 km. The area-road length suitability (ARLS) decreased by 8.71% to 64.199. The reduction in the distance between enterprises and their parcels increases operational efficiency, which is one of the main objectives of land consolidation. The decrease in distance results in lower fuel consumption, reduced labor, and less time spent. This indicates that the land consolidation project has a positive economic impact on enterprises and support the second hypothesis.

The results of the study indicate that the land consolidation projects implemented in Tekirdağ province have failed to meet social expectations and have led to dissatisfaction among farmers. After the consolidation, the percentage of farmers who believed it was beneficial decreased from 93.07% to 41.58%, and 84.16% of the farmers raised objections regarding the process. Additionally, 48.08% of the farmers reported that the promises made were not fulfilled, and 32.69% stated that there were errors in the implementation. Based on these findings, the study's third hypothesis should be rejected.

While the primary goals of consolidation projects often center around economic and structural benefits, the social benefits can significantly affect the long-term success and perception of these projects. In this study, although land consolidation in Tekirdağ province resulted in tangible economic improvements such as reduced fuel consumption and enhanced operational efficiency, the social outcomes were less favorable. The significant drop in the percentage of farmers who believed that consolidation would be beneficial indicates a gap between expectations and outcomes. This dissatisfaction was largely due to the perceived shortcomings in communication and execution, with many farmers feeling that their concerns were either inadequately addressed or ignored.

Farmers' objections to the process, particularly related to the new parceling and ownership arrangements, further underscore the need for more inclusive and transparent project management. Over 84% of the farmers raised objections during the implementation phase, with many citing issues such as changes in parcel locations and dissatisfaction with parcel sizes. These objections highlight a broader issue of farmer engagement in the planning stages. For future projects,

it is crucial to establish more effective channels for farmer participation, where their input is not only solicited but genuinely integrated into the decision-making process. The success of land consolidation projects should be measured not only by economic gains but also by the level of social harmony and farmer satisfaction they achieve.

To address these social challenges, land consolidation efforts must prioritize the education and involvement of farmers from the earliest stages. Informational meetings alone are not enough; there needs to be a concerted effort to ensure that the information provided is clear, accessible, and tailored to the specific needs and concerns of the farming community. Additionally, building trust through consistent and transparent communication is essential. Farmers need to feel that they are active participants in the process and that their livelihoods and opinions are valued. By fostering a more participatory approach and addressing social concerns head-on, future land consolidation projects can not only improve economic efficiency but also contribute to stronger, more resilient agricultural communities.

Farmers in the region generally attend information meetings. However, due to insufficient understanding of the information provided at these meetings, farmers have reported that they are not adequately informed. The importance of farmers' participation in these meetings should be emphasized more. To ensure farmers are satisfied with land consolidation projects and for the projects to achieve successful outcomes, it is essential to accurately convey problems and demands during consultations and to gain farmers' trust. Farmers living outside the village have indicated that there are delays in receiving information about the meetings. To address this issue, new information dissemination methods need to be implemented. Sending information messages to farmers' registered mobile phone numbers and, if available, to their email addresses will ensure that meeting dates reach more farmers.

Farmers have reported that the lands allocated to them after the consolidation project are not suitable for cultivation (e.g., due to elevation differences, gullies, riverbeds). This issue is thought to stem from discrepancies between actual data and recorded data. The cadastral records are not up-to-date, riverbeds have shifted over time, and there are unregistered streams and small creeks that do not appear as rivers on maps, leading to inconsistencies between the mapped and actual land structures. Therefore, the database underpinning the consolidation, both spatial and non-spatial (title deeds and farmer information), must be current, complete, and accurate.

More than 90% of the farmers reported incurring additional expenses due to the land consolidation. Land improvement services within the fields are carried out after the completion of consolidation in nearby parcels. However, farmers undertake tasks such as land leveling and boundary adjustments themselves to avoid missing the planting season, as waiting for officials would cause them to miss out on the next year's crop. Therefore, such tasks should be completed before the planting preparation period to ensure farmers do not miss the cultivation season.

The primary reason for the positive perception of the land consolidation among farmers was determined to be the provision of roads to each parcel post-consolidation. The increase in the number of parcels with road access not only provides economic advantages to the enterprises but also contributes to social harmony.

In order to minimize the issues encountered in land consolidation and achieve the set goals, it is essential to prioritize educational and extension activities that foster a positive outlook among producers toward consolidation. During these activities, all details of the consolidation projects should be explained to farmers, and necessary information should be provided using data from successfully completed consolidation projects. It is believed that such information meetings can help eliminate farmers' prejudices about land consolidation.

The increase in successful consolidation projects could encourage agricultural landowners to adopt consolidation and contribute to its broader acceptance**.**

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Ethical Statement

This study was prepared under the permission numbered 254168, dated 05/01/23, from the Ethics Committee of Tekirdağ Namık Kemal University Social and Human Sciences Scientific Research and Publication.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Yılmaz, D.İ.; Design: Yılmaz, D.İ., Yılmaz, F.; Data Collection or Processing: Yılmaz, D.İ., Yılmaz, F.; Statistical Analyses: Yılmaz, D.İ., Yılmaz, F.; Literature Search: Yılmaz, D.İ., Yılmaz, F.; Writing, Review and Editing: Yılmaz, D.İ., Yılmaz, F.

References

Akçay. Y. and Angın. N. (1989). Land consolidation and evaluation of the applications on this subject in Turkey. U*nion of Turkish Chambers of Agriculture. Farmer and Village Journal*, 5(51): 9-14 (In Turkish).

Akdeniz, M. and Temizel, K. (2018). Evaluation of success in land consolidation projects by different indicators. *Anadolu Journal of Agricultural Sciences*, 33(2): 149- 161 (In Turkish).

Akkaya Aslan, Ş. T. (2018). Analysis of land fragmentation change before and after land consolidation: A case study of Denizli-Tavas province Pınarlar village. *Turkish Journal of Agricultural and Natural Sciences*, 5(3): 364-371 (In Turkish).

Aktaş, E., Bilgili, M. E., Akbay, A. Ö. and Bal, T. (2006). Determining Socioeconomic Factors Affecting Farmer Decision on Land Consolidation in Yemişli Village, Karataş Township of Adana Province. *VII. National Agricultural Economics Congress*, 13-15 September, P. 564-571, Antalya, Türkiye.

Arslan, H. and Tunca, E. (2013). Effect of land consolidation on the performance of irrigation projects. *Anadolu Journal of Agricultural Sciences*, 28(3): 126-133 (In Turkish).

Ayten, T. and Çay, T. (2017). Effects of the purpose expropriation of land consolidation to landholding. *World Academy of Science, Engineering and Technology International Journal of Environmental and Ecological Engineering*, 11(1): 79- 82.

Bilgin, C. (2014). *Land consolidation`s effectiveness and evaluation on farmers at Thracian region* (MSc. Thesis) Namik Kemal University, The Institute of Natural Sciences, Tekirdag, Türkiye.

Boztoprak, T., Demir, O., Çoruhlu, Y.E. and Nişancı, R. (2015). Investigating the land consolidations' effects on agricultural enterprises. *Selcuk University Journal of Engineering, Science and Technology*, 3(3): 1-11 (In Turkish).

Dağdelen, N., Tunalı, S.P., Gürbüz, T., Akçay, S. and Yılmaz, E. (2017). Assessment of land consolidation effectiveness in the Hamzabali Village of Aydin-Yenipazar. *Adnan Menderes University Journal of Agricultural Faculty*, 14(1): 45-50 (In Turkish).

Demetriou, D., Stillwell, J. and See, L. (2013). A new methodology for measuring land fragmentation. *Computers, Environment and Urban Systems*, 39(2013): 71-80.

Durduran, S. S., Cora, T., Bozdağ, A. and Okka, C. T. (2018). Spatial and functional evaluation of land consolidation application in Topraklık neighborhood in Konya province. *Omer Halisdemir University Journal of Engineering Sciences*, 7(2): 661-671 (In Turkish).

