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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Utilizing Phenotypic Selection to Enhance Yield and Develop *T. urticae* Resistance in Interspecific Hybrid Tomatoes Derived from *S. habrochaites*

Mohammad DAWOOD[1*], John SNYDER[2]

Abstract

Tomatoes play a significant role in global agriculture, but they face challenges from pests and diseases, including the *T. urticae*. Researchers have been investigating various approaches to undertake this problem and improve tomato yield. One such strategy being explored is interspecific hybridization, which involves breeding two distinct species belonging to the same genus. This study investigated the genetic basis of resistance to spider mites in 13 13 BC3F7 generation lines (IS) and two F1 hybrid tomato cultivars (T1: Maglia Rosa and T2: Roma 1). The results showed that the IS lines had significantly higher fruit counts plant^{-1} than the T lines, with the ISD90-89 displaying the highest fruit count. However, the total fruit weight plant^{-1} was greater in the T lines than in the IS hybrids, with the IS having relatively smaller fruit weight. In terms of *7-epizingiberene* content, no significant differences were observed within the lines of a particular IS family. However, a significant difference in *7-epizingiberene* content was obtained between the two IS families, with the IS-F22 family demonstrating higher levels compared to the IS-D90 family. Notably, no *7-epizingiberene* content was detected in the T and cultivated cultivars. Regarding repellency, the T1 and T2 tomato varieties were found to be susceptible to spider mites, while the genotypes in the D-90 and F-22 families exhibited varying levels of repellency. Additionally, the analysis revealed a significant negative correlation between average plant yield and *7-epizingiberene* content in the ISs (r=-0.731). As the content of *7-epizingiberene* increased, the yield tended to decrease, suggesting a potential yield penalty associated with its production. On the other hand, there was a positive correlation of 0.743 between fruit weight plant^{-1} and total weight plant^{-1}, indicating that higher fruit weights were linked to increased total plant weights. Additionally, a positive correlation of 0.431 was obtained between fruit number plant^{-1} and *7-epizingiberene* concentration. The results of this study provide valuable insights into the genetic basis of resistance, yield, and *7-epizingiberene* production in ISs. This knowledge will contribute to the advancement of breeding programs and the development of sustainable pest management strategies in tomato cultivation.

Keywords: Tomato, Interspecific hybrid, *7-epizingiberene*, *T. urticae*, Yield, Repellency

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1. Introduction

Tomatoes (*Solanum lycopersicum*) are a globally significant crop, but they are susceptible to various pests and diseases, including the two-spotted spider mite (*Tetranychus urticae*), which can cause substantial damage and yield loss (Weinblum et al., 2021). To address this issue and enhance crop productivity, researchers have been exploring different strategies, such as utilizing interspecific hybridization. Interspecific hybridization involves crossing two different species within the same genus. In the case of tomatoes, *Solanum habrochaites*, specifically the WT-LA2329 accession, is a promising wild species used for interspecific hybridization due to its resistance to pests and diseases. This species is also known to produce a compound called *7-epizingiberene* (*Figure 1*), which has shown potential as a natural defense mechanism against herbivorous insects. *7-epizingiberene* is a semi-volatile compound synthesized by plants of *S. habrochaites* and is a major anti-insect chemical found in its leaf trichomes (Antonious and Snyder, 2006; Dawood and Snyder, 2020; Snyder et al., 1993). The presence of *7-epizingiberene* in *S. habrochaites* is localized within types IV and VI glandular trichomes (Guo et al. 1993; Antonious and Kochhar 2003; Antonious and Snyder 2006). This naturally occurring compound is synthesized through the isoprenoid pathway using farnesyl pyrophosphate (FPP) as a precursor (Xie et al., 2021). The significance of *7-epizingiberene* lies in its association with resistance against arthropods such as spider mites, aphids, and whiteflies when present in the trichomes of tomatoes (Weston and Snyder 1990, Aragão et al. 2000, Maluf et al. 2001, Freitas et al. 2002, Gonçalves et al. 2006, Bleeker et al. 2011). Additionally, *7-epizingiberene* has been recognized for its medicinal properties (Bhatt et al. 2010, da Silveira Vasconcelos et al. 2019).

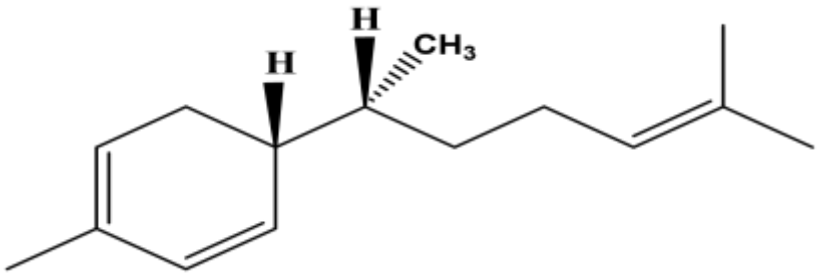

Figure 1. The molecular configuration of 7-epi-zingiberene (C15H24) is depicted, illustrating the presence of two conjugated double bonds within the ring structure.

The two-spotted spider mite, scientifically known as *Tetranychus urticae* Koch, is a significant pest of tomato plants, particularly in dry and hot environments. When *T. urticae* feeds on the leaf surface of the plant, it adversely affects photosynthesis and leaf transpiration. A study by Sances et al. (1979) demonstrated an undesirable correlation between the intensity and duration of mite feeding and the yield of tomato plants. The short lifespan of *T. urticae*, coupled with its high productivity and resistance to various acaricides, has made chemical control of this pest highly challenging (Turhan and Özmen, 2021) As a result, integrated pest management (IPM) techniques, including host plant resistance, have become crucial for *T. urticae* control. Host plant resistance can be mediated by specific chemical components present in the glandular trichomes of the tomato plant (Luczynski et al., 1990).

The inclusion of high levels of *7-epizingiberene* from wild tomatoes into cultivated types has gained attention among tomato breeders worldwide. The objective is to improve tomato's resistance to arthropods like spider mites, aphids, and whiteflies, as *7-epizingiberene* has been associated with such resistance (Zanin et al., 2021). However, the synthesis of *7-epizingiberene* is energy-intensive for the tomato plant due to its oily nature, and this may lead to a negative association between yield and *7-epizingiberene* production (Weston and Snyder, 1990). Additionally, interspecific hybrids may experience reduced yield due to genic incompatibilities, known as Bateson-Dobzhansky-Muller interactions (Demuth and Wade, 2005; Lynch and Force, 2000). This research is the first to report on the yields of interspecific hybrid tomatoes with high concentrations of *7-epizingiberene*.

Tomato is the second most important vegetable crop, with global production reaching 189 million metric tons from 5.02 million hectares (~12.4 million acres) in 2023 (FAO, 2023). In breeding program, genetic variation from wild tomato relatives has been a valuable resource for enhancing yield, fruit quality, and disease and insect resistance (Rick and Chetelat, 1995). Genetic selection for yield in self-pollinated crops like tomatoes requires careful attention from breeders, as it is a genetically complex trait (de Souza et al., 2012). Understanding the

available genetic diversity is crucial for improving tomato yields, and morphological features have often been used to estimate this diversity (Fufa et al., 2005).

This study aims to evaluate and select interspecific hybrid families derived from *S. habrochaites* for their resistance to *T. urticae*, yield potential, and *7-epizingiberene* content.

2. Materials and Methods

The experiment was conducted in 2020 at the Horticulture Research Farm in Lexington, Kentucky. The experimental plots were arranged in a randomized complete block design. Each plot consisted of four tomato plants, with a spacing of 0.61 meters (2 feet) between each plant within the row. The rows were set 2.13 meters (7 feet) apart in raised beds, which were equipped with trickle irrigation and covered with black plastic mulch. The study included a total of 13 interspecific hybrid breeding lines (Inbred lines**)** and two F1 hybrid tomato cultivars, T2 and T1. The genotypes were categorized into three groups, Tomato (T1: Maglia Rosa and T2: Roma 1), D-90 family (ISD90-23, ISD90-68, ISD90-70, ISD90-73, ISD90-83, ISD90-87, ISD90-89, and ISD90-91), and F-22 family (ISF22-13, ISF22-17, ISF22-18, ISF22-19, and ISF22-37). The *7-epizingiberene* concentration was measured in µg cm^2, while the repellency was categorized as HR denotes high resistance, IR denotes intermediate resistance, and S denotes susceptibility to spider mites. These cultivars were evaluated in three blocks, with each block containing the breeding lines and cultivars. The BC3F7 generation lines used in this study were derived through the crossbreeding of two distinct tomato varieties. The first parent was *S. habrochaites* (WT-LA2329), a wild tomato relative known for its natural resistance to spider mites and other arthropods (Savi et al., 2022; Snyder, and Min, 2008). The second parent was Zaofen-2, a determinate variety with pink fruit that was commercially introduced in 1962, known to be susceptible to spider mite infestations. The BC3F7 lines were specifically selected for their high yield and production of zingiberene, a chemical compound found in tomatoes. Among the breeding lines, eight were chosen from the IS-D90 family and five were selected from the IS-F22 family. The experiment timeline is as follows: On April 9th, the seeds were soaked in a 50% sodium hypochlorite solution for 30 minutes. Afterward, they were directly sown into 72-cell flats filled with Fort Light compost-based potting soil from Vermont Compost Co. The transplanting of the seedlings took place on May 10th, when they were moved from the flats to the field. Throughout the cultivation period, standard transplant and field production methods were followed, as outlined in ID-36, available at https://www2.ca.uky.edu/agcomm/pubs/id/id36/id36.pdf The harvest commenced on July 21st, and the tomato plants were harvested weekly for a duration of four weeks. The harvested tomatoes were weighed and counted to assess the yield of each plot.

2.1. Determination of 7-epizingiberene in plant leaves

To collect samples, a specific procedure was followed. From each plot, a sample was obtained from the central one-third portion of a leaflet positioned on either the third or fourth leaf of each of the four plants. The sample was carefully placed in a 20 ml vial. Subsequently, 2 ml of a *n*-hexane solution containing 20 µL L of *n*-tetradecane as an internal standard was added to the vial. To ensure thorough mixing, the vials underwent vortexing for a duration of 30 seconds. The concentration of *7-epizingiberene* present in the extract was then determined using gas chromatography, employing the methodology previously outlined in our published study (Dawood and Snyder, 2020). Additionally, the area of the extracted leaflets was determined using image analysis (ImageJ 1.47v, National Institutes of Health, USA). The results were reported as microgram of *7-epizingiberene* per square centimeter (µg cm^2) of leaflet.

2.2. Bridge bioassay

The developed bridge bioassay, following the protocols described by Snyder et al. (2011) and Guo et al. (1993), was employed as a simple and effective method for assessing the repellent properties against two-spotted spider mites (TSSM) in natural products, specifically oleoresins obtained from interspecific hybrids and cultivated F1 hybrids, as well as chromatography-purified compounds. Each concentration of the tested oleoresin or compound was subjected to evaluation with 30 individual mites, resulting in 30 replications for each tested concentration. The evaluation of oleoresins was performed in three separate experiments, while the assessment of purified compounds was conducted twice. Quantification of the compounds in the bridge bioassays was accomplished using GC-FID, following the methodology described in our previous study (Dawood and Snyder, 2020).

2.3. Statistical analysis

The data obtained from this investigation underwent statistical analysis using the Generalized Linear Model (GLM) procedure in SAS version 9.4, a statistical software developed by SAS Institute, Inc., situated in Cary, NC (Der and Everitt, 2015). For comparing the means, either the LSMeans option or Duncan's multiple range test was utilized, depending on the particular analysis requirements. To assess the association between yield and the concentration of *7-epizingiberene* as well as the repellency of spider mites in the interspecific hybrids, the Pearson correlation coefficient was computed for these two variables. The effectiveness of spider mite control was assessed using a method outlined by Snyder et al. (2011). The repellency of *7-epizingiberene* against spider mites was assessed through chi-squared (X^2) analysis. This approach involved examining the exit ratios of different concentrations of each fraction in a bridge bioassay. To ensure the reliability of the experimental setup, the homogeneity between the two bridges within the arena was evaluated using chi-squared (X^2) test (Snyder et al., 2005).

3. Results and Discussion

The analysis of variance conducted in this study revealed significant variations among different families with respect to yield, number of fruits per plant and average fruit weight. Notably, the number of fruits per plant was significantly higher in interspecific lines when compared to the tomato cultivars, specifically T1 and T2. Among inbred lines, line ISF22-89 exhibited the highest number of fruits, producing 80 fruit plant^{-1}, whereas ISF22-37 had the lowest count of 46 fruit plant^{-1}. T1 yielded 34 fruit plant^{-1}, while T2 produced 45 fruit plant^{-1}. Regarding the total fruit weight, the average was found to be 11.4±0.7 kg plant^{-1} for the cultivars, whereas the interspecific hybrid lines had an average of 7.6±0.3 kg plant^{-1}. The interspecific hybrids had significantly smaller fruits, weighing around 0.6±0.01 kg fruit^{-1}, compared to the larger fruits produced by the hybrid cultivars, weighing approximately 1.1±0.02 kg fruit^{-1}.

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In this study, a correlation in *Table 1* was utilized to investigate the relationships between various variables, including *7-epizingiberene* concentration, fruit weight plant^{-1}, total weight plant^{-1}, and fruit number plant^{-1}. The results revealed important insights into the interplay of these factors on tomato plant development and yield.

Table 1. Correlation analysis of 7-epizingiberene concentration with fruit weight, total weight, and fruit number in tomato plants

Variable	*7-epizingiberene* (µg cm²)	Fruit weight (g plant^{-1})	Total weight (kg plant^{-1})
Fruit weight (g plant^{-1})	-0.731		
Total weight (kg plant^{-1})	-0.671	0.743	
Number of fruits per plant	0.431	-0.731	-0.159

The *7-epizingiberene* concentration displayed a negative correlation of -0.731 with fruit weight plant^{-1}, indicating that as the concentration of *7-epizingiberene* increased, the fruit weight plant^{-1} tended to decrease. Similarly, a negative correlation of -0.671 was observed between *7-epizingiberene* concentration and total weight plant^{-1}, suggesting that an increase in *7-epizingiberene* concentration was associated with a decrease in the total weight of the plant. On the other hand, there was a positive correlation of 0.743 between fruit weight plant^{-1} and total weight plant^{-1}, indicating that higher fruit weights were linked to increased total plant weights. Additionally, a positive correlation of 0.431 was obtained between fruit number plant^{-1} and *7-epizingiberene* concentration. However, negative correlations were observed between fruit number plant^{-1} and fruit weight plant^{-1} (-0.731) as

well as total weight plant^{-1} (-0.159). This suggests that while higher concentrations of *7-epizingiberene* may promote greater fruit production, a higher number of fruits may lead to reduced individual fruit and total plant weights.

3.1. 7-epizingiberene content (µg cm² of leaf) and repellency

The *Table 2* displays the *7-epizingiberene* (µg cm²) levels for different genotypes of tomatoes, specifically T1 and T2, and various genotypes of D-90 and F-22 tomato varieties. The range of *7-epizingiberene* levels in the samples is from 0 µg cm² (for T1 and T2) to 49.022 µg cm² (for ISF22-13). The average level of *7-epizingiberene* across all genotypes was calculated by summing the values and dividing by the total number of observations, yielding an average of approximately 28.48 µg cm². These results suggest that there is variability in the production of *7-epizingiberene* among the different genotypes, with the highest levels observed in ISF22-13 of the F-22 variety. The results also presented statistically significant consequences concerning the repellency of different genotypes, as assessed through the chi-square (X^2) test. In the tomato family, genotypes T1 and T2 exhibited similar susceptibility to spider mites, with no notable divergence in their response behavior. Within the D-90 family, several genotypes, including ISD90-23, ISD90-68, ISD90-73, ISD90-83, ISD90-87, and ISD90-91, demonstrated a high level of resistance (HR) to spider mites. Notably, ISD90-23 and ISD90-68 exhibited a statistically significant deviation from the expected exit ratio, further emphasizing their exceptional resistance capabilities. Moving on to the F-22 family, ISF22-13, ISF22-17, ISF22-19, and ISF22-37 exhibited high resistance (HR) to spider mites, as indicated by their significantly lower exit counts. Furthermore, genotype ISF22-18 within the F-22 family exhibited a remarkable level of resistance (HR) to spider mites, with a significant departure from the expected exit ratio.

Table 2. Mite repellency levels and 7-epizingiberene concentration (µg cm²) of T1, T2 inbred lines from D-90 Family (ISD90-23, ISD90-68, ISD90-70, ISD90-73, ISD90-83, ISD90-87, ISD90-89, and ISD90-91), and inbred lines from IS-F22 family (ISF22-13, ISF22-17, ISF22-18, ISF22-19, and ISF22-37)

Family	Genotype	*7-epizingiberene* (µg cm²)	Repellency	Leaflet wash exit	Control exit	X^2 value
Tomato	T1	0	S	18	15	0.60^{ns}
Tomato	T2	0	S	17	13	0.53^{ns}
D-90	ISD90-23	25.08	HR	7	23	8.53**
D-90	ISD90-68	32.497	HR	8	22	6.53**
D-90	ISD90-70	28.449	IR	11	19	2.13*
D-90	ISD90-73	30.856	HR	10	20	3.33**
D-90	ISD90-83	18.609	HR	10	20	3.33**
D-90	ISD90-87	31.318	HR	8	22	6.53**
D-90	ISD90-89	20.586	IR	12	18	1.20*
D-90	ISD90-91	20.072	HR	2	28	22.53***
F-22	ISF22-13	49.022	HR	8	22	6.53**
F-22	ISF22-17	43.756	IR	8	22	6.53**
F-22	ISF22-18	41.917	HR	3	27	19.20***
F-22	ISF22-19	22.32	HR	9	21	4.80**
F-22	ISF22-37	19.013	IR	12	18	1.20*

Note: The abbreviations "HR" denoted high resistance, "MR" referred to mid resistance, and "S" indicated susceptibility to spider mites. A notable deviation from the expected 1:1 exit ratio, as determined by X^2, was represented by significant symbols (***P< 0.001, **P< 0.01, *P< 0.05), while the symbol "ns" represented no significance or susceptibility

3.2. Fruit number

In this investigation, a randomized complete block design was employed to assess the fruit number plant^{-1} across various genotypes. The analysis of variance (ANOVA) consequences provided compelling evidence supporting the influence of genotype on fruit number plant^{-1} $F(14, 28) = 5.63$, $p < 0.0001$). To further elucidate

the dissimilarities, *Figure 2* was constructed to visually represent the fruit yield plant^{-1} for each genotype. Remarkably, T1 and T2 genotypes exhibited the most substantial and second-highest fruit numbers plant^{-1}, respectively. Among the D-90 genotypes, ISD90-70 and ISD90-73 demonstrated the highest fruit numbers plant^{-1}. Similarly, within the F-22 genotypes, ISF22-13 and ISF22-17 manifested relatively elevated fruit numbers plant^{-1}.

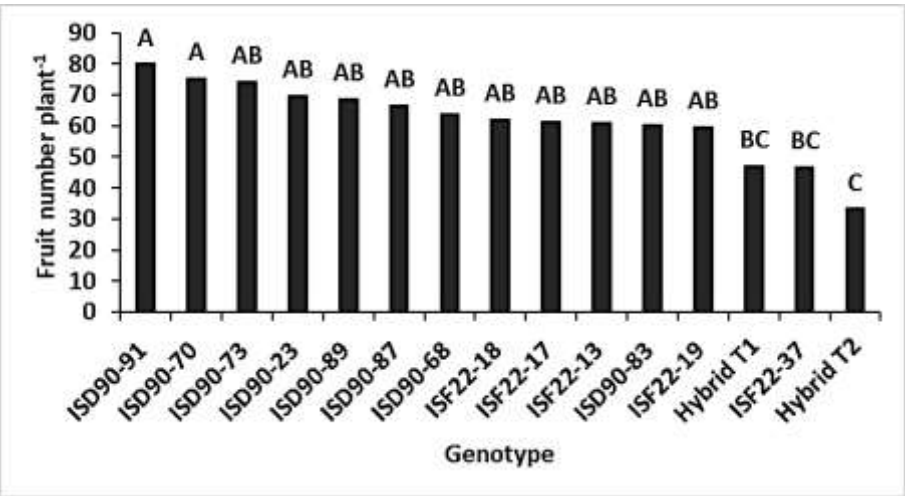

Figure 2. A comparative analysis of fruit number plant^{-1} in different genotypes: Evaluating the effects of T1, T2,* inbred lines *from D-90 Family (ISD90-23, ISD90-68, ISD90-70, ISD90-73, ISD90-83, ISD90-87, ISD90-89, and ISD90-91), and* inbred lines *from IS-F22 family (ISF22-13, ISF22-17, ISF22-18, ISF22-19, and ISF22-37). These Inter-Specific (IS) lines are the result of breeding between S. habrochaites (WT-LA2329), a wild tomato relative, and Zaofen-2, a cultivated tomato variety

3.3. Average *fruit weight*

The statistical analysis conducted indicated a highly significant influence of genotypes on fruit weight ($F = 102.85$, $p < 0.001$), highlighting considerable genetic variation associated with this trait (*Figure 3*). Examining the

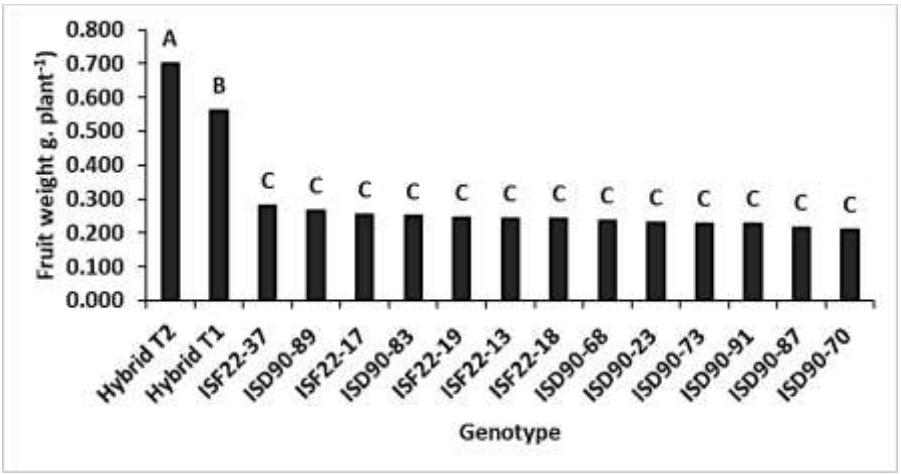

Figure 3. Average weight of fruits (g) of T1, T2, inbred lines from D-90 family (ISD90-23, ISD90-68, ISD90-70, ISD90-73, ISD90-83, ISD90-87, ISD90-89, and ISD90-91), and inbred lines from IS-F22 family (ISF22-13, ISF22-17, ISF22-18, ISF22-19, and ISF22-37). These Interspecific (IS) lines are the result of breeding between S. habrochaites (WT-LA2329), a wild tomato relative, and Zaofen-2, a cultivated tomato variety

average fruit weight for each genotype revealed noticeable distinctions among them. Within the tomato genotypes, T1 exhibited an average fruit weight of 0.566 g, while T2 displayed a slightly higher mean of 0.7033 g. In the D-90 family, the genotype ISD90-23 had the lowest mean fruit weight of 0.2333 g, followed by ISD90-68 (0.240 g) and ISD90-70 (0.213 g). Conversely, ISD90-89 exhibited the highest mean fruit weight within this group, measuring 0.270 g. Moving to the F-22 family, ISF22-37 demonstrated the highest mean fruit weight of 0.283 g,

while the remaining genotypes in this family displayed mean fruit weights ranging from 0.246 to 0.256 g. These results provide compelling evidence for substantial genetic variation in fruit weight across different genotypes.

3.4. Total fruit weight

The analysis reveals significant variation in the total fruit weight plant^{-1} across the different genotypes (*Figure 4*). For instance, the mean fruit weight for T1 is 12.15 g, while T2 has a slightly lower mean of 10.627 g. Among the D-90 genotypes, ISD90-23 exhibits a mean fruit weight of 7.397 g, whereas ISD90-68, ISD90-70, and ISD90-73 have mean values ranging from 6.867 to 7.713 g. In the F-22 family, ISF22-13, ISF22-17, and ISF22-18 demonstrate mean fruit weights of approximately 6.757 to 7.087 g, whereas ISF22-19 and ISF22-37 have lower means of 6.857 and 6.023 g, respectively.

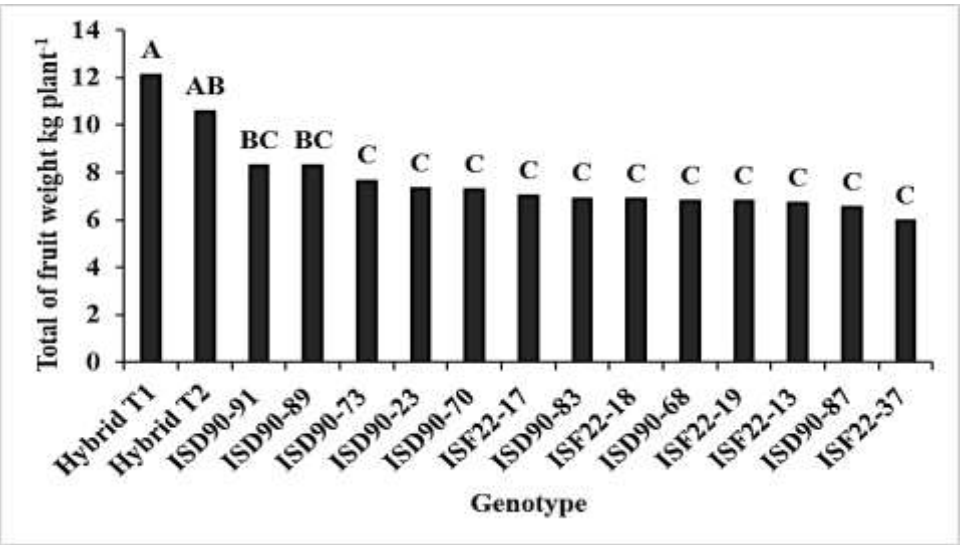

Figure 4. Average of total fruit weight (kg plant^{-1}) of T1, T2, inbred lines from D-90 Family (ISD90-23, ISD90-68, ISD90-70, ISD90-73, ISD90-83, ISD90-87, ISD90-89, and ISD90-91), and inbred lines from IS-F22 family (ISF22-13, ISF22-17, ISF22-18, ISF22-19, and ISF22-37). These inbred lines are the result of breeding between S. habrochaites (WT-LA2329), a wild tomato relative, and Zaofen-2, a cultivated tomato variety

The study examined the outcomes and provided empirical evidence to support a negative correlation between the concentration of *7-epizingiberene* in interspecific hybrids and the average plant yield. It was observed that higher levels of *7-epizingiberene* were associated with a decline in yield, despite the potential benefits of increased concentrations of this compound in terms of pest resistance. These findings enhanced our understanding of the complex relationships between *7-epizingiberene* concentration, fruit productivity, and overall plant productivity. Consequently, researchers can now make informed decisions regarding the breeding of tomato plants and optimizing yield.

Regarding the content and repellency of *7-epizingiberene*, our findings were agreed with De Oliveira et al. (2020) 's research, emphasizing the significant influence of specific genotypes on spider mite populations due to their heightened resistance mechanisms. These findings were further supported by Snyder et al. (2005), who reported similar susceptibility levels among tomato genotypes. Additionally, the study's outcomes corroborated the work of Zanin et al. (2018), De Oliveira et al. (2018), Santamaria et al. (2020), Panizzon Diniz et al. (2022), and Savi et al. (2022), collectively demonstrating the importance of genotypes in effectively combating spider mite infestations. The experiment revealed variations in *7-epizingiberene* levels, resistance to spider mites, and mite exit ratios across different tomato genotypes. Some genotypes showed statistically significant deviations from the expected exit ratio, indicating varying levels of resistance to spider mites. Notably, genotypes with higher concentrations of *7-epizingiberene* exhibited increased repellency against pests, as supported by Lucini et al.'s (2015) findings. Further research is necessary to understand the underlying mechanisms and practical applications of these genotypes in pest management strategies, as emphasized by Ulyshen and Shelton (2012).

Furthermore, the study shed light on the significant influence of genotype on fruit yield plant^{-1}. The results highlighted the impact of genotype on variations in fruit production, with implications for breeding prog and strategies aimed at improving crops. These findings aligned with the research conducted by Wang et al. (2019), which further emphasized the presence of genetic traits that positively affect fruit weight, indicating potential avenues for enhancement through breeding prog. Therefore, further investigations are required to unravel the underlying mechanisms responsible for the observed variations in fruit weight. Gaining a comprehensive understanding of the genetic factors and physiological processes associated with fruit development and weight accumulation can facilitate targeted breeding strategies to increase fruit weight in tomato plants, as suggested by Hui et al. (2016) (Cay and Aykaş, 2013).

Regarding the total fruit weight plant^{-1}, the study revealed significant variation among the examined genotypes. Genetic factors influencing fruit development and growth were identified as the primary determinants of these observed differences. These findings were consistent with Mohamed et al. (2012) and Saravanan et al. (2019), both of which emphasized the pivotal role of genotype in determining fruit weight in tomatoes. The study also acknowledged the potential contributions of environmental conditions and cultural practices to the observed variation in fruit weight. Therefore, further investigations are necessary to understand the underlying mechanisms and explore potential strategies for enhancing fruit production.

In summary, the study findings suggest that producing high levels of *7-epizingiberene* may result in a decrease in yield, indicating a potential trade-off associated with its synthesis. However, in this research, interspecific hybrids were successfully developed, exhibiting yields comparable to the recurrent parent while maintaining significant levels of *7-epizingiberene* production. These results offer promising prospects for breeding tomato hybrids with desirable traits, such as high yield and pest resistance, without compromising the production of secondary metabolites like *7-epizingiberene*. Consequently, further research is warranted to uncover the intricacies of *7-epizingiberene* biosynthesis, its impact on yield, and the trade-offs involved. These insights can provide valuable guidance to breeders and researchers in their efforts to develop tomato varieties with enhanced pest resistance and productivity.

4. Conclusions

The findings of the present study have unveiled that interspecific hybrid families exhibited a greater number of fruit plant^{-1} compared to the tested tomato cultivars. Conversely, the total yield plant^{-1} was higher in the cultivars than in the interspecific hybrids. Moreover, a negative correlation was observed between the average weight of fruit plant^{-1} and the content of 7-epizingeberene, indicating the necessity for further investigation into the true association between *7-epizingiberene* production and yield. These preliminary outcomes offer a promising prospect of developing tomatoes through breeding techniques that combine high yield and adequate 7-epizingebrene levels in their leaves. The results obtained from the bridge-bioassay test suggest that there are certain unknown neutral substances that exhibit repellent activity in the bioassay, influencing the behavior of spider mites. However, it remains unclear whether these substances specifically contribute to leaflet repellency. Further investigation is required to determine the exact role and impact of these unidentified substances on the repellent properties of the leaflets. This potential achievement could potentially result in enhanced resistance against plant pests and increased overall yield. Further research in this area will undoubtedly shed light on the intricate relationship between *7-epizingiberene* content and yield, providing invaluable insights for future advancements in tomato breeding and agricultural practices.

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Ethical Statement

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

Conflicts of Interest

The authors declare no conflict of interest.

Authorship Contribution Statement

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

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Element Contents and Health Risk Assessment of Some Commercial Coffees in Türkiye

Türkiye'deki Bazı Ticari Kahvelerin Element İçeriklerinin Belirlenmesi ve Sağlık Riski Değerlendirmesi

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Abstract

Coffee is one of the most consumed beverages worldwide, which has become an integral part of people's daily lives. The increasing demand for coffee consumption has led to the creation of many coffee brands producing various types of coffee around the world. One of the reasons for the widespread consumption of coffee is that it contains elements necessary for human health. Supplementation of food intake with essential minerals, which are present in large quantities in the body, and trace minerals, which are present in smaller quantities, is an important parameter in nutrition. Determining the total concentrations of the elements in coffee allows the assessment of its nutritive quality and at the same time, its adverse effects on human health can be decided. In the present study, essential- zinc (Zn), selenium (Se), phosphorus (P), sodium (Na), manganese (Mn), magnesium (Mg), potassium (K), iron (Fe), copper (Cu), chromium (Cr), cobalt (Co), calcium (Ca) and boron (B)- and non-essential - titanium (Ti), antimony (Sb), lead (Pb), nickel (Ni), molybdenum (Mo), cadmium (Cd), barium (Ba), arsenic (As) and aluminium (Al)- element content in some coffee types from different brands was analyzed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) and the results were interpreted in terms of human health. Percentages of elements ingested with daily consumption of 300 mL of selected coffee types were also calculated on a person-by-person basis according to gender. Health risk assessment was performed involving carcinogenic risk and non-carcinogenic risk evaluation. In all coffee types, K element concentration has been reported as the highest element. As, Cd, Mo, Sb, and Ti elements were not detected in all types of coffees. A female's highest daily element intake percentage is Mg for all types of coffee with the highest concentration of 15.561% (decaffeinated coffee, P1). For a male, the Mg element daily intake percentage is also the highest except Milicano and filter coffee of P2 and Turkish coffee of P4. The hazard index (HI) of all samples was less than 1, thus, daily consumption of 300 mL of these coffees is defined in a low-risk group. The target carcinogenic risk (TCR) value was calculated below 1×10^{-4} for all coffee types except Classic (Product 1). Classic coffee of Product 1 should be consumed less than 300 mL/day since its TCR value is higher than 1×10^{-4}.

Keywords: Coffee, Essential and non-essential elements, ICP-OES, Risk assessment

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Öz

Kahve, insanların günlük yaşamlarının ayrılmaz bir parçası haline gelen ve dünya çapında en çok tüketilen içeceklerden biridir. Kahve tüketimine yönelik artan talep, dünya çapında çeşitli kahve türleri üreten birçok kahve markasının oluşmasına yol açmıştır. Kahvenin yaygın olarak tüketilmesinin nedenlerinden biri de insan sağlığı için gerekli elementleri içermesidir. Vücutta büyük miktarlarda bulunan başlıca mineraller ve daha küçük miktarlarda bulunan eser minerallerin gıda alımıyla desteklenmesi beslenmede önemli bir parametredir. Kahvede bulunan elementlerin toplam konsantrasyonlarının belirlenmesi, kahvenin besleyici kalitesinin değerlendirilmesini sağlar ve aynı zamanda insan sağlığı üzerindeki olumsuz etkilerine karar verilebilir. Bu çalışmada, farklı markalara ait bazı kahve türlerinde esansiyel -çinko (Zn), selenyum (Se), fosfor (P), sodyum (Na), mangan (Mn), magnezyum (Mg), potasyum (K), demir (Fe), bakır (Cu), krom (Cr), kobalt (Co), kalsiyum (Ca) ve bor (B)- ve esansiyel olmayan - titanyum (Ti), antimon (Sb), kurşun (Pb), nikel (Ni), molibden (Mo), kadmiyum (Cd), baryum (Ba), arsenik (As) ve alüminyum (Al) element içeriği indüktif eşleşmiş plazma-optik emisyon spektroskopisi (ICP-OES) ile analiz edilmiş ve sonuçlar insan sağlığı açısından yorumlanmıştır. Seçilen kahve türlerinin günlük 300 mL tüketimi ile alınan element yüzdeleri de cinsiyete göre kişi bazında hesaplanmıştır. Kanserojen risk ve kanserojen olmayan risk değerlendirmesini içeren sağlık riski değerlendirmesi yapılmıştır. Tüm kahve türlerinde K elementi konsantrasyonu en yüksek element olarak rapor edilmiştir. As, Cd, Mo, Sb, Ti elementleri tüm kahve türlerinde tespit edilmemiştir. Kadınların günlük Mg elementi alım yüzdesi tüm kahve türleri için %15,561 ile en yüksek olarak belirlenmiştir (kafeinsiz kahve, P1). Erkeklerde ise Mg elementi günlük alım yüzdesinin Milicano (P2), filtre kahve (P2) ve Türk kahvesi (P4) ürünleri dışında en yüksek olduğu tespit edilmiştir. Tüm örneklerin tehlike indeksi (HI) 1'den küçüktür, bu nedenle bu kahvelerin günlük 300 mL tüketimi düşük risk grubunda tanımlanmaktadır. Hedef kanserojen risk (TCR) değeri Klasik (Ürün 1) hariç tüm kahve türleri için 1×10^{-4}'ün altında hesaplanmıştır. Ürün 1'in klasik kahvesinin TCR değeri 1×10^{-4}'ten yüksek olduğu için günde 300 mL'den az tüketilmelidir.

Anahtar Kelimeler: Kahve, Esansiyel ve esansiyel olmayan elementler, ICP-OES, Risk değerlendirmesi

1. Introduction

As a result of increasing awareness for healthy nutrition to provide a health body, attention has also increased to the food contents. Healthy nutrition affects the health of the cells the smallest part of the body. Maintaining a balance of about two-thirds of the body fluids inside the cells and one third outside is vital for cell life. The cells direct the movement of the major minerals for controlling the water movement. Major elements or macrominerals are essential mineral nutrients constituted in the human body in amounts larger than 5 g whereas trace elements or microminerals are found in amounts smaller than 5 g. Sodium (Na), chlorine (Cl), potassium (K), magnesium (Mg), phosphorous (P), calcium (Ca), sulphur (S) are some examples of major essential elements and manganese (Mn), copper (Cu), iron (Fe), zinc (Zn), selenium (Se), fluorine (F), chromium (Cr), iodine (I) and molybdenum (Mo) are classified as micro essential elements (Rolfes et al., 2008; Ozdemir Dere et al., 2014; Derun, 2014; Eser and Adiloglu, 2020). Essential elements play important roles in maintaining the functional and structural integrity of living systems (Cacan et al,. 2023). Besides essential elements, non-essential elements include heavy metals that are contained in the food supply by soil, water, and air pollution way. Aluminium (Al), cadmium (Cd), lead (Pb), mercury (Hg), barium (Ba), antimony (Sb), molybdenum (Mo), arsenic (As), nickel (Ni) and titanium (Ti) are some examples of non-essential toxic elements (Rolfes et al., 2008; Ozdemir Dere et al., 2014; Derun, 2014). Knowing and monitoring the essential and non-essential (toxic) element contents of the foods and beverages that are frequently consumed in daily life is important for conscious consumption and product quality, in addition to preventing nutritional deficiency (Bigucu et al., 2016).

Coffee is the fruit of a tree species from the genus Coffea of the *Rubiaceae* family (Acikalin and Sanlier, 2021). It is obtained by processing cores within this fruit. Coffee is involves materials such as caffeine, cafestol, kahveol, trigonelline, chlorogenic acids, various minerals, and trace elements and it consumed the form of beverage widely (Bianchin et al., 2020). Coffee ranks second among the products traded in the world after petroleum, and its consumption with an estimated 165 million 60 kg bags consumed per year is becoming more widespread every day (Agunbiade et al., 2022; Carter et al., 2022). Since coffee is a beverage frequently consumed in the daily nutrition routine, there are several studies in the literature on its element content (essential and non-essential) in terms of nutritional value and healthy nutrition. Várady et al. (2024), determined the heavy metal amounts of green and roasted specialty coffees originated different regions as Kenya, Guatemala, Ethiopia, Nicaragua, Burundi, Rwanda and Peru. The heavy metals aluminium (Al), cadmium (Cd), nickel (Ni), copper (Cu), chromium (Cr), and lead (Pb) were detected by utilizing inductively coupled plasma mass spectrometry. They statistically reported that the technique of process affected the composition of Al, Hg, Cr, Ni, Cd, and Pb in the roasted and green coffees ($p < 0.001$) (Várady et al., 2024). Baqueta et al. (2024), analyzed Conilon and Robusta species of Brazilian Canephora coffees according to their essential element content (Fe, Ca, Zn, Mg, Mn, Cu, and K) by flame atomic absorption spectrometry using diluted nitric acid. Essential element composition data was estimated within independent components-discriminant analysis (IC-DA) which is a type of chemometric tool. When the specificity and sensitivity of the analyses compared, IC-DA showed higher then partial least square-discriminant analysis (PLS-DA). Results implicated that IC-DA is suitable to maintain supervised discrimination of species based on their essential elemental content (Baqueta et al., 2024). Weinberger et al. (2024), used EDXRF (Energy dispersive X-ray fluorescence spectrometry) to determine the K, Ca, Mn, Fe, Cu, Zn, Sr and Rb element composition of some coffees. Different sample treatment methods such as loose powder and pressed pellets and quantification techniques were studied. Several chemometric methods explored for different coffee types showed that the application of PLS-DA on the raw EDXRF spectra is suitable and the fitting and quantification of elemental concentrations is not necessary (Weinberger et al., 2024). Junior et al. (2020), studied the effect of organic and conventional management systems on absorption, storage, and hot water solubility of Mg through chemical fractionation of P and Mg in arabica, commercial, ground, and roasted coffee utilizing acid digestion and flame atomic absorption spectrometry. Results showed that in these samples Mg is possibly mostly exhibited as different inorganic salts (Junior et al., 2020). Silva et al. (2020), performed an extraction of coffee leaves reaped from Brazil and assessed polyphenol and trace element content (Mg, Al, Cu, Sn, Mn, Ni, and Zn) by using ICP-OES. For the establishment of trace elements and polyphenolic content in the leaves to rust infection resistance role, principal component analysis (PCA) was assigned. As a result; polyphenolic concentration was decreased in impressionable cultivars and a diametric impact was seen between Mg and Mn concentrations (Silva et al., 2020). Pohl et al. (2018), aimed to clarify the specimen preparing process of ground (GCs) and soluble coffee (SCs) brew previous

to their custom analysis by ICP-OES for the chosen elements (Zn, Mn, Ni, Sr, Fe, Mg, Ca, Cu, Al and Ba). It was found that the contents of elements in brews of SCs were greater those decided in infusions of GCs (Pohl et al., 2018). Habte et al. (2016), were reported the establishment of elemental profiling and provenance of coffee samples obtained from different major coffee fabricating locations of Ethiopia. ICP-OES, direct mercury analyser (DMA), and ICP-MS tests were utilized to analyse forty-five elements in 129 samples. From their results; as a macro element, the concentration of Fe was measured least and K showed the highest levels. The content of micro elements was sorted as Mn > Cu > Sr > Zn > Rb > Ni > B (Habte et al., 2016). Barbosa et al. (2014), evaluated 34 non-organic and 20 organic coffees on the authority of their micro and macro element contents by ICP-MS and determined thirty-eight element contents. Results showed that chemical element contents are higher in conventional coffee (Barbosa et al., 2014). Stelmach et al. (2013), analysed Zn, Mn, Mg, Fe, Cu, and Ca content of coffee specimens by using flame atomic absorption spectrometry and assessed differences in the leachability of elements from one specified coffee into its infusions processed under divergent infusion environments. According to the results; the highest element contents were reported as Mg and Ca in each coffee sample (average data of 14.3 × 103 μg g^{-1} and 1.8 × 103, respectively) and were followed by Mn and Fe (mean concentrations of 25.0 μg g^{-1} and 31.3 μg g^{-1}, respectively). Zn (6.8 μg g^{-1}) and Cu (14.1 μg g^{-1}) had the lowest concentration in coffee samples (Stelmach et al., 2013).

In this study, it is aimed to determine and compare essential (Na, Se, P, Zn, K, Mn, Mg, Co, Fe, Cu, Cr, B, and Ca) and non-essential (Pb, Ni, Ba, and Al) element content of ten types of coffees (classic, milicano, green, gold, decaffeinated, filter and Turkish coffee) from four different product (P1, P2, P3, and P4). For this purpose; infusion process of the selected coffee samples was acquired and element concentrations were interfered with by ICP-OES. Moreover, a health risk assessment study involving non-carcinogenic and carcinogenic risks was accomplished.

2. Materials and Methods

Classic, green, gold, and decaffeinated coffee from Product 1, milicano and gold coffee from Product 2, gold and decaffeinated coffee from Product 3, and filter and Turkish coffee from Product 4 were supplied from a provincial market in Türkiye. GFL distillation unit water purification system (Lauda, GFL) was used to obtain pure water (0,07 μs/cm). PerkinElmer Optima 2100 DV ICP-OES (PerkinElmer Inc., MA, USA) equipped with an AS-93 autosampler was utilized to analyze the element contents of samples. ICP-OES analysis was acquired with power of 1.45 kW, a plasma flow of 15.0 L min^{-1}, an auxiliary flow of 0.8 L min^{-1}, and a nebulizer flow of 1 L min^{-1}. Nitric acid (HNO^3) in 65% purity was obtained from Merck chemicals (Merck KgaA, Darmstadt, Germany) for the standard solution preparation. 2 grams of each coffee sample were weighed and infused with 100 ml of pure water nearly at boiling point (90-100°C), separately. After five minutes, extracted coffee samples were filtered and the filtered coffees were made up with distilled water. For the preparation of the standard solution; 0.3% HNO_3 solution was prepared with ultra-pure water and placed in a standard tube and the elements to be determined were added to the acid solution in predetermined amounts. In the last step, ICP-OES analysis was accomplished for the diluted coffee samples. 3 parallel experiments were conducted and from the analyses results one-way analysis of variance (ANOVA) was used to evaluate significant differences in the data at $P < 0.05$.

2.1. Health Risk Assessment

Non-carcinogenic risk

THQ is the risk factor applied to noncarcinogens and it associates the dose distributed at the exposure point to a toxicological end-point (Bleam, 2016). THQ value below 1 means there is not non-carcinogenic health effect condition. On the other hand, if the THQ is above 1 then there may be contrary health influences. Hazard index (HI) indicates an entire number of the single target hazard quotients of the analysed elements for each type of beverage or food. In the basis of HI, a particular type of food intake would result in coincident disclosure to various potentially toxic elements (Antoine et al., 2017). THQ and HI can be calculated by using the below Equations (1) and (2) (Demir et al., 2020).

$$THQ = \frac{EF \times ED \times FIR \times C}{RfD \times B_W \times A_T} \quad \text{(Eq. 1)}$$

$$\mathrm{HI} = \sum_{i}^{n} \mathrm{THQ_i} \quad \text{(Eq. 2)}$$

where EF is 365 days/year; ED is 73 years; FIR is in mL/person/day; C is in mg/L; RfD (mg/kg/day) is specific to the trace element being assessed; Bw is 60 kg and AT is 365 days/year × 73 years. The RfD data are 1 for Al, 2 × 10-1 for Ba, 2 × 10-2 for Ni and 36 × 10-4 for Pb (Demir et al., 2020; WHO, 2023; Yalcin Gorgulu et al., 2022).

Carcinogenic risk

TCR identifies the possible risk estimation attached to carcinogenic agents receiving end during the lifespan disclosure interval. Behalf an oral reference dose, a CSF is utilized in the decision of TCR. The presumption of overabundance cancer risk throughout the lifetime of the endangered person together with the carcinogen dose is determined within this factor (Antoine et al., 2017). TCR is calculated by applying Equation 3:

$$\mathrm{TCR} = \frac{\mathrm{C} \times \mathrm{CSF} \times \mathrm{ED} \times \mathrm{EF} \times \mathrm{FIR}}{\mathrm{A_T} \times \mathrm{B_w}} \qquad \text{(Eq. 3)}$$

where CSF is in (mg/kg/day)-1 and the CSF values are 17 × 10-1 for Ni and 85 × 10-4 for Pb (Demir et al., 2020).

3. Results and Discussion

The resulting data about the essential and non-essential element contents in selected coffee types are given in *Table 1* and limits of detection and quantification values by ICP-OES are also included in *Table 2*. According to the results, the most abundant element in all analysed coffees was Potassium (K) with the highest concentration of 1186 mg/L in Milicano coffee of P2. Other elements differ according to the type of coffee for several reasons such as coffee plant growing conditions, different processing techniques, errors that may occur during experimental studies. If the coffees are examined according to the essential element contents; the elements in Classic (P1) can be shown as K > Mg > Ca > P > Na > B > Mn > Fe > Se > Co, respectively. Likewise, the elements found in Gold (P1) are K > Mg > P > Ca > Na > B > Mn > Fe> Zn > Se > Cu, and the elements found in Green (P1), Millicano (P2) are K > Mg > P > Ca > Na > Fe > B > Mn, respectively.

The elements in Filter coffee of P2 are K > P > Mg > Ca > Na > Mn > B > Cu > Fe > Zn, in Turkish Coffee (P4) are K > Ca > Mg > P > Na > B > Mn > Zn > Cu > Fe , in Gold coffee (P3) are K > Mg > P > Ca > Na > Mn > Fe > B > Se > Zn > Cr > Co, in Decaf (P3) can be shown as K > Mg > Na > P > Ca > Fe > B > Zn > Mn > Se, respectively.

When the coffees are assessed according to the non-essential element contents, Al is the highest element except Milicano coffee of P2 and decaffeinated coffees of Product 1 and Product 3. Non-essential elemental contents of Classic (P1), Milicano (P2), Gold (P1), Gold (P2), Gold (P3), Decaffeinated (P3), Decaffeinated (P1) are Al > Ni > Ba; Ba > Ni > Al; Al > Ba > Ni; Al > Ba > Pb > Ni; Al > Ba > Pb; Ba > Al > Pb; Ba > Al > Pb > Ni. Non-essential element contents of Green coffee (P1), Filter coffee (P2) and Turkish Coffee (P4) are Al > Ba. Lead is not detected in whole coffees except gold coffees of P2 and P3 and decaffeinated coffees of P1 and P3. As, Cd, Mo, Sb, Ti were not detected in all type of coffees. Essential and non-essential element contents of all selected coffee varieties are statistically analysed and resulted in confidence interval with $p < 0.1$.

The elements found in Gold (P2) are K > Mg > P > Ca > Na > Fe > B > Se > Mn > Zn > Co > Cu > Cr, respectively. The elements found in Decaf (P1) are K > Mg > P > Ca > Na > Zn > Mn > Fe > B > Se > Co > Cr.

Table 1. Essential and non-essential element contents in various types of coffees

Element	Classic (P1)	Milicano (P2)	Green (P1)	Gold (P1)	Gold (P2)
B (µg/L)	225.00±7.1	134.50±9.2	271.50±20.5	171.00±4.2	137.50±2.1
Ca (mg/L)	57.00±4.48	21.07±0.04	21.40±0.51	22.58±2.16	21.01±0.47
Co (µg/L)	6.70±0.4	n.d.	12.50±0.7	n.d.	12.50±0.7
Cr (µg/L)	n.d.	n.d.	13.10±1.3	n.d.	6.00±0.7
Cu (µg/L)	n.d.	5.0±0.0000	8.00±0.7	4.70±0.4	6.60±0.6
Fe (µg/L)	104.00±4.2	409.50±24.7	361.00±15.6	86.50±0.7	287.50±3.5
K (mg/L)	649.50±24.3	1186.00±41.0	728.00±6.7	659.30±32.9	571.90±48.6
Mg (mg/L)	60.52±1.33	50.89±0.16	76.56±0.62	59.97±0.73	53.54±4.00
Mn (µg/L)	206.50±4.9	130.50±0.7	140.00±1.4	170.50±2.1	115.00±7.1
Na (mg/L)	20.60±0.74	13.50±0.01	8.40±0.45	13.36±0.49	10.79±0.02
P (mg/L)	51.49±2.67	43.51±0.20	63.78±2.23	50.78±0.71	53.00±0.35
Se (µg/L)	49.50±3.5	45.00±1.4	77.00±2.8	29.00±2.8	125.50±7.8
Zn (µg/L)	n.d.	n.d.	44.00±2.8	52.00±1.4	49.00±2.8
Al (µg/L)	57.50±2.1	8.50±0.7	34.00±1.4	57.50±2.1	33.00±2.8
As	n.d.	n.d.	n.d.	n.d.	n.d.
Ba (µg/L)	16.50±0.7	22.50±0.7	25.00±0.7	19.50±0.7	20.00±1.4
Cd	n.d.	n.d.	n.d.	n.d.	n.d.
Mo	n.d.	n.d.	n.d.	n.d.	n.d.
Ni (µg/L)	26.50±2.1	12.50±0.7	n.d.	7.50±0.7	7.50±0.7
Pb (µg/L)	n.d.	n.d.	n.d.	n.d.	11.50±0.7
Sb	n.d.	n.d.	n.d.	n.d.	n.d.
Ti	n.d.	n.d.	n.d.	n.d.	n.d.
Element	**Gold (P3)**	**Decaffeinated (P3)**	**Decaffeinated (P1)**	**Filter (P2)**	**Turkish Coffee (P4)**
B (µg/L)	193.50±2.1	270.0±21.2	155.50±10.6	68.50±6.4	133.00±12.7
Ca (mg/L)	34.93±1.54	35.33±2.10	37.49±0.70	7.98±0.45	78.49±3.22
Co (µg/L)	7.50±0.7	n.d.	15.00±1.4	n.d.	n.d.
Cr (µg/L)	11.50±0.7	n.d.	10.50±0.7	n.d.	n.d.
Cu (µg/L)	n.d.	n.d.	n.d.	28.50±2.1	9.50±0.7
Fe (µg/L)	384.00±32.5	934.00±93.3	287.50±4.9	15.50±0.7	8.00±0.7
K (mg/L)	711.60±27.9	770.00±3.5	607.50±27.0	372.90±13.3	294.80±11.7
Mg (mg/L)	129.05±2.05	69.45±0.16	160.80±12.16	19.40±0.67	21.46±0.23
Mn (mg/L)	1.89±0.0587	0.16±0.0007	0.33±0.0007	0.10±0.0042	0.07±0.0028
Na (mg/L)	21.67±1.97	53.23±0.48	4.52±0.12	0.83±0.01	0.81±0.01
P (mg/L)	71.09±4.30	44.29±0.08	67.31±2.72	20.14±0.47	17.99±0.28
Se (µg/L)	139.00±9.9	12.0±0.7	95.00±1.4	n.d.	n.d.
Zn (µg/L)	57.00±2.8	189.00±2.8	575.00±49.5	6.70±0.4	61.50±2.1
Al (µg/L)	57.50±0.7	43.00±0.6	56.50±2.1	25.50±2.1	15.50±0.7
As (µg/L)	n.d.	n.d.	n.d.	n.d.	n.d.
Ba (µg/L)	27.50±0.7	72.50±0.7	68.50±0.7	16.00±0.6	8.00±0.7
Cd	n.d.	n.d.	n.d.	n.d.	n.d.
Mo	n.d.	n.d.	n.d.	n.d.	n.d.
Ni (µg/L)	n.d.	n.d.	7.50±0.7	n.d.	n.d.
Pb (µg/L)	20.50±0.7	36.00±2.8	19.00±1.4	n.d.	n.d.
Sb	n.d.	n.d.	n.d.	n.d.	n.d.
Ti	n.d.	n.d.	n.d.	n.d.	n.d.

*n.d.: Not detected

Table 2. Limits of detection and quantification values by ICP-OES

Element	Limits of detection (mg/L)	Limits of quantification (mg/L)
Ca	0.0063	0.0209
Co	0.0005	0.0016
Cr	0.0001	0.0005
Cu	0.0004	0.0013
Fe	0.0017	0.0055
K	0.0015	0.0049
Mg	0.0010	0.0035
Mn	0.0004	0.0013
Na	0.0029	0.0096
P	0.0038	0.0125
Se	0.0036	0.0120
Zn	0.0002	0.0006
Al	0.0020	0.0069
As	0.0015	0.0053
Ba	0.0018	0.0053
Cd	0.0003	0.0012
Mo	0.0003	0.0011
Ni	0.0008	0.0028
Pb	0.0018	0.0060
Sb	0.0007	0.0024
Ti	0.0003	0.0012

Daily element intake percentages of 300 mL/day selected coffee consumption are also calculated for a person according to gender and given in *Table 3*. According to the table, the highest element intake percentage of a female is Mg for all types of coffee with the highest concentration of 15.561% (decaffeinated coffee, P1). For a male, Mg element intake percentage is also the highest except Milicano and filter coffee of P2 and Turkish coffee of P4. The highest Mg intake percentage of a male can be seen in decaffeinated coffee, P1 as 12.060%.

3.1. Risk assessment

Risk assessment is undertaken to assess the probability of a particular potential harmful health effect occurring over a period of time (Mohammadi et al., 2019).

3.1.1 Non-carcinogenic risk

To evaluate noncarcinogenic human health risks from heavy metal intake, THQ data of non-essential elements in selected coffees were determined and presented in *Table 4*. For the determination of THQ values for each element and coffee type, Equation (1) was utilized. Since the THQ results of each metal for the analysed coffee sample were calculated at less than 1, these coffees can be consumed within safe limits (Yalcin Gorgulu et al., 2014). HI generated by non-essential elements was measured by employing THQ values of the coffee samples and Equation (2). Since the HI number of coffees was estimated below 1, ingestion of 300 mL of these coffees is described in a low-risk group.

3.1.2 Carcinogenic risk

The increased possibility of developing cancer as a result of exposure to a potential carcinogen during a person's lifetime has been defined as target carcinogen risk (TCR) by the US EPA. In the Guidelines for Carcinogen Risk Assessment, the measure of tolerable risk is between 1×10^{-6} and 1×10^{-4}. TCR numbers of evaluated coffee samples were measured and presented in *Table 4*. Consistent with the results, the TCR value was calculated lower than 1×10^{-4} for whole coffees except Classic (P1). Classic coffee of P1 should be consumed less than 300 mL/day as its TCR value is higher than 1×10^{-4}.

Table 3. Daily element intakes (%) for a person who drinks 3 cup of coffee daily (300 mL)

Element	Gender	Classic (P1)	Milicano (P2)	Green (P1)	Gold (P1)	Gold (P2)
B	M	0.338	0.202	0.407	0.257	0.206
Ca	M	0.684 - 1.710	0.253 - 0.632	0.257 - 0.642	0.271 - 0.677	0.252 - 0.630
Co	M	0.201	n.a.	0.375	n.a.	0.375
Cr	M	n.a.	n.a.	11.23	n.a.	5.14
Cr	F	n.a.	n.a.	15.72	n.a.	7.20
Cu	M	n.a.	0.015 - 0.167	0.024 - 0.267	0.014 - 0.157	0.020 - 0.218
Fe	M	0.069 - 0.390	0.273 – 1.536	0.241 – 1.354	0.058 – 0.324	0.192 – 1.078
Fe	F	0.069 – 0.173	0.273 – 0.683	0.241 – 0.602	0.058 – 0.144	0.192 – 0.479
K	M	4.145	7.570	4.646	4.208	3.650
Mg	M	4.539	3.816	5.742	4.497	4.015
Mg	F	5.857	4.924	7.409	5.803	5.181
Mn	M	0.563 – 2.693	0.356 – 1.702	0.382 – 1.826	0.465 – 2.224	0.314 – 1.500
Mn	F	0.563 – 3.442	0.356 – 2.175	0.382 – 2.333	0.465 – 2.842	0.314 – 1.917
Na	M	0.269 – 0.412	0.176 – 0.270	0.110 – 0.168	0.174 – 0.267	0.141 – 0.216
P	M	0.386 – 2.207	0.326 – 1.865	0.478 – 2.733	0.381 – 2.176	0.398 – 2.271
Se	M	3.71 – 27.00	3.38 – 24.55	5.78 – 42.00	2.18 – 15.82	9.41 – 68.45
Zn	M	n.a.	n.a.	0.033 – 0.120	0.039 – 0.142	0.037 – 0.134
Zn	F	n.a.	n.a.	0.033 – 0.165	0.039 – 0.195	0.037 – 0.184

Element	Gender	Gold (P3)	Decaffeinated (P3)	Decaffeinated (P1)	Filter (P2)	Turkish Coffee (P4)
B	M	0.290	0.405	0.233	0.103	0.200
Ca	M	0.419 - 1.048	0.424 - 1.060	0.450 - 1.125	0.096 - 0.239	0.942 - 2.355
Co	M	0.225	n.a.	0.450	n.a.	n.a.
Cr	M	9.86	n.a.	9.00	n.a.	n.a.
Cr	F	13.80	n.a.	12.60	n.a.	n.a.
Cu	M	n.a.	n.a.	n.a.	0.086-0.950	0.029-0.317
Fe	M	0.256 – 1.440	0.623 – 3.503	0.192 – 1.078	0.010 – 0.058	0.005 – 0.030
Fe	F	0.256 – 0.640	0.623 – 1.557	0.192 – 0.479	0.010 – 0.026	0.005 – 0.013
K	M	4.542	4.915	3.878	2.380	1.882
Mg	M	9.679	5.208	12.060	1.455	1.610
Mg	F	12.489	6.720	15.561	1.877	2.077
Mn	M	5.164 – 24.698	0.438 – 2.093	0.899 – 4.298	0.275 – 1.317	0.202 – 0.965
Mn	F	5.164 – 31.558	0.438 – 2.675	0.899 – 5.492	0.275 – 1.683	0.202 – 1.233
Na	M	0.283 – 0.433	0.694 – 1.065	0.059 – 0.090	0.011 – 0.017	0.011 – 0.016
P	M	0.533 – 3.047	0.332 – 1.898	0.505 – 2.885	0.151 – 0.863	0.135 – 0.771
Se	M	10.43 – 75.82	0.86 – 6.27	7.13 – 51.82	n.a.	n.a.
Zn	M	0.043 – 0.155	0.142 – 0.515	0.431 – 1.568	0.005 – 0.018	0.046 – 0.168
Zn	F	0.043 – 0.214	0.142 – 0.709	0.431 – 2.156	0.005 – 0.025	0.046 – 0.231

M: male, F: female
n.a.: not available

Table 4. THQ, HI and TCR values of risk elements in analysed coffee samples

Element	Classic (P1)	Milicano (P2)	Green (P1)	Gold (P1)	Gold (P2)
Al	0.0002875	0.0000425	0.00017	0.0002875	0.000165
Ba	0.0004125	0.0005625	0.000625	0.0004875	0.0005
Ni	0.006625	0.003125	n.d.	0.001875	0.001875
Pb	n.d.	n.d.	n.d.	n.d.	0.015972
Σ HI	0.007325	0.00373	0.000795	0.00265	0.018512222
Pb	n.d.	n.d.	n.d.	n.d.	4.8875E-07
Ni	0.000225	0.000106	n.d.	0.00006375	0.00006375
Σ TCR	0.000225	0.000106	n.d.	0.00006375	6.42E-05
Element	**Gold (P3)**	**Decaffeinated (P3)**	**Decaffeinated (P1)**	**Filter (P2)**	**Turkish Coffee (P4)**
Al	0.0002875	0.000215	0.0002825	0.0001275	0.0000775
Ba	0.0006875	0.0018125	0.0017125	0.0004	0.0002
Ni	n.d.	n.d.	0.001875	n.d.	n.d.
Pb	0.028472	0.05	0.026389	n.d.	n.d.
Σ HI	0.029447222	0.0520275	0.030258889	0.0005275	0.0002775
Pb	8.7125E-07	0.00000153	8.075E-07	n.d.	n.d.
Ni	n.d.	n.d.	0.00006375	n.d.	n.d.
Σ TCR	8.7125E-07	0.00000153	6.46E-05	n.d.	n.d.

*n.d.: Not detected

4. Conclusions

Essential and non-essential element concentrations in some commercial coffees was analysed by ICP-OES and health risk assessment of these coffees were concluded. In all coffee types, it was seen that K element concentration was the highest as essential element. Al concentration was the highest non-essential element in Classic, Green, Gold coffee of P1, Gold coffee and filter coffee of P2, Gold coffee of P3 and Turkish coffee of P4. Ba concentration was the highest non-essential element in decaffeinated coffee of P1 and P3, and Milicano coffee of P2. As, Cd, Mo, Sb, Ti as non-essential elements were not detected in all type of coffees. Results are statistically significant with p value less than 0.1 ($p<0.1$) and in confidence interval. Taking into consideration that HI values of all samples were less than 1, daily consumption of 300 mL of these coffees is defined in low-risk group. Furthermore, the TCR value was calculated lower than 1×10^{-4} for all coffee species except Classic (P1). Classic coffee of P1 should be consumed less than 300 mL/day since its TCR value is higher than 1×10^{-4}.

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Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Kipcak, A.S., Derun, E.; Design: Kipcak, A.S., Derun, E.; Data Collection or Processing: Demir, F.; Statistical Analyses: Uygunoz, D., Kipcak, A.S., Derun, E.; Literature Search: Demir, F., Uygunoz, D.; Writing, Review and Editing: Uygunoz, D., Kipcak, A.S., Derun, E.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Effects of Charcoal Production on Livelihood and Environment in Sapele Local Government Area, Delta State, Nigeria

Theophilus Miebi GBİGBİ[1], Oghenekevwe Abigail OHWO[2*], Pearl Rukevwe OKPOTO[3]

Abstract

Economic hardship, poverty, unemployment, and the escalating cost of oil have driven Nigerians to explore diverse avenues for sourcing domestic cooking energy to support their livelihoods. Trade in forest products have significantly influenced livelihood of market participants. This paper examines the many-sided impacts of charcoal production on livelihoods and the environment in Sapele Local Government, Delta State, Nigeria. The study involved 100 respondents and used descriptive statistics and multiple regression analyses. The findings showed that charcoal producers are predominantly male-dominated, with most respondents being married and having secondary education. They produce 21-40 bags of charcoal and have 10-19 years of production experience. The total variable cost of charcoal production amounted to ₦394.736.50, with a total fixed cost of ₦16.983.00. Total cost of production equaled ₦449.596.00, resulting in a gross margin of ₦54.859.5 and a net income of ₦37.876.50, leading to a return on investment of ₦9.20. The overall model fit was determined to be 59.3% (R^2 = 0.593, $p < 0.05$), indicating that the variables could accurately predict 59.3% of income derived from charcoal production. Marital status, production size, and experience were identified as factors influencing profitability. Charcoal production was found to have positive impacts on livelihoods, including savings for future, paying children's school fees, and asset acquisition and access to health services. However, it had negative environmental consequences, such as tree felling, increased erosion, and elevated temperatures. Constraints identified included timber quality and availability. The study recommends policy interventions to address issue of timber quality to enhance charcoal production and stresses the importance of establishing woodlots to ensure sustainable development and mitigate wood scarcity.

Keywords: Charcoal production, Livelihood, Profitability, Energy source

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1. Introduction

Economic hardship, poverty, unemployment, and the escalating cost of oil have driven Nigerians to explore diverse avenues for sourcing domestic cooking energy to support their livelihoods. In bygone eras, firewood and charcoal stood as the primary sources of energy. However, with the march of civilization and technological advancements, electricity, fossil fuels (like kerosene), and gas became prevalent choices for households. Alas, this transition has not been seamless, as per Drewello (2022), where an estimated 2.5 billion people lack access to modern energy services due to unreliable power supply, energy scarcity, and soaring oil and gas prices, subsequently limiting their prospects for economic development and improved living standards. They've resorted to conventional biomass sources like wood fuel, agricultural waste, and animal dung for their basic energy needs, as affirmed by Kumar et al. (2023). Charcoal, due to its cleanliness and affordability, has become a preferred choice for domestic and outdoor cooking energy in Nigeria, reflecting a global trend noted by Food and Agriculture Organization (FAO, 2016).

In Nigeria, Charcoal Production (CP) emerges as a substantial economic generator but is not without its environmental concerns, as highlighted by Bede-Ojimadu and Orisakwe (2020). With a burgeoning population, developing nations are compelled to produce more charcoal to meet the escalating demand. Urbanization, as reported by Yiran et al. (2020), contributes to a 14 percent increase in charcoal usage for every one percent rise, underscoring the imperative of this energy source in developing world. In Sub-Saharan Africa (SSA), charcoal reigns supreme as the primary income source, cooking, and heating energy for about 80 percent of households, according to Kariuki (2021). The convenience of charcoal usage has swayed consumer preference, leading to an upsurge in its production in many African countries, a trend reported by Ibe and Kollur (2024). Charcoal not only aids economic growth, especially in SSA countries like Nigeria but also stands as a locally renewable energy source, which can have a transformative impact on local economy. Moreover, the escalating prices of alternative domestic energy sources like kerosene, gas, and electricity make charcoal even more attractive to households. This, coupled with its ease of transport and greater acceptability, as noted by Billig et al. (2022), further solidifies charcoal's position as a pivotal energy source.

However, CP comes at an environmental cost. The process entails deforestation, including tree felling, log cