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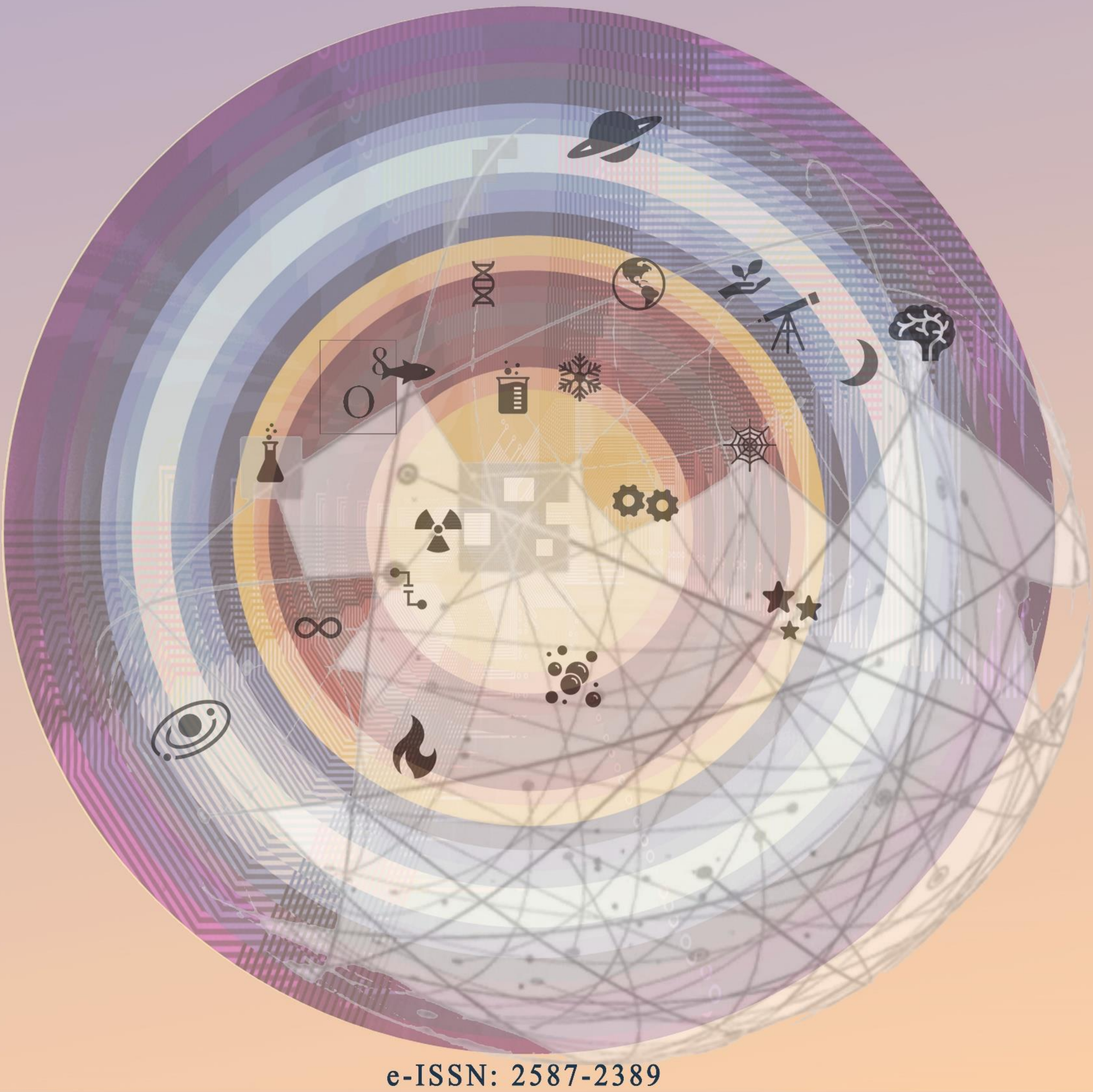

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Yazışma Adresi

(Address for Correspondence)

Kafkas Üniversitesi Fen Bilimleri Enstitüsü Dergisi
Kafkas Üniversitesi Fen Bilimleri Enstitüsü
36100-Kars/ Türkiye
Phone: +90 474 2128850
Fax: +90 474 2123867
E-mail: kaufbed@kafkas.edu.tr

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Farklı Kiriş Teorilerine Göre Kısa Fiber Takviyeli Nano Kirişlerin Kritik Burkulma Yüklerinin Değerlendirilmesi

Uğur KAFKAS[1*]

[1] Kütahya Dumlupınar Üniversitesi, Kütahya Teknik Bilimler MYO, İnşaat Teknolojisi, Kütahya, Türkiye

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Anahtar Kelimeler:
Kısa Fiber Takviyeli Kirişler,
Kritik Burkulma Yükü,
Yerel Olmayan Elastisite Teorisi,
Euler-Bernoulli Kiriş Teorisi,
Timoshenko Kiriş Teorisi,
Levinson Kiriş Teorisi.

Özet: Bu çalışmada, kısa fiber takviyeli nano kirişlerin burkulma davranışları, yerel olmayan elastisite teorisi çerçevesinde, Euler-Bernoulli, Timoshenko ve Levinson kiriş teorileri kullanılarak analiz edilmiştir. Yerel olmayan elastisite teorisi, nanoyapıların küçük ölçekli etkilerini dikkate alarak daha gerçekçi bir modelleme sunmakta ve nano ölçekteki malzemelerin yüzey etkileri, atomik kuvvetler ve mikro yapıların özelliklerinin burkulma davranışları üzerindeki etkilerinin incelenmesine olanak tanımaktadır. Yerel olmayan elastisite teorisi çerçevesinde gerçekleştirilen bu analizlerde, fiber hacim oranı, fiberin uzunluk/çap oranı, elastisite modülü oranı ve yerel olmayan parametre gibi önemli parametrelerin kritik burkulma yükleri üzerindeki etkileri incelenmiştir. Analizler sonucu ortaya çıkan sonuçlar grafiksel olarak sunulmuştur. Analizler, yerel olmayan parametrenin artışının, kirişlerin kritik burkulma yüklerinde belirgin bir düşüşe neden olduğunu göstermektedir. Fiber hacim oranının artması ise, kirişlerin burkulma direncini artırarak kritik burkulma yüklerinin yükselmesine neden olmaktadır. Ayrıca, fiber uzunluk/çap oranının artışı da burkulma direncini güçlendirmekte, özellikle uzun ve ince fiberlerin kullanıldığı yapılar daha yüksek burkulma yüklerine ulaşmaktadır. Elastisite modül oranı artışı ise, kirişlerin burkulma yüklerini daha da yükselterek, özellikle rijitliği yüksek fiberlerin yapısal performansa katkısını açıkça ortaya koymaktadır. Bu çalışma, mikro ve nano ölçekli uygulamalarda kullanılacak kompozit nano kirişlerin tasarımı ile ilgili önemli bilgiler sunmakta olup, gelecekteki araştırmalar için de önemli bir temel oluşturmaktadır.

Evaluation of Critical Buckling Loads of Short Fiber Reinforced Nanobeams According to Different Beam Theories

Keywords:
Short Fiber Reinforced Beams,
Critical Buckling Load,
Nonlocal Elasticity Theory,
Euler-Bernoulli Beam Theory,
Timoshenko Beam Theory,
Levinson Beam Theory.

Abstract: This study analyzed the buckling behavior of short fiber reinforced nanobeams within the framework of nonlocal elasticity theory using Euler-Bernoulli, Timoshenko, and Levinson beam theories. The nonlocal elasticity theory provides a more realistic modeling approach by considering the effects of surface interactions, atomic forces, and the characteristics of microstructures, allowing for an examination of the impact of these factors on the buckling behavior of nanoscale materials. The analyses, conducted under the framework of nonlocal elasticity theory, investigated the effects of essential parameters such as fiber volume fraction, fiber length-to-diameter ratio, elastic modulus ratio, and the nonlocal parameter on critical buckling loads. The results, presented graphically, reveal that an increase in the nonlocal parameter leads to a significant reduction in the critical buckling loads of the beams, indicating a decrease in rigidity. An increase in fiber volume fraction enhances the buckling resistance of the beams, resulting in higher critical buckling loads. Additionally, increasing the fiber length-to-diameter ratio further strengthens the buckling resistance, particularly in beams with long and slender fibers. The increase in the elastic modulus ratio also leads to higher critical buckling loads, particularly highlighting the significant contribution of highly rigid fibers to structural performance. This study provides important insights into the design of composite nano-beams for micro- and nano-scale applications and provides an important basis for future research.

*İlgiliyazar: *ugur.kafkas@dpu.edu.tr*
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1. GİRİŞ

Nanoteknoloji, malzeme biliminde devrim yaratmış ve mühendislik yapılarında yeni nesil çözümler sunmuştur. Gelişen malzeme teknolojileri ile birlikte mühendislik yapılarında kullanılan malzemelerin özellikleri büyük bir dönüşüm geçirmiştir. Son yıllarda özellikle takviyeli yapıların analizi üzerine birçok çalışma yapılmıştır (Borjalilou ve ark., 2019; Civalek ve ark., 2022a, 2023a; Esen ve ark., 2021; Gul ve Aydogdu, 2023; Haddouch ve ark., 2024; Salehipour ve ark., 2024). Kısa fiber takviyeli nanokompozitler, üstün mekanik özellikleri sayesinde geleneksel malzemelere göre daha hafif, dayanıklı ve çok yönlü kullanım imkanı sunmaktadır (Pakravan ve ark., 2017). Kısa fiber takviyeli nanokirişler, malzeme içinde dağılan kısa liflerin etkisiyle yüksek mukavemet, düşük yoğunluk ve esneklik gibi üstün özelliklere sahiptir. Bu nanokirişler, özellikle hafif yapılar gerektiren uygulamalarda tercih edilmektedir (Hosseini, 2017). Liflerin nanokirişe entegre edilmesi, malzemenin yük taşıma kapasitesini artırmakta ve yapının stabilitesini güçlendirmektedir (Wang ve ark., 2022).

Nano kirişlerin kısa fiber takviyesi ile güçlendirilmesi, mikroyapısal özelliklerin iyileştirilmesi ve mekanik performansın artırılması gibi avantajlar sunmaktadır. Bu nedenle, kısa fiber takviyeli nano kirişler, ileri mühendislik uygulamalarında önemli bir malzeme seçeneği olarak öne çıkmaktadır (Pervaiz ve ark., 2021). Kısa fiber takviyeli nano kirişler, birçok mühendislik alanında yaygın olarak kullanılmaktadır. Özellikle havacılık, otomotiv, denizcilik, inşaat ve savunma sanayii gibi hafif ama güçlü malzemelerin kritik olduğu alanlarda önemli rol oynarlar. Örneğin, uçak kanat yapılarında veya hafif otomotiv parçalarında kullanılan bu nano kirişler, hem yapının ağırlığını azaltmakta hem de dayanıklılığını artırmaktadır (Ramu ve ark., 2019). Bunun yanı sıra, nano/mikroelektromekanik sistemlerde (NEMS, MEMS), sensör teknolojilerinde ve biyomedikal uygulamalarda da kullanılmaktadır. Bu çok yönlü kullanım alanları, nano kirişlerin mühendislik tasarımında vazgeçilmez bir bileşen olmasını sağlamaktadır (Dong ve ark., 2021). Daikh ve ark. (2024), karbon nanotüp ile takviye edilmiş fonksiyonel derecelendirilmiş nanokirişlerin eğilme davranışlarını incelemiş ve NEMS ile MEMS gibi uygulamalarda yüksek dayanım ve hafif yapıların sağladığı avantajları vurgulamıştır. Akpınar ve ark. (2024a), kısa lif takviyeli nano kirişlerin termo-mekanik titreşim frekanslarını analiz ederek bu tür yapıların yüksek sıcaklıklarda stabilitelerini koruma ve frekans kontrol yeteneklerini araştırmışlardır. Bir başka çalışmalarında Akpınar ve ark. (2024b), kısa fiber takviyeli nano kirişlerin titreşim özelliklerini inceleyerek, klasik teorilere ek olarak ikinci derece gerinim gradyan teorisini uygulamış ve titreşim frekanslarının lif-matris oranı gibi parametrelerle nasıl değiştiğini analiz etmiştir.

Klasik kiriş teorileri, yapısal analizlerde sıklıkla kullanılan ve kirişlerin yük taşıma kapasitesini belirlemek için geliştirilen modellerdir. Bu teoriler arasında en yaygın olanları Euler-Bernoulli ve Timoshenko teorileridir. Euler-Bernoulli kiriş teorisi, basit ve genellikle uzun kirişler için uygun olan bir model sunarken, Timoshenko kiriş teorisi kesme etkilerini de hesaba katarak, kiriş uzunluğunun enkesit yüksekliğine oranının küçük olduğu kirişlerde kullanılmaktadır (Khadem ve Euler, 1992; T Kaneko, 1975). Levinson kiriş teorisi (Levinson, 1981) ise Timoshenko kiriş teorisinden farklı olarak daha yüksek mertebeden kayma şekil değiştirmesini de içerir.

Klasik kiriş teorileri, kirişlerin küçük boyut etkilerini göz ardı ettiği için mikro ve nano boyutlu yapıların deformasyonunu doğru bir şekilde tahmin edememektedir (Yaylı, 2019a). Bu tür mikro ve nano ölçeklerdeki sınırlamalar nedeniyle, bilim insanları yüksek merteben yerel olmayan elastisite teorilerini geliştirmiştir. Yaygın olarak kullanılan bazı yüksek mertebe teorileri arasında Eringen'in yerel olmayan elastisite teorisi (Eringen, 1983; Eringen ve Edelen, 1972), gerilme çifti teorisi (Toupin, 1962), değiştirilmiş gerilme çifti gerilim teorisi (Yang ve ark., 2002), şekil değiştirme değişimi teorisi (Mindlin, 1964, 1965) ve yerel olmayan şekil değiştirme değişimi teorisi (Lim ve ark., 2015) yer almaktadır. Literatürde, yüksek mertebe elastisite teorileri kullanılarak, nano yapıların eğilme (Abdelrahman ve Eltaher, 2022; Akgöz ve Civalek, 2015; Civalek ve ark., 2020), titreşim (Akbaş, 2018; Togun ve Bağdatlı, 2016a, 2016b; Yaylı, 2017, 2018a, 2019b, 2020), burulma (Arda ve Aydogdu, 2018; Aydogdu ve Arda, 2016; Civalek ve ark., 2022b; Yaylı, 2013, 2018b, 2018c, 2018d) ve burkulma (Civalek ve ark., 2022c; Civalek ve ark., 2023b; Kafkas ve ark., 2023; Yaylı, 2017) davranışları üzerine bir çok çalışma bulunmaktadır. Bu çalışmada, yerel olmayan elastisite teorisinin klasik kiriş teorilerine entegre edilmiş versiyonları incelenmiştir.

Burkulma, yapıların belirli bir kritik yük seviyesinde denge konumlarından sapması ve ani stabilite kaybı ile karakterize edilen bir yapısal davranıştır. Burkulma yükü yapı elemanlarının yapısal çöküşüne neden olabilir (Dubina ve ark., 2013; Moses, 1982; Serna ve ark., 2006). Bu olgu, özellikle ince ve uzun yapı elemanlarında belirgindir; ancak nano ölçekli yapılar için de önemli bir güvenlik sorununu temsil eder (I-Ling, 2011). Nano yapılar, atomik boyutta düzenlemelere sahip olan malzemelerdir ve yüksek mukavemet, esneklik, düşük yoğunluk gibi benzersiz özelliklere sahiptirler. Ancak bu yapılar küçük boyutta olduklarından, burkulma gibi stabilite problemlerine karşı daha hassas tepki verebilirler (Silvestre ve ark., 2014). Kısa fiber takviyeli nano kirişler, geleneksel kirişlerin aksine, nanokompozit malzeme yapısına sahiptir ve içinde kısa, yönlendirilmiş fiberler barındırır. Bu kısa fiberler, malzemenin mekanik özelliklerini önemli ölçüde iyileştirir; özellikle burkulma, çekme ve eğilme yükleri altında daha yüksek dayanım sağlarlar. Kısa fiberler, matrise homojen olarak dağılır ve nano kirişlerin rijitliğini, mukavemetini ve stabilitesini artırır (Nunes ve ark., 2016). Böylece bu kirişler, mühendislik yapılarında daha güvenli ve dayanıklı bir yapı elemanı olarak kullanılır.

Bu çalışmada, kısa fiber takviyeli nano kirişlerin kritik burkulma davranışları, yerel olmayan elastisite teorisi çerçevesinde, Euler-Bernoulli, Timoshenko ve Levinson kiriş teorileri kullanılarak analiz edilmiştir. Yerel olmayan elastisite teorisi, nanoyapıların küçük ölçekli etkilerini dikkate alarak daha gerçekçi bir modelleme sunmakta ve nano ölçekteki malzemelerin yüzey etkileri, atomik kuvvetler ve mikro yapıların özelliklerinin burkulma davranışları üzerindeki etkilerinin incelenmesine olanak tanımaktadır.

Yerel olmayan elastisite teorisi çerçevesinde gerçekleştirilen bu analizlerde, farklı kiriş teorileri, fiber hacim oranı, fiberin uzunluk/çap oranı, elastisite modülü oranı ve yerel olmayan parametre gibi önemli parametrelerin kritik burkulma yükleri üzerindeki etkileri incelenmiştir. Analizler sonucu ortaya çıkan sonuçlar grafiksel olarak sunulmuştur.

2. MATERYAL VE METOT

2.1. Kısa Fiber Takviyeli Malzemelerin Yapısal Özellikleri

Kısa fiber takviyeli kompozitler, yüksek mukavemet-ağırlık oranları ve iyileştirilmiş mekanik özellikleri nedeniyle mühendislik yapılarında yaygın olarak kullanılmaktadır. Bu malzemeler, matris içerisine dağılmış kısa fiberlerin oluşturduğu kompozit yapısıyla, geleneksel malzemelere göre üstün performans sergiler. Fiberlerin yönelim, uzunluk/çap oranı ve hacim fraksiyonu gibi parametreler, kompozitin genel mekanik davranışını doğrudan etkiler. Bu çalışmada, kısa fiber takviyeli malzemelerin elastisite modüllerinin tahmini için yaygın olarak kullanılan Halpin-Tsai denklemleri kullanılmaktadır (Agarwal ve ark., 2006).

Kısa fiber takviyeli kompozitlerin elastik özellikleri, matris ve fiberin bireysel elastisite modüllerine, fiberin yönelimi ve hacim fraksiyonuna bağlı olarak değişir. Bu tür kompozitler, belirli yönlerde üstün dayanım gösterirken, fiber yönelim ve dağılımına bağlı olarak farklı mekanik davranışlar sergilerler. Halpin-Tsai denklemleri, kısa fiber takviyeli kompozitlerin modüllerini belirlemek için oldukça faydalıdır ve hem boyuna hem de enine modüllerin hesaplanmasına olanak tanır (Agarwal ve ark., 2006). Bu denklemler, fiberlerin matris içerisindeki etkisini dikkate alarak malzemenin genel davranışını tahmin eder. Boyuna ve enine elastisite modülleri şu şekilde ifade edilir (Civalek ve ark., 2023):

$$E_B = E_m\left(\frac{1 + (2l/d)\eta_B V_f}{1 - \eta_B V_f}\right) \quad (1)$$

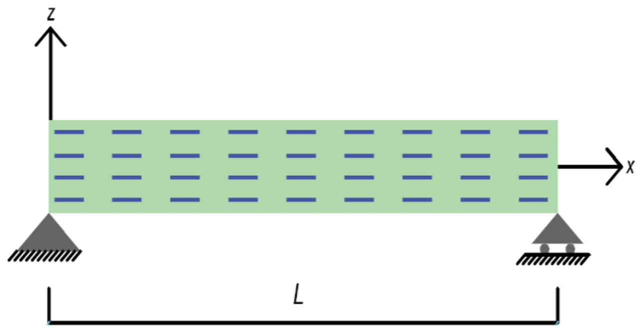
$$E_E = E_m\left(\frac{1 + 2\eta_E V_f}{1 - \eta_E V_f}\right) \quad (2)$$

Burada, E_B, E_E ve E_m sırasıyla fiberin boyuna elastisite modülünü, fiberin enine elastisite modülünü ve matrisin elastisite modülünü, l/d fiber uzunluk/çap oranını, V_f fiber hacim dağılımını ve η_B ve η_E ise fiber ve matris arasındaki elastisite modülü oranlarına bağlı katsayıları ifade eder ve E_f fiber malzemenin elastisite modülü olmak üzere, aşağıdaki gibi tanımlanır (Agarwal ve ark., 2006):

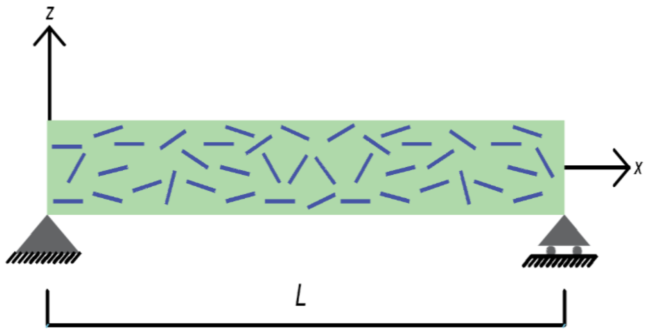
$$\eta_B = \frac{\left(\frac{E_f}{E_m}\right) - 1}{\left(\frac{E_f}{E_m}\right) + 2\left(\frac{l}{d}\right)} \quad (3)$$

$$\eta_E = \frac{\left(\frac{E_f}{E_m}\right) - 1}{\left(\frac{E_f}{E_m}\right) + 2} \quad (4)$$

Şekil 1'de görüldüğü gibi kısa fiber takviyeli kompozitlerin yönlendirilmiş ve rastgele yönelimli olmak üzere iki türlü imalatı mevcuttur. Halpin-Tsai denklemleri, özellikle yönlendirilmiş kısa fiber takviyeli kompozitler için elastisite modülü tahmininde kullanışlıdır (Agarwal ve ark., 2006). Bu denklemler, fiberin uzunluğu, çapı ve hacim oranının elastisite modülleri üzerindeki etkisini değerlendirmede önemli bilgiler sunar. l/d oranı arttıkça, boyuna elastisite modülü önemli ölçüde artarken, enine modül üzerinde daha sınırlı bir etki gözlemlenir. Ayrıca, V_f arttıkça hem boyuna hem de enine modüller yükselir, bu da kompozitin genel mukavemetini artırır.



a) Yönlendirilmiş



b) Rastgele yönelimli

Şekil 1. Kısa fiber takviyeli kompozit nano kirişin şematik gösterimi: a) Yönlendirilmiş b) Rastgele yönelimli.

Rastgele yönelimli kısa fiber kompozitler için, Halpin-Tsai denklemlerinin doğrudan kullanımı uygun olmayabilir. Bu tür kompozitlerin elastik modülleri genellikle aşağıdaki ortalama denklemler ile tahmin edilir (Agarwal ve ark., 2006):

$$E_R = \frac{3}{8}E_B + \frac{5}{8}E_E \quad (5)$$

$$G_R = \frac{1}{8}E_B + \frac{1}{4}E_E \quad (6)$$

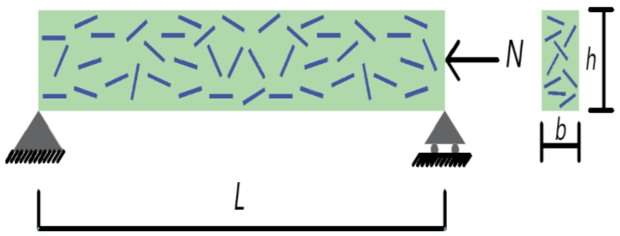
Burada E_R, rastgele yönelimli fiber kompozitlerin ortalama elastisite modülünü; G_R ise rastgele yönelimli fiber kompozitlerin ortalama kayma modülünü temsil etmektedir.

Bu denklemler, rastgele yönelimli fiberlerin etkisini daha gerçekçi bir şekilde temsil eder.

2.2. Kiriş Teorileri ve Kritik Burkulma Yükü Hesapları

Kiriş teorileri, yapısal elemanların taşıma kapasitesini, stabilitesini ve davranışını analiz etmek için mühendislikte yaygın olarak kullanılmaktadır. Özellikle ince yapısal elemanlar olan kirişler, yük altında eğilme ve burkulma gibi kritik mekanik davranışlar sergilerler. Kirişlerin burkulma yükleri, stabilite açısından büyük önem taşır; çünkü bu yüklerin aşılması, yapının ani ve tehlikeli bir şekilde stabilitesini kaybetmesine yol açabilir. Bu nedenle, mühendislik yapılarında kirişlerin kritik burkulma yüklerinin doğru bir şekilde hesaplanması, yapısal güvenliği sağlamada önemli bir rol oynar.

Gelişen malzeme teknolojileri ve mikro/nano ölçekli yapıların analiz gereksinimleri, yerel olmayan elastisite teorisinin kullanılmasını gerektirmektedir. Yerel olmayan elastisite teorisi, klasik kiriş teorilerinin ötesine geçerek, küçük ölçekli yapılar üzerinde uzun menzilli kuvvet etkilerini de hesaba katar (Yaylı, 2019). Yerel olmayan parametrelerin burkulma yükleri üzerindeki etkisi, özellikle kısa fiber takviyeli nano kirişlerin stabilitesi açısından kritik bir öneme sahiptir.



Şekil 2. Basit mesnetli rastgele yönelimli kısa fiber takviyeli kompozit nano kirişin ve kesitinin şematik gösterimi.

Bu bölümde, Şekil 2'de görülen, uzunluğu *L,* kesit genişliği *b*, kesit yüksekliği *h* olan ve *N* eksenel yükü ile yüklenmiş, basit mesnetli rastgele yönelimli bir kısa fiber takviyeli nano kiriş için, Euler-Bernoulli, Timoshenko ve Levinson kiriş teorilerinin yerel olmayan etkilerle genişletilmiş hareket denklemleri sunularak, bu teorilere göre kısa fiber takviyeli nano kirişlerin kritik burkulma yükleri hesaplanacaktır.

2.2.1. Hareket denklemleri

2.2.1.1. Euler-Bernoulli kiriş teorisi

Euler-Bernoulli kiriş teorisi, kirişlerin eğilme ve burkulma davranışlarını modellemek için kullanılan en temel teorilerden biridir. Bu teori, kayma şekil değiştirmesini ihmal eder. Teori, özellikle kiriş uzunluğunun enkesit yüksekliğine oranının büyük olduğu kirişlerin analizinde etkili olup, mühendislik yapılarında yaygın olarak kullanılmaktadır. Euler-Bernoulli kiriş teorisi, yerel olmayan etkiler eklenerek daha karmaşık yapılar için de kullanılabilir hale getirilebilir.

Euler-Bernoulli teorisinin yerel olmayan elastisite teorisi ile genişletilmiş hareket denklemi aşağıdaki gibidir (Reddy, 2007):

$$\begin{aligned}&\frac{\partial^2}{\partial x^2}\left(-E_R I\frac{\partial^2 w^E}{\partial x^2}\right)\\&+(e_0a)^2\frac{\partial^2}{\partial x^2}\left[\frac{\partial}{\partial x}\left(N^E\frac{\partial w^E}{\partial x}\right)-q+\rho A\frac{\partial^2 w^E}{\partial t^2}\right.\\&\left.-\rho I\frac{\partial^4 w^E}{\partial x^2\partial t^2}\right]+q-\frac{\partial}{\partial x}\left(N^E\frac{\partial w^E}{\partial x}\right)\\&=\rho A\frac{\partial^2 w^E}{\partial t^2}-\rho I\frac{\partial^4 w^E}{\partial x^2\partial t^2}\end{aligned} \tag{7}$$

Bu denklemi, klasik Euler-Bernoulli teorisinden farklılaştıran yerel olmayan etkiler, $e_0 a$ terimiyle ifade edilen yerel olmayan parametredir ve burada e_0 malzemeye bağlı bir sabiti ve a'da malzeme iç karakteristik uzunluğu ifade eder. Ayrıca bu denklemde A ve I sırasıyla kesit alanı ve atalet momentini, ρ yoğunluğu, q kirişe etki eden düşey yayılı kuvveti, N^E ve w^E ise sırasıyla Euler-Bernoulli kiriş teorisine göre kiriş üzerindeki eksenel kuvveti ve kirişin düşey yer değiştirmesini ifade eder.

2.2.1.2. Timoshenko kiriş teorisi

Timoshenko kiriş teorisi, kirişlerin burkulma ve eğilme davranışlarını daha gerçekçi bir şekilde modellemek için geliştirilmiş bir teoridir. Euler-Bernoulli teorisinden farklı olarak, Timoshenko teorisi kirişin eğilmesi sırasında ortaya çıkan kayma şekil değiştirmelerini de hesaba katar. Bu özellik, Timoshenko teorisini özellikle kayma şekil değiştirmelerinin etkisinin önemli olduğu kiriş uzunluğunun enkesit yüksekliğine oranının büyük olduğu kirişlerin analizinde daha doğru bir model haline getirir. Kayma şekil değiştirmesinin dahil edilmesi, yapının gerçekte gösterdiği davranışları daha iyi temsil eder, bu da Timoshenko teorisinin geniş bir mühendislik uygulama alanı bulmasını sağlar.

Timoshenko kiriş teorisinin bir diğer önemli avantajı, dinamik analizlerde sağladığı hassasiyettir. Kesme kuvvetlerinin ve rotasyonel hareketlerin dahil edilmesi, yüksek frekanslı titreşim analizlerinde ve kısa fiber takviyeli nano kirişler gibi kompleks yapıların modellenmesinde kritik bir rol oynar. Teorinin kapsamı, klasik kiriş teorilerinin ötesine geçerek, yerel olmayan etkilerin de bu tür analizlere eklenmesini sağlar.

Timoshenko teorisinin yerel olmayan etkilerle genişletilmiş hareket denklemi, kirişin burkulma, eğilme ve titreşim davranışlarını tanımlar. Bu teorinin denklemleri, kirişin hem statik hem de dinamik yükler altında nasıl davrandığını anlamak için kritik öneme sahiptir. Aşağıda, Timoshenko kiriş teorisinin yerel olmayan etkilerle genişletilmiş hareket denklemi sunulmaktadır (Reddy, 2007):

$$\frac{\partial}{\partial x}\left[G_R A K_s\left(\phi^T+\frac{\partial w^T}{\partial x}\right)\right]+q-\frac{\partial}{\partial x}\left(N^T\frac{\partial w^T}{\partial x}\right) - (e_0a)^2\frac{\partial^2}{\partial x^2}\left[q - \frac{\partial}{\partial x}\left(N^T\frac{\partial w^T}{\partial x}\right)\right] = \rho A\left(\frac{\partial^2 w^T}{\partial t^2} - (e_0a)^2\frac{\partial^4 w^T}{\partial x^2\partial t^2}\right) \quad (8)$$

$$\frac{\partial}{\partial x}\left(E_R I\frac{\partial \phi^T}{\partial x}\right)-G_R A K_s\left(\phi^T+\frac{\partial w^T}{\partial x}\right) = \rho I\frac{\partial^2\phi^T}{\partial t^2} - (e_0a)^2\rho I\frac{\partial^4\phi^T}{\partial x^2\partial t^2} \quad (9)$$

Burada K_s kesme düzeltme faktörünü, ϕ^T, N^T ve w^T ise sırasıyla Timoshenko kiriş teorisine göre kirişin dönme açısını, kiriş üzerindeki eksenel kuvveti ve kirişin düşey yer değiştirmesini ifade eder.

2.2.1.3. Levinson kiriş teorisi

Levinson kiriş teorisi, klasik Euler-Bernoulli ve Timoshenko kiriş teorilerinin ötesine geçerek hem kesme hem de dönme etkilerini daha doğru bir şekilde modelleyen gelişmiş bir teoridir. Bu teori, özellikle kiriş uzunluğunun enkesit yüksekliğine oranının büyük olduğu kirişlerin analizi için uygundur ve yerel olmayan etkilerle birleştirildiğinde, mikro ve nano ölçekteki yapıların dinamik davranışlarının daha iyi anlaşılmasına yardımcı olur. Levinson teorisinin hareket denklemi, kirişin eğilme, kesme ve dönme etkilerini bir araya getirir ve bu etkilerin kiriş üzerindeki karmaşık etkileşimlerini tanımlar. Aşağıda Levinson kiriş teorisinin genişletilmiş hareket denklemi sunulmuştur (Reddy, 2007):

$$\frac{\partial}{\partial x}\left[G_R A\left(\phi^L+\frac{\partial w^L}{\partial x}\right)\right]+q-\frac{\partial}{\partial x}\left(N^L\frac{\partial w^L}{\partial x}\right) + (e_0a)^2\frac{\partial^2}{\partial x^2}\left[-q + \frac{\partial}{\partial x}\left(N^L\frac{\partial w^L}{\partial x}\right)\right] = \rho A\left(\frac{\partial^2 w^L}{\partial t^2} - (e_0a)^2\frac{\partial^4 w^L}{\partial x^2\partial t^2}\right) \quad (10)$$

$$\frac{\partial}{\partial x}\left(E_R I\frac{\partial \phi^L}{\partial x}\right)-\frac{4}{3h^2}E_R J\left(\frac{\partial^2\phi^L}{\partial x^2}+\frac{\partial^3 w^L}{\partial x^3}\right) - G_R A\left(\phi^L+\frac{\partial w^L}{\partial x}\right) = \rho I\frac{\partial^2\phi^L}{\partial t^2} - (e_0a)^2\rho I\frac{\partial^4\phi^L}{\partial x^2\partial t^2} \quad (11)$$

Burada I 'nın atalet momenti olduğunu belirtilmişti. I kesit alanının 2. dereceden standart atalet momentiyken, J ise kesit alanının 4. dereceden atalet momentini temsil etmektedir. h kiriş kesit yüksekliğini, ϕ^L, N^L ve w^L ise sırasıyla Levinson kiriş teorisine göre kirişin dönme açısını, kiriş üzerindeki eksenel kuvveti ve kirişin düşey yer değiştirmesini ifade eder.

2.2.2. Analitik çözüm

Şekil 2'de görülen basit mesnetli ve herhangi bir N eksenel yük ile yüklenmiş nano kiriş için, kirişin uç noktalarındaki ($x = 0$ ve $x = L$) sınır şartları aşağıdaki gibi ifade edilebilir (Şimşek, 2019):

$$w = 0, \qquad \frac{\partial^2 w}{\partial x^2} = 0. \quad (12)$$

Genel yer değiştirmeler w ve ϕ fonksiyonları Fourier serisine açılarak yazılırsa (Reddy, 2007):

$$w(x,t) = \sum_{m=1}^{\infty} W_m \sin\frac{m\pi x}{L}e^{i\omega_m t} \quad (13)$$

$$\phi(x,t) = \sum_{m=1}^{\infty} \Phi_m \cos\frac{m\pi x}{L}e^{i\omega_m t} \quad (14)$$

Burada m mod numarasını ve ω_m de titreşim frekansını ifade eder. Benzer biçimde yayılı yük için de seri açılımı sonucu aşağıdaki gibidir (Şimşek, 2019):

$$q(x) = \sum_{m=1}^{\infty} Q_m \sin\frac{m\pi x}{L} \quad (15)$$

Buradan Q_m şu şekilde tanımlanır:

$$Q_m = \frac{2}{L}\int_0^L q(x)\sin\frac{m\pi x}{L}dx \quad (16)$$

2.2.2.1. Euler-Bernoulli kiriş teorisi

Denklem (13)-(16)'yı Denklem (7)'de yerlerine yazarsak Euler-Bernoulli kiriş teorisi için hareket denklemi aşağıdaki gibi zamandan bağımsız halde yazılabilir (Reddy, 2007):

$$\left[\left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)\left[N^E\left(\frac{m\pi}{L}\right)^2 + \omega_m^2\left\{\rho A+\rho I\left(\frac{m\pi}{L}\right)^2\right\}\right] - E_R I\left(\frac{m\pi}{L}\right)^4\right]W_m + \left[1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right]Q_m = 0 \quad (17)$$

Burkulma problemi için q ve tüm zaman türevleri sıfır olarak alınarak hareket denklemi tekrar yazılabilir:

$$\left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)\left[N^E\left(\frac{m\pi}{L}\right)^2 + \omega_m^2\left\{\rho A+\rho I\left(\frac{m\pi}{L}\right)^2\right\}\right] - E_R I\left(\frac{m\pi}{L}\right)^4 = 0 \quad (18)$$

Kritik burkulma yükü N_{kr}^E'nin hesaplanabilmesi için $\omega_m = 0$ olarak alınması gerekir. $m = 1$ için kritik burkulma yükü (Şimşek, 2019), N_{kr}^E aşağıdaki gibi hesaplanabilir (Reddy, 2007):

$$N_{kr}^E = \frac{1}{\left[1+\frac{(e_0a)^2\pi^2}{L^2}\right]}\frac{\pi^2 E_R I}{L^2} \quad (19)$$

2.2.2.2. Timoshenko kiriş teorisi

Denklem (13)-(16)'yı Denklem (8) ve (9)'da yerlerine yazarsak Timoshenko kiriş teorisi için hareket denklemi aşağıdaki gibi zamandan bağımsız halde yazılabilir (Reddy, 2007):

$$-G_R A K_s\left(\frac{m\pi}{L}\right)\left(\Phi_m+\frac{m\pi}{L}W_m\right) + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)Q_m + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)N^T\left(\frac{m\pi}{L}\right)^2 W_m + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)\rho A\omega_m^2 W_m = 0 \quad (20)$$

$$-E_R I\left(\frac{m\pi}{L}\right)^2\Phi_m - G_R A K_s\left(\Phi_m+\frac{m\pi}{L}W_m\right) + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)\rho I\omega_m^2\Phi_m = 0 \quad (21)$$

Kritik burkulma yükü N_{kr}^T'nin hesaplanabilmesi için; q, tüm zaman türevleri ve ω_m sıfır olarak alınmasıyla, $m = 1$ alınarak aşağıdaki gibi hesaplanır (Reddy, 2007):

$$N_{kr}^T = \frac{1}{\left[1+\frac{(e_0a)^2\pi^2}{L^2}\right]\left[1+\frac{\pi^2 E_R I}{G_R A K_s L^2}\right]}\frac{\pi^2 E_R I}{L^2} \quad (22)$$

2.2.2.3. Levinson kiriş teorisi

Son olarak da Levinson kiriş teorisi için zamandan bağımsız hareket denklemi Denklem (13)-(16)'yı Denklem (10) ve (11)'de yerlerine yazılarak elde edilir (Reddy, 2007):

$$-G_R A\left(\frac{m\pi}{L}\right)\left(\Phi_m+\frac{m\pi}{L}W_m\right) + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)Q_m + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)N^L\left(\frac{m\pi}{L}\right)^2 W_m + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)\rho A\omega_m^2 W_m = 0 \quad (23)$$

$$-E_R I\left(\frac{m\pi}{L}\right)^2\Phi_m - \left[G_R A - \frac{4}{3h^2}E_R J\left(\frac{m\pi}{L}\right)^2\right]\left(\Phi_m+\frac{m\pi}{L}W_m\right) + \left(1+(e_0a)^2\left(\frac{m\pi}{L}\right)^2\right)\rho I\omega_m^2\Phi_m = 0 \quad (24)$$

Levinson kiriş teorisi için de kritik burkulma yükü N_{kr}^L, Timoshenko kiriş teorisinin kritik burkulma yükü ile kesme düzeltme faktörü haricinde aynıdır (Reddy, 2007):

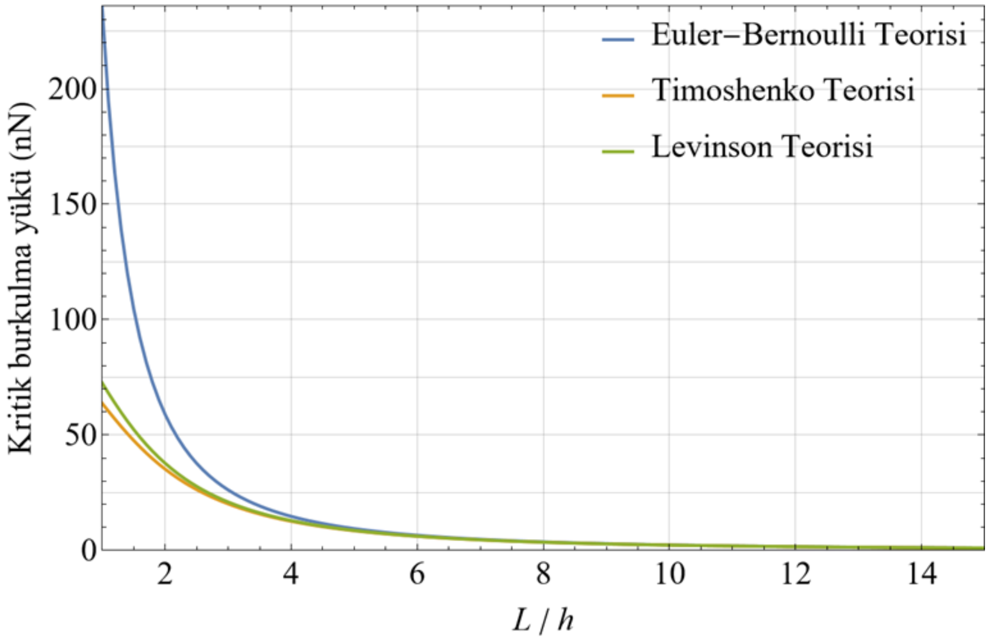
$$N_{kr}^L = \frac{1}{\left[1+\frac{(e_0a)^2\pi^2}{L^2}\right]\left[1+\frac{\pi^2 E_R I}{G_R A L^2}\right]}\frac{\pi^2 E_R I}{L^2} \quad (25)$$

3. BULGULAR VE TARTIŞMA

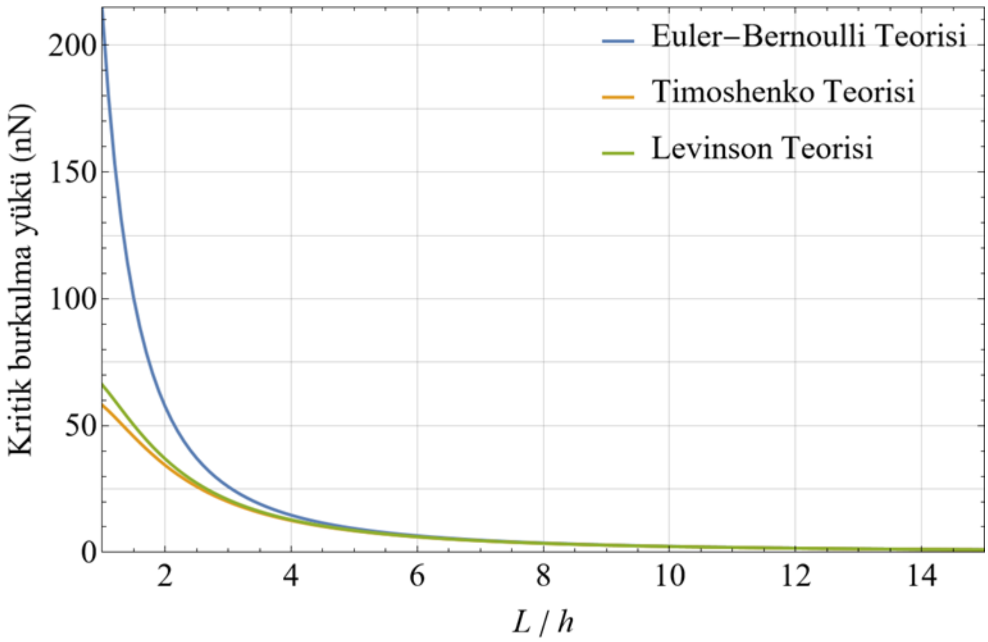
Bu bölümde, kısa fiber takviyeli nano kirişlerin farklı kiriş teorilerine göre kritik burkulma yüklerinin sayısal analizleri sunulmaktadır. Çalışmada, Euler-Bernoulli, Timoshenko ve Levinson kiriş teorilerinin burkulma davranışları karşılaştırılmış ve yerel olmayan parametre (e_0a) ve diğer değişkenlerin etkisi incelenmiştir. Kritik burkulma yükleri, farklı parametreler altında analiz edilmiş ve sonuçlar grafikler aracılığıyla görselleştirilmiştir. Bu analizler, yapısal güvenliğin sağlanmasında hangi teorinin daha uygun olduğunu anlamak için önemlidir.

Kiriş teorileri, yapısal analizlerde kirişlerin burkulma ve eğilme davranışlarını modellemek için kullanılan temel araçlardır. Bu çalışmada ele alınan Euler-Bernoulli, Timoshenko ve Levinson kiriş teorileri, farklı varsayımlar ve modelleme yaklaşımları ile kirişlerin burkulma analizlerinde kritik rol oynar. Euler-Bernoulli kiriş teorisi, en basit ve klasik yaklaşımı sunar; kayma şekil değiştirmelerini ihmal eder ve sadece eğilme etkilerini dikkate alır. Bu yaklaşım, uzun ve ince kirişler için uygun sonuçlar sağlasa da kiriş uzunluğunun enkesit yüksekliğine oranının büyük olduğu için yetersiz kalabilir. Timoshenko kiriş teorisi, kayma şekil değiştirmesini hesaba katarak daha karmaşık ve gerçekçi bir model sunar. Bu teori, özellikle kiriş uzunluğunun enkesit yüksekliğine oranının büyük olduğu kirişlerin analizinde önemli avantajlar sağlar. Kesme etkilerinin dikkate alınması, kirişin stabilitesi ve burkulma yükü üzerindeki etkilerin daha doğru bir şekilde modellenmesine olanak tanır. Levinson kiriş teorisi ise, Timoshenko teorisinin bir adım ötesine geçerek, daha gelişmiş bir kayma şekil değiştirmesi modeli sunar. Bu teoriler, yerel olmayan elastisite teorisiyle birleştirildiğinde, küçük ölçekli yapıların uzun menzilli kuvvet etkileri de göz önüne alınarak, daha doğru ve güvenilir analizler yapılabilmektedir.

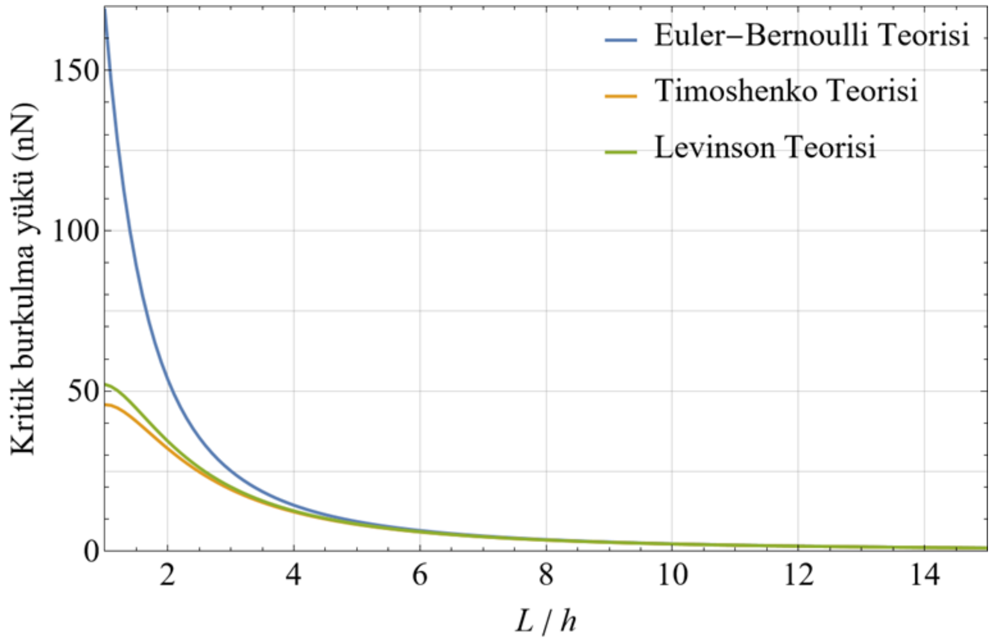
Bu bölümde, öncelikle kiriş teorilerinin burkulma yükleri üzerindeki etkileri karşılaştırılmak için, farklı L/h oranları ve yerel olmayan parametre değerleri için, $E_f = 72.40$ GPa, $E_m = 2.76$ GPa, $V_f = 0.2$ (Agarwal ve ark., 2006), $l = 5$ nm, $d = 1$ nm, $b = 5$ nm ve $h = 10$ nm değerleri alınmıştır. Şekil 3-5'te, $e_0a = 0.1, 1, 2$ değerleri için farklı L/h oranları ile elde edilen sayısal sonuçların grafiksel gösterimleri sunulmaktadır.



Şekil 3. Farklı L/h oranları için kritik burkulma yükleri ($e_0a = 0.1$).



Şekil 4. Farklı L/h oranları için kritik burkulma yükleri ($e_0a = 1$).



Şekil 5. Farklı L/h oranları için kritik burkulma yükleri ($e_0a = 2$).

Şekil 3-5'e bakıldığında, Euler-Bernoulli teorisinin basit varsayımlarla eğilme etkilerini dikkate alırken, kayma şekil değiştirmesini ihmal etmesinin sonuçları açık biçimde görülmektedir. Bu durum, özellikle düşük L/h oranlarında, Euler-Bernoulli teorisinin diğer teorilere göre daha yüksek kritik burkulma yükleri tahmin etmesine neden olmaktadır. Diğer yandan, Timoshenko ve Levinson teorileri kayma şekil değiştirme etkilerini modellemeleri nedeniyle, burkulma yüklerinde daha düşük değerler sunmaktadır. Bu iki teoriden Timoshenko, kesme etkilerini daha güçlü bir şekilde dahil ederek, genellikle en düşük burkulma yükü sonuçlarını verirken, Levinson teorisi biraz daha yüksek sonuçlar sunmaktadır. Bu fark, Timoshenko teorisinde bulunan K_s kesme düzeltme faktöründen kaynaklanmaktadır. L/h oranı arttıkça kiriş teorilerinin kritik burkulma yükleri yakınlaşmaktadır. Örneğin $e_0a = 0.1$, $L/h = 1$ durumunda, Timoshenko kiriş teorisi Euler-Bernoulli kiriş teorisine göre yaklaşık % 72 oranında daha düşük kritik burkulma yükü tahmin ederken, $L/h = 15$ durumunda ise bu oran % 1'e kadar düşmüştür. Analizler, yerel olmayan parametre e_0a'nın kritik burkulma yükleri üzerindeki önemli etkisini de ortaya koymuştur. e_0a parametresi arttıkça, kritik burkulma yüklerinde belirgin bir düşüş gözlenmiştir. Bu düşüş, kirişin yerel olmayan etkiler sebebiyle rijitliğinin azaldığını ve burkulmaya karşı direncinin düştüğünü göstermektedir. Mikro ve nano ölçekli yapılarda, uzun menzilli kuvvet etkileşimleri ve moleküler seviyedeki etkiler klasik teorilerde öngörülen rijitliği zayıflatmakta, bu da kritik burkulma yüklerinin daha düşük olmasına neden olmaktadır. Bu nedenle, yerel olmayan etkiler dikkate alınmadan yapılan analizler, kirişlerin burkulmaya karşı gerçek direncini olduğundan daha yüksek tahmin edebilir, bu da yapısal güvenlik açısından yanılgılara yol açabilir.

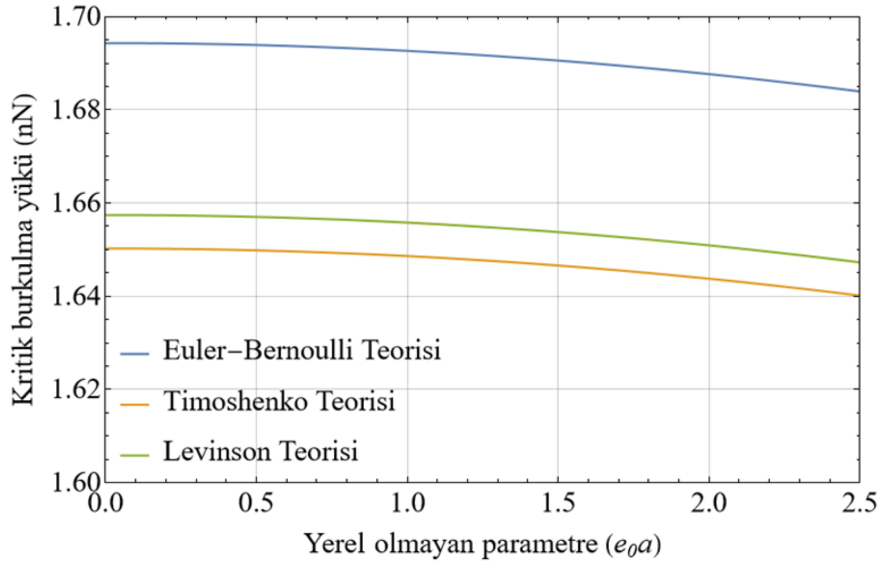
Çalışmanın bu kısmında ise, farklı fiber hacim oranları ve yerel olmayan parametre değerleri kullanılarak, kiriş teorilerinin burkulma yükleri üzerindeki etkileri Şekil 6-8'de karşılaştırılmıştır. Şekillerdeki ortak eğilimler, kiriş teorilerinin burkulma davranışlarını ve yerel olmayan etkilerin bu davranışlara nasıl etki ettiğini net bir şekilde ortaya koymaktadır.

Şekillerden de gözlemlendiği gibi, e_0a değerinin artışı, kirişlerin kritik burkulma yüklerinde bir düşüşe yol açmaktadır. Bu düşüş, kiriş rijitliğinde azalmayı işaret eder ve yerel olmayan etkilerin yapı üzerindeki baskınlığını gösterir. Kritik burkulma yüklerindeki bu düşüş, yerel olmayan parametrenin yapının genel rijitliğini zayıflattığı anlamına gelir. Mikro ve nano ölçekli yapılarda uzun menzilli kuvvet etkileşimleri, klasik teorilerin öngördüğü yükleri düşürerek, yapının stabilitesini olumsuz etkiler.

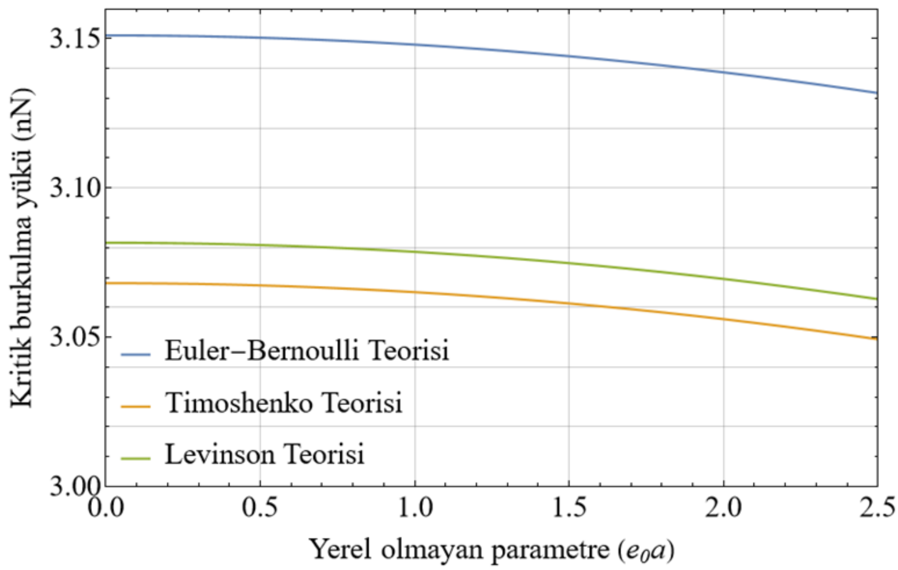
Buna ek olarak, fiber hacim oranı kritik burkulma yükleri üzerinde pozitif bir etkiye sahiptir. Grafiklerde görüldüğü üzere, V_f arttıkça, burkulma yükleri de belirgin bir şekilde artmaktadır. Örneğin, $V_f = 0.1$ ile $V_f = 0.5$ arasında kritik burkulma yüklerinde, tüm kiriş teorilerinde yaklaşık 3 kata kadar artışlar gözlemlenmiştir. Bu durum, fiber takviyesinin kiriş rijitliğini artırarak burkulma direncini yükselttiğini açıkça göstermektedir.

Şekil 6-8'e bakıldığında e_0a değerinin artması, kiriş rijitliğini düşürürken, V_f değerinin artışı yapının burkulma yüklerini kayda değer şekilde artırmaktadır. Bu bulgular, kiriş analizlerinde doğru parametrelerin seçiminin yapısal güvenlik açısından kritik olduğunu ve özellikle mikro ve nano ölçekli yapılarda yerel olmayan etkilerin mutlaka dikkate alınması gerektiğini bir kez daha ortaya koymaktadır.

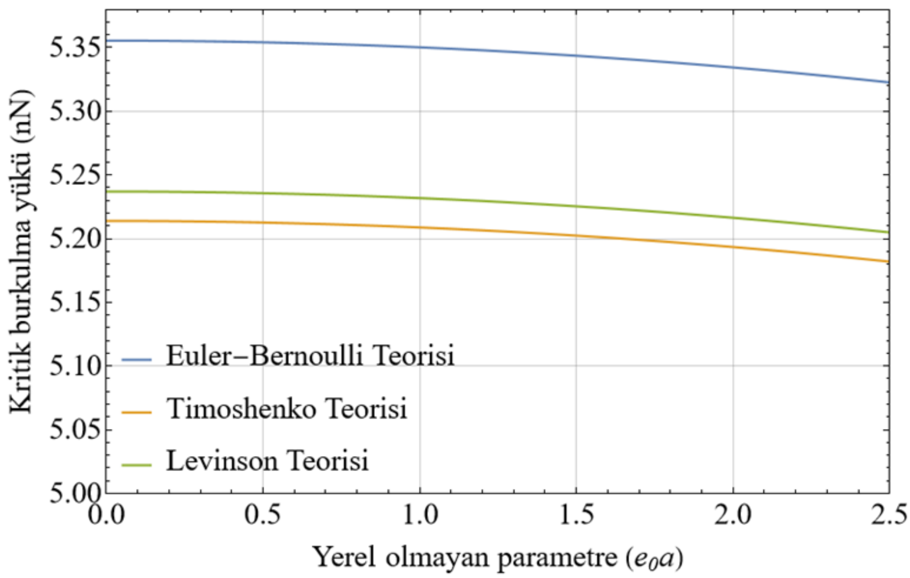
Şekil 9-10'da ise Timoshenko kiriş teorisi kullanılarak, $e_0a = 0.2$ durumunda, farklı fiber hacim oranları ($V_f = 0.1, 0.3, 0.5, 0.7$) ve farklı fiber uzunluk/çap oranları (l/d) için kritik burkulma yükleri çizilmiştir. Bu analizler, özellikle Timoshenko teorisinin kesme ve kayma şekil değiştirme etkilerini içerdiği için en düşük burkulma yüklerini tahmin etmesi durumunu yansıtmaktadır. Şekillerin detaylı incelenmesi, kritik burkulma yüklerinin bu parametrelere nasıl tepki verdiğini ortaya koymaktadır.



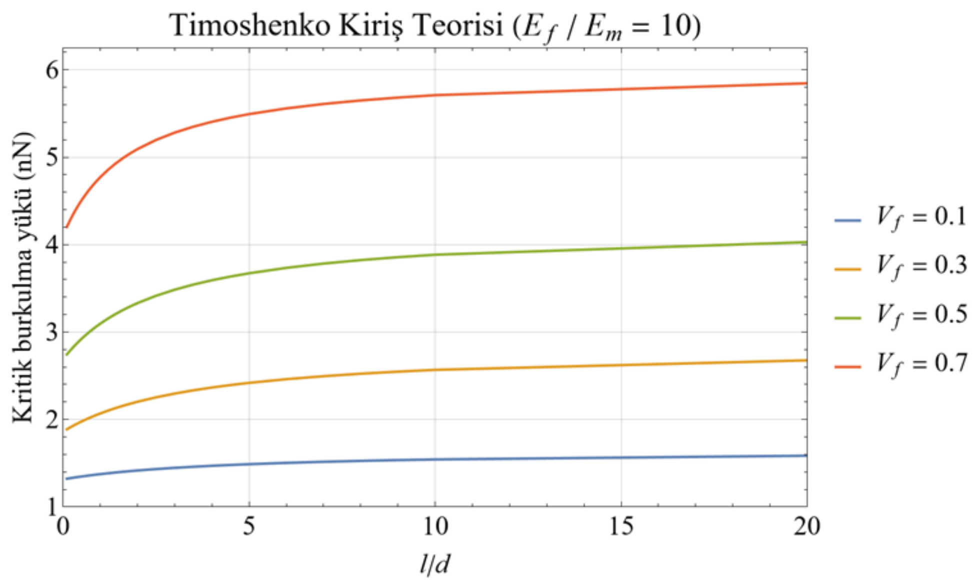
Şekil 6. Farklı e_0a değerleri için kritik burkulma yükleri ($V_f = 0.1$).



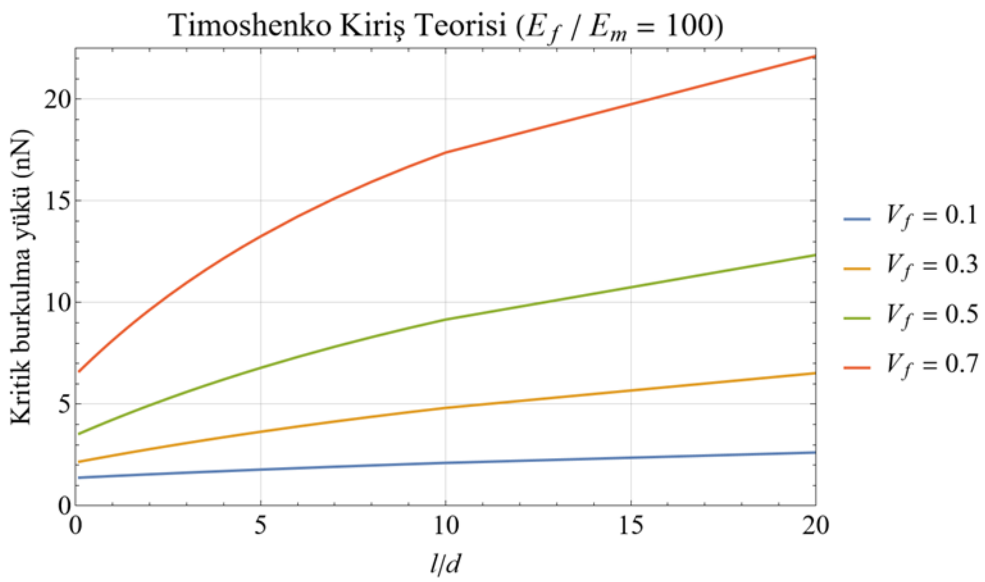
Şekil 7. Farklı e_0a değerleri için kritik burkulma yükleri ($V_f = 0.3$).



Şekil 8. Farklı e_0a değerleri için kritik burkulma yükleri ($V_f = 0.5$).



Şekil 9. Timoshenko kiriş teorisine göre farklı V_f ve l/d değerleri için kritik burkulma yükleri.



Şekil 10. Timoshenko kiriş teorisine göre farklı V_f ve l/d değerleri için kritik burkulma yükleri.

Şekil 9 ve 10'a bakıldığında, fiber hacim oranı arttıkça kritik burkulma yüklerinin belirgin bir şekilde yükseldiği gözlemlenmektedir. Bu artış, fiber takviyesinin kiriş rijitliğini güçlendirdiğini ve böylece burkulma direncinin arttığını ortaya koymaktadır. Yüksek fiber hacim oranları, yapıların stabilitesini olumlu yönde etkileyerek kritik yüklerin daha yüksek seviyelere çıkmasına katkıda bulunmaktadır. Bunun yanı sıra, fiberin uzunluk/çap oranı arttıkça kritik burkulma yüklerinin de arttığı görülmektedir. Uzun ve ince fiberlerin kiriş yapısına entegrasyonu, burkulma direncini artırarak kritik yüklerin yükselmesine neden olmaktadır. Bu durum, fiber uzunluğunun kirişin burkulma davranışında belirleyici bir parametre olduğunu göstermektedir. Özellikle yüksek l/d oranları, yapının burkulma direncini artırarak güvenli yapısal tasarıma katkı sağlamaktadır.

Elastisite modül oranı da kritik burkulma yükleri üzerinde önemli bir etkiye sahiptir. Grafikteki sonuçlar, E_f/E_m oranının artmasıyla birlikte kritik burkulma yüklerinin belirgin şekilde arttığını göstermektedir. Özellikle $E_f/E_m = 100$ durumu, $E_f/E_m = 10$ durumuna kıyasla çok daha yüksek burkulma yükleri sunmaktadır. Bu artış, daha rijit bir fiber malzemenin kiriş yapısının rijitliğini büyük ölçüde güçlendirdiğini ve burkulma direncini artırdığını ortaya koymaktadır. Daha yüksek E_f/E_m oranlarında, uzunluk/çap oranına göre kritik burkulma yüklerinin artış hızı da önemli ölçüde yükselmektedir. $E_f/E_m = 100$ olduğunda, uzun ve ince fiberlerin etkisi daha belirgin hale gelmekte ve burkulma yüklerinin daha hızlı artmasına neden olmaktadır. Bu, rijitliği yüksek fiberlerin kirişin burkulma direncini daha etkili bir şekilde artırdığını göstermektedir.

4. SONUÇ

Bu çalışmada, kısa fiber takviyeli nanokompozit kirişlerin kritik burkulma davranışları, Euler-Bernoulli, Timoshenko ve Levinson gibi çeşitli kiriş teorileri kullanılarak ve yerel olmayan elastisite etkileri dikkate alınarak incelenmiştir. Elde edilen sonuçlar, kiriş teorisi seçiminin ve yerel olmayan etkilerin, özellikle mikro ve nano ölçekli uygulamalarda, öngörülen kritik burkulma yükleri üzerinde önemli bir etkiye sahip olduğunu göstermektedir.

Analizler, yerel olmayan parametre arttıkça kritik burkulma yüklerinde bir düşüş olduğunu ortaya koymuştur. Bu durum, nanoyapılarda uzun menzilli etkileşimlerin kiriş rijitliğini zayıflatarak burkulma direncini azalttığını göstermektedir. Tüm kiriş teorilerinde gözlenen bu düşüş, klasik modellerin yerel olmayan etkileri dikkate almadığı durumlarda burkulma direncini olduğundan yüksek tahmin edebileceğini ortaya koymaktadır.

Nano kirişlerin boyuna göre kalınlıklarının oranı da kritik burkulma yüklerini etkilemektedir. L/h oranı yükseldikçe nano kirişlerin kritik burkulma yükleri belirgin bir düşüş göstermektedir. L/h oranı arttıkça kiriş teorilerinin kritik burkulma yükleri de yakınlaşmaktadır. Örneğin $e_0a = 0.1$, $L/h = 1$ durumunda, Timoshenko kiriş teorisi Euler-Bernoulli kiriş teorisine göre yaklaşık % 72 oranında daha düşük kritik burkulma yükü tahmin ederken, $L/h = 15$ durumunda ise bu oran % 1'e kadar düşmüştür.

Fiber hacim oranının artışı, kirişlerin kritik burkulma yüklerini olumlu yönde etkilemekte ve kiriş rijitliğini artırarak burkulma direncini güçlendirmektedir. Çalışma, V_f değerinin 0.1'den 0.5'e çıkmasının kritik burkulma yüklerini 3 kat arttırdığını göstermiştir. Bu bulgu, fiber takviyesinin yapısal performansı artırmadaki önemli rolünü açıkça ortaya koymaktadır. Uzunluk/çap oranı (l/d) arttıkça bu etki daha da belirgin hale gelmekte ve uzun ince fiberlerin kiriş rijitliğine katkısı daha da artmaktadır.

Elastisite modül oranı da kritik burkulma yükleri üzerinde önemli bir etkiye sahiptir. $E_f/E_m = 100$ durumunda elde edilen burkulma yükleri, $E_f/E_m = 10$ durumuna göre çok daha yüksek olup, daha rijit fiberlerin kirişin burkulma direncine önemli bir katkı sağladığını göstermektedir. Bu etki, özellikle yüksek l/d oranlarında daha da belirginleşmekte ve rijitliğin artışıyla birlikte burkulma yükleri hızla yükselmektedir.

Sonuç olarak, bu çalışma, nanokompozit kirişlerin burkulma analizinde yerel olmayan etkilerin, uygun kiriş teorisi seçiminin ve mikro ve nano ölçekli uygulamalarda yapısal stabilitenin doğru tahmin edilebilmesi için yerel olmayan etkileşimlerin göz önünde bulundurulmasının önemini ortaya koymaktadır. Ayrıca, fiber hacim oranı, uzunluk/çap oranı ve elastisite modül oranı gibi parametrelerin dikkatlice seçilmesi, yapı elemanlarının burkulma direncini hesaplamak açısından son derece önemlidir. Gelecekteki çalışmalarda bu teorik bulguların deneysel doğrulamalarının yapılması ve burkulma davranışı üzerinde etkili olabilecek diğer yapısal parametrelerin de incelenmesi faydalı olacaktır.

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The Role of Pesticide Technology in Agriculture 4.0: The Smart Farming Approach

Hatice DİLAVER[1*], Kâmil Fatih DİLAVER[2]

[1] Niğde Ömer Halisdemir University, Department of Eurasia Studies, 51200, Niğde, Türkiye
[2] Niğde Ömer Halisdemir University, Faculty of Engineering, Department of Electric and Electronics, 51200 Niğde, Türkiye

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Abstract: The agricultural sector forms the cornerstone of humanity's survival by providing the fundamental need for food production. However, factors such as population growth, climate change, and dwindling natural resources underscore the need to make agriculture more efficient, sustainable, and productive. In this context, the concept of "Agriculture 4.0" has emerged as a smarter, more innovative, and technology-driven approach compared to traditional agricultural methods. Agriculture 4.0 aims to integrate agricultural production processes with digital technologies to make agriculture more efficient, sustainable, and competitive. This approach seeks to optimize agricultural production by providing farmers with increased productivity, lower costs, and reduced environmental impact. Pesticide technology is a crucial component of Agriculture 4.0. Pesticides are essential agricultural practices used to combat harmful organisms and control plant diseases. Traditional pesticide methods may often be time-consuming, costly, and environmentally unfriendly. However, with the advent of Agriculture 4.0, smart pesticide technologies are offering various innovative solutions to address these challenges. This article will examine the importance and impact of integrating pesticide technology into Agriculture 4.0, conduct a relevant literature review, explain the methodology, evaluate the findings, and lay the groundwork for future discussions. The abstract should consist of a single paragraph of no more than 200 words and should provide an appropriate overview of the study. Without a title Background (the purpose of the study should be emphasized by placing the question in broad context), Methods (the main methods or treatments applied should be briefly described) Results (summarizing the main findings of the article, providing the main conclusions or comments). The abstract should be an objective representation of the article, should not contain unverified results not presented in the main text, and the main results should not be exaggerated.

Akıllı Tarımda (Tarım 4.0) İlaçlama Teknolojisi

Anahtar Kelimeler:
Tarım 4.0,
Pestisit Teknolojisi,
Akıllı Tarım.

Özet: Tarım sektörü, insanlığın hayatta kalması için temel bir ihtiyaç olan gıda üretiminin temelini oluşturur. Ancak, nüfus artışı, iklim değişikliği ve doğal kaynakların azalması gibi faktörler, tarımın daha verimli, sürdürülebilir ve verimli hale getirilmesi gerektiği gerçeğini ortaya koymaktadır. Bu bağlamda, geleneksel tarım yöntemlerine kıyasla daha akıllı, yenilikçi ve teknoloji odaklı bir yaklaşım olan "Tarım 4.0" kavramı ortaya çıkmıştır. Tarım 4.0, tarımsal üretim süreçlerini dijital teknolojilerle entegre ederek, tarımın daha verimli, sürdürülebilir ve rekabetçi hale gelmesini amaçlar. Bu yaklaşım, çiftçilere daha fazla verimlilik, daha düşük maliyetler ve daha az çevresel etki sağlayarak tarımsal üretimi optimize etmeyi hedefler. İlaçlama teknolojisi, Tarım 4.0'un önemli bir bileşenidir. İlaçlama, zararlı organizmalarla mücadele etmek ve bitki hastalıklarını kontrol altında tutmak için kullanılan önemli bir tarımsal uygulamadır. Geleneksel ilaçlama yöntemleri genellikle zaman alıcı, maliyetli ve çevre dostu olmayabilir. Ancak, Tarım 4.0 ile birlikte gelişen akıllı ilaçlama teknolojileri, bu sorunları ele almak için çeşitli yenilikçi çözümler sunmaktadır. Bu makalede, Tarım 4.0'unilaçlama teknolojisine entegrasyonunun önemi ve etkisi incelenecek, ilgili literatür taraması yapılacak, metodoloji açıklanacak, elde edilen sonuçlar değerlendirilecek ve gelecekteki tartışmalar için bir temel oluşturulacaktır.

*Corresponding author: haticedilaver509@gmail.com
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1. INTRODUCTION

Agriculture encompasses both plant and animal production, including forestry and fisheries activities, as well as the preservation, processing, and transportation of agricultural products, and the rental of agricultural tools and machinery to other farmers (Karluk, 1999). Agricultural activities meet the most fundamental needs of humans, namely nutrition and clothing, ensuring their sustainable livelihoods. Agriculture has been the primary occupation and source of livelihood for humans from ancient times to the present day. With the onset of the Industrial Revolution, a process of modernization began in agriculture, transitioning from extensive (primitive) farming to intensive (intensive) farming (Karabağ, 2016). In response to both global population growth and urbanization, efforts have been made to meet the increasing demand for food and achieve food security by adopting the Green Revolution, a method of plant production. However, the transition to intensive agriculture and the associated Green Revolution has led to increasing problems related to food security worldwide. The rapid increase in the world's population, economic instability, inadequate education levels, and escalating environmental pollution have exacerbated nutrition problems and made it increasingly difficult to ensure food safety. Therefore, globalization has made food security concepts crucial in developed and/or developing countries (Arıkan & Tozkoparan, 2022). Intensive chemical pesticides (plant protection) and fertilizer (plant nutrition) input applications, known as modern agriculture, cause serious damage to nature and also disrupt the structure of living soil due to indiscriminate fertilization, irrigation, and spraying in plant production. Furthermore, factors such as the destruction and depletion of forest assets, soil erosion, erroneous agricultural practices, overgrazing, inappropriate crop rotation, and the unbalanced use of fertilizers and pesticides have led to a gradual decrease in arable agricultural land. Although chemical pesticides and fertilizers have provided high yields in a short period, it is commonly accepted in the globalized world that they will ultimately harm the natural environment. As environmental awareness grows, there is a need for environmentally friendly sustainable practice activities. In addition, with the increase in income and education levels due to the dynamic lifestyle of our era, there is also an increase in the demand for safe food consumption. In line with this awareness, people want to be sure that all purchased food products, especially directly consumed agricultural products, are safe (Söğüt et al., 2020a; Söğüt et al., 2020b). Within the scope of food and environmental safety, agricultural production methods that already have environmentally friendly sustainability and combat methods against diseases and pests have been updated. . Agriculture 4.0 aims to integrate agricultural production processes with digital technologies to make agriculture more efficient, sustainable, and competitive. This approach seeks to optimize agricultural production by providing farmers with increased productivity, lower costs, and reduced environmental impact. Pesticide technology is a crucial component of Agriculture 4.0. Pesticides are essential agricultural practices used to combat harmful organisms and control plant diseases. Traditional pesticide methods may often be time-consuming, costly, and environmentally unfriendly. However, with the advent of Agriculture 4.0, smart pesticide technologies are offering various innovative solutions to address these challenges.

2. MATERIAL AND METHODS

2.1. Study Area and Crops

The study was conducted in a designated agricultural research field, where a variety of crops including wheat, corn, and fruit orchards (apple and vineyard) were cultivated. The selected crops represent common agricultural practices and present different challenges for pest and disease management.

2.2. Early Warning Systems

2.2.1. Internet of Things (IoT) Devices

IoT devices equipped with various sensors were deployed across the study area. These included:
Soil Moisture Sensors: To monitor soil moisture levels and detect changes that may indicate pest activity.
→Weather Stations: To record temperature, humidity, wind speed, and precipitation.
→Leaf Wetness Sensors: To detect conditions favorable for disease development.
→Pest Traps with Sensors: To monitor pest populations and activity in real-time.

2.2.2. Data Collection and Analysis

The data collected from the IoT devices were transmitted to a central cloud-based system for real-time analysis using artificial intelligence (AI) algorithms. This system was designed to:
→Analyze environmental conditions to predict pest and disease outbreaks.
→Generate alerts for farmers regarding the need for pest or disease management interventions.
→Provide recommendations for targeted actions based on real-time data.

2.3. Remote Sensing for Identifying Plant Diseases and Pests

Spectral Imaging: Hyperspectral and multispectral cameras were used to capture images of the crops. These cameras were mounted on drones and a fixed-position ground-based platform.

Spectral Analysis: The spectral images were analyzed to identify specific wavelengths that correspond to plant stress caused by pests or diseases. Key indicators included:
→Changes in chlorophyll content.
→Pigment destruction.
→Necrotic lesions or pustules.

2.4. Principles of Monitoring Plant Diseases and Pests

2.4.1. Types of Damage Monitored

→Reduction in Biomass and Leaf Area Index (LAI): Monitored using aerial imagery to detect large-scale foliage loss.
→Lesions and Pustules: Identified through detailed spectral analysis.
→Pigment Destruction: Detected using hyperspectral imaging to identify changes in chlorophyll and other pigments.
→Wilting: Monitored using thermal imaging to detect dehydration and turgor loss.

2.4.2. Monitoring Techniques

→Remote Sensing (RS): Utilized UAVs (drones) and ground-based platforms equipped with hyperspectral and multispectral cameras.
→Image Processing: Analyzed captured images to detect early signs of disease and pest infestation.
→Spectral Analysis: Focused on specific bands to identify physiological changes in the plants.

2.5. Existing Remote Sensing Systems

2.5.1. Visible and Near-Infrared (VIS-NIR) Systems

Used to monitor plant health and detect stress indicators.

2.5.2. Fluorescence and Thermal Systems

Employed to identify changes in plant physiology such as water stress and pigment content.

2.5.3. Synthetic Aperture Radar (SAR) and LiDAR Systems

Utilized for structural analysis of plant canopies and to provide detailed 3D models of crop fields.

2.6. Smart Spraying System

2.6.1. Target Detection System

→Image Sensors and Spectrometers: Used for real-time detection of weed and pest presence.
→Data Processing and Decision-Making: Integrated with AI algorithms to determine the severity of infestations and recommend targeted spraying.

2.6.2. Spraying System

→Electrostatic Sprayers: Applied pesticides with charged droplets to ensure even coverage and reduce drift.
→Variable Rate Technology (VRT): Enabled precise application of pesticides based on real-time detection, reducing chemical use and environmental impact.

2.6.3. Implementation

→Ground Sprayers and Product Sprayers: Different types of sprayers were used depending on the crop type and field conditions.
→Fruit Orchard Sprayers: Specialized equipment was used for orchards to account for the unique shape and size variations of the trees.

2.7. Evaluation and Validation

2.7.1. Field Trials

Conducted in different sections of the study area to evaluate the effectiveness of the early warning systems and smart spraying technologies.

2.7.2. Data Collection

Yield data, pest and disease incidence rates, and environmental impact metrics were collected throughout the growing season.

2.7.3. Statistical Analysis

Performed to compare the effectiveness of traditional pest management methods with the smart systems employed in this study. Key metrics included yield improvement, reduction in chemical use, and environmental impact. By integrating IoT, remote sensing, and smart spraying technologies, this study aims to enhance pest and disease management in agriculture, promoting sustainability and increasing productivity.

3. RESULTS AND DISCUSSION

3.1. Early Warning Systems in Smart Agriculture and Their Operating Principles

Protection against widespread biotic stresses such as diseases, insect infestations, and weed competition in crop production is an essential practice in agricultural production. Many studies and experiments have reported that although the widespread use of chemicals such as pesticides, fungicides, and herbicides has increased productivity, it has also led to serious residues in foods and serious damage to human and environmental health (Gil & Sinfort, 2005). On the one hand, the need to increase the effectiveness of chemical pest control and, on the other hand, to reduce off-target pollution, such as sensitive environmental areas, humans, and non-target products, has raised a new issue (Song et al., 2015). In terms of food and environmental safety and sustainability, there is an increasing trend in the use of quarantine, cultural, physical, mechanical, biotechnical, biological, integrated pest management, biofertilizers as alternatives to chemical fertilizers, phytostimulants, bioremediation, and biodegradation in combating diseases, pests, and weeds. In the scope of food and environmental safety and sustainability, various types of agriculture such as Industrial, Organic, Ecological, Terrace, Dry, Irrigated (Rain-fed), Urban, Sustainable, Collective, Biodynamic, Smart, Climate-smart agriculture have been developed (Anonymous, 2022). The World Trade Organization has established a protocol within the scope of "Animal and Plant Health" in international standards for agricultural products and external trade to ensure reliable food and sustainable environmental objectives.

With the impact of "Industry 4.0," the agricultural sector has also been affected by digitization in the industry. Due to the rapid advancements in technology and the great changes brought about by the Industry 4.0 process, concepts such as the internet, computers, and sensors, which have now become part of our daily lives, along with developments in nanotechnology, have forced the whole world into a digital transformation. With the entry of concepts such as wireless and machine-to-machine communication technologies, cloud systems, and the Internet of Things (IoT) into our lives, the use of mobile devices integrated with agricultural software has also increased in the agricultural sector. The reflection of this process on agricultural production has made digital transformation in agriculture compulsory. All agricultural machinery used in agricultural production stages (soil preparation, planting and harvesting of crops, fertilization and irrigation of plants, plant protection applications, etc.) has entered the agricultural sector with the "Internet of Things" by being equipped with sensors, and Smart Agriculture, i.e., "Agriculture 4.0," has emerged by ensuring that machines communicate with each other throughout the production stages. Thanks to digitalization, data obtained with smart tools are analyzed in real-time with artificial intelligence technology. These smart tools not only facilitate agricultural cultivation activities by analyzing in detail which parts of the cultivated land need to be fertilized and sprayed with which types and amounts of fertilizers and pesticides, combating pests, providing the minerals and irrigation processes required by plants, analyzing the soil condition, weather conditions (relative humidity, temperature, evaporation intensity, wind speed, etc.), and predicting harvest time in detail and real-time, but also reduce input costs. The main goal of these applications is to maximize agricultural yield compared to traditional methods (Klavuz & Erdem, 2019). With the mechanization within Industry 4.0, global warming is increasing due to the increase in greenhouse gases such as carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3), as well as climate change, which leads to productivity problems in agriculture worldwide, causing crop prices to rise both globally and in Turkey. Controlling diseases, pests, and weeds, which are biotic factors causing product losses, is crucial in minimizing these problems. With the advancement of technology, Tarım 4.0, also known as Agriculture 4.0, allows early warning systems to be developed by analyzing data in real-time with artificial intelligence technology for combating diseases, pests, and weeds with appropriate integrated methods in the right place, at the right time, using appropriate equipment. Machine vision, spectral reflection, remote sensing, and other sensing technologies play a critical role in precise operations in all smart farming systems (Song et al., 2015). Knowing the occurrence, extent, and severity of plant diseases and pests, which are serious threats to agriculture and forestry worldwide, is essential for guiding plant protection procedures (Oerke, 2006; Strange & Scott, 2005). Considering that traditional field surveys for plant diseases and pests are labor-intensive, prone to subjectivity, and generally show low efficiency, remote sensing (RS) techniques can be an important complement to monitoring plant diseases and pests at a coarse scale (Mahlein, 2016).

3.2. Remote Sensing for Identifying Plant Diseases and Pests

Detecting and monitoring plant diseases and pests are crucial for the sustainability and productivity of agriculture. Remote sensing techniques provide the opportunity for early diagnosis of plant diseases and pests, enabling prompt intervention. Within the scope of this study, various spectral and morphological features have been investigated for the identification of plant diseases and pests through remote sensing.

3.3. Principles of Monitoring Plant Diseases and Pests

There are four types of damage (perceptual challenges) associated with remote sensing between symptoms caused by diseases or pests and physiological changes in plants. (1) Reduction in biomass and LAI (Leaf Area Index). This type of damage usually occurs in some insect attacks. Pests (e.g., caterpillars in corn) can consume plant parts (e.g., leaves, stems), leading to significant leaf area and biomass loss (Zhang et al., 2015). However, due to the lack of spectral specificity in this destruction, monitoring is often faced with a high level of uncertainty. (2) Lesions or pustules due to infection. Necrotic tissue lesions or pustules caused by diseases and pests are the most common symptoms. Lesions and pustules tend to vary in color and shape between diseases and pests. The distribution and abundance of these lesions and pustules (e.g., evenly distributed within the canopy or localized underneath) are believed to have a significant impact on their detectability (Cao et al., 2013; Moshou et al., 2004). (3) Destruction of pigment systems. In most cases, disease infection and pest infestation can lead to the destruction of chloroplasts or other organelles, resulting in changes in pigment contents (e.g., chlorophyll (Chl), carotenoid (Car), and anthocyanin). Hyperspectral remote sensing observations are usually required to detect this type of response (Grisham et al., 2010; Zhang et al., 2012a). (4) Wilting. Loss of turgor due to dehydration is not a common symptom of plant diseases and pests and can be easily confused with drought stress. The piercing and sucking behavior of some pests (e.g., insects or aphids) will cause plants to wilt (Cheng et al., 2010). Additionally, in some severe infection cases, damage to the vascular system will block the flow of water in plants, leading to dehydration in all plants (Calderón et al., 2013).

3.4. Existing Remote Sensing Systems for Monitoring Plant Diseases and Pests

Various remote sensing (RS) systems are available for detecting and monitoring plant diseases and pests. These RS systems, performing with both passive and active radiation, enable data collection ranging from gamma-ray to microwave. Efforts have been made to apply different RS systems to capture infection symptoms (lesions, pustules, etc.), physiological responses (changes in pigment content, water content, etc.), and structural changes caused by plant diseases and pests (canopy structure, landscape structure, etc.) effectively (Hahn, 2009; Mahlein, 2016; Sankaran et al., 2010). Based on detection principles and technical maturity, detection systems for monitoring plant diseases and pests can generally be classified into three types:

(1) Visible and Near-Infrared (VIS-SWIR) spectral systems;
(2) Fluorescence and thermal systems; and
(3) Synthetic Aperture Radar (SAR) and Light Detection and Ranging (Lidar) systems.

3.5. Smart Spraying System General System

A general-purpose autonomous chemical spraying system typically comprises two fundamental technologies: detection technology for targeted sensing (machine vision, spectral sensing) and robotic spray application (micro-spraying, cutting, thermal, electric shock) (Slaughter et al., 2008). Therefore, a smart spraying system generally consists of a target detection system and a chemical spraying system. Figure 1 illustrates a smart spraying system based on detection technology. The detection system integrates targeted detection sensors, data processing, and decision-making systems; the spraying systems include a spraying control unit and a nozzle.

3.5.1.Target Detection System

The essence of targeted detection, given the necessity for high-yield and low-labor production in agriculture, focuses on weed classification and localization, identification of damaged and diseased plants, and estimation of severity in the field. In weed control, weeds are the primary objects identified, among crops or trees. There are two research directions: one is weed detection, where all plants are detected and weeds are identified, and the other is crop detection, where field crops are detected, and all other plants are considered weeds. In pesticide management, plant growth status, often related to disease rate and severity level, is measured and analyzed. In orchard chemical spraying, target detection generally focuses on plant position, shadow volume, disease rate, and severity level.

Various sensors can be applied in targeted detection, including image sensors, spectrometers, remote sensing, thermography, etc. (Figure 2). All are developed based on spectrum technology, showing electromagnetic absorption at different wavelengths ranging from 1023 nm to 109 nm. The spectrum generally refers to green vegetation, from visible (400º-nm-700º-nm) to near-infrared spectrum (NIR, 700º-nm-2500º-nm). Typically, the implementation of spectrum technology can be divided into two groups: image processing and spectral analysis (Lacar et al., 2001). Based on the spectrum range, images can be divided into color images (RGB images in the visible band) and spectral images (visible and NIR bands). A color image, containing RGB (red 600-700º-nm /green 490-600º-nm /blue 400-490º-nm) color information for each pixel, is the most well-known descriptor by humans. The spectral image usually displays an image that provides information not only in the visible band but also in the near-infrared band. It can be classified as multispectral and hyperspectral images. Multispectral data contain several to hundreds of bands, while hyperspectral data contain hundreds to thousands of contiguous bands. The morphological features and spectral properties of the image are crucial.

3.5.2. Spraying system

Air-assisted, electrostatic, and hydraulic are the basic techniques of chemical spraying (Giles et al., 2008). Traditional air-assisted sprayers operate by delivering the spray mixture into an air stream using a pressure pump. This air stream is produced by a large fan and serves to transport the spray to the target. One of the advantages of this technique is that the spray is rapidly delivered, and the entire air volume of the orchard can be treated with a pesticide-laden mist. However, one of the main disadvantages is drift; most of the mist is dispersed into the air before reaching the targets (Wise et al., 2010). The electrostatic spraying technique applies electrostatic technology based on attracting and repelling opposite charges. As the chemical mixture exits the nozzle, it is subjected to a negative charge. These charged droplets are then attracted to the positively charged leaf surface (Zhao et al., 2008). Electrostatic spraying technology has been considered an applicable method to improve the deposition of pesticides and reduce waste, consequently reducing environmental impact (Giles and Blewett, 1991; Giles et al., 2009). Hydraulic sprayers transport chemicals to plants with pump pressure. The spraying material is usually applied as a "wet" or "drip". Nozzles on the boom break the spray into small droplets and direct it onto the leaves. They have larger droplets than air-assisted and electrostatic sprayers (Sumner and Herzog, 2000).

There are three general spraying patterns, as shown in Figure 3: Broadcast, band, and targeted spraying. Broadcast spraying with the traditional method is applied with a high inefficiency when the sprayer passes over targets, with or without targets, and usually causes off-target losses of up to 60-70% (Edward Law, 2001). To reduce off-target losses and environmental pollution, band and targeted spraying methods have been developed. The band application pattern applies the spray according to the selected area rather than the entire wide area. In the field, band application and mechanical application have been shown to not only decrease chemical use in traditional chemical applications but also careful chemical selection can lead to minimal environmental impact (Niazmand et al., 2008). The targeted spraying system requires the detection of plants in damaged or infected parcels in the field and then controls the timing of spraying. Brown et al. (2008) compared targeted spraying ground deposits with conventional broadcast sprays in dormant orchards and found that targeted spray reduced ground deposits by 41% and reduced pesticide concentration in surface runoff by 44%.

The tunnel sprayer, which is a recycling sprayer for row crops, has been developed using an electrostatic method based on band patterns. It is a type that has shields covering the heights of at least one row's opposite sides to a significant extent. Enclosing fans are used to create an airflow parallel to the flow of the application liquid and to deliver the sprayed liquid to both sides of the row through corresponding nozzles. To prevent dispersion due to wind drift, limit losses in the air, and restrict excess liquid from dripping onto the ground, a shield operating on the other side of the row absorbs the applied liquid. It has been proven that the tunnel sprayer effectively prevents drift and sediment formation on leaf surfaces (Doruchowski and Holownicki, 2000; Viret et al., 2003). Additionally, a system that combines targeted detection and the tunnel sprayer will be one of the most efficient smart sprayers. While tunnel application is limited by plant shape or size, it is recommended for specialized plants in orchards.

In precision spraying systems, sprayers typically have a boom with multiple spraying sections that can be independently controlled. They are designed for variable chemical control according to targeted detection and adjustable nozzle settings (Zheng et al., 2004). Variable-rate application systems for herbicides have been designed and documented to provide real-time spraying with chemical reduction in the field (Al-Gaadi and Ayers, 1999). Pulse-width modulation technology has been applied in variable-rate field spraying machines and has proven to be an effective method in weed control spraying machines (Pierce and Ayers, 2001). Bui (2005) reported a Var Target nozzle with the capability of controlling flow rate and droplet size. It combines variable-area orifices and spray holes, allowing for variable flow rates in both areas during operation, which can be used with pressure regulators or automatic speed controls. Today, smart sprayers are emerging as devices that provide targeted detection, automatic control, and visual feedback to operators, allowing for the recording of ground speed, nozzle pressure, flow rate, area coverage, and the volume of spray used.

3.6. Ground Sprayers and Product Sprayers

Smart sprayers reduce environmental impact by optimizing chemical use in agricultural fields while also helping farmers reduce costs and support sustainable farming goals. Designed to meet future crop production requirements, these technologies represent a significant advancement in the agricultural sector (Ahmad et al., 2020).

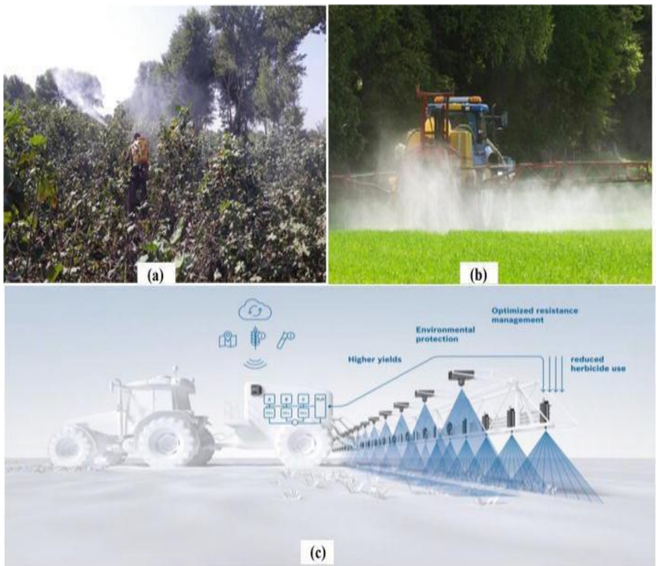

Figure 1. a) Cotton Field Using Backpack Sprayer; b) Wheat Field Using Boom Sprayer c) Schematic Diagram of Smart Sprayer

3.6.1. Fruit Orchard Sprayers

To achieve higher yields and quality in fruit orchards and vineyards, a strong and effective plant protection method has been widely adopted (Fox et al., 2008). Applying spray across the entire area of the plant is challenging due to shape and size variations from plant to plant in orchards and vineyards. It was even more difficult in the past when suitable spraying equipment for orchard spraying was not available. Developments in mechanical equipment from the 1890s to the 1940s, such as steam power, gasoline engines, pressure regulators, and adjustable spray guns for applying pesticide sprays to trees, saw some advancements (Brann, 1956), as shown in Figure 5. Tree structure, including canopy size, shape, and density, varies significantly during different growth periods and different positions (Chen et al., 2011). Therefore, special spray working parameters (flow rate and air flow) along the adjustment facilities are needed to conform to the geometry of the plant (Li et al., 2018). These parameters cannot be calculated with conventional spraying equipment because conventional fruit orchard spraying machines continuously apply pesticides and do not have the capability of variable rate application, generating significant spray drift leading to environmental pollution (Yang et al., 2015) and posing risks to human health.

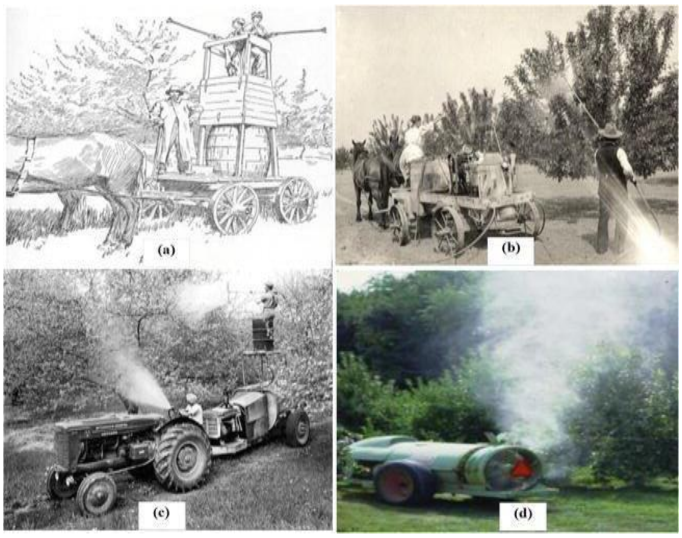

Figure 2. Old Sprayers for Orchard Spraying: (a) Hand-operated Sprayer (b) Steam-powered Sprayer (c) Pressure-regulated Motorized Sprayer (d) Traditional VRT Sprayer (Fox et al., 2008).

To enhance the performance of orchard sprayers, a variety of new mechanisms have been introduced, such as automatic variable rate (VAR), electrostatic, air-assisted, air-jet, and air-supported systems (Li et al., 2018). Real-time sensors are used for the detection of shade characteristics (density, size, shape, and height) to achieve precise spray fluid control. Therefore, the characterization of plants and products is a fundamental concern for pesticide applications. Accurate knowledge of the geometric properties of the product allows for improved spraying performance while reducing environmental and economic impact (Rosell & Sanz, 2012). Various sensors are employed for the detection of plant geometry, including ultrasonic sensors, infrared sensors, LiDAR sensors, and computer vision-based technology. Ultrasonic sensors detect the target distance from the sprayer but are sensitive to environmental conditions such as humidity and temperature (Li et al., 2018). Infrared sensors are electronic sensors that detect the target area by measuring

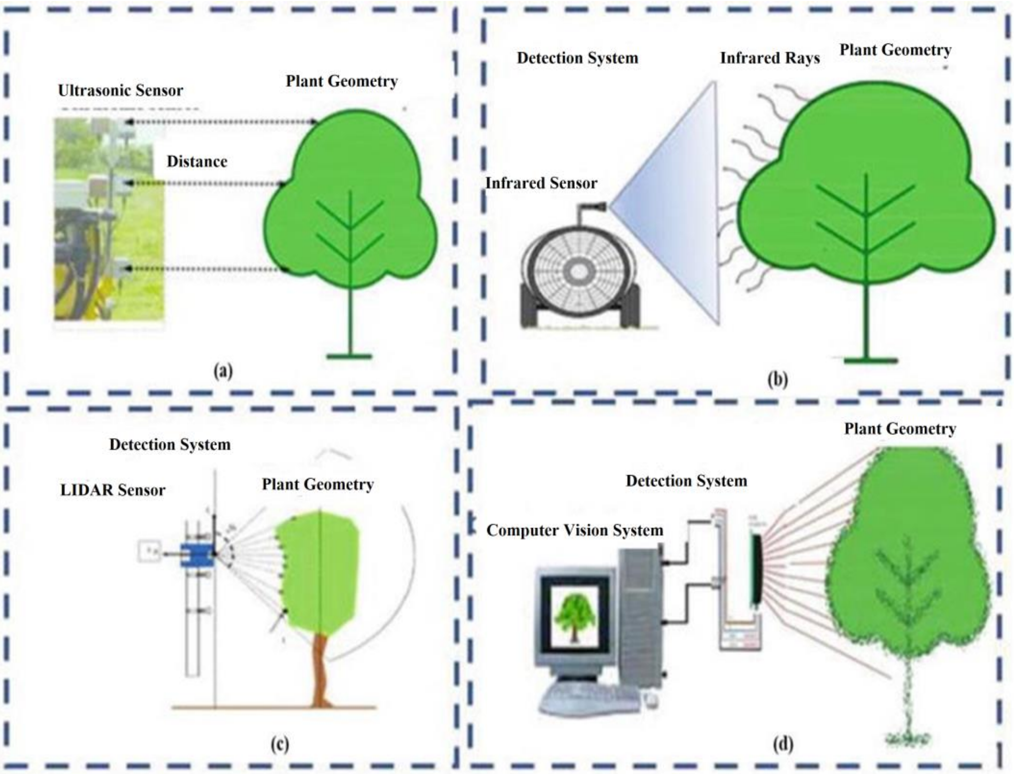

Figure 3. Sensor-Based VR Sprayers. (a) Ultrasonic Sprayer (b) Infrared Sensor Sprayer (c) LiDAR Sensor Sprayer (d) Computer Vision-Based Spraying Technology

the infrared light emitted from objects in the field of view (Zhang et al., 2018b). LiDAR sensor technology is a precise remote sensing technique for distance measurements (Bietresato et al., 2014). The LiDAR sensor measures the time between the transmission of a pulsed laser beam and the reception of its echo from a reflective object to determine distance (Zhang et al., 2018b). In computer vision-based technology, cameras are placed on sprayers to differentiate between plant-like areas, height, density, and physical parameters of plants (See Figure 3).

Tunnel sprayers have played a significant role in the growth of small fruit trees (such as apples and vineyards) in the past decade. These are closed-target spraying application technologies. Some tunnel sprayers operate based on the recirculation principle to recycle excess spray from the target area. Tunnel sprayers are suitable for operation in all weather conditions. Tower sprayers are air-assisted type sprayers that discharge the spray horizontally at the vertical level with the direction of airflow from the fan. Tower sprayers are used for very tall plants (Pergher and Petris, 2009).

Due to the high airspeed in air blast sprayers, the spray can enter the canopies and improve spray deposition on plant leaves, reducing spray drift. Variable-rate sprayers produce a very fine spray mist (150 to 250 μL/m) that reduces the amount of pesticide from the nozzles and increases the spray coverage area. However, this droplet size is very sensitive to air parameters and airspeed. In high humidity and low-temperature conditions, very fine droplets that do not reach the target and remain suspended in the air can cause spray drift, while in low humidity and high-temperature conditions, these droplets evaporate into the air without reaching the target, increasing the loss of pesticide and posing a risk to the environment and human health.

Figure 4. (a) VAA Fruit Orchard Sprayer (b) Tunnel Sprayer (c) Tower Sprayer (d) Multi-Channel Airblast Sprayer (Jadav et al., 2019).

These advanced spraying technologies have greatly improved the efficiency and effectiveness of pesticide application in fruit orchards. By utilizing sensors for real-time detection of canopy characteristics and environmental conditions, these sprayers can adjust their spraying parameters accordingly, ensuring precise and targeted pesticide application while minimizing environmental impact and pesticide waste.

3.6.2. Ultra-low volume (ULV) sprayers

Ultra-low volume (ULV) spraying is a widespread and advanced spraying method (Maas, 1971). It is considered the most effective and standard technique for controlling pests using chemicals and is widely used by cotton producers to control pests and insects. The ULV sprayer is designed to produce very small droplets (50 to 150 µL/m2), which help achieve uniform coverage with low spraying volumes. The ultra-low volume (ULV) fungicide application sprayer was initially developed as thermal fogging (Niekerk and Mavuso, 2011). The ULV sprayer aims to increase insect and disease control while reducing liquid application rates, drift, and chemical waste. Conventional tractor-mounted boom sprayers apply spray to the upper side of leaves; however, most sheltering pests [Aphidae (aphids), Aleyrodidae (whiteflies), jassids, thrips, etc.] are found on the undersides of the upper leaves of the cotton plant and are not only protected from sprays but also reach leaf shade from the umbrella cover. Therefore, chemical spraying done using conventional sprayers fails to reach the exact target and results in the material being scattered on the ground and in the air. Various pests and insects require different numbers of droplets per cm2 that can only be applied using a ULV sprayer (Ali et al., 2011). Vehicle-mounted ULV sprayer is shown in Figure 8. Pesticide droplets accumulated on the upper side of the leaf using traditional sprayers can be washed away by rain or, in some cases, overhead irrigation. Some researchers have concluded that up to 80% of the total pesticide applied to the plant can eventually reach the soil (Courshee, 1960).

Figure 5. Vehicle-Mounted Ultra Low Volume Sprayer

Traditional spraying approaches are generally considered inefficient due to the higher spectrum of droplet size that does not reach the target surface and eventually becomes part of the waste material (150 to 250 µL/cm2). Nevertheless, the use of ULV (Ultra Low Volume) sprayers has significantly altered spraying technology, as they produce relatively small droplets. Due to the Volume Application Rate (VAR), ULV sprayers use less liquid, typically less than 5 l/ha for field crops or less than 50 l/ha for trees/shrubs (Ali et al., 2011). Electrostatic sprayers represent the latest development in ultra-low volume pesticide application.

Air-assisted electrostatic sprayers are a new advancement in plant protection machinery that enhances pesticide application efficiency on crops, vineyards, orchards, plants, and trees. The electrostatic spray method reduces off-target drift, environmental concerns, and human health risks (Patel, 2016). It is believed that the electrostatic spraying technique has revolutionized spraying machinery through higher droplet deposition and retention on plant leaves (Patel et al., 2015). It is considered a viable method to overcome complications associated with conventional agricultural chemical spraying, such as volatilization and drift of spray droplets due to temperature and wind effects. Electrostatic space charge and induced image charge forces enhance spray uniformity, transfer efficiency, bioactivity, and adhesion on the target surface. These electrostatic forces minimize the effect of gravitational force, which is the main cause of spray drift (Shrimpton, 2003) (See Figure 6). Electrostatic spray application extends the spray retention time on the target. There is an interaction between the formulation effects on the robustness of a deposit and the surface of the leaf onto which it adheres. Droplets tend to bounce off waxy leaves (often an age-related characteristic), and weak retention may occur, especially in water-based formulations with high dynamic surface tensions. However, in ULV electrostatic sprayers, droplets, negatively charged from the nozzles by air injection, repel each other, reaching the target individually without coalescing and creating a charge that produces adhesion forces to stay on the plant leaf for an extended period, reducing spray drift.

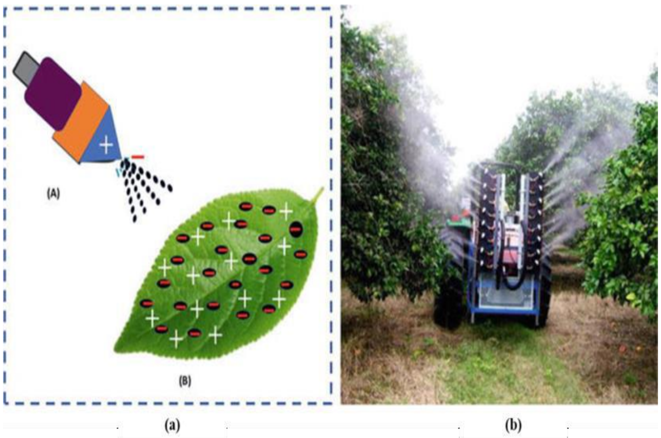

Figure 6. (a) Electrostatic Spraying Mechanism (b) Variable Speed Multi-Channel Electrostatic Sprayer

Ultra-low volume (ULV) spraying is considered an effective and standard technique for controlling pests using chemicals and is widely employed by cotton growers to control pests and insects. ULV sprayers are designed to create very small droplets (50 to 150 µL/m2) to assist in uniform coverage with low spray volumes. The ULV fungicide application sprayer was initially developed as a thermal fogger (Niekerk & Mavuso, 2011). The purpose of ULV spraying is to increase insect and disease control while reducing liquid application rates, drift, and chemical waste. Conventional tractor-mounted boom sprayers apply spray to the upper side of the leaf; however, the shelters of most sucking insects [Aphidae (aphids), Aleyrodidae (whiteflies), jassids, thrips, etc.] are found beneath the upper leaves of the cotton plant and not only are they shielded from sprays but they also reach the leaf underside from the umbrella cover. Therefore, chemical spraying done using conventional sprayers often fails to reach the precise target and leads to the scattering of spraying material onto the ground and into the air. Various pests and insects require different numbers of droplets per cm2 that can only be achieved by using a ULV sprayer (Ali et al., 2011). A vehicle-mounted ULV sprayer is shown in Figure 8. Some researchers have concluded that up to 80% of the total pesticide applied to the plant may end up in the soil (Courshee, 1960).

3.6.3.Aerial spraying

Aerial spraying, although it has been used since the mid-20th century, is considered a significant advancement in agricultural spraying and plant protection engineering due to its immense advantages over traditional ground sprayers. Monitoring crops and assessing the timely on-site needs for pesticides and fertilizers is an important parameter for effectively utilizing inputs to increase productivity (Gayathri et al., 2020). Aerial spraying using Unmanned Aerial Vehicles (UAVs) has gained significant attention worldwide (Zhang et al., 2018c). Therefore, UAVs are currently known as the most advanced spraying technology that assists in effective and precise spraying. Unmanned aerial sprayers potentially play a significant role in reducing the environmental and human impact of pesticides during the farm-level application process (Ahmad et al., 2020). The use of UAVs facilitates crop production practices and enables spraying in crops with long stalks like corn, and cotton, and crops with water puddles like rice. UAV aerial spraying capability is not limited to plant protection but is also used in fertilizer applications (Muhammad et al., 2019).

The idea of aerial spraying through UAVs was initially developed based on unmanned helicopter technology developed by Yamaha Corporation (Japan) for rice planting (Giles & Billing, 2015). Chemicals such as pesticides and fertilizers are mostly applied using ground sprayers, aerial crop spraying, and broadcasting methods without real-time assessment of specific conditions (Lan et al., 2017). The UAV sprayer enhances the downward washing airflow created by the UAV rotor interacting with the crop canopy and forms a conical vortex shape in the crop plant (Guo et al., 2019). Droplet deposition efficiency is one of the major concerns in UAV spraying operations. During UAV sprayer application, while some droplets penetrate the plant canopy, others often drift away, leading to wastage of pesticides, reduced control efficacy, and even environmental pollution and poisoning (Zhang et al., 2017a).

Regulations for spraying systems on UAVs have not yet been optimized to accompany spraying models based on appropriate nozzle selection (Moltó et al., 2017). Droplet size, weather conditions, and operational parameters of sprayers affect spraying coverage, absorption, and adhesion to the target (Qin et al., 2016). The impact of climatic conditions (temperature, humidity, wind direction speed, etc.) on UAV spraying efficiency must be clearly understood by practitioners (Songchao et al., 2017). Unmanned aerial vehicles (UAVs) are operated autonomously along pre-planned routes using telemetry with visual contact between the operator and the aircraft remotely or using GPS or inertial guidance (Giles & Billing, 2015).

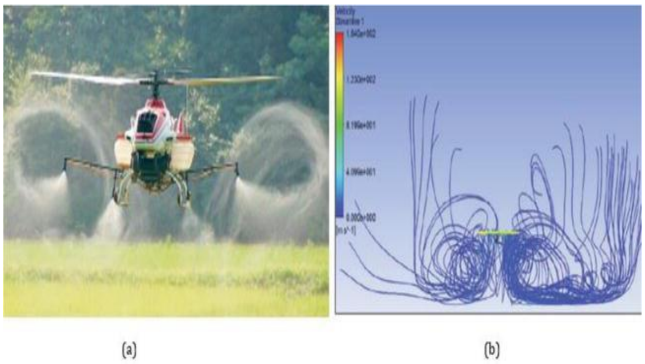

Figure 7. (a) Effect of Rotor Blades on Spray Drift (Chen et al., 2021) (b) Streamlines of Flow Field Below the Rotor (Shi et al., 2019).

6.4.Fruit Orchard Sprayers

A powerful and effective plant protection method has been widely adopted in orchards and vineyards to achieve higher production and quality (Fox et al., 2008). However, the different growth characteristics and geometry of plants like fruit trees and vineyards make the use of traditional spraying equipment challenging (Chen et al., 2011). Therefore, specialized spraying machines that can be adjusted to fit the specific spraying parameters (flow rate and air flow) are required (Li et al., 2018).

With the introduction of new mechanisms, spraying techniques in fruit orchards have also evolved (Li et al., 2018). For example, automatic variable rate, electrostatic, air-assisted, air-supported, and airblast spraying systems are some of the various sprayer types used in fruit orchard spraying. These machines enhance spraying efficiency by applying precise and measurable amounts of pesticide and reducing environmental impact (Jadav et al., 2019).

In particular, electrostatic spraying technology increases spraying efficiency by achieving high droplet deposition and adhesion to plant leaves (Patel et al., 2015). This technology uses less spraying material compared to traditional methods and causes less harm to the environment (Patel, 2016).
Additionally, the use of unmanned aerial vehicles (UAVs) is also a significant development in fruit orchard spraying (Zhang et al., 2018c). UAVs optimize pesticide use and enhance farm productivity by providing precise and effective spraying (Ahmad et al., 2020).

4. CONCLUSION

This study has developed a model to evaluate the performance of various spraying systems used in orchards. This model expresses spraying efficiency as P=(E,T,R)P=f(E,T,R), where:

PP represents spraying efficiency,
EE denotes the type of energy used,
TT represents the type of spraying technique, and
RR represents environmental impacts.

The development and implementation of this model can help make spraying processes in orchards more efficient and sustainable. The results obtained can provide valuable insights to decision-makers and practitioners in the fields of agricultural spraying and plant protection engineering.

The findings can assist in identifying the most suitable type of energy and spraying technique to increase spraying efficiency. Additionally, it can be beneficial in determining the factors to consider in reducing environmental impacts. For example, the use of a specific spraying technique may reduce energy consumption and minimize environmental impacts.

The results of this study can contribute to promoting sustainable practices in the agricultural industry and reducing environmental impacts. Furthermore, they may enable future researchers to develop similar models and design better spraying systems.

Based on the results of this study, various recommendations can be made for making current spraying systems more effective and efficient. These include:

→Technological Improvements: Existing technological improvements in spraying systems can enhance spraying efficiency. For instance, the use of electrostatic spraying systems can improve spraying effectiveness by ensuring better adherence of the sprayed liquid to the plant surface.

→Targeted Application: Sensor technologies and artificial intelligence can enable spraying systems to be more precisely directed toward the target. This can reduce waste by ensuring the application of spraying materials in the correct amounts and at the right times.

→Reduction of Environmental Impact: More efforts should be made to reduce environmental impacts during the spraying process. This may involve the use of more environmentally friendly materials in the design and operation of spraying systems.

→Education and Awareness: It is important to educate and raise awareness among agricultural practitioners and decision-makers about spraying technologies. This can help promote the adoption of more sustainable farming practices and reduce environmental impacts.

These recommendations support efforts to make current spraying systems more effective and efficient. It is hoped that future research will develop new methods to implement these recommendations and make spraying technologies more sustainable. As the study progresses, it can delve deeper into specific aspects of spraying efficiency and environmental impact mitigation. This could involve conducting field experiments to validate the model's predictions and refine its parameters. Additionally, further research could explore the economic aspects of implementing different spraying systems in orchards, considering factors such as initial investment costs, operating expenses, and long-term savings. Moreover, the study can investigate the potential integration of emerging technologies, such as artificial intelligence and machine learning, into spraying systems to optimize performance and reduce environmental impact. These technologies could enable real-time monitoring and adjustment of spraying parameters based on environmental conditions and plant characteristics. Furthermore, collaboration with agricultural stakeholders, including farmers, agricultural engineers, and policymakers, can provide valuable insights into practical challenges and opportunities related to implementing advanced spraying systems in orchards. This collaboration can help ensure that the developed models and recommendations are aligned with the needs and realities of the agricultural sector. In conclusion, by continuing to expand and refine the research, the study can contribute to the development of more sustainable and efficient spraying practices in orchards, ultimately benefiting both agricultural productivity and environmental conservation efforts. Continuing the research, it would be beneficial to explore the potential synergies between different spraying systems and practices. This could involve investigating how combining multiple techniques, such as using UAVs for initial aerial surveys followed by ground-based precision spraying, could enhance overall efficiency and effectiveness while minimizing environmental impact. Furthermore, conducting lifecycle assessments of various spraying systems would provide valuable insights into their overall environmental footprint. This would involve evaluating not only the direct impacts during operation but also considering factors such as manufacturing, transportation, and end-of-life disposal of equipment and chemicals. Additionally, exploring the social and economic dimensions of adopting advanced spraying technologies in orchards is crucial. This could involve assessing factors such as labor requirements, skill levels, and accessibility for different types of farmers. Understanding these aspects would help identify potential barriers to adoption and inform strategies for promoting a more widespread uptake of sustainable spraying practices. Moreover, engaging with local communities and stakeholders through participatory approaches can facilitate the co-design and implementation of spraying solutions that are tailored to specific contexts and needs. This collaborative approach can help build trust, foster knowledge exchange, and ensure that spraying practices are socially acceptable and culturally appropriate. Overall, by addressing these additional dimensions and considerations, the research can contribute to the development of holistic and contextually relevant solutions for improving spraying practices in orchards, ultimately promoting sustainable agricultural development and environmental stewardship.

Expanding the research to include a comparative analysis of the economic costs and benefits associated with different spraying systems would provide valuable insights for decision-makers. This analysis could include factors such as initial investment costs, operating expenses, labor requirements, and potential yield improvements or reductions in crop losses. By quantifying these economic aspects, stakeholders can make more informed decisions about the adoption of advanced spraying technologies. Furthermore, incorporating a risk assessment component into the research would help identify potential hazards and uncertainties associated with different spraying systems. This could involve evaluating factors such as pesticide drift, chemical exposure risks to workers and nearby communities, and the potential for resistance development in pest populations. By understanding and mitigating these risks, researchers and practitioners can ensure the safe and responsible use of spraying technologies. Additionally, considering the scalability and adaptability of spraying systems to different orchard sizes, crop types, and geographic locations is important. Research could explore how well different systems perform under varying conditions and identify any limitations or challenges that may arise in different contexts. This information would be valuable for farmers and policymakers seeking to implement spraying solutions across diverse agricultural landscapes. Moreover, integrating stakeholder perspectives and local knowledge into the research process can enhance the relevance and applicability of findings. Engaging with farmers, agricultural extension workers, industry representatives, and environmental organizations can provide valuable insights into on-the-ground realities, challenges, and opportunities related to spraying practices in orchards. By addressing these additional aspects and considerations, the research can contribute to the development of comprehensive and contextually appropriate strategies for improving spraying practices in orchards. This holistic approach can lead to more sustainable and resilient agricultural systems that support both environmental conservation and agricultural productivity.

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Sayma Verisi Modelleri Üzerine Bir Karşılaştırma: Konut Sayısına Etki Eden Faktörler Türkiye Örneği

Onur ŞENTÜRK[1*], Hülya OLMUŞ[1]

[1] Gazi Üniversitesi, Fen Bilimleri Enstitüsü, İstatistik, Ankara, Türkiye

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Anahtar Kelimeler:
Sayıma Dayalı Regresyon Modelleri, Sıfır Yığılmalı Regresyon Modelleri, Sıfır Kesilmiş Regresyon Modelleri.

Özet: Yoksulluk çok boyutlu bir kavramdır. Yoksulluk göstergelerden bir tanesi hanenin sahip olduğu konut sayısıdır. Bu çalışmada, hane halkı bireyinin sahip olduğu konut sayısına etki eden faktörleri belirlemek için sayıma dayalı regresyon modelleri kullanılmıştır. Ayrıca, veriye en iyi uyum sağlayan regresyon modeli araştırılmıştır. Sayıma dayalı regresyon modellerinden en sık kullanılanlar klasik sayıma dayalı regresyon modelleri ve sıfır yığılmalı sayıma dayalı regresyon modelleridir. Ancak literatürde önerilmiş diğer bir regresyon modeli sıfır kesilmiş sayıma dayalı regresyon modelleridir. Bu modeller tüm veriyi analiz etmenin yarattığı zaman ve maliyet kaybının önüne geçmektedir. Bu nedenle, bu modeller sayıma dayalı verilerin olduğu durumlarda modellemede kullanılmak için iyi bir seçenektir. Çeşitli sayıma dayalı regresyon modelleri uygulamasını TÜİK'in yaptığı Gelir ve Yaşam Koşulları Araştırması veri setine uygulanmıştır. Çalışmada ele alınan modellerin performans değerlendirilmesi yapılmıştır. Bu değerlendirmeler için Akaike Bilgi Kriteri ve Log olabilirlik değeri kullanılmıştır. Sonuç olarak, sıfır kesilmiş negatif binom regresyon modeli gerçek veri setine en iyi uyum gösteren modeldir.

A Comparison on Count Data Models: Factors Affecting the Number of Houses Example of Türkiye

Keywords:
Count Data Regression Models, Zero Inflated Regression Models, Zero Truncated Regression Models.

Abstract: Poverty is a multidimensional concept. One of the indicators of poverty is the number of houses owned by the household. In this study, counting regression models were used to determine the factors affecting the number of houses owned by household members. Moreover, it was investigated which regression model would best fit the data. The most commonly used count regression models are classical count regression models (such as Poisson and negative binomial) and zero truncated regression models. However, another count regression model proposed in the literature is zero-truncated count regression models. These models prevent the loss of time and cost caused by analyzing all the data when there is a desired range in the data. Therefore, these models are a good option to use in modeling situations where count data is available. Various count regression models were applied to the Income and Living Conditions Survey data set by TURKSTAT. The performance evaluation of the models considered in the study was made. Akaike Information Criterion and Log Likelihood value were used to compare the suitability of the models. As a result, the zero-truncated negative binomial regression model is the model that best fits the real data set.

**İlgiliyazar: senturkonur@yandex.com*
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1. GİRİŞ

Regresyon analizi istatistiksel analizler sırasında en sık kullanılan yöntemlerdendir. Çok sayıda regresyon türü mevcuttur. Doğru regresyon modeli seçiminde yanıt değişkenin durumu önem arz etmektedir. Çünkü doğru regresyon modeli ile sağlıklı parametre tahminleri elde edilebilir. Diğer veri türlerinde olduğu gibi herhangi bir sayıma dayalı olarak elde edilen değişkenlerin bulunduğu verilerde de bu duruma uygun regresyon modellerinin seçilmesi önemlidir. Sayıma dayalı verilerde göz ardı edilmemesi gereken bir diğer nokta ise veri setinde var olan sıfırların yoğunluğudur. Veride fazla sayıda sıfır olması durumunda sıfır yığılmalı modellerin tercih edilmesi gerekmektedir.

Yapılan bu çalışmada sayıma dayalı verilerin analizinde kullanılan bazı yöntemler ele alınmıştır. Bu veri setlerinde, sıfır değerinde yığılma söz konusudur. Bu tarz verilerin analizinde klasik doğrusal regresyon analizi varsayımları sağlanamamaktadır. Doğrusal regresyon yerine sayıma dayalı veriyi modellemek için literatürde farklı regresyon modelleri vardır. Bu modeller; Poisson Regresyon, Negatif Binom Regresyon, Sıfır Yığılmalı Poisson Regresyon, Sıfır Yığılmalı Negatif Binom Regresyon, Sıfır Kesilmiş Poisson Regresyon ve Sıfır Kesilmiş Negatif Binom Regresyon modelleridir.

Son yıllarda literatürde konu ile ilgili olarak yapılan çalışmalar incelenmiştir. Bu çalışmalardan bazılarına ait özet bilgiler sunulmuştur. Yeşilova, Kaydan ve Kaya (2010), sıfır yığılmalı veri setlerinde aşırı yayılım problemini ele alarak sıfır yığılmalı negatif binom regresyon modelinin, sıfır yığılmalı Poisson modeline kıyasla daha iyi performans gösterdiğini bulmuşlardır. Bu model, bitki koruma çalışmalarında böcek yumurtası verilerinde sıklıkla karşılaşılan fazla sıfır gözlemlerinin analizinde etkili bir yaklaşım sunmaktadır. Türkiye'deki gençlerin günlük sigara tüketimlerini etkileyen faktörleri belirlemek için Tüzen ve Erbaş (2017), sayıma dayalı farklı regresyon modelleri kullanmıştır. Bu çalışmada, sıfır yığılmalı negatif iki terimli ve negatif Binom Hurdle regresyon modellerinin veriye en iyi uyan modeller olduğuna karar verilmiştir. Altun (2018), aşırı yayılım ve sıfır yığılmalı veri kümelerinin modellenmesi için sıfır yığılmalı Poisson-Lindley regresyon modelini önermiştir. Yapılan uygulamalar, bu modelin sıfır yığılmalı ve aşırı yayılım gösteren veri setlerinde, sıfır yığılmalı Poisson regresyon modeline göre daha iyi uyum sağladığını göstermektedir. Kim ve arkadaşları (2019), sıfır yığılmalı regresyon modellerini aşırı sıcaktan ölen bireylere ilişkin ölüm sayısını tahmin etmek için kullanmışlardır. Çalışma sonucunda sıfır yığılmalı Poisson regresyonun, sıfır değeri alan gözlemler durumunda iyi bir istatistiksel yaklaşım olduğunu göstermişlerdir. Alwani ve ark. (2021), sayıma dayalı regresyon modellerini incelemişler ve sıfır kesilmiş modelleri kullanarak Malezya'da hava kirliliği ve iklim değişkenleri gibi faktörler arasındaki ilişkiyi incelemişlerdir. Çalışma sonucunda, sıfır kesilmiş negatif binom regresyon modelinin en iyi model olduğunu vurgulamışlardır. Worku ve ark. (2022), 2019 yılında Etiyopya'da anne başına doğan çocuk sayısını tahmin etmek için sıfır kesilmiş regresyon modellerini kullanmışlardır. Bu veri için sıfır kesilmiş negatif binom modelin sıfır kesilmiş Poisson modelden daha iyi olduğunu ortaya koymuşlardır. Ayrıca doğum sayısına etki eden faktörleri de incelemişler ve eğitim düzeyinin en etkili değişken olduğunu ortaya koymuşlardır. Lawal (2022), NHIS verilerine en uygun sıfır kesilmiş regresyon modelini araştırmıştır. Bu amaçla sıfır kesilmiş genelleştirilmiş Poisson, sıfır kesilmiş Poisson ve sıfır kesilmiş negatif binom regresyon modellerinin veriye uyumunu incelemiştir. Sıfır kesilmiş Poisson modelin daha iyi uyum sağladığı sonucuna ulaşmıştır. Gevrekçi ve ark. (2022), Holstein sığırlarında ölü doğum verilerini modellemek için Poisson, negatif binom, sıfır-yığılmalı Poisson, sıfır-yığılmalı negatif binom, Poisson-logit hurdle ve negatif binom-logit hurdle regresyon modellerini karşılaştırmıştır. Modellerin performansı değerlendirilmiş ve negatif binom-logit hurdle modelinin en iyi uyumu sağladığı belirlenmiştir. Cinsiyet, doğurganlık durumu ve sürü-yıl-mevsim faktörlerinin ölü doğum üzerindeki etkileri önemli bulunmuş, erkeklerde ölü doğum oranının daha yüksek olduğu ve doğurganlık arttıkça azaldığı gözlenmiştir. Durmuş ve İşçi Güneri (2020), aşırı yayılım içeren veri setlerinde Poisson regresyon modelinin yetersiz kaldığını ve bu durumlarda genelleştirilmiş Poisson regresyon modelinin daha uygun olduğunu göstermişlerdir. 1984-2017 yılları arasında Türkiye'deki grev sayıları üzerine yapılan çalışmada, genelleştirilmiş Poisson modelinin daha iyi uyum sağladığı belirlenmiştir. İşçi Güneri ve Durmuş (2021) aşırı yayılım içeren sayısal verilerin analizinde Poisson regresyon modelinin yetersiz kaldığını ve bu durumlarda genelleştirilmiş Poisson, genelleştirilmiş negatif binom ve sıfır-yığılmalı yayılım modellerinin daha uygun olduğunu belirtmektedir. Çalışmalarında, çeşitli genelleştirilmiş regresyon modellerinin aşırı sıfır içeren veri setleri üzerindeki performanslarını karşılaştırmışlardır.

Yapılan bu çalışmada Poisson Regresyon, Negatif Binom Regresyon, Sıfır Yığılmalı Poisson Regresyon, Sıfır Yığılmalı Negatif Binom Regresyon, Sıfır Kesilmiş Poisson Regresyon, Sıfır Kesilmiş Negatif Binom Regresyon modelleri ele alınmıştır. 2018 yılına ait Türkiye İstatistik Kurumu (TÜİK) Gelir ve Yaşam Koşulları Araştırması (GYKA) gerçek verisi kullanılarak analizler gerçekleştirilmiştir. GYKA, Avrupa Birliği İstatistik Ofisi (Eurostat) tarafından koordine edilen ve TÜİK tarafından yürütülen bir araştırmadır. GYKA, 2006 yılından itibaren her yıl düzenli olarak yapılmaktadır. Araştırma, hanehalklarının gelir düzeyleri, yaşam koşulları ve sosyal içerme durumları hakkında bilgi toplamak amacıyla yapılmaktadır. Araştırmanın ana hedefi, hanehalklarının ekonomik ve sosyal durumunu değerlendirerek yoksulluk ve sosyal dışlanma ile ilgili politikaların geliştirilmesine katkıda bulunmaktır. Söz konusu bu modellerin veriye uygunluğunu göstermek için Akaike Bilgi Kriteri ve Log Olabilirlik değerleri kullanılmıştır. En uygun bulunan model için parametre tahminleri ve bu tahminlere ilişkin yorumlar yapılmıştır.

2. MATERYAL VE YÖNTEM

Sayıma dayalı veri, negatif olmayan tamsayı değeri alan, sayımdan kaynaklanan verilerdir. Bu verilere başta sağlık olmak üzere aktüerya, eğitim, diş hekimliği ve çevre bilimi gibi farklı alanlarda sıkça rastlamak mümkündür.

Bu veriler ile gerçek dünya problemlerinde sıklıkla karşılaşıldığından modelleme çalışmaları sırasında da sayıma dayalı regresyon modellerinin kullanımı yaygındır. En çok tercih edilen modellerin başında Poisson, negatif binom regresyon ile bunların sıfır yığılmalı halleri ve sıfır kesilmiş halleri gelmektedir. Bu bölümde kısaca bu yöntemler tanıtılacaktır.

2.1. Poisson Regrasyon (PR)

PR modeli, sayıma dayalı verinin modellenmesinde sıklıkla kullanılmaktadır ve bu alanda ortaya konulan ilk modellerin başında gelmektedir. Bu nedenle, farklı sayıma dayalı modellerin temelini oluşturmaktadır.

PR, belli bir zaman aralığında gerçekleşen olaylar ile açıklayıcı değişkenler arasında bir bağlantı kurmak amacıyla kullanılır. Bu bağlantı, log bağlantı fonksiyonu kullanılarak yapıldığı için Loglineer model olarakta adlandırılmaktadır (Agresti, 2002).

Yanıt değişkeni Poisson dağılıma sahip olduğunda, veriyi analiz etmek için PR modeli kullanılabilir. Modelde Yi, i. gözlem için yanıt değişken olsun. Poisson dağılımının λ ortalamasına sahip olduğu varsayılsın. Poisson dağılımına ilişkin olasılık fonksiyonu Eş 1. de verilmiştir.

$$P(y_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!} \qquad y_i = 0,1,\ldots \tag{1}$$

Beklenen değer ve varyansı birbirine eşittir.

$$E(Y_i) = Var(Y_i) = \lambda_i$$

Y_i'nin beklenen değerinin negatif değerler almamasını sağlamak için, beklenen değer ile açıklayıcı değişkenler arasındaki ilişkiyi gösteren bağlantı fonksiyonu (Cameron ve Trivedi, 2013):

$\log(\lambda_i) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m$ veya

$\lambda_i = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m) = e^{x_i'\beta}$ şeklinde gösterilir.

Burada $\beta_0, \beta_1, \ldots, \beta_m$ bilinmeyen parametreleri temsil eder.

2.2. Negatif Binom Regrasyon (NBR) Modeli

NBR modeli, aşırı yayılım gösteren verilerin modellenmesinde sıklıkla kullanılır. Aşırı yayılım var olması halinde PR modelinin tercih edilmesi durumunda yanlı parametre tahminlerine ve hatalı sonuçlara neden olacaktır (Hilbe, 2014).

λ ortalama ve α yayılım parametresini göstermek üzere bu modelin olasılık fonksiyonu Eş. 2 de verilmiştir.

$$P(Y_i = y_i) = \frac{\Gamma(y_i+\alpha^{-1})}{\Gamma(y_i+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\lambda_i}\right)^{\alpha-1}\left(\frac{\lambda_i}{\alpha^{-1}+\lambda_i}\right)^{y_i}, \alpha > 0 \tag{2}$$

(2) nolu denklemde; α, aşırı yayılım parametresini gösterir. Aşırı yayılım parametresi sıfır olursa model, Poisson modele yakınsar. Ayrıca, λ ve α'nın sıfırdan büyük olması aşırı yayılımın bir göstergesidir. Bu model için beklenen değeri ve varyansı aşağıdaki gibidir.

$$E(Y_i|\lambda_i, \alpha) = \lambda_i$$

$$\text{Var}(Y_i|\alpha) = \lambda_i(1 + \alpha\lambda_i)$$

NBR'de, PR için yazılan eşitliklerde verilen log bağlantı fonksiyonu kullanılarak beklenen değer ile açıklayıcı değişkenler arasındaki ilişki ifade edilebilir.

2.3. Sıfır Yığılmalı Poisson Regrasyon (ZIP)

ZIP modelinde yanıt değişkeni iki farklı veri grubundan oluşur. İlk grup, yalnızca sıfır değerlerini alan Poisson dağılımlı verilerden, ikinci grup ise daima sıfır değerini içermektedir. Bu modelde, yanıt değişkeninin hangi veri grubuna dahil olduğunu belirlemek için lojit fonksiyonu kullanılır. Poisson dağılımına uygun bulunan grup PR ile modellenir (Min ve Agresti, 2005). ZIP modeline ilişkin olasılık fonksiyonu Eş. 3 de verilmiştir.

$$P(Y = y_i) = f(x) = \begin{cases} w_i + (1 - w_i)\exp(-\lambda_i), y_i = 0 \\ (1 - w_i)\frac{\lambda_i^{y_i}}{y_i!}\exp(-\lambda_i), y_i > 0 \end{cases} \tag{3}$$

Burada $0 \le w_i \le 1$dır. w_i, verideki sıfır yığılma oranını ifade eder ve $w_i = 0$ ise ZIP model PR'ye döner. $w_i>0$ olması sıfırda var olan yığılmanın göstergesidir.

Bu modelde, log kısmı için log(λ)=Bβ denklemi, lojit kısmı için ise denklemler aşağıdaki gibidir. Bu denklemlerde B ve G ortak değişken matrisleridir.

$$logit(w) = \log\left(\frac{w}{1-w}\right) = G_\gamma$$

$$w = \frac{e^{G_\gamma}}{1 + e^{G_\gamma}}$$

$$(1 - w) = \frac{1}{1 + e^{G_\gamma}}$$

2.4. Sıfır Yığılmalı Negatif Binom Regrasyon (ZINB) Modeli

ZIP modeline alternatif olarak geliştirilen ZINB modeli, aşırı yayılım yanında sıfır değerlerinde de aşırı yığılmanın olduğu durumlarda verileri modellemek için önerilmiştir (Greene, 1994). ZINB modeli için olasılık fonksiyonu Eş. 4 de verilmiştir:

$$P(Y = y_i) = \begin{cases} p_i + (1 - p_i)\left(\frac{\alpha^{-1}}{\alpha^{-1}+\lambda_i}\right)\alpha^{-1} & , y_i = 0 \\ (1 - p_i)\frac{\Gamma(y_i+\alpha^{-1})}{\Gamma(y_i+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\lambda_i}\right)^{\alpha^{-1}} \left(\frac{\lambda_i}{\alpha^{-1}+\lambda_i}\right)^{y_i} & , y_i > 0 \end{cases} \tag{4}$$

2.5. Sıfır Kesilmiş Poisson Regrasyon (ZTPR) Modeli

ZTPR modelinin, klasik Poisson modelinden farkı yanıt değişkenin sıfır değerini almamasıdır. ZTPR modelinin olasılık fonksiyonu Eş. 5 de verilmiştir.

$$P(Y_i = j|Y_i > 0) = \frac{\exp(-\lambda_i)\lambda_i^j}{j!}[1 - F_P(0)]^{-1} = \frac{\lambda_i^j}{(\exp(\lambda_i)-1)j!} \tag{5}$$

Bu model denkleminde, j yalnızca 0'dan büyük pozitif tamsayı değerlerini alır (Grogger ve Carson, 1991). Fp(0), Poisson dağılımının dağılım fonksiyonunda 0 değerini almasını ifade eder.

2.6. Sıfır Kesilmiş Negatif Binom Regrasyon (ZTNB) Modeli

ZTNB modeli, kesilmiş sayıma dayalı verilerde pozitif değerler alan yanıt değişkenin aşırı yayılım göstermesi durumunda yansız tahminler elde etmek için kullanılır. Bu modele ilişkin olasılık fonksiyonu Eş. 6 da verilmiştir.

$$P(Y_i = j|Y_i > 0) = \frac{\Gamma\left(j+\frac{1}{\alpha}\right)}{\Gamma(j+1)\Gamma\left(\frac{1}{\alpha}\right)}(\alpha\lambda_i)^j[1+\alpha\lambda_i]^{-(j+1/\alpha)}[1-F_{NB}(0)]^{-1} \quad (6)$$

Bu model denkleminde, j sıfırdan büyük bir tamsayıyı göstermek üzere, Γ gama fonksiyonunu, α aşırı yayılım parametresini, λ ortalamayı ve ve $FNB(0)$ ise negatif binom dağılımının dağılım fonksiyonunda 0 değerini almasını ifade eder.

2.7. Model Seçimi

Bu çalışmada en uygun olan modeli belirlemek için, çalışmada kullanılan sayıma dayalı regresyon modellerine ait Akaike Bilgi Kriteri (AIC) ve log olabilirlik değerleri kullanılmıştır.

$$AIC = -2L + 2k = -2(L - k) \quad (7)$$

(7) nolu denklemde,

L : log olabilirliği

k : tahmin edici veya parametre sayısını

n : modeldeki gözlem sayısını (Akaike, 1973; Hilbe, 2014) göstermektedir. En küçük AIC değerine sahip modelin tercih edilmesi gerekmektedir.

Log olabilirlik (LL) değeri için ise durum AIC de olanın tam tersidir. Yani burada en büyük LL değeri alan modelin en iyi model olduğu sonucuna ulaşılır.

3. BULGULAR VE TARTIŞMA

Bu çalışmada Türkiye İstatistik Kurumu'nun (TÜİK) Gelir ve Yaşam Koşullar Araştırması (GYKA) 2018 yılı mikro veri seti kullanılmıştır. GYKA' da gelir ve yoksulluk ile diğer yaşam koşullarına ilişkin çeşitli göstergeler hesaplanmaktadır. Bu göstergeler ile konut, gayrimenkul sahipliği, eğitim, iş gücü durumu ve gelir durumu gibi çeşitli kategorilerde bilgiler derlenmektedir.

Bu çalışmada, hanehalkının oturduğu konut dışında sahip olduğu konut adedi yanıt değişkeni olarak ele alınmıştır. Amaç, hanehalkının oturduğu konut dışında sahip olduğu toplam konut sayısına etki eden diğer faktörleri araştırmaktır. Bunun yanında, açıklayıcı değişken olarak hanehalkı sorumlusuna ait yaş, eğitim durumu, cinsiyet, hanenin yıllık geliri, geçinme durumu ve çalışma durumu alınmıştır.

Yapılan analizler R Studio programı ile yapılmış ve Political Science Computational Laboratory (pscl) ve Modern Applied Statistics with S (mass) paketleri modelleme aşamasında kullanılmıştır. Bu çalışmada verilerin aşırı yayılım gösterdiği analiz edilerek gösterilmiştir. Poisson regresyon modeli için Pearson Ki-kare istatistiği hesaplanmıştır. Eğer Pearson Ki-kare istatistiğinin serbestlik derecesine bölünmesiyle elde edilen değer 1'den büyükse, aşırı yayılım olasılığı yüksektir. 1.47>1 olduğu için veri setinde aşırı yayılım olasılığı yüksektir. Negatif Binom regresyon modelinin AIC değerlerinin de daha düşük olduğu ve aşırı yayılımın varlığına işaret ettiği görülmektedir.

Sayıma dayalı yanıt değişken olan "konut sayısı" na ilişkin hanelere göre dağılımı Tablo 3.1'de verilmiştir.

Tablo 3.1. Konut sayısı dağılım tablosu.

		Konut sayısı	
		Sayı	**Yüzde (%)**
Aldığı Değer	0	19100	79.40
	1	3636	15.10
	2	840	3.50
	3	261	1.10
	4	115	0.50
	5 ve üstü	101	0.40
	Toplam değer	24053	100

Tablo 3.1'e göre oturulan konut haricinde başka bir konuta sahip olmayan hanelerin oranı %79.40 iken, oturduğu konut dışında yalnızca 1 konutu mevcut olan hanelerin oranı da %15.10'a karşılık gelmektedir.

Tablo 3.2'de sayıma dayalı regresyon modellerinden veriye uygun olan en iyi modeli belirlemek için AIC ve LL değerleri elde edilmiştir. Bu çizelgeye göre veri setini en iyi açıklayan en küçük AIC ve en büyük LL değerine sahip olan Sıfır Kesilmiş Negatif Binom Regresyon modelidir.

Tablo 3.2. AIC ve LL değerleri.

	AIC	**LL**
PR	31717.010	-15837.510
NB	30181.670	-15068.840
ZIP	30740.600	-15328.300
ZINB	30101.600	-15007.800
ZTNB	8463.342	-4209.671

Tablo 3.3 incelendiğinde, çalışma durumu değişkenin istihdam kategorisi, cinsiyet değişkeninin kadın kategorisi, zor geçinme durumu ve gelir durumunun tüm kategorileri %95 güven düzeyinde istatistiksel olarak anlamlı bulunmuştur. Bu çizelgeye göre aşağıdaki önemli yorumlamalar yapılabilir:

Hanehalkı sorumlusunun cinsiyeti erkek olan hanelerin, hanehalkı sorumlusunun cinsiyeti kadın olan hanelere göre oturduğu konut dışında sahip olduğu konut sayısının 1.68 kat daha fazla olduğu gözlenmiştir.

Tablo 3.3. ZTNB modeline ait parametre tahminleri.

Değişkenler		Tahmin	Standart Hata	z değeri	p değeri	$e^{\hat{\beta}_i}$
	Sabit Terim	-10.804	47.318	-0.228	0.819	0.00002
Yaş	25-34	-0.428	0.607	-0.706	0.480	0.651
	35-44	0.0832	0.586	0.142	0.887	1.086
	45-54	0.287	0.584	0.491	0.623	1.332
	55-64	0.630	0.584	1.078	0.280	1.878
	65 >	1.101	0.587	1.875	0.060	3.008
Çalışma Durumu	İşsiz	-0.310	0.328	-0.945	0.344	0.733
	İstihdam	-0.296	0.085	-3.473	0.000515 *	0.743
Cinsiyet	Kadın	-0.516	0.108	-4.764	1.90e-06 *	0.596
Geçinme Durumu	Zor	0.868	0.241	3.593	0.000327 *	2.382
	Biraz zor	0.308	0.212	1.454	0.145	1.361
	Biraz kolay	0.263	0.167	1.575	0.115	1.301
	Kolay	0.055	0.124	0.445	0.656	1.056
	Çok kolay	-0.139	0.089	-1.570	0.116	0.869
Gelir Durumu	25 000-50 000 TL	0.448	0.114	3.914	9.07e-05 *	1.565
	50 000-75 000 TL	0.595	0.131	4.517	6.28e-06 *	1.814
	75 000 TL >	1.103	0.142	7.731	1.07e-14 *	3.015
Eğitim Durumu	okuryazar değil	0.230	0.239	0.963	0.335	1.259
	lise altı	0.306	0.170	1.800	0.071	1.359
	lise	-0.009	0.191	-0.050	0.959	0.990
	yükseköğrenim	0.061	0.187	0.328	0.743	1.063

Geçinme durumu zor olan hanelerin, geçinme durumu çok zor olan hanelere göre oturduğu konut dışında sahip olduğu konut sayısının 2.38 kat daha fazla olduğu ifade edilir.

Yıllık geliri 75000 TL üstünde olanların, yıllık geliri 25000 altında olanlara göre hane halkının oturduğu konut dışında sahip olduğu konut sayısının 3.02 kat daha fazla olduğu, yıllık geliri 50000 TL – 75000 TL ve yıllık geliri 25000 TL – 50000 TL arasında olan hanelerin, yıllık geliri 25000 altında olanlara göre oturduğu konut dışında sahip olduğu konut sayısının sırasıyla 1,81 kat ve 1,56 kat daha fazla olduğu görülmektedir.

4. SONUÇ

Bu makalede, sıklıkla tercih edilen sayıma dayalı regresyon modelleri ele alınmıştır. Gerçek bir veri seti kullanılarak hangi modelin veriye daha uygun olduğu belirlenmeye çalışılmıştır. Veri setine en uygun model için parametre tahmin sonuçları verilmiştir. Ayrıca kullanılan tüm modellere ait model seçim kriterlerinin sonuçlarına yer verilmiştir.

2018 yılı verilerine göre, Türkiye nüfusunun %59'unun kendilerine ait bir konutu olduğu elde edilmiştir (TÜİK, 2018). Bu nedenle, sayıma dayalı yanıt değişkeni konut sayısı olarak alınmıştır. Bu değişken sağa çarpık bir dağılıma sahip olup, fazla sayıda sıfır içermektedir. Yanıt değişkeni olan konut sayısının yaş, cinsiyet, eğitim durumu, çalışma durumu, hanehalkı geliri ve geçinme durumu ile ilişkisi incelenmiştir. Yapılan bu çalışmada amaç, konut sayısına etki eden faktörlerin belirlenmesidir. Yapılan analizler sonucunda, sıfır kesilmiş negatif binom regresyon modelinin veriyi temsil eden en iyi model olduğu belirlenmiştir.

Literatürde sayıma dayalı regresyon modelleri konusu geniş yer bulmaktadır. Ancak kesilmiş (truncated) regresyon modelleri üzerine yapılan çalışma sayısı diğer regresyon modellerine göre daha azdır. Bu modele ilişkin çalışmalar genişletilebilir.

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Measurement of Health Services Vocational School Students' Knowledge, Attitudes and Behaviors About Radon: Van Province Example

Halime ERZEN YILDIZ[1*], Canan DEMİR[1], Ali Rıza KUL[2]

[1] Van Yuzuncu Yil University, Health Services Vocational School, Department of Medical Services and Techniques, Van, Turkey
[2] Van Yuzuncu Yil University, Faculty of Science, Department of Chemistry, Van, Turkey.

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Radon,
Student,
Survey.

Abstract: Almost 50% of the natural radiation that is constantly present in our environment is caused by radon gas and its short-lived decay products. Radon (^{222}Rn) is a gas and can become trapped in closed spaces and rise to dangerous levels. Because ^{222}Rn is colorless, odorless and tasteless, it is impossible to detect without special equipment and may not be perceived as a health risk by the public due to these properties. It is important to investigate individual risk perception in order to prevent the negative health effects of radon. In this study, which aimed to determine the knowledge and awareness of students studying in Radiotherapy and Medical Imaging Programs regarding radon gas, a survey consisting of 15 questions was applied to the participants. According to the findings, 54.2% of the participants stated that they had heard of radon and 51.1% stated that radon was harmful. The rate of those who responded that school was their source of information was 33.3%, and most of them were 2nd grade students. The rate of those who did not know the causes of radon in residences was 47%. Although the proportion of those who think that radon testing should be done in homes is high (86.3%), there are many who do not know how to test (94%). The study showed that the level of knowledge about radon among the participants is not high enough. Considering the carcinogenic effect of radon, there is a need to create more awareness among the members of the society.

Sağlık Hizmetleri Meslek Yüksekokulu Öğrencilerinin Radonla İlgili Bilgi, Tutum ve Davranışlarının Ölçülmesi: Van İli Örneği

Anahtar Kelimeler:
Anket,
Öğrenci,
Radon.

Özet: Çevremizde sürekli var olan doğal radyasyonun neredeyse %50'si radon gazı ve onun kısa ömürlü bozunum ürünlerinden kaynaklanmaktadır. Radon (^{222}Rn) bir gaz olduğundan kapalı mekanların içinde sıkışıp kalarak tehlikeli seviyelere çıkabilir. ^{222}Rn renksiz, kokusuz ve tatsız olduğundan özel ekipman olmadan tespit edilmesi imkansızdır ve bu özellikleri nedeniyle halk tarafından sağlık riski algılanamayabilir. Radonun olumsuz sağlık etkilerinin önlenmesi için bireysel risk algısının araştırılması önemlidir. Radyoterapi ve Tıbbi Görüntüleme Programlarında öğrenim gören öğrencilerin radon gazına ilişkin bilgi ve farkındalıklarının belirlenmesinin amaçlandığı bu çalışmada katılımcılara 15 sorudan oluşan anket uygulanmıştır. Elde edilen bulgulara göre, katılımcıların %54.2'si radonu duyduğunu, %51.1' i radonun zararlı olduğunu belirtmiştir. Bilgi kaynağı olarak okul yanıtını verenlerin oranı %33.3 olup bunların çoğu 2. Sınıf öğrencisidir. Konutlardaki radon sebeplerini bilmeyenlerin oranı %47'dir. Evlerde radon testi yapılması gerektiğini düşünenlerin oranı yüksek (%86.3) olmasına rağmen nasıl test edileceğini bilmeyenler fazla sayıdadır (%94). Çalışma, katılımcılar arasında radona ilişkin bilgi düzeyinin yeterince yüksek olmadığını göstermiştir. Radonun kanserojen etkisi göz önüne alındığında, toplum üyeleri için daha fazla farkındalık oluşturmaya ihtiyaç vardır.

* *Corresponding author:* *halimeyildiz@yyu.edu.tr*
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1. INTRODUCTION

Almost 50% of the natural radiation that is constantly present in our environment is caused by radon gas and its short-lived decay products. Radon is formed by the decay of the ^{226}Ra (Radium) nucleus in the ^{238}U (Uranium) radioactive series found in nature. Since uranium is found in all rocks and soils, radon gas is also present everywhere. Radon (^{222}Rn) has a half-life of 3.82 days and is found at very low levels in open air. Since ^{222}Rn is a gas, it can pass from rocks into both water and ambient air and become trapped inside homes and other closed spaces, reaching unsafe levels. Since ^{222}Rn is colorless, odorless and tasteless, it is impossible to detect without special equipment (Polat and Sarıtaş., 2016). Exposure to radon can increase the risk of lung cancer, making it a significant public health problem. High levels of radon exposure are the second leading cause of lung cancer after smoking. Pooled studies in the United States, Europe, and China have identified radon as an independent risk factor for lung cancer, regardless of smoking status (Neri et al., 2018). The decay products of radon, ^{218}Po (Polonium) and ^{214}Po, emit alpha particles that disrupt cellular DNA and can lead to the development of lung cancer. The International Commission on Radiation Protection (ICRP) has set a reference level for indoor radon ranging from 100-300 Bqm^{-3} (Cronin et al., 2020). The World Health Organization (WHO) estimates that radon exposure causes 3-14% of lung cancer deaths worldwide, and the limit value for indoor radon is 100 Bqm^{-3} (Pacella et al., 2023). The United States Environmental Protection Agency (EPA) has recommended that homeowners with indoor radon levels above 4pCi/L take mitigation measures. Radon reduction is a preventive health behavior (Esan et al., 2020); Kennedy et al., 1991). In 1988, the International Agency for Research on Cancer (IARC) stated that radon and its decay products are classified as Group 1 carcinogens. Radon is not widely known and due to its specific properties, the health risk is perceived by the public as uncertain and is easily underestimated. The health risk from radon is cumulative and the risk of developing lung cancer can be mitigated by reducing exposure (Cori et al., 2022).

In order to prevent the effects of radon on health, it is of great importance to investigate individual risk perception. In this respect, determining and developing the awareness levels of individuals towards radon, which can also occur as a result of the geological structure of the city they live in, ensures the formation of positive attitudes and behaviors towards the environment. Individuals who are aware of the risks are better equipped to protect themselves and others from harm. Literature information reveals that although many people have "heard" of radon, many segments of society, especially those under the age of thirty and less educated, do not know what radon is (Vogeltanz-Holm and Schwartz., 2018).

This research is a cognitive study aimed at determining the knowledge and awareness of radon gas among university students who are candidates to work in radiation fields. Another aim is to determine the gains of the participants in radiation-related courses they have taken during their university education and to reveal their contribution to the level of awareness.

2. MATERIAL AND METHODS

2.1. Type of Research

The research is a descriptive type of study.

2.2. Place and Time of Study

The survey form prepared in line with the purpose of the study was conducted between April and May 2024 with 1st and 2nd year students studying in the Radiotherapy and Medical Imaging departments of Van Yuzuncu Yil University Health Services Vocational School using the face-to-face interview technique.

2.3. Universe and Sample of the Study

A sample was not taken from the population, and a total of 168 volunteer students studying in the Radiotherapy and Medical Imaging departments who agreed to participate in the study were included.

2.4. Data Collection Tools

Those who agreed to participate in the study were informed about the study and a 15-question survey form was filled out face to face. 5 of the questions included socio-demographic characteristics and 10 included radon information. The prepared questionnaire included questions about age, gender, class, department, high school graduation and radon awareness level.

2.5. Statical Analysis

While some descriptive statistics are given for the continuous variable of age, frequency distributions are given for categorical variables. Chi-square test was used to determine the relationship between categorical variables. SPSS statistical software version 19.0 (SPSS Inc, Chicago, III, USA) package and excel program were used in the calculations.

2.6. Etichal Aspects of Research

In order to conduct the research, the necessary permissions were obtained from the Van Yuzuncu Yil University Non-Interventional Clinical Research Ethics Committee (Decision no: 2024/03-05, Date: 08.03.2024) and the School Directorate. In addition, informed consent was obtained from the participants before starting the study.

3. RESULTS AND DISCUSSION

Since the age variable among socio-demographic characteristics is continuous, some descriptive statistics of this variable are presented in Table 1. When Table 1 is examined, it is seen that the ages of the participants ranged from 18 to 37 and the average age was approximately 21. In addition, the standard error for age was found to be 0.1583 and the standard deviation was 2.0517. The socio-demographic characteristics of the participants and their responses to the survey questions are given in Table 2.

Table 1. Descriptive statistics for the age variable.

	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation
Age	168	19.00	18.00	37.00	21.0060	0.1583	2.0517

Table 2. Socio-demographic characteristics and radon awareness of the participants.

		Number	%
Sex	Woman	118	70.2
	Man	50	29.8
Department	Radiotherapy	76	45.2
	Radiology	92	54.8
Class	1st Grade	89	53
	2nd Grade	79	47
Graduated from high school	Regular High School	3	1.8
	Anatolian High School	108	64.3
	Vocational High School	12	7.1
	Science High School	9	5.4
	Health High School	26	15.5
	Other	10	6
Have you heard of radon, a naturally occurring radioactive gas?	Yes	93	55.4
	No	75	44.6
If your answer to the previous question is yes, from which source did you get the information about radon gas?	TV	6	5.3
	Internet	37	32.7
	Family Members	1	0.9
	School	56	49.6
	Friends, Neighbours	2	1.8
	Other	11	9.7
Is radon gas harmful?	I don't know	80	47.6
	Yes	86	51.2
	No	2	1.2
Do you think radon is carcinogenic?	I don't know	74	44
	Yes	85	50.6
	No	9	5.4
Is there a history of lung cancer in your family?	I don't know	8	4.8
	Yes	16	9.5
	No	144	85.7
What are the causes of radon in homes?	Building materials	33	19.6
	Water	7	4.2
	Heating Systems	14	8.3
	Outdoors	6	3.6
	All	29	17.3
	I don't know	79	47
Should radon measurements be made in homes?	I don't know	12	7.1
	Yes	145	86.3
	No	11	6.5
Has the air in your home been tested for the presence of radon gas?	I don't know	31	18.5
	Yes	2	1.2
	No	135	80.4
Do you know how to test your home for the presence of radon gas?	I don't know	89	53
	Yes	10	6
	No	69	41
Do you or anyone in your household plan to have the air in your home tested for radon within the next year?	I don't know	85	50.6
	Yes	14	8.3
	No	69	41.1

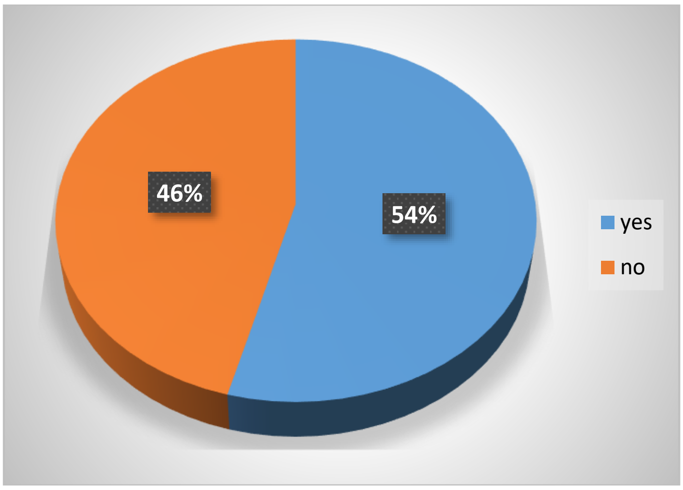

Figure 1. Do you know about radon?

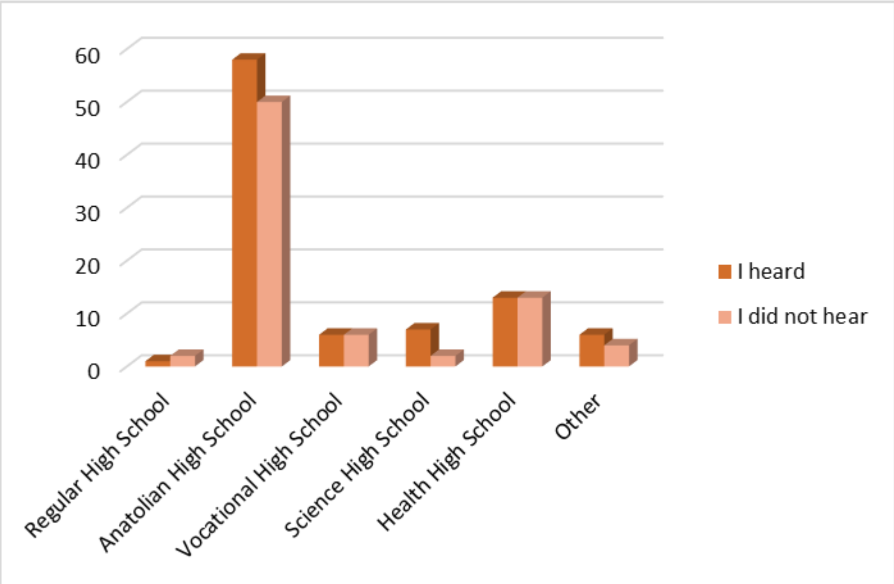

Figure 2. Distribution of radon knowledge level according to high school graduation.

70.2% of the students were female and 29.8% were male. 45.2% of the participants were studying in the Radiotherapy Program and 54.8% in the Medical Imaging (Radiology) Program. Most of the students (64.3%) graduated from Anatolian high schools. When asked if they had ever heard of radon, 54.2% of the students answered yes, and most of those who knew were Anatolian high school graduates (Figure 1 and Figure 2). No statistically significant difference was found between the participants' knowledge level and the high school they graduated from.

Have you heard of radon, a naturally occurring radioactive gas? 93 people who answered yes to the question were asked what their sensory sources were. Answers; When the participants' sources of information were questioned, it was determined that 49.6% responded "school", 32.7% "internet", 5.3% "television", 1.8% "friends and neighbors", 0.9% "family members" and 9.7% "other". The distribution of sources of information by grade is given in Figure 3. Accordingly, most of those who answered school were 2nd grade students. While 51.2% of the participants thought radon was harmful, 47.6% did not know whether radon was harmful or not. Similarly, the rate of those who stated that radon had a carcinogenic effect was 50.6%, while the rate of those who did not know was 44%. When the participants were asked about their family history of lung cancer, the rate of those who said yes was 9.5%, while the rate of those who said no was 85.7%.

The answers to the question “What are the causes of radon in homes?” are given in Figure 4. As can be seen from Table 2 and Figure 4, the rate of those who do not know the causes of radon in homes is higher than the other options (47%). The rate of those who think that radon testing should be done in homes is 86.3%, while the rate of those who do not know and no how to test is 94%. Very few of the participants (1.2%) have had radon measurements done in their homes, and the rate of those who plan to have it done in the future is also low (8.3%).

It was found that the number of people who heard radon was higher in the Radiotherapy program, while the number of people who did not hear it was higher in the Medical Imaging program (Figure 5).

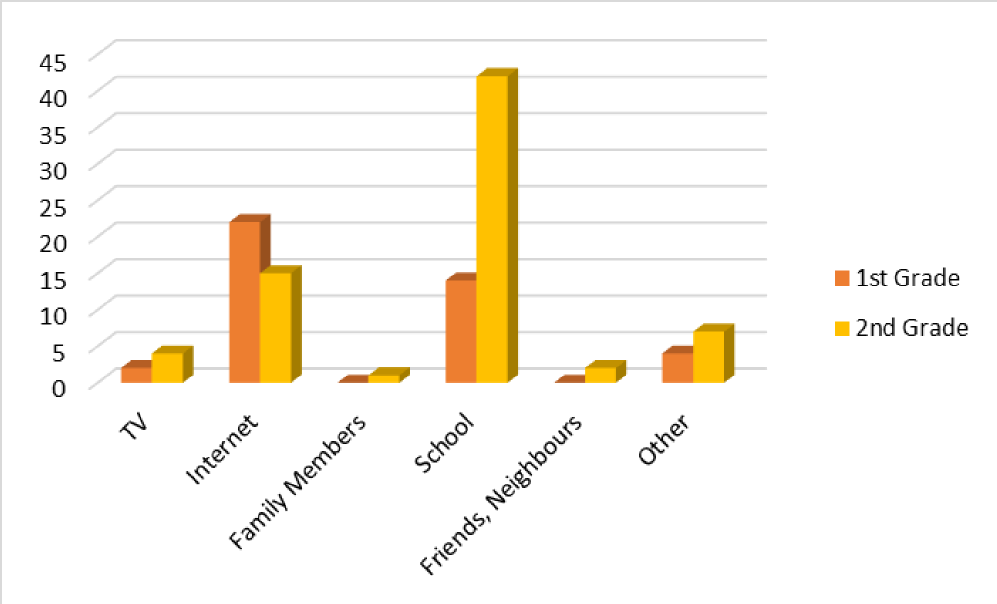

Figure 3. Distribution of radon information sources by class.

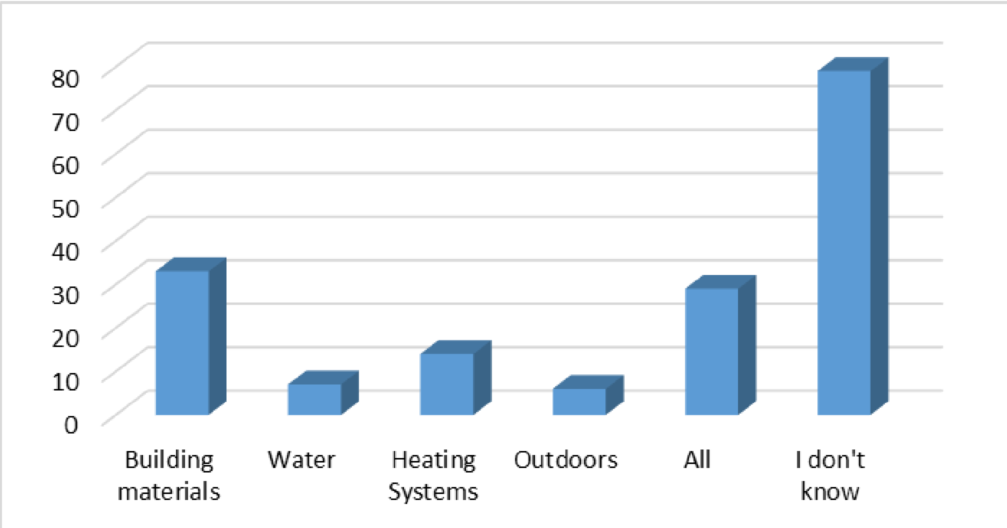

Figure 4. Causes of radon in residences.

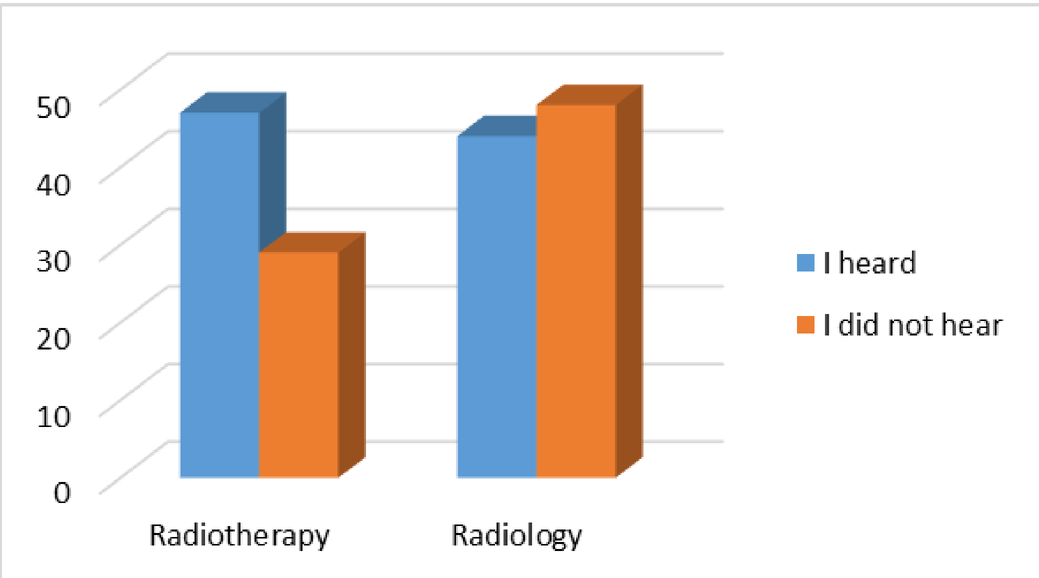

Figure 5. Distribution of radon awareness by departments

Table 3. Comparison results between lung cancer history and radon being carcinogenic.

		Family history of lung cancer			
		I don't know	Yes	No	p
Is radon carcinogenic?	I don't know	5	3	66	0.871
		62.5%	18.8%	45.8%	
	Yes	3	13	69	
		37.5%	81.3%	47.9%	
	No	0	0	9	
		0.0%	0.0%	6.3%	

The relationship between the answers to the question "Is radon carcinogenic?" and "Is there a family history of lung cancer?" is given in Table 3. According to the table, although this relationship is not statistically significant, 81.3% of those with a positive family history of lung cancer know that radon is carcinogenic.

There is radon exposure in all closed areas (housing, school, subway station, shopping mall, mines). In this study examining the level of awareness regarding radon, more than half of the students stated that they had heard of radon. Those who know about radon are mostly Anatolian high school graduates. In high school education in Turkey, radon information is given under various titles in courses such as physics, chemistry, biology, and geography. Especially in chemistry courses, it is expressed as "radon gas" as a noble gas. However, in addition to this information, radon gas is a source of environmental pollution. In a study investigating radon awareness among high school students, it was found that the vast majority of students had never heard of radon and that there was no significant difference between those who knew about radon and the type of school (Polat and Sarıtaş, 2016). In the current study, no correlation was found between the type of school and radon information.

The average age of the participants was 21, and most of them were female. No correlation was found between the level of radon knowledge and gender and age. Most of the participants stated that they received their radon knowledge from school. Radiotherapy students had more knowledge about radon compared to Medical Imaging. This may be because radioactivity is explained more in the Radiotherapy department. Students in both departments take both theoretical and practical radiation-related courses, and radon gas is explained in theoretical courses. It is expected that most of the participants who had knowledge were sophomores. Since the current study was conducted in April-May, sophomores are in a period close to graduation. Cronin et al. (2020) reported that the most frequently reported source of information among those who stated that they had heard of radon was TV commercials (31%). 51.2% of the students know that radon is harmful and 50.6% know that radon is carcinogenic. Radon and its decay products can remain in the lungs when inhaled, undergo radioactive decay, and emit alpha particles, causing lung damage (lung cancer in cumulative dose exposure) (Appleton, 2012; Kang et al., 2019). Since it was thought that the participants may have heard of radon gas during their research on the causes of lung cancer, they were asked whether they had a family history of lung cancer. Radon gas is known to be the primary cause of lung cancer in non-smokers and the secondary cause in smokers. In addition, indoor radon exposure and cigarette consumption have a synergistic effect on the formation of lung cancer. Lung cancer, an aggressive cancer, is the most common cause of cancer-related deaths worldwide (Park et al., 2020). In Turkey, among all cancer cases, lung cancer ranks first in men (55.5%) and fifth in women (10.9%) (General Directorate of Public Health, 2023). In the current study, although 81.3% of the participants with a positive family history of lung cancer knew that radon was carcinogenic, no statistical significance was found. According to the results of a survey conducted among faculty members working at Obafemi Awolowo University in Nigeria, radon awareness was low (Esan et al., 2020).

Radon can enter buildings through cracks in the building structure after being released from rocks into the soil and water. For this reason, building materials, natural gas, external atmosphere, consumed water can leak into the building due to the difference in internal and external pressure in houses and cause radon pollution in the house (Skeppström and Olofsson, 2007). The rate of participants who do not know the cause of radon in houses was found to be higher than other options. Considering that radon is an indoor air pollutant, a high level of awareness about radon leads individuals to correct attitudes and behaviors over time. For example, knowing indoor radon sources can lead a person to learn reduction strategies. Studies show that a high level of awareness strengthens the attitude-behavior relationship (Polat and Sarıtaş, 2016).

Although the proportion of participants who think that radon testing should be done in their homes is high, most do not know how to do it and very few people plan to do it in the future. Radon testing and reduction are among the preventive health behaviors (Kennedy et al., 1991). Laflamme and Van Derslice (2004) reported that less than one-third of the participants in their study knew how to test for radon and the proportion of households planning to test for radon gas was also low. Some states in the United States have existing radon notification policies that require buyers, sellers and real estate agents involved in the purchase of single-family homes to receive an informative brochure about radon (Neri et al., 2018). Since radon is odorless, colorless and tasteless, the only way to know if the levels are safe is to test the air quality using commercially available test kits or to work with a radon testing professional (Cronin et al., 2020). The level of awareness of the indoor radon hazard in Turkey is low. If the public's perception of radon risk is low, there will be no motivation to keep exposure levels low through individual actions such as home testing and remediation measures. Digital radon detectors that provide short- and long-term radon measurements in real time (i.e., do not require sending a test kit to a laboratory and waiting for results) are available at prices that are affordable to most homeowners (Mainous and Hagen, 1993).

4. CONCLUSION

The study showed that the level of knowledge about radon among the participants was not high enough. Increasing the level of knowledge about radon, which is an important risk factor for lung cancer, especially among non-smokers, may lead to increased radon testing, mitigation of radon and ultimately a decrease in lung cancer deaths.

Some strategies to improve risk awareness and management include: Providing education and training to individuals can help them prepare for the risks they face. Effective communication can raise public awareness of how to reduce potential risks and respond in an emergency. Public institutions can help the public develop appropriate strategies to manage radon-related risks. Even collaboration between individuals, government agencies, and civil society can help improve risk management. Therefore, there is a need to raise awareness among community members through media, public lectures, and mass campaigns to help them make informed decisions about indoor radon exposure and to encourage them to have their homes tested for radon. Additionally, installing radon detectors in homes that produce visible or audible alarms to signal high radon levels can support remediation.

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Industry 4.0 and Agriculture

Hatice DİLAVER[1*], Kâmil Fatih DİLAVER[2]

[1] Niğde Ömer Halisdemir University, Department of Eurasia Studies, 51200, Niğde, Türkiye
[2] Niğde Ömer Halisdemir University, Faculty of Engineering, Department of Electric and Electronics, 51200 Niğde, Türkiye

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Keywords:
Precision Agriculture,
Artificial Intelligence,
Remote Sensing.

Abstract: Smart agriculture system creates an unprecedented power asymmetry suitable for agro-industrial production. In addition, it will bring to the producers the convenience when measured by the current use of the smart agriculture system. It is increasing the power of potential monopoly companies in the fields. It is useful for agricultural production as well as seeds, pesticides and fertilizers. It has been observed that it is difficult to protect producers or countries with low or limited economic resources in terms of food safety. It is also difficult to find answers that will both eliminate the concerns about the sustainability of traditional knowledge and lead to the destruction of local knowledge, genetic resources and biodiversity. In line with current globalization trends, it is taking shape.

Tarım ve Endüstri 4.0.

Anahtar Kelimeler:
Hassas Tarım,
Yapay Zekâ,
Uzaktan Algılama.

Özet: Akıllı tarım sisteminin mevcut kullanım şekli ile ölçüldüğünde, üreticilere getireceği kolaylığa ek olarak, tarımsal sanayi üretimine elverişli eşi görülmemiş bir güç asimetrisi yaratacak, potansiyel tekel şirketlerinin tarlalardaki gücünü artıracaktır. Tohum, ilaç ve gübrelerin yanı sıra tarımsal üretime de faydalıdır. Gıda güvenliği açısından ekonomik kaynakları az veya sınırlı olan üreticileri veya ülkeleri korumanın zor olduğu, hem geleneksel bilginin sürdürülebilirliği ile ilgili endişeleri giderecek hem de yerel bilginin tahribatına yol açacak cevaplar bulmanın zor olduğu gözlemlenmiştir. Genetik kaynaklar ve biyolojik çeşitlilik mevcut küreselleşme eğilimleri doğrultusunda şekillenmektedir.

* *Corresponding author:* *haticedilaver509@gmail.com*
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1. INTRODUCTION

The demand for food is driven by both the increase in world population and the increase in urbanization, is increasing day by day. Soil erosion in farming areas, deforestation, misuse, overgrazing, improper crop rotation and unbalanced use of fertilizers use increase the importance of smart agriculture. Reasons has decreased. In addition, different climatic conditions cause a decrease in agricultural yield and agricultural production. The destruction of fields suitable for agriculture in the world over time and decrease in usable water resources, differentiation of climatic conditions this led to the focus of attention on agriculture. Agriculture production was increased to meet the food needs of the growing population. This production method is called green revolution throughout the world. Intense chemical input this production, which is also called modern agriculture, where practices are made, its shape is known to cause serious damage in nature. Vegetable in production, unconscious fertilization, irrigation and spraying even if there is a high yield opportunity in a long time, it will destroy the nature in the long run. It is accepted as a common view all over the world that environmentally friendly practices are needed. The increase in education level and the brisk life offered by our age have also increased the consumption of safe food. With this awareness, individuals should prioritize directly consumed agricultural foods. The individuals must be ensured that all food products purchased are safe. (B. Söğüt, M. R. Taysı, H. İnci, E. Karakaya,2020)

“World Trade Organization” (WTO) and The Organization “Animal and Plant Health” established a protocol with regulations for agricultural products and foreign trade food safety in order to maintain international standards. In addition, future wars over food and water. The scenarios where it can happen again reveal the importance of agriculture. Today, with the effect of "Industry 4.0", the agricultural sector has also been affected by the digitalization process. All machinery used in the stage of agricultural production are equipped with sensors. The “Internet of Things” has entered the agricultural sector and has provided that all production machines are in communication with each other. Thanks to digitalization the data which is achieved with smart tools was analyzed. By analyzing aquaculture activities in a timely manner, these smart tools allow to detect and determine where and how much and what kind of fertilizers should be applied, how many and what kind of minerals that the plants need, the effect of weather conditions on agriculture, needs of irrigation, the condition of the soil, pest state and the estimated harvest time. The aim of these applications; agricultural yield is to be maximized compared to traditional methods. As a result, productivity problems in agriculture are increasing, and product prices are rising, parallel to climate change with global warming. The need for the application of new methods in agriculture is increasing.

The demand for food is increasing day by day, driven by the growing world population and urbanization. Factors such as soil erosion in farming areas, deforestation, misuse, overgrazing, improper crop rotation, and the unbalanced use of fertilizers highlight the importance of smart agriculture. Additionally, varying climatic conditions reduce agricultural yield and production. The ongoing destruction of arable fields and diminishing water resources have brought agricultural issues to the forefront. Historically, agricultural production increased during the "Green Revolution" to meet the needs of a growing population, but this method, known for its heavy use of chemical inputs, has caused significant environmental damage. Unconscious fertilization, irrigation, and pesticide application may offer high yields in the short term but harm nature in the long run. There is a global consensus on the need for environmentally friendly practices in agriculture.

The rise in education levels and the dynamic lifestyle of our era have increased the demand for safe food. This awareness necessitates prioritizing directly consumed agricultural foods and ensuring the safety of all purchased food products. The World Trade Organization (WTO) and the Animal and Plant Health Organization have established protocols for agricultural products and food safety in international trade. Future conflicts over food and water further underline the importance of agriculture.

With the advent of "Industry 4.0," the agricultural sector has also been affected by the digitalization process. All machinery used in agricultural production stages are now equipped with sensors. The Internet of Things (IoT) has entered the agricultural sector, enabling communication among all production machines. Thanks to digitalization, data collected from smart tools is analyzed to optimize aquaculture activities. These tools help determine where, how much, and what type of fertilizers should be applied, the mineral needs of plants, the effects of weather conditions on agriculture, irrigation needs, soil condition, pest status, and estimated harvest time. The aim of these applications is to maximize agricultural yield compared to traditional methods . As a result, productivity problems in agriculture are increasing, and product prices are rising in parallel with climate change and global warming. The need for new agricultural methods is becoming more urgent.

1.1. Basic Concepts

1.1.1 Industry 4.0 and Agriculture

Industry 4.0, seen as the fourth industrial revolution, introduces automation through information and communication technologies. It integrates horizontal and vertical data exchange models in business processes. This revolution has enabled the use of smart systems in agriculture, based on four basic elements: sustainability in production, consumer demands, new business models, and data utilization. (Klaus Schwab, "The Fourth Industrial Revolution", World Economic Forum, 2016).

Industry 4.0 is seen as the fourth industrial revolution and is a new industry. It uses automation, which is a function of information and communication technologies, horizontal integration in business processes, and vertical data exchange models process (S. Kılıç, R. M. Alkan,2018). The rapid development in information technology has enabled to use of the smart systems in agriculture. Industry 4.0 is based on 4 basic elements. These are sustainability in agricultural production, consumer demands, new business models and data in agriculture. Smart agriculture needs qualified manpower and limited resources. Digitalization, on the other hand, is the driving force in the industry, and is at the center of transformation. Big data analysis in the digitalization makes it easier to understand customer demands more comprehensively. This analysis allows the companies to produce customized products. With the integration of fully automated systems and smart systems, the interaction of "man-machine" and "machine-machine“are widespread. It also increases the need for skilled workforce. This too qualified to adapt to the innovations brought by digital transformation does not mean the training of the workforce(TÜSİAD, 2017). Rapid and portable computers are the another of the developments recorded. Computers interact with the users like a smart assistant (Anonim, Türk Tarımının Global Entegrasyonu ve Tarım 4.0 Projesi Sonuç Raporu, İzmir Ticaret Borsası ve Ege Üniversitesi İktisadi ve İdari Bilimler Fakültesi, 2017).

Industry 4.0 and the Agricultural Revolution: Embracing Digitalization for Sustainable Smart Farming.In the midst of the ever-evolving technological landscape, Industry 4.0 has emerged as the fourth industrial revolution, heralding a new era of automation driven by information and communication technologies. ("Industry 4.0: The Future of Productivity and

Growth in Manufacturing Industries", Boston Consulting Group, 2015). This transformative concept goes beyond traditional manufacturing to revolutionize various sectors, including the fundamental backbone of society agriculture (Anonim, Türk Tarımının Global Entegrasyonu ve Tarım 4.0, Ege Üniversitesi İktisadi ve İdari Bilimler Fakültesi, Ocak, 2019).

1.1.1.1. The Fusion of Industry 4.0 and Agriculture

The fusion of Industry 4.0 with agriculture is a dynamic process, capitalizing on automation, information technologies, and innovative business models. Automation, propelled by information and communication technologies, has become a cornerstone in agricultural processes. Horizontal integration streamlines business operations, while vertical data exchange models enhance communication and decision-making processes (Anonim, Türk Tarımının Global Entegrasyonu ve Tarım 4.0, Ege Üniversitesi İktisadi ve İdari Bilimler Fakültesi, Ocak, 2019).

1.1.1.2. Smart Agriculture: Meeting Challenges with Innovation

The swift advancement of information technology has paved the way for the implementation of smart systems in agriculture. In the context of Industry 4.0, smart agriculture revolves around four key elements: sustainability in production, responsiveness to consumer demands, exploration of new business models, and the effective utilization of data in agriculture. As the agricultural landscape becomes increasingly complex, the demand for qualified manpower and the judicious use of limited resources become pivotal for the industry's successA. Jatav, ("Smart Farming System Using IoT", International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE), 2018).

Smart agriculture meets challenges through innovation. It requires qualified manpower and the judicious use of limited resources. Digitalization is the driving force in this industry, making it easier to understand customer demands through big data analysis. This approach allows companies to produce customized products. The integration of fully automated and smart systems has increased the need for a skilled workforce capable of navigating and optimizing these advanced systems.(S. Rajasekaran, "Smart Farming: IoT Based Smart Sensors Agriculture Monitoring System", 2020).

1.1.1.3. Digitalization as the Propelling Force

At the heart of Industry 4.0 lies digitalization—a force propelling the agricultural sector into a new era of efficiency and sustainability. The analysis of big data, a crucial component of digitalization, enables a comprehensive understanding of customer demands. This data-driven approach empowers agricultural companies to tailor their products to meet specific market needs, fostering a more agile and responsive industry ("Digital Agriculture Transformation Strategy", European Commission, 2020).

At the heart of Industry 4.0 is digitalization, which propels the agricultural sector into a new era of efficiency and sustainability. Big data analysis, a crucial component of digitalization, enables a comprehensive understanding of customer demands and allows agricultural companies to tailor their products to meet specific market needs ("Digital Transformation in Agriculture: A Roadmap for Development", Food and Agriculture Organization (FAO), 2019).

1.1.1.4. Integration of Automated and Smart Systems

The integration of fully automated systems and smart technologies has ushered in an era where the interaction between "man-machine" and "machine-machine" is ubiquitous. This integration not only enhances operational efficiency but also underscores the growing need for a skilled workforce capable of navigating and optimizing these advanced systems. It is important to note that the qualification to adapt to the innovations brought by digital transformation is not an inherent trait but rather requires continuous training and development ("Digital Transformation in Agriculture: A Roadmap for Development", Food and Agriculture Organization (FAO), 2019). The integration of fully automated systems and smart technologies has enhanced operational efficiency and underscored the growing need for a skilled workforce. This workforce must continuously adapt and develop to keep pace with digital transformation ("Digital Agriculture Transformation Strategy", European Commission, 2020).

1.1.1.5. The Rise of Rapid and Portable Computers

In this dynamic agricultural landscape, the evolution of computers has played a pivotal role. Rapid and portable computers have become indispensable tools, seamlessly interacting with users and functioning as smart assistants (Anonim, Türk Tarımının Global Entegrasyonu ve Tarım 4.0 Projesi Sonuç Raporu, İzmir Ticaret Borsası ve Ege Üniversitesi İktisadi ve İdari Bilimler Fakültesi, 2017). This development has further contributed to the integration of technology into various aspects of agriculture, simplifying processes and enhancing the overall user experience (K. Kumar, "Integration of Smart Farming and IoT for Enhanced Agriculture", Journal of the Indian Society of Remote Sensing, 2020).

1.1.1.6. The Future of Agriculture in the Hands of Innovation

As Industry 4.0 continues to unfold, it becomes increasingly evident that the synergy between automation, smart systems, and digitalization is reshaping agriculture on a fundamental level (D. A. Benton, "The Role of Portable Computers in Agricultural Development", Journal of Agricultural Engineering Research, 2021). This transformation not only addresses the challenges of sustainability and resource limitations but also opens up new avenues for innovation and customized solutions (M. S. Holthaus, "Mobile and Embedded Systems: The New Face of Modern Agriculture", Embedded Computing Design, 2019). The future of agriculture lies in the hands of those who can adapt, learn, and harness the power of Industry 4.0 to cultivate a more sustainable and technologically advanced landscape. It is a call for the agricultural sector to embrace the digital age and chart a course towards a future defined by efficiency, innovation, and environmental responsibility (A. A. Balsiger, "Automation in Agriculture", Automation World, 2018).

1.2. Leading Competition in Digital Transformation Status of Countries in the Industry

Digital transformation has become a decisive factor in competition among industries in today's world. The adoption of digital technologies plays a critical role in influencing the economic and industrial successes of countries. In this article, we will focus on understanding how competition in the industry is shaped by examining the status of countries leading in digital transformation ("Digital Economy and Society Index (DESI) 2023", European Commission, 2023).

1.2.1. Status of Leading Countries in Digital Transformation

Many countries worldwide are striving to improve their economic and industrial processes by embracing digital transformation. However, some countries stand out with their leadership in digitization. The success of these countries in digital transformation is turning into a competitive advantage, positioning them as leaders in the global market.

1.2.1.1. Digital Skills and Infrastructure

Leading countries in digital transformation possess a robust digital infrastructure and a skilled workforce. High-speed internet access, broadband infrastructure, and advanced digital education programs make these countries pioneers in digitization.

1.2.1.2. Investment and Innovation

Countries leading in digital transformation make significant investments in Research and Development (R&D) and focus on innovation. By rapidly adapting to technological innovations, these countries set industry standards and gain a competitive advantage in the global market.

1.2.1.3. Effective Use of Digital Strategies

Leading countries in digital transformation excel in developing and implementing effective digital strategies. Collaboration between the public and private sectors is a critical factor in accelerating and sustaining the digitization process.

Sustainable gain in almost every field around the world, new digital technologies within the framework of digital transformation in the industry It is known that it is related to developing and adopting. International Telecommunication Union's "Information Society" According to the book with the content of "Measurement", "Information and Communication Technologies". It included the "Development Index". The index with 176 countries according to the statistics, Iceland ranked first in 2017, followed by South Korea and Switzerland. Among 176 countries, Turkey is in the 67th place with its index value 6.08 (Anonim, Türk Tarımının Global Entegrasyonu ve Tarım 4.0, Ege Üniversitesi İktisadi ve İdari Bilimler Fakültesi, Ocak, 2019). China has taken important steps in the digital transformation in the industry. The country in question is making efforts to preserve its current share in the global value chain. It is acting with foresight in order to raise it even more. Considering these, China; it has the status of a country that should be taken as an example for Turkey (B. A. Topcu,2005). USA: In addition to the identification and development of digital technology, it demonstrates a strategic approach in public support by taking acompetency and opportunity-based strategic approach. In addition, the USA has determined its technological priorities in terms of advanced production and is preparing a separate strategic action plan on artificial intelligence technologies. England: It has positioned "artificial intelligence" as one of the building blocks of its industrial strategy. South Korea: It has adopted the concept of smart factories as the digital transformation process of the manufacturing industry. It allocates huge budgets for R&D studies within the state policy for these areas. France: Focused on featured products such as robotics, big data, and internet of things, high performance programming, energy efficient cars, and cloud computing and electric airplanes. Netherlands: It is taking concrete steps in the digital transformation of the manufacturing industry within the scope of innovation centers they call "Field Labs". Germany: Contrary to other European countries, it is among the leading countries, especially in the manufacturing industry, due to the developments in digital transformation (T.C. Tarım ve Orman Bakanlığı, Erişim Tarihi:30.05.2021 https://www.kesantb.org.tr/docs/atprapor-2019).

With the introduction of "Industry 4.0" into our lives and technological developments, artificial intelligence, which has become a part of our daily life together, wireless communication networks, cloud system, machine-to-machine communication and with concepts such as the internet of things, mobile devices have become more as a result of intensive and effective use, in all areas of our lives as well as the use of relevant technologies in the agricultural sector. Efficiency, sustainability, speed, food safety, competitiveness, environmentally friendly practices, and input cost started to show itself with the pressures to reduce it. Many new techniques by combining agriculture and information technologies the term has also been used. Including smart agriculture digital farming, precision farming, driverless vehicles and farm management software can be counted (Anonim, Türk Tarımının Global Entegrasyonu ve Tarım 4.0, Ege Üniversitesi İktisadi ve İdari Bilimler Fakültesi, Ocak, 2019). Environmental effects of inputs used in agricultural production, and the pressures to reduce costs, are increasing with developing technology day by day. Not particularly uniform soil, geographical and physical variables of agricultural land, inputs environmental impact, environmental and product factors, and increasing cost, show an increasing intensity. Precision agriculture is of importance for reducing environmental pollution, effectively using of products, and ensuring uniformity in product quality. For this reason, establishment of registration order in agriculture, obtaining quality product and reduction of chemical inputs (such as pesticides and fertilizers) are among the targets of precision agriculture. In the technological development process of Agriculture 4.0, the data acquisition process has started quite comprehensively, and the data analyzed implementation of business decisions depending on the results point has been reached. At this point, what the farmers are curious about and the question they ask the experts is that precision-applied agriculture technology whether it is economical or not and how it affects profitability. Size of agricultural lands, production pattern, status of enterprises, adaptation of enterprises to current problems and intensive applications of technology are the most important factors. They effect on the economics of precision farming practices. The increase in the world's population has led to the problem of nutrition, which is a basic need, and has led to the search for solutions for sustainability. This has led people to turn to smart agriculture. Green With the intense chemical input called revolution, this problem has a certain has been resolved up to this stage, but this solution comes with it. It also brought some fundamental environmental problems. Greenhouse gas in the world between 11% and 15% of its emissions are due to industrial agriculture applications. Considering that it occurs as a result of the uncontrolled production increase, The negative impact of climate change is now an indisputable problem. Appears. In addition, with urbanization, agriculture It has also caused a decrease in agricultural areas and agricultural workforce.

All Use of Global Positioning System (GPS) in agriculture with the beginning of the 1990s, the agriculture 3.0 process started. This agriculture, which is also called "Precision Agriculture", "manual guidance" thanks to GPS technology, harvesting with the "Variable Rate Applications" system applied to the machines technologies such as monitoring the fertilization process in particular has been applied. Industry 4.0 in the 2010s Parallel to these developments, developments have also occurred in the agricultural sector. Named as Digital Agriculture, E-Agriculture, and Smart agriculture, this microprocessors, sensors, cloud-based information and to the smart agriculture sector, which includes communication technologies and sensors.is the implementation. Smart Agriculture Application Areas Smart agriculture, "product and soil management to increase agricultural production to increase product yield and to increase the resources in this process at an optimum level. It is a technique that minimizes the damage to the environment by using It In this context, "conventional agriculture is abandoned, and the land is homogeneous. of a form of practice that deals with a non-variable approach. The main element aimed here is, when inputs applied in agricultural production are needed, it is used in place and amount". The global market size of smart agriculture in the world is approximately It is around 9.58 billion dollars and is 23.14 in a 5-year period Billion dollars (Statista, https://www.statista.com/statistics/720062/market-value-smart-agricultureworldwide ,ErişimTarihi:31.05.2021,Online).Especially the EU member states that the development of this application is politically member country development policies work programs (Ş. Ercan, R. Öztep, D. Güler, G. Saner, 2019). The main Smart Agriculture application areas are as follows grouping is possible. Land Classification For the precision agriculture application to be carried out, the cultivated product in the field It's important to know. However, with multiple images Although it is a prerequisite for high success in classification, different characteristics of plants/objects such as multiple sensors and SAR. They can offer higher classification accuracy because they carry (M. Teke, H. S. Deveci, F. Öztoprak, M. Efendioğlu, R. Küpçü, C. Demirkesen ve E. Yıldırım;2016). Fertilization Map systems-based applications used to make it happen.

With the help of GPS data determination of the composition of nutrients in the soil and accordingly, in addition to the preparation of re-fertilization programs, smart tillage tools to be used in tillage Can be used with the help of GPS signal Irrigation With smart irrigation, the amount of water consumption of farmers can be significantly reduced. Can be reduced so that agricultural practices can affect the environment. It will make you more sensitive. However, especially smart significant water savings with the sprinkler system (U. Türker, B. Akdemir, M. Topakcı, B. Tekin, İ. Ü. A. Aydın, G. Özoğul, ve M.Evrenosoğlu,2015)

1.2.1.3.1. Yield Mapping

Timely and accurate yield forecasts for agricultural production and agricultural It is a very important issue for all industry stakeholders connected to production. It forecasts are financial and strategic both locally and globally. There is a long chain from producers to politicians in making decisions. Provides significant advantages (M. Teke, H. S. Deveci, F. Öztoprak, M. Efendioğlu, R. Küpçü, C. Demirkesen ve E. Yıldırım, 2016).

1.2.1.3.2. Livestock Practices

The fully automated "monitoring and control systems" with regard to the reproduction, production, health and environment of animals.to the development of animal husbandry, as it will make the interaction with will make a great contribution. However, smart farming technology with this, producers can monitor animals one by one and production and cultivation with the most appropriate cultural techniques develop their techniques. Greenhouse Application Areas Vertical, which has become popular especially in recent years, with greenhouse cultivation. Smart agriculture applications have started in agricultural applications. With this In addition to greenhouse automation, in parallel with environmental data applications such as ventilation of greenhouses, irrigation and lighting, etc. Can be done automatically.

1.2.1.3.3. Smart Agriculture and Technologies in Türkiye Status

Smart agriculture, farmers, private sector, public institutions in Turkey, a joint organization consisting of cooperatives and unions and universities. Sector area. Farmers Weather forecasting and weather forecasting via warning systems and satellites in smart agriculture agricultural struggle, decrease in agricultural inputs, workers and production reduction in costs, technological materials In addition to increasing the amount and efficiency, it is beneficial for human health and nature. Production, which is important, is included in these concepts.

1.2.1.3.4. Private Sector

Technological applications in agriculture, increasing productivity and efficiency, the use of technology in this application, automation, digitalization and ensuring synchronization, reducing input costs, etc. Institutions and organizations that deal with applications.

1.2.1.3.5. Cooperatives and Unions

Harvesting and processing starting from the early stages of agricultural production. Technologies and at almost every stage from the marketing process. Using appropriate sensor, drone and computer technologies. Have been included in the field of smart agriculture application.

1.2.1.3.6. University and Other Public Institutions

Unlike traditional agricultural production and practices, smart agriculture environment-friendly practices and nature's variability management, production planning, final product has gone through all the stages it has gone through until its use traceability, sustainability, use of sensors, cost estimation, quality management, protective on agriculture and the use and protection of its resources. Included in the smart agriculture application in the form of directing its activities have been developed.

1.2.2. Existing Smart Agriculture in Türkiye Applications

Turkey, its population, area, ecological features, agricultural areas and the leading countries in the world in terms of arable land are among. However, the country's agricultural product export when we look at the values of these resources, our country has not yet does not appear to be used effectively. Such as the Netherlands and Israel. Used the achievements of countries in agriculture and agricultural products. It seems possible with their technology. smart agriculture Agricultural product export and import of the countries that have adapted the process When we look at the values of the countries in question in this area, appear to have values. With the developments in the field of smart agriculture in the world, has accelerated its work in this field. agricultural product In Turkey, which has a high potential in the production of R&D studies in the field of agricultural technology in years; state policies, research centers, universities and private sectors developed with the support of "Ankara university "and "Aegean University" with its national and international studies.

These collaborations have increased. In addition, agricultural equipment, R&D, especially GSM companies and the number of software producing companies and patent applications are increasing day by day. Support for rural development in cooperation with Vodafone Turkey and TABİT for this purpose, they started the Smart Village projects. Turk cell Filiz, providing instant data about its cultivated area to its user, a mobile device for use with an air-earth station is the application. Türk Telekom works on smart agriculture with IoT and M2M carries out. Cultivation Area/Greenhouse Control and Management, Intelligent Irrigation, Animal Tracking and Coop/Shelter Monitoring, Flow and Depth Measurement It offers solutions with applications.

1.3. Digital Agricultural Applications and Country Samples

The current called Agriculture 4.0 or digital agriculture is the evolution of agricultural engineering based on the precision farm production system and its main purpose is to automate sustainable production in agriculture (CEMA, Erişim Tarihi: 20.01.2023.https://www.cema-agri.org/images/publications/position-papers/CEMA_Digital_Farming_-_Agriculture_4.0 13_02_2017_0pdf).

The vehicles used at every stage of agricultural production are equipped with sensors, ensuring that the machines are in communication with each other during the entire production period. With agricultural tools and fields equipped with sensors, it is aimed to maximize the yield by giving detailed information to the farmers on what field and what kind of fertilizer they should use, weather conditions, the amount of mineral and irrigation needed by the plant, the condition of the soil, and the estimated harvest time. In this way, producers have the opportunity to manage and monitor the entire cultivation area with smart technology devices, minimize labor power and production input costs, and have the opportunity to obtain high-quality and high-quality products (H. Kahraman, "Endüstri 4.0'la Birlikte Gelen Akıllı Tarım", Erişim Tarihi: 20.01.2023). The point reached in digital agriculture is not the result of a process that develops all of a sudden. These phases

Agriculture 1.0: Combined use of animal power and mechanization,

Agriculture 2.0; The start of the use of engines and tractors in agriculture,

Agriculture 3.0; Switching to guidance systems and precision farming practices and

Agriculture 4.0; Connected farming practices.

Changes in agriculture to meet the food demand of the growing population in the mid- 1600s in England paved the way for the 1st Industrial Revolution. These changes in agriculture were known as the "Agricultural Revolution". Many historians have concluded that without these changes there would be no industrialization (University of Stellenbosch Business School Agriculture Report, "The future of the Western Cape agricultural sector in the context of The Fourth Industrial Revolution", Erişim Tarihi: 18.01.2023).

As a result of the consolidation of agricultural lands into large farms in England, production began to be managed better, and productivity and profitability increased with the emergence of agricultural machinery. In the 1840s, productivity increased even more with the use of fertilizers. With the 2nd Industrial Revolution (1870-1914), the transition to electricity and mass production led to mass production, chemical fertilizers, and pesticides to combat agricultural pests were used in agriculture, and mechanization (such as sorting, collection) in agriculture increased. The third industrial revolution, called the computer and digital revolution, started in the 1960s, and the changes in agriculture with new products, irrigation, fertilization, pesticides, mechanization, transfer of technological knowledge were called the "Green Revolution". Although all the developments made are to feed the increasing world population, environmental problems have emerged as production costs have increased and it has become ecologically unsustainable. The rapid change in agricultural technologies, the use of tractors, the emergence of genetically modified products that are claimed to be resistant to agricultural pests have changed the face of agriculture ("Global Innovation Index (GII) 2023", World Intellectual Property Organization (WIPO), 2023). The agricultural sector was introduced to satellite technologies in 1994 in order to better monitor and plan farms. In the 2000s, software and mobile devices started to help farmers to increase yields. In 2011, the German Federal Government explained its advanced technology strategy with the term Industry 4.0. Along with this industrialization process, the use of technology in agriculture has also increased and the emergence of the use of large amounts of data (Big Data) in 2015 has led to significant developments in agriculture. Farmers have started to use the power of information to make more informed decisions and to use their resources more effectively. The use of digital technologies in agriculture such as smartphones, tablets, field sensors, drones and satellites has become widespread, offering a range of agricultural solutions such as remote measurement of soil conditions, better water management and monitoring of livestock and crops. While digitalization increases profitability with cost minimization, it also helps to reduce the environmental impact of agriculture (University of Stellenbosch Business School Agriculture Report, “The future of the Western Cape agricultural sector in the context of The Fourth Industrial Revolution”, Erişim Tarihi: 18.01.2023).It is aimed to maximize the productivity in agriculture with smart agriculture applications made using information and communication technologies solutions, which is called Agriculture 4.0 in short.

As a result of the sensors and every part of the smart system working in harmony with each other, the system administrator can work and intervene effectively (İ. H. İnan, B. Gülçubuk, C. Ertuğrul, E. Kantürer, E. A. Baran ve Ö. Dilmen,2000) One of the implemented examples in this regard is John Deere tractors. In these tractors, an automation has been prepared in which the internet of things will be used, and the farmers can observe the product efficiency. With this automation, it has become possible to observe factors such as the performance of the tractor and the estimated time of the area to be planted (Ş. Topal, “Atos’tan Yenilikçi Endüstri 4.0 Uygulamaları”, Erişim Tarihi: 19.01.2023. https://www.endustri40.com/endustri-4-0-uygulamada-atostan-yenilikci-endustri-4-0-ugulama-ornekleri). However, in order to maximize efficiency and output with the Internet of Things (IoT), all machines/animals in a farm must be equipped with a smart system. The system integrated into the farm analyzes all the factors required for production and presents the appropriate conditions for the producer in a report. Therefore, the producer has instant access to the information he wants and has the opportunity to intervene remotely with devices such as phones/tablets if he deems it necessary. BI Intelligence, one of the Business Insider (BI) premium research services, revealed that IoT devices in agriculture in 2015.It is estimated that this figure will increase to 75 million in 2020, while it was 30 million in 2017. It is predicted that this will provide a growth increase of approximately 20 percent to the country's economy. In addition, On farm, which makes a farm IoT platform with the internet of things, determined in its study that with the application of Industry 4.0 solutions to agriculture, the efficiency will increase by 1.75 percent, the energy cost can decrease by $ 7-13 per acre and the water use rate will decrease by 8 percent (B. Kesayak, “Endüstri 4.0 Tarım Sektörünü Nasıl Etkileyecek”, Erişim Tarihi:19.01.2023).

Major developments with Agriculture 4.0 include cheap and advanced sensors, low-cost microprocessors, high-bandwidth cellular communication and cloud-based ICT systems and big data analytics (CEMA, Erişim Tarihi:20.01.2023.https://www.cema-agri.org/images/publications/position-papers/CEMA_Digital_Farming_- Agriculture_4.0 13_02_2017_0.pdf).

Increasing the efficiency of the value chain (Direct delivery to the consumer, meal kits, food e-commerce, etc.),

Drones, robots, big data and sharing platforms as well as irrigation, soil and crop technologies,

Innovations in agrochemicals, biomaterials, and bioenergy to reduce the ecological footprint.

Plant-based foods for sustainable protein needs,

Indoor and vertical farming, Smart greenhouses

Today, European countries have started a digital revolution in the agriculture sector by supporting special plans and offering financial incentives to farms with Agriculture 4.0. It is estimated that the trends affecting agricultural practices and structures will be implemented in developed economies until 2030. By this year, the integration of precision agriculture and digital technology will become the most influential trend in Europe as the growing number of farmers begin to adopt digital technologies to run their businesses. The European Joint Research Center has estimated that precision agriculture could save a great deal of carbon dioxide in European agriculture by 2030. The storage and processing of this information depends on the development of the internet network (A. Lamborelle and L. F. Álvarez, “Farming 4.0: The Future of Agriculture”, Erişim Tarihi: 20 .01.2023 https://www.euractiv.com/section/agriculture-food/infographic/farming-4-0-the-future-of-agriculture/).

2. CONCLUSION

The integration of Industry 4.0 into agriculture is transforming the sector, addressing sustainability and efficiency challenges while opening new avenues for innovation. Digitalization, automation, and smart systems are essential for modern agriculture, requiring continuous adaptation and development of a skilled workforce. Leading countries in digital transformation set examples for integrating these technologies into agriculture, positioning themselves competitively in the global market. Smart agriculture practices, such as precision farming and smart irrigation, play crucial roles in reducing environmental impact and enhancing productivity. The future of agriculture lies in embracing these digital advancements to create a more sustainable and efficient agricultural landscape.

The agricultural sector is undergoing a significant transformation with digitalization, making traditional methods more efficient and offering farmers the potential for better production management and sustainability. In this article, we will explore the advantages brought by digitalization in agriculture and how it is reshaping the industry.

2.1. Precision Farming

At the core of digital agriculture is precision farming, aiming to optimize agricultural processes using technologies such as sensors, GPS, and data analysis. Farmers can make more informed decisions by analyzing a range of data, from soil moisture to weather conditions. This can reduce input costs and increase efficiency.

2.2. Smart Agricultural Equipment

Agricultural machinery is also adapting to the trend of digitalization. Smart tractors, drones, and robots offer farmers the opportunity to automate challenging and time-consuming tasks. These devices can make farming operations faster and more effective, resulting in labor savings.

2.3. Data Analysis and Big Data

Agriculture generates vast amounts of data. Through digitalization, analyzing and understanding this data becomes more accessible. Farmers can use data on soil characteristics, climate conditions, and crop growth to better plan future harvests. This optimizes resource use and supports sustainable farming practices.

2.4. Internet of Things (IoT)

Agriculture is becoming a sector supported by the Internet of Things (IoT). Sensors and connected devices continuously monitor conditions on agricultural land, providing farmers with real-time information. This allows farmers to make quick decisions and intervene as needed.

Digitalization in Agriculture is making the agricultural sector more sustainable, efficient, and competitive. These technologies empower farmers with more control and information, shaping the future of agriculture to meet the global demand for food. Digitalization transforms agriculture from merely a production process into a data-driven industry. This anticipates more innovation and sustainability in agriculture in the future.

In addition to agricultural production and arable agricultural land, a suitable has a say in the field of agricultural production in our country, which is in an ecological position. The resources it has in order to compete in the same lane with the countries for the sustainability of the production in question, as well as the effective use of technological progress and progress technologies to be integrated into agricultural production as soon as possible must be provided addition, general determinations about the current situation of Turkey and solution proposals can be summarized briefly as follows.

In order not to encounter any problems in digital transformation good planning is essential. The shortest possible time to address the inadequacies of domestic technology supplier companies. Remediation in time. In order for the investments to reach the target, the stakeholder institutions determine their strategies well and choose an appropriate way accordingly map needs to be drawn. An effective and fast way of digitization in the public and private sectors needs to be followed. In addition, institutions and organizations related to digitalization organizations should be supported by the government. Need for qualified human resources in digitalization has. This area should be compensated as soon as possible required. Priority to domestic technology suppliers and solution partners should be given. The age level of individuals engaged in agriculture in Turkey is high technology-based approach to the young population engaged in agriculture. Adopting the data and in this process, the young population with smart agriculture must be brought into agriculture. Smart agriculture or digital agriculture for farmers and producer association awareness training should be given, especially pioneering farmers should be equipped.

Declaration Of Ethical Code

In this study, the authors undertake that they comply with all the rules within the scope of "Higher Educati on Institutions Scientific Research and Publication Ethics Directive" and that they do not perform any of the actions under the heading "Actions Contrary to Scientific Research and Publication Ethics" of the relevant directive.

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