Ekinci, K. and Sayılı, M. (2010). A review of legislation to prevent fragmentation of agricultural land. *Journal of Agricultural Faculty of Gaziosmanpaşa University*, 27(2): 121-129 (In Turkish).

Eser, Ö. and Uçan, K. (2012). Determination of effectiveness of the land consolidation. *Kahramanmaraş Sütçü İmam University Journal of Agriculture and Nature*, 15(2): 38- 45 (In Turkish).

Gözener, B., Sayılı, M. and Mollaoğlu, E. (2016). Determination of Farmers' Behaviors Regarding Land Consolidation: The Example of Bafra District of Samsun Province. *XII. Agricultural Economics Congress*, 25-27 May, P. 263-272, Isparta, Türkiye.

Gürgenç Irmaklı, P. and Aydın, A. (2022). Contribution of land consolidation to agriculture and agricultural mechanization; Çanakkale-Biga-Derekoy example. *Journal of Tekirdag Agricultural Faculty*, 19(3): 582-599 (In Turkish).

İkikat Tümer, E., Akbay, C. and Şahin, Z. (2016). Analysis of the Effects of Land Consolidation on Producers: The Case of Şanlıurfa Province. *XII. Agricultural Economics Congress*, 25-27 May, P. 281-288, Isparta, Türkiye.

Januszewski, J. (1968). Index of land consolidation as a criterion of the degree of concentration. *Geographia Polonica*, 14: 291-296.

Kesici Bahar, S. (2019). *Evaluation of agricultural management costs pre-and postland consolidation projects*. (MSc. Thesis). Bursa Uludağ University, The Institute of Natural Sciences, Bursa, Türkiye.

Kır, M. (2012). *Evaluaton of land consolidation according to the agricultural land services in the village of Cemalettin, Boyabat, Sinop*. (MSc. Thesis). Gaziosmanpaşa University, The Institute of Natural Sciences, Tokat, Türkiye.

Kirmikil, M. and Aydus, D. (2018). The effects of land consolidation projects on fuel costs and agricultural mechanization in rural areas. *Süleyman Demirel University Journal of Agricultural Faculty*, 1st International Congress on Agricultural Structures and Irrigation Special Issue: 31-42 (In Turkish).

Kumbasaroğlu, H. and Dağdemir, V. (2007). Economic analysis of farms with respect to land fragmentation in Central district of Erzurum province. *Atatürk University Journal of Agricultural Faculty*, 38 (1): 49-58 (In Turkish).

Küsek, G. (2014). Legal status and historical developments of land consolidation in Turkey. *Çukurova University Journal of the Faculty of Agriculture*, 29 (1):1-6 (In Turkish).

Kuşlu, Y. and Ertem, E. (2019). Evaluation of the land consolidation project of the Beypınarı district of Erzurum province in terms of road network adequacy. *Atatürk University Journal of Agricultural Faculty*, 50 (3): 274-281 (In Turkish).

Kuzu, H. and Değirmenci, H. (2020). The effect of land consolidation projects on agricultural mechanization management. *Kahramanmaraş Sütçü İmam University Journal of Agriculture and Nature*, 23(3): 655-662 (In Turkish).

Kuzu, H., Arslan, F. and Değirmenci, H. (2018). Analysis of roads in land consolidation projects: A case study of Türkeli village in Şanlıurfa/Turkey. *Süleyman Demirel University Journal of Agricultural Faculty,* 1st International Congress on Agricultural Structures and Irrigation Special Issue: 19-25 (In Turkish).

Lök, E. and Değirmenci, H. (2019). Land fragmentation analysis of land consolidation project: A case study of Hasaköy and Bağlama villages in Niğde. *Kahramanmaraş Sütçü İmam University Journal of Agriculture and Nature*, 22(5): 744-750 (In Turkish).

Mc Garigal, K. and Marks, B. J. (1995). FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. General Technical Report. PNWGTR-351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 122 p.

Mesci, O. and Karlı, B. (2018). Socio-economic analysis of farms in the area of land consolidation in Isparta province. *Mustafa Kemal University Journal of Agricultural Faculty*, 23(1): 106-114 (In Turkish).

Official Gazette (2017). Decision on land consolidation in some places and exclusion of some places from the scope of land consolidation. https://www.resmigazete.gov.tr/eskiler/2017/03/20170311-28.pdf (Accessed Date: 12.07.2023).

Official Gazette (2019). Land consolidation and on-field development services implementation regulation https://www.resmigazete.gov.tr/eskiler/2019/02/20190207-5.htm (Accessed Date: 10.07.2023).

Platonova, D., Setkovska, L. and Jankava, A. (2011). Assessment Principles of Land Fragmentation: Baltic Surveying. *11. International Scientific Conference of Agriculture Universities of Baltic States*, 11 - 13 May, P. 117-124, Jelgava, Latvia.

Polat, H. E. and Manavbaşı, İ. D. (2012). Determining the effects of land consolidation on fuel consumption and carbon dioxide emissions in rural area. *The Journal of Agricultural Sciences*, 18(2): 157-165 (In Turkish).

Popov, A. (2017). Assessment of land fragmentation of agricultural enterprises in Ukraine. *Economics and Management of National Economy*, 167(3-4): 56-60.

Sağlam, Ö. (2022). *Land consolidation effect on agriculture*. (MSc. Thesis). Bursa Uludağ University, The Institute of Natural Sciences, Bursa, Türkiye.

Sayın Kaya, M. and Şişman, A. (2020). Investigation of objections in parceling phase in land consolidation projects. *Turkish Journal of Land Management*, 2(1): 25-32 (In Turkish).

Simmons, A. J. (1964). An index of farm structure with a Nottinghamshire example. *East Midlands Geographer*, 3: 255-261.

Şişman, C. and Bilgin, C. (2016). The success of land consolidation applications at farm level in Thrace region. *Journal of Tekirdag Agricultural Faculty*, 13(4): 52-60 (In Turkish).

Takka, S. (1993). Land Consolidation, Kültür Teknik Derneği Yayınları, Ankara, Türkiye (In Turkish).

Tunalı, S. P., Dağdelen, N. (2018). Evaluation of Some Land Consolidation Studies Made in Denizli - Tavas Plain. *COMU Journal of Agriculture Faculty*, 6(2): 58-65 (In Turkish).

Yamane, T. (2001). Basic Sampling Methods. (tran.. Esin, A., Aydın, C. and Bak, M.A.). Literatür Yayıncılık, İstanbul, Türkiye.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Mikrodalga Kurutma Yöntemiyle Üretilen Karpuz Cipslerinde Güç değerlerinin Kuruma Kinetikleri, Enerji Tüketimi ve Renk Kriterleri Özelliklerine Etkisi

Effect of Power Values on Drying Kinetics, Energy Consumption and Color Criteria Properties of Watermelon Chips Produced by Microwave Drying Method

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Öz

Karpuz birçok besin değerini bünyesinde barındıran ve bol sulu kabakgillerden olan tarımsal bir üründür. Karpuz cipsi üretiminin gelişmesi hem ülke olarak hem de küresel boyutta taze ürünlere alternatif fonksiyonel bir gıda olması açısından önemlidir. Bu çalışmada, karpuz cipsi üretimi için mikrodalga tekniği kullanılarak 180, 360 ve 540 W güç değerlerinde taze karpuz dilimleri kurutulmuştur. Çalışmanın amacı, karpuz cipsi üretiminde kinetik, kalite özellikleri ve enerji tüketim parametreleri açısından en uygun mikrodalga güç seviyesini tespit etmektir. Kurutma işlemlerinde için kuruma süresi, kuruma oranı, nem oranı, renk parametreleri, efektif nem difüzyonu, özgül nem çekme oranı (SMER) ve özgül enerji tüketimi (SEC) değerleri belirlenmiştir. Karpuz cipsi üretiminde en kısa kuruma süresi 540 W güçte kurutulan örneklerde 11 dakika olarak belirlenmiştir. En uzun kuruma süresi ise 180 W güçte 48.50 dakika olarak belirlenmiştir. Kurutma işlemlerinde 180, 360 ve 540 W mikrodalga güç değerleri için tespit edilen kuruma oranları sırayla 0.200, 0.530 ve 0.939 g nem g kuru madde.dakika^{-1} olarak tespit edilmiştir. Taze karpuz dilimlerin *L*, *a* ve *b* değerleri sırasıyla 43.17, 31.32 ve 20.59 olarak belirlenmiştir. Taze dilimlere en yakın renk değerleri 360 W güç değerinde kurutulan örneklerde belirlenmiştir. Mikrodalgada 360 W güç değerinde kurutulan örneklerin *L*, *a* ve *b* değerleri sırasıyla 41.35, 16.56 ve 12.07 olarak tespit edilmiştir. Kurutma işlemlerinin efektif nem difüzyon değerlerinin 3.74x10^{-11}-2.27.10^{-10} m^2.s^{-1} arasında değiştiği tespit edilmiştir. En yüksek özgül nem çekme oranı (SMER) 540 W güçte kurutulan örneklerde ortalama 0.0662 kg.kWh^{-1} olarak belirlenmiştir. En düşük özgül enerji tüketim (SEC) değeri 540 W güçte kurutulan örneklerde 14.52 kW.kg^{-1} olarak hesaplanmıştır. Bu çalışmada kuruma süresi, efektif nem difüzyonu ve enerji parametreleri açısından karpuz dilimlerinin mikrodalgada 540 W güç değerinde kurutulması önerilmektedir. Renk değerleri açısından karpuz cipsi üretiminde 360 W mikrodalga güç değerinde kurutulması önerilmektedir.

Anahtar Kelimeler: Karpuz cipsi, Kuruma kinetiği, Renk kalitesi, Enerji tüketimi, Mikrodalga enerji

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Abstract

Watermelon is an agricultural product belonging to the cucurbit family, known for its high water content and various nutritional values. The development of watermelon chip production is important as it serves as a functional food alternative to fresh products, both nationally and globally. In this study, fresh watermelon slices were dried using the microwave technique at power values of 180, 360, and 540 W. The aim of the study is to identify the optimal microwave power values in terms of drying kinetics, quality characteristics, and energy consumption parameters for watermelon chip production. During the drying processes, the drying time, drying rate, moisture content, color parameters, effective moisture diffusion, specific moisture extraction rate (*SMER*), and specific energy consumption (*SEC*) values were determined. The shortest drying time was found to be 11 minutes for samples dried at 540 W. The longest drying time was determined to be 48.50 minutes at 180 W. The drying rates for 180, 360, and 540 W microwave power values were found to be 0.200, 0.530, and 0.939 g moisture g.dry matter.minute^{-1}, respectively. The *L*, *a*, and *b* values of fresh watermelon slices were determined as 43.17, 31.32, and 20.59, respectively. The closest color values to fresh slices were found in samples dried at 360 W, with *L*, *a*, and *b* values of 41.35, 16.56, and 12.07, respectively. The effective moisture diffusion values during the drying processes were found to range between 3.74x10^{-11} and 2.27x10^{-10} m^2.s^{-1}. The highest *SMER* was determined to be an average of 0.0662 kg.kWh^{-1} for samples dried at 540 W. The lowest *SEC* value was calculated as 14.52 kW.kg^{-1} for samples dried at 540 W. This study recommends drying watermelon slices in a microwave at a power level of 540 W in terms of drying time, effective moisture diffusion, and energy parameters. For color values, drying at 360 W microwave power is suggested for watermelon chip production.

Keywords: Watermelon chips, Drying kinetics, Color quality, Energy consumption, Microwave energy

1. Giriş

Kabakgiller familyasından olan karpuz (*Citrullus lanatus*) Afrika ülkelerine ait bir kültür bitkisidir (Doymaz, 2014). Yüksek nem içeriği ve tatlı aromasıyla birlikte özellikle yaz aylarında susuzluk giderici meyve olarak tüketilmektedir (Nakilcioğlu-Taş ve ark., 2021). Karpuz yüksek nem içeriği (~%90), antioksidan, fenolik bileşikler, karotenoidler (β-karoten ve likopen), vitaminler (A, B, C ve E) ve belirli aminoasitler (sitrullin) bünyesinde bulundurmaktadır (Akyıldız ve ark., 2017). Karpuz bünyesinde bulundurduğu maddeler sayesinde insanları kansere karşı ve DNA gibi molekülleri oksidatif hasara karşı korumakta bünyesinde bulundurduğu likopen sayesinde kırmızı rengi almaktadır (Oberoi ve Sogi, 2015a). Taze karpuz meyvesinin, mevsimlik bir ürün olmasından dolayı tüm yıl boyunca bulunması zordur. Meyvenin yüksek besin içeriği göz önünde bulundurulursa yıl boyunca tüketilmesi sağlık açısından yararlı olabilir (Nakilcioğlu-Taş ve ark., 2021). Dünya genelinde doğal gıda ve sağlıklı atıştırmalıklara artan talep yeni ürünleri ortaya çıkartmayı gerekli hale getirmiştir. Kurutulmuş ürünler bu talepleri karşılamak açısından tüketiciler için yenilikçi bir ürün alanı olarak büyük öneme sahiptir. Meyve cipsleri ağırlıkta ve hacimde sağladığı avantajlardan dolayı nakliye masraflarını en aza indirmekte ve bununla birlikte biyoaktif maddelerin daha yoğun hale gelmesinden dolayı insan diyetlerinde çok fazla tercih edilmektedir (Du ve ark., 2013; Zou ve ark., 2013). Meyve cipsi üretiminde uygulanan yağda kızartma yöntemi lezzet ve gevreklik açısından insanlar tarafından beğenilen bir yöntemdir. Ancak yağda kızartma yöntemiyle üretilen meyveler çok fazla yağ emmesinden dolayı sağlık açısından olumsuz yönler içermektedir vardır (Saxena ve ark., 2012; Taib ve ark., 2013). Kurutma işlemi, belirtilen olumsuz yöntemlerden uzak kalarak ve sunduğu bazı avantajlardan dolayı kurutma işlemi meyve cipsi üretiminde uygulanan en genel yöntemlerdendir.

Kurutma işlemi kısaca, nem içeriğinin taze üründen uzaklaştırılması olarak tanımlanabilir. Bu işlemdeki temel amaç enzimatik reaksiyonlar sonucunda oluşabilecek bozulmaları önlemek ve bu süreçte ürünlerin aroma, tat ve renk özelliklerini korumaktır (Bonazzi ve Dumoulin, 2011). Bilenen en eski kurutma yöntemi açık alanlara serilerek güneşte ve gölgede kurutmadır. Maliyet açısından önemli avantajlar sağlayan çevreci bir yöntem olsa da güneşte kurutma işleminin yılın her döneminde yapılamaması, geniş alanlara ihtiyaç duyulması, ürünün istenilen nem seviyesine düşürülememesi ve çevresel faktörlerden (toz, yağmur rüzgâr, böcekler, kuşlar vb.) olumsuz etkilenmesi gibi bazı dezavantajları vardır (Purohit ve ark., 2006; Sharma ve ark., 2009; Taşkın ve ark., 2021). Kurutma işlemlerinde yaygın olarak kullanılan diğer bir yöntem ise sıcak havayla kurutmadır. Sıcak havayla kurutma işleminde, ısı ürünün dışından içerisine doğru difüze olur. Bu yöntem kuruma süresinin uzamasına, daha fazla enerji tüketilmesine ve daha düşük kalite özelliklerinin meydana gelmesine neden olmaktadır (Aksüt ve ark., 2023). Günümüzde popüler hale gelen mikrodalga kurutma işleminde ısı sıcak havayla kurutma işleminden farklı olarak içerden dışarı doğru difüze olur. Bu durum kuruma süresinin azalmasına ve daha az enerji tüketilmesine neden olmaktadır (Yılmaz ve Alibaş, 2021). Kurutma işlemlerinde gerçekleşen enerji tüketimi değerlerinin yüksek olduğu bildirilmektedir. Ülkelerin toplam enerji tüketimlerinin ortalama %10-25 oranının yalnızca kurutma endüstrisi ve işlemlerinde tüketildiği bilinmektedir (Mujumdar ve Law, 2010). Bu nedenle hem üretim maliyetinin azalması hem de sürdürülebilir olması için kurutma işlemlerinde enerji tüketiminin azaltılmasına yönelik farklı tekniklerin geliştirilmesi önemlidir. Karpuz kurutma ile ilgili literatürde bazı çalışmalar vardır. Akyıldız ve ark. (2017), çalışmalarında karpuz dilimlerini konveksiyonel (70 ºC) ve dondurarak (-66 ºC, +5 mtorr) kurutmuş ve bazı kalite özelliklerini incelemişlerdir. Çalışma sonucunda dondurularak kurutulan ürünlerin L (parlaklık) ve hue değerleri artarken, kırmızılık (a) değerinin azaldığını ve en fazla toplam renk değişim (ΔE) değerlerinin gerçekleştiğini bildirmişlerdir. Chakraborty ve Mondal (2017), çalışmalarında karpuzun ozmotik dehidrasyonu ve kızılötesi destekli vakumlu kurutucuda kuruma hızını artırmak amacıyla aralıklı zorlanmış CO_2 konveksiyon yöntemiyle kurutmuşlardır. Çalışma sonucunda ozmotik dehidrasyonu ön işlem olarak önerdikleri, aralıklı taşıyıcı gazın (CO_2) kontrol grubuna göre kuruma süresini 30 dakika kadar azalttığını daha düşük aktivasyon enerjisi ve yüksek enerji verimliliği sağladığını bildirmişlerdir. Tepe (2023), doktora tezi çalışmasında kavun ve karpuz cipsi üretmek için farklı kurutma yöntemlerinin ve ön işlemlerin kuruma ve bazı kalite parametrelerine olan etkilerini araştırmıştır. Karpuz örneklerini konvektif kurutucuda, mikrodalga kurutucuda ve hibrit (sıcak hava+mikrodalga) kurutucuda kurutmuştur. Çalışma sonucunda ön işlem, sıcaklık ve güç artışıyla kuruma sürelerinin azaldığını tespit ederken efektif kütle difüzyon değerlerinin arttığını belirtmiştir. En yüksek renk değişim değerlerinin mikrodalga ve hibrit kurutma yöntemlerinde meydana geldiğini bildirmiştir.

Bu çalışmada, karpuz cipsi üretiminde mikrodalga güç değerlerinin kuruma oranı, nem oranı, renk değerleri, efektif nem difüzyonu, özgül nem çekme oranı ve özgül enerji tüketimine olan etkilerini belirlemek amaçlanmıştır.

2. Materyal ve Metot

2.1. Ham materyal

Çalışmada kullanılan karpuz Tokat İli'n deki yerel bir semt pazarından satın alınarak çalışma sonlanana kadar buzdolabı koşullarında +4±0.5 ºC sıcaklıkta muhafaza edilmiştir. Kurutma işlemleri Tokat Gaziosmanpaşa Üniversitesi Biyosistem Mühendisliği bölümü kurutma laboratuvarında gerçekleştirilmiştir.

2.2. Kurutma işlemi

Kurutma işlemleri için Vestel Marka MD-GD23 model 2450 MHz (Türkiye) mikrodalga kurutma fırını kullanılmıştır ve ürünler yaş baza göre (y.b) < % 7 nem değerine kadar kurutulmuştur. Kurutma işlemleri mikrodalga kurutucuda 180, 360 ve 540 W güç değerlerlerinde yapılmıştır. Kurutulan örneklerin ağırlık değişimini takip etmek için AND marka GF-300 model hassas terazi (0.01 g) kullanılmıştır. Kurutma işlemleri sonlanana kadar karpuz örnekleri 30 saniye ve 1 dakika aralıklarla ağırlık ölçümleri yapılmıştır.

2.3. Kuruma oranı (KO)

Karpuz cips örneklerinin kuruma oranlarının hesaplanması için 1 numaralı eşitlik kullanılmıştır (Doymaz ve ark., 2006).

$$DR = \frac{M_t - M_{(t+dt)}}{dt} \quad \text{(Eş. 1)}$$

Burada: M_t; t anındaki nem içeriği (g nem.g kuru madde^{-1}), dt; dakika, DR; kuruma oranı (g nem.g kuru madde dakika^{-1}).

2.4. Nem oranı (NO)

Kurutma işlemi esnasında karpuz cips örneklerinden uzaklaşan nem miktarının süreye bağlı oranlarını belirlemek için 2 numaralı eşitlik kullanılmıştır (Maskan, 2000).

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \text{(Eş. 2)}$$

Burada: MR; Nem oranı, M; Ürünün anlık nem içeriği (g nem.g kuru madde^{-1}), M_e; Ürünün denge nem içeriği (g nem.g kuru madde^{-1}), M_o; Ürünün ilk nem içeriğidir (g nem.g kuru madde^{-1}).

2.5. Efektif nem difüzyonu

Kurutma işlemlerinde karpuz cipslerinden uzaklaşan nemin efektif nem difüzyon değerlerini hesaplamak için 3 numaralı eşitlik kullanılmıştır (Corzo ve ark., 2008).

$$\ln MR = ln\frac{8}{\pi^2} - \frac{\pi^2 \cdot D_{eff} \cdot t}{4L^2} \quad \text{(Eş. 3)}$$

Burada: D_{eff}; kütle difüzyon değerini (m^2 s^{-1}), L; ürünün kalınlık değerinin (m) yarısı, t: ise ürünün kuruma süresini göstermektedir.

2.6. Özgül nem çekme oranı

Kurutma işlemlerinde birim enerji değerine karşılık uzaklaşan nem miktarını (SMER) hesaplamak için 4 numaralı eşitlik kullanılmıştır (Surendhar ve ark., 2019).

$$SMER = \frac{Kurutma\ işleminde\ uzaklaşan\ nem\ (kg)}{Kurutucunun\ tükettiği\ enerji\ (kWh)} \quad \text{(Eş. 4)}$$

Burada: SMER; özgül nem çekme oranı (kg kWh^{-1}).

2.7. Özgül enerji tüketimi

Kurutma işlemlerinde bir kilogram nemi uzaklaştırmak için harcanan enerji miktarını ise 5 numaralı eşitlik kullanılarak hesaplanmıştır (Tan ve ark., 2012).

$$SEC = \frac{E_t}{m_w} \quad \text{(Eş. 5)}$$

Burada: *SEC*; özgül enerji tüketimi (kWh.kg nem^{-1}), E_t; toplam tüketilen enerji (kWh), m_w; uzaklaşan nem miktarı (kg).

2.8. Renk değerleri

Taze ve cips haline gelen karpuz örneklerinin parlaklık (*L*), kırmızı/yeşil (*a*) ve sarı/mavi (*b*) değerlerini ölçmek için CR400 model/Japan renk ölçüm cihazı kullanılmıştır. Ölçülen değerler laboratuvar ölçüm değerleri olup bunlar kullanılarak kroma, hue ve toplam renk değişim değerleri hesaplanmıştır. Kroma değeri ürünün renk tonunu belirtirken solgun renklerde düşük, canlı renklerde ise yüksek değerler hesaplanmaktadır. Hue değeri ürün renk değerlerinin 360º'lik bir radyanttaki yerini belirtmektedir. Sınır açısı değerlerinden 0º; kırmızı, 180º; yeşil, 90 º; sarı ve 270º; mavi ana renkleri temsil etmektedir. Toplam renk değişim değeri ise kurutma işlemlerinde ısıyla parçalanan (enzimatik olmayan) renk pigmentlerinin toplam değişimini göstermektedir. Hesaplanan renk değerleri daha çok ürünün ticari değeri ve tüketici için karar verici olması açısından önemlidir. Bu değerleri hesaplamak için 6, 7 ve 8 numaralı eşitlikler kullanılmıştır.

Renk değeri	Eşitlik	Kaynak	No
Kroma	$C = (a^2 + b^2)^{1/2}$	Ramallo ve Mascheroni (2012)	(Eş. 6)
Hue	$h^\circ = \tan^{-1}(\frac{b}{a})$	Alemrajabi ve ark. (2012)	(Eş. 7)
Toplam renk değişimi	$\Delta E = \sqrt{(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2}$	Tan ve ark. (2001)	(Eş. 8)

L, a ve *b* değerleri taze ürünlere ait parlaklık, kırmızılık ve sarılık renk değerlerini göstermektedir *L*, a** ve *b** değerleri kurutulan örneklere ait parlaklık, kırmızılık ve sarılık renk değerlerini göstermektedir.

2.10. İstatistiksel analiz

Üretilen karpuz cipslerinin renk, ve fiziko-kimyasal özelliklerini istatistiksel açıdan değerlendirmek için SPSS 22. programında Duncan çoklu karşılaştırma testi *(P<0.05)* yapılmıştır.

3. Araştırma Sonuçları ve Tartışma

3.1. Kuruma verileri

Karpuz örnekleri mikrodalga kurutucuda belirtilen nem seviyesine kadar (%7) kurutulmuştur. Kuruma süreleri 180, 360 ve 540 W güçte sırasıyla 48.5, 19.5 ve 11 dakika olarak belirlenmiştir. Mikrodalga kurutucuda kurutulan karpuz cipslerine ait kuruma eğrileri *Şekil 1*' de verilmiştir.

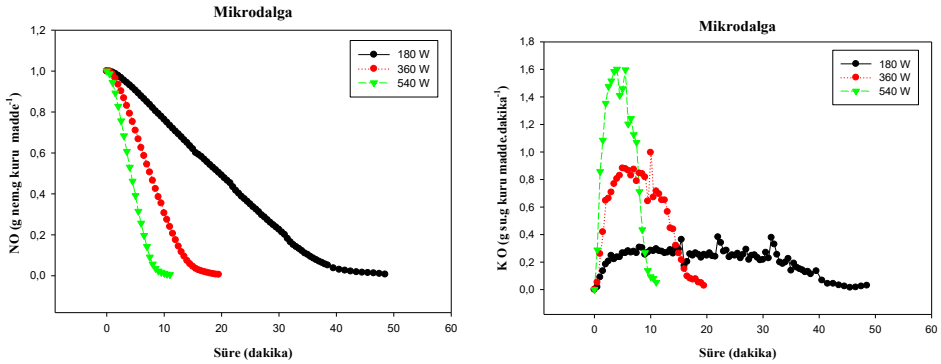

Figure 1. Drying kinetics curves

Şekil 1. Kuruma kinetiği eğrileri

Şekil 1' e göre karpuz dilimlerine uygulanan farklı mikrodalga güç değerleri ürünlerin kuruma ve nem oranlarını etkilemiştir. Güç değerlerindeki artış istenilen nem seviyesine daha kısa sürede ulaşmasını sağlamıştır. Mikrodalga güç değerlerindeki artışın karpuz dilimlerinin doku yapısındaki direnci daha iyi kırdığı ve üründen nem difüzyonunun daha yüksek olmasına sebep olduğu düşünülmektedir. Taşova ve ark. (2023a), çalışmalarında balkabağı cipslerinde benzer sonuçlar bulduklarını ifade etmişlerdir. Kurutma işlemlerinin 180, 360 ve 540 W mikrodalga güç değerlerine göre kuruma oranları sırayla 0.200, 0.530 ve 0.939 g nem g kuru madde.dakika^{-1} olarak hesaplanmıştır. Bu durumda, mikrodalga güç artışının karpuz örneklerinin hücre yapısındaki basınç değerlerini yükselterek nemin daha hızlı uzaklaşmasına neden olduğu düşünülmektedir. Yıldız ve Reyhan (2023) çalışmasında mikrodalga güç değerinin limondan uzaklaşan nem miktarı arasında olumlu bir korelasyon olduğunu bildirmişlerdir. Arslan ve ark. (2021) infrared kurutma sistemiyle kurutulmuş geleneksel ve organik biber üretmişlerdir. Çalışmalarında infrared sıcaklık değerinin artmasıyla kurutma işlemlerin nem oranı ve kuruma oranı değerleri artmıştır. Literatürde Doymaz (2014) ve Dhurve ve ark. (2022), karpuz çekirdekleri için benzer sonuçlar elde ettiklerini ifade etmişlerdir.

3.2. Efektif nem difüzyon değerleri

Karpuz cipslerinin efektif nem difüzyon değerine mikrodalga güçlerinin etkisi *Tablo 1*' de verilmiştir.

Tablo 1. Karpuz cipslerine ait efektif nem difüzyon değerleri

Table 1. Effective moisture diffusion values of watermelon chips

Mikrodalga güç değerleri	Efektif nem difüzyon (m^2 s^{-1})	R^2
180 W	$3.74x10^{-11}$	0.838
360 W	$1.22x10^{-10}$	0.910
540 W	$2.27x10^{-10}$	0.925

Tablo 1' e göre karpuz örneklerinin kütle difüzyon değerlerine mikrodalga güç değerlerinin etkili olduğu tespit edilmiştir. Mikrodalga güç değerlerinin artmasının karpuz dilimlerinin kütle difüzyon değerlerine artırıcı bir etki yaptığı tespit edilmiştir. Taşova ve ark. (2023b), mikrodalga (360 ve 720 W), sıcaklık kontrollü mikrodalga (50 ve 70 ºC) ve hibrit (mikrodalga+sıcak hava (350 W+50 ºC ve 350 W+70 ºC)) kurutucular ile kuruttukları balıkların kurutma işlemlerinde sıcaklık ve mikrodalga güç değerlerinin artmasıyla efektif difüzyon değerlerinin de arttığını saptamışlardır. Literatürdeki ve bu çalışmadaki bulguların uyumlu olduğu görülmüştür. Oberoi ve Sogi (2015b), karpuz posasını akışkan yataklı kurutucuda ve konvektif kurutucuda farklı sıcaklıklarda (50, 60 ve 70 ºC) ve arklı besleme hızlarında (2, 4 ve 6 kg/m^2) kurutmuşlardır. Kurutma işlemlerinin kütle difüzyon değerlerinin $0.35\text{-}3.54x10^{-8}$ m^2 s^{-1} arasında değiştiğini bildirmişlerdir. Nguyen ve ark. (2022), çalışmalarında düşük sıcaklık (20, 25 ve 30 ºC) ve düşük mikrodalga güçlerinde (1.5, 3.0 ve 4.5 W/g) çalışan hibrit bir kurutucu ile acı kavun kurutma çalışması yapmışlardır. Çalışma sonucunda ise kütle difüzyon değerlerini $1.14\text{-}2.59x10^{-8}$ m^2 s^{-1} aralığında değiştiğini tespit etmişlerdir. Literatürdeki çalışma kapsamında tespit edilen bulguların bu çalışmada elde edilen verilerden kısmen daha büyük olduğu görülmektedir. Bu noktada, kullanılan karpuz örneklerinin ilk nem içeriği, doku yapısı, ürünün yapısındaki besin maddelerinin (şeker, lif vb.) oranının, kütle difüzyonun daha büyük olmasına neden olduğu düşünülmektedir.

3.3. Enerji tüketim parametreleri

Karpuz örneklerine ait kurutma işlemlerinin SMER, SEC ve toplam enerji tüketim değerleri *Tablo 2*'de verilmiştir**.**

Tablo 2. Karpuz örneklerine ait enerji parametreleri

Table 2. Energy parameters of watermelon samples

Yöntem	Mikrodalga güç değerleri	*SMER* (kg kWh^{-1})	*SEC* (kWh kg^{-1})	Toplam enerji tüketimi (kWh)
Mikrodalga	180 W	0.0429	23.30	0.226
	360 W	0.0587	17.04	0.176
	540 W	0.0662	14.52	0.156

Kurutma işlemleri esnasında zamana bağlı (anlık) tüketilen enerji değerleri *Şekil 2*' de verilmiştir.

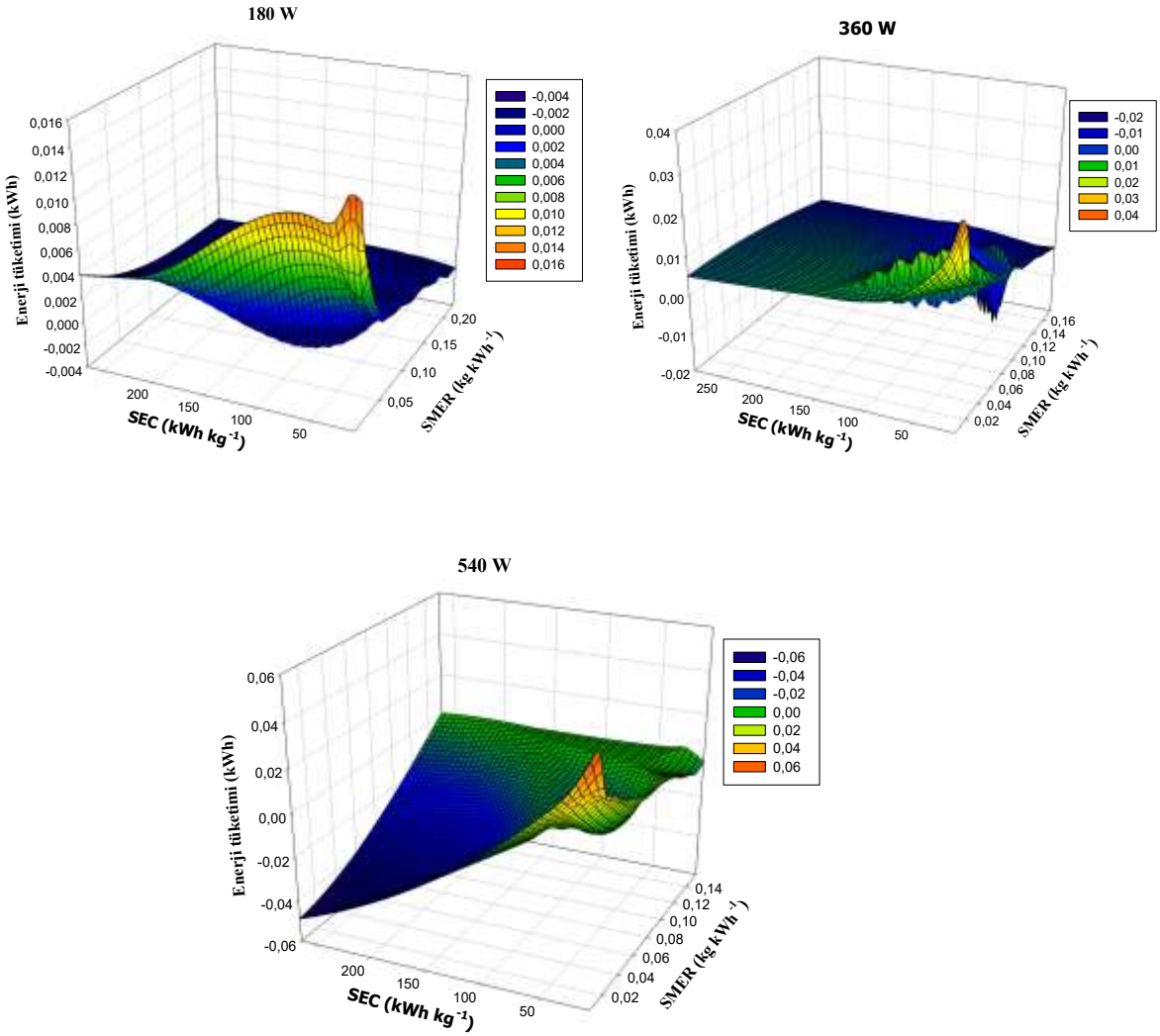

Figure 2. SMER, SEC and total energy consumption values

Şekil 2. SMER, SEC ve toplam enerji tüketim değerleri

Tablo 2' ye göre mikrodalga güç değerleri kurutma işlemlerinin enerji parametrelerini etkilemiştir. Taşova ve Dursun (2024), çalışmalarında mikrodalga güç değerlerinin özgül nem çekme oranı ve özgül enerji tüketim değerlerini etkilediğini ifade etmişlerdir. Çalışmada mikrodalga güç değerlerinin artmasıyla işlemin kuruma süresi azalmıştır ve bu sebeple özgül nem çekme oranı (*SMER*) değerlerinin arttığı gözlemlenmiştir. Bu durum, yüksek mikrodalga güç değerlerinde yapılan kurutma işlemlerinde üründen daha fazla nem uzaklaştırıldığı için kWh enerji tüketim değerine düşen nem miktarının da artmasından kaynaklanmaktadır. Tunckal ve ark. (2022), ısı pompalı kurutucu ile kavun dilimlerini kurutma çalışması gerçekleştirmişlerdir. Çalışma sonucunda özgül nem çekme oranının (*SMER*) 0,125 ile 0,215 kg kWh^{-1} arasında değiştiğini bildirmişlerdir. Bu çalışmada literatürdeki çalışmadan daha düşük değerler elde edilmesinin nedeni, çalışmalardaki kurutucuların farklılığından kaynaklandığı düşünülmektedir. Literatürdeki çalışmada kullanılan kurutucu ile bu çalışmadaki kurutucu karşılaştırıldığında literatürdeki çalışmada kullanılan ısı pompalı kurutucunun kuruma süresi ve enerji tüketiminin daha yüksek olması etkili olduğu düşünülmektedir. Taşova ve Dursun (2024), köpük kurutma yöntemiyle kavun tozu ürettikleri çalışmada hazırladıkları kavun pürelerini mikrodalga kurutucuda (360, 540, 720 ve 900 W) kurutmuşlardır. Çalışma sonucunda kurutma işlemlerinin *SMER* değerlerini 0.024-0.047 kg kWh^{-1} arasında değiştiğini tespit etmişlerdir. Literatürdeki ve bu çalışmadaki farklılıkların kurutulacak olan ürünün fiziki (nem, doku yapısı ve hücre yapısı vb.) yapısından püre içerisine ekledikleri köpürtücü ve köpüğü stabilize etmek için kullandıkları maddelerden kaynaklı olduğu tahmin edilmektedir. Bu çalışmada, mikrodalga güç değerlerinin artmasıyla özgül enerji tüketim (*SEC*) değerleri azalmıştır. Bunun nedeni mikrodalga güç değerlerinin artmasıyla ürünün kuruma süresi azaldığı için tüketilen toplam enerji miktarları da azalmıştır. Bu

durum *SEC* değerlerinin azalmasına neden olmuştur. Zadhossein ve ark. (2021), çalışmalarında mikrodalga gücündeki bir artışın *SEC* değerlerini önemli ölçüde azaltabileceğini bildirmişlerdir. Çalışma kapsamında elde edilen bulguların literatürdeki bulgular ile uyumlu olduğu görülmektedir. Bu çalışmada elde edilen veriler doğrultusunda *SMER*, *SEC* ve toplam enerji tüketim değerlerinin birlikte olduğu 3D gösterimi *Şekil 2*' de verilmiştir.

3.4. Renk parametreleri

Taze ve kurutulmuş karpuz örneklerine ait ölçülen ve hesaplanan renk değerleri *Tablo 3*' te verilmiştir.

Tablo 3. Renk değerleri

Table 3. Color values

Yöntem	Mikrodalga güç değerleri	*L*	*a*	*b*	*C*	*h°*	*ΔE*
Taze	-	43.17^{a}	31.32^{a}	20.59^{a}	37.72^{a}	33.71^{a}	-
Mikrodalga	180 W	40.95^{a}	12.25^{c}	9.02^{c}	15.23^{c}	35.94^{a}	30.04^{a}
	360 W	41.35^{a}	16.56^{b}	12.07^{b}	20.50^{b}	35.06^{a}	28.71^{b}
	540 W	36.09^{b}	10.90^{c}	8.20^{c}	13.64^{c}	36.61^{a}	25.95^{b}

Tablo 3' e göre kurutularak elde edilen karpuz cipsi ile taze karpuz örneği arasında kırmızı (*a*), sarı (*b*) ve kroma (*C*) değerleri açısından istatistiksel olarak ($p<0.05$) fark bulunmuştur. Üretilen karpuz cipslerinin tazeye göre *L* (540 W hariç) ve hue (*h°*) değerini koruduğu tespit edilmiştir. Üretilen karpuz cipslerinin *a* ve *b* değerlerini tazeye göre koruyamadığı belirlenmiştir. Bunun nedeninin güç değerleri ve ısıl işleme maruz kalma süresi ile ilgili olduğu düşünülmektedir. Song ve ark. (2017), hibrit kurutucuda (mikrodalga+vakum) kabak kurutma çalışması gerçekleştirmişlerdir. Çalışma sonucunda *a* ve *b* değerlerindeki değişikliklerin karoten bozulmasına bağlı olabileceğini bildirmişlerdir. Mikrodalga kurutucuda kurutulan karpuz örneklerinin kroma değerlerinin tazeye göre azaldığı belirlenmiştir. Zia ve ark. (2023), yaptıkları karpuz kabuğu kurutma çalışmasında mikrodalga güç değerlerinin kroma değerlerini azalttığını tespit etmişlerdir. Bunun sebebinin üründeki proteinlerin, karbonhidratların ve karotenoidlerin termal bozulmaya karşı hassas olmasından kaynaklandığını ve bununla birlikte Maillard reaksiyonu gibi belirli reaksiyonların başladığını ifade etmişlerdir. Toplam renk değişimi (*ΔE*) en yüksek 180 W güçte kurutulan örneklerde tespit edilmiştir. Bu durum kuruma süresinin uzaması sonucunda örneklerin daha fazla ısıl işleme maruz kalmasından dolayı renk pigmentlerinin daha fazla kaybolmasından ileri gelmektedir. Bustos ve ark. (2018), yaptıkları çalışma sonucunda toplam renk değişimlerinin enzimatik ve enzimatik olmayan esmerleşme reaksiyonları ve uzun süreli kurutma işlemi sırasında renk pigmentlerinin bozulmasına neden olduğunu ifade etmişlerdir. Akyıldız ve ark. (2017), karpuz dilimlerini konveksiyonel (70 ºC) ve dondurarak (-66 ºC, +5 mtorr) kurutmuş ve bazı kalite özelliklerini incelemişlerdir. Çalışma sonucunda konveksiyonel yöntemle kuruttukları karpuz örneklerinin *L, a, b, C*, *h°* ve *ΔE* değerleri sırasıyla 50.47, 26.27, 28.26, 38.62, 47.15 ve 12.03 olarak belirlemişlerdir. Dondurarak kuruttukları karpuz örneklerinin *L, a, b, C*, *h°* ve *ΔE* değerlerini sırasıyla 72.50, 11.62, 20.10, 23.22, 59.99 ve 21.80 olarak tespit etmişler. Bu çalışma ve literatürdeki çalışmanın farklılığın nedeni farklı kurutucuların kullanılmasından dolayı olduğu düşünülmektedir. Çalışma sonucunda elde edilen bulgular doğrultusunda karpuz cipsi üretiminde mikrodalga kurutma yöntemi ile 360 W gücün uygulanması en uygun renk değerlerinin elde edilmesi açısından önerilmektedir.

4. Sonuç

Üretilen karpuz cipsilerinin kuruma kinetiği, enerji parametreleri ve kalite özelliklerine mikrodalga güç değerlerinin etki ettiği gözlemlenmiştir. Mikrodalga güç değerlerinin artmasının karpuz dilimlerinin kuruma ve nem oranları, efektif nem difüzyonu ve *SMER* değerlerinde artırıcı bir etki yaptığı gözlemlenirken, *SEC* değerlerinde azaltıcı bir etki yaptığı saptanmıştır. Kuruma süresi, efektif nem difüzyonu ve enerji parametreleri açısından karpuz cipsi üretiminde 540 W güç değerinin seçilmesi önerilirken, renk değerleri açısından 360 W güç değerinde kurutulması önerilmektedir. Bundan sonraki çalışmalarda karpuz cipsi üretiminde enerji ve kalite parametrelerini iyileştirmek için ön işlem ve farklı kurutucular kullanılarak araştırma yapılmasının mevcut sayısal verilere daha olumlu etkiler yapacağı düşünülmektedir.

Etik Kurul Onayı

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

Çıkar Çatışması Beyanı

Makale yazarları olarak aramızda herhangi bir çıkar çatışması olmadığını beyan ederiz.

Yazarlık Katkı Beyanı

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Kaynakça

Aksüt, B., Dursun, S. K., Polatcı, H. and Taşova, M. (2023). Effects of microwave dryers on the properties of Jerusalem artichoke: physico-chemical, thermo-physical, energy consumption. *Journal of Microwave Power and Electromagnetic Energy*, 57(1): 28-43. https://doi.org/10.1080/08327823.2023.2166005

Akyıldız, A., Polat, S. ve Ağçam, E. (2017). Konveksiyonel ve dondurarak kurutma yöntemlerinin karpuzun bazı kalite özelliklerine etkisi. *Gıda*, 42(2): 169-176. https://doi.org/10.15237/gida.GD16070

Alemrajabi, A. A., Rezaee, F., Mirhosseini, M. and Esehaghbeygi, A. (2012). Comparative evaluation of the effects of electrohydrodynamic, oven, and ambient air on carrot cylindrical slices during drying process. *Drying Technology*, 30: 88–96. https://doi.org/10.1080/07373937.2011.608913

Arslan, A., Soysal, Y. and Keskin, M. (2021). Infrared drying kinetics and color qualities of organic and conventional sweet red peppers. *Journal of Tekirdag Agricultural Faculty,* 18(2): 260-272. https://doi.org/10.33462/jotaf.750623

Bonazzi, C. and Dumoulin, E. (2011). Quality changes in food materials as influenced by drying processes. *Modern Drying Technology,* 3: 1-20. https://doi.org/10.1002/9783527631667.ch1

Bustos, M. C., Rocha-Parra, D., Sampedro, I., Pascual-Teresa, S. and Leon, A. E. (2018). The Influence of different air-drying conditions on bioactive compounds and antioxidant activity of berries. *Journal of Agricultural and Food Chemistry*, 66(11): 2714-2723. https://doi.org/10.1021/acs.jafc.7b05395

Chakraborty, R. and Mondal, P. (2017). Effects of intermittent CO_2 convection under far-infrared radiation on vacuum drying of pre-osmodehydrated watermelon. *Journal of the Science of Food and Agriculture*, 97(11): 3822-3830. https://doi.org/10.1002/jsfa.8246

Corzo, O., Bracho, N., Pereira, A. and Vasquez, A. (2008). Weibull distribution for modeling air drying of coroba slices. *LWT - Food Science and Technology*, 41(10): 2023-2028.

Dhurve, P., Arora, V. K., Yadav, D. K. and Malakar, S. (2022). Drying kinetics, mass transfer parameters, and specific energy consumption analysis of watermelon seeds dried using the convective dryer, *Materials Today: Proceedings*, 59(1): 926-932. https://doi.org/10.1016/j.matpr.2022.02.008

Doymaz, İ. (2014). Experimental study and mathematical modeling of thin-layer infrared drying of watermelon seeds. *Journal of Food Processing and Preservation*, 38(3): 1377-1384. https://doi.org/10.1111/jfpp.12217

Doymaz, İ., Tugrul, N. and Pala, M. (2006). Drying characteristics of dill and parsley leaves. *Journal of Food Engineering*, 77: 559-565.

Du, L. J., Gao, Q. H., Ji, X. L., Ma, Y. J., Xu, F. Y. and Wang, M. (2013). Comparison of flavonoids, phenolic acids, and antioxidant activity of explosion-puffed and sun-dried jujubes (ziziphus jujuba mill.). *Journal of Agriculture Food Chemical*, 61: 11840-11847.

Maskan, M. (2000). Microwave/air and microwave finish drying of banana. *Journal of Food Engineering*, 44: 71-78.

Mujumdar, A. S. and Law, C. L. (2010). Drying technology: trends and applications in postharvest processing. *Food Bioprocess Technology*, 3: 843-852.

Nakilcioğlu-Taş, E., Coşan, G. and Ötleş, S. (2021). Optimization of process conditions to improve the quality properties of healthy watermelon snacks developed by hot-air drying. *Journal of Food Measurement and Characterization*, 15: 2146–2160. https://doi.org/10.1007/s11694-020-00808-3

Nguyen, T. V. L., Nguyen, P. B. D., Tran, T. T. V., Tran, B. L. and Huynh, T. P. (2022). Low-temperature microwave-assisted drying of sliced bitter melon: Drying kinetics and rehydration characteristics. *Journal of Food Process Engineering*, 45(12): e14177. https://doi.org/10.1111/jfpe.14177

Oberoi, D. P. S. and Sogi, D. S. (2015a). Effect of drying methods and maltodextrin concentration on pigment content of watermelon juice powder. *Journal of Food Engineering,* 165: 172-178. https://doi.org/10.1016/j.jfoodeng.2015.06.024

Oberoi, D. P. S. and Sogi, D. S. (2015b). Drying kinetics, moisture diffusivity and lycopene retention of watermelon pomace in different dryers. *Journal of Food Science and Technology*, 52: 7377-7384. https://doi.org/10.1007/s13197-015-1863-7

Purohit, P., Kumar, A. and Kandpal. T. C. (2006). Solar drying vs. open sun drying: A framework for financial evaluation. *Solar Energy*, 80(12): 1568-1579.

Ramallo, L. A. and Mascheroni, R. H. (2012). Quality evoluation of pineapple fruit during drying process. *Food and Bioproducts Processing*, 99: 275-283.

Saxena, A., Bawa, A. S. and Raju, P. S. (2012). Effect of minimal processing on quality of jackfruit (*Artocarpus heterophyllus* L.) bulbs using response surface methodology. *Food and Bioprocess Technology*, 5(1): 348–358.

Sharma, A., Chen, C. R. and Lan, N. V. (2009). Solar-energy drying systems: A review. *Renewable Sustainable Energy Review*, 13(6–7): 1185-1210.

Song, J., Wang, X., Li, D. and Liu, C. (2017). Degradation kinetics of carotenoids and visual colour in pumpkin (Cucurbita maxima L.) slices during microwave-vacuum drying. *International Journal of Food Properties*, 20(sup1): 632-643. https://doi.org/10.1080/10942912.2017.1306553

Surendhar, A., Sivasubramanian, V., Vidhyeswari, D. and Deepanraj, B. (2019). Energy and exergy analysis, drying kinetics, modeling and quality parameters of microwave-dried turmeric slices. *Journal of Thermal Analysis and Calorimetry*, 136: 185–197.

Taib, M. R., Muhamad, I. I., Ngo, C. L. and Ng, P. S. (2013). Drying kinetics, rehydration characteristics and sensory evaluation of microwave vacuum and convective hot air dehydrated jackfruit bulbs. *Jurnal Teknologi*, 65(1): 51-57.

Tan, M, Chua, K. J., Mujumdar, A. S. and Chou, S. K. (2001). Effect of osmotic pre-treatment and infrared radiation of drying rate and color changes during drying of potato and pineapple. *Drying Technology*, 19(9): 2193-2207.

Taşkın, O., İzli, G. and İzli, N. (2021). Physicochemical and morphological properties of European cranberry bush powder manufactured by freeze-drying. *International Journal of Fruit Science*, 21(1): 1008-1017.

Taşova, M. and Dursun, S. K. (2024). Comparison of microwave assisted foam drying processes to improve the physicochemical properties and to reduce GHG values of the melon powder processes. *Biomass Conversion Biorefinery*, 1-8. https://doi.org/10.1007/s13399-024-05680-5

Taşova, M., Dursun, S. K., Özalan, O. N. and Çezik, F. (2023a). Effects of osmotic processes on the bio-active properties and physico-chemical of pumpkin chips produced by convective drying. *Iranian Journal of Chemistry and Chemical Engineering*, 43(4). https://doi.org/10.30492/IJCCE.2023.2001502.6008

Taşova, M., Polatcı, H. and Dursun, S. K. (2023b). Comparison of the performance of a modified temperature-controlled microwave dryer to improve heat-mass transfer, increase energy efficiency and preserve quality characteristics of shad (Alosa fallax nilotica). *International Communications in Heat and Mass Transfer*, 144: 106772. https://doi.org/10.1016/j.icheatmasstransfer.2023.106772

Tepe, T. K. (2023). *Kavun ve karpuz cipsi üretiminde farklı kurutma yöntemleri ve ön işlemlerin bazı kuruma ve kalite parametreleri üzerine etkisi.* (Doktora Tezi) Pamukkale Üniversitesi Fen Bilimleri Enstitüsü, Denizli, Türkiye.

Tunckal, C., Ozkan-Karabacak, A., Tamer, C.E., Yolcı-Omeroglu, P. and Goksel, Z. (2022). Mathematical modelling and optimization of melon slice drying with response surface methodology in a heat pump drying system. *Latin American Applied Research*, 52: 101–110. https://doi.org/10.52292/j.laar.2022.851

Yıldız, Z. ve Reyhan, S. (2023). Ozmotik dehidrasyon ve mikrodalga kurutma ile birlikte limon halkalarının kurutma koşullarının optimizasyonu. *Tekirdağ Ziraat Fakültesi Dergisi*, 20(4): 845-856. https://doi.org/10.33462/jotaf.1222365

Yılmaz, A. and Alibaş, İ. (2021). The impact of drying methods on quality parameters of purple basil leaves. *Journal of Food Process Preservation*, 45: e15638.

Zadhossein, S., Abbaspour-Gilandeh, Y., Kaveh, M., Szymanek, M., Khalife, E. D. Samuel, O., Amiri, M. and Dziwulski, J. (2021). Exergy and energy analyses of microwave dryer for cantaloupe slice and prediction of thermodynamic parameters using ANN and ANFIS algorithms. *Energies*, 14(16): 4838. https://doi.org/10.3390/en14164838

Zia, S., Khan, M. R. and Aadil, R. M. (2023). Kinetic modeling of different drying techniques and their influence on color, bioactive compounds, antioxidant indices and phenolic profile of watermelon rind. *Food Measure*, 17: 1068–1081. https://doi.org/10.1007/s11694-022-01674-x

Zou, K., Teng, J., Huang, L., Dai, X. and Wei, B. (2013). Effect of osmotic pretreatment on quality of mango chips by explosion puffing drying. *LWT Food Science Technology,* 51: 253–259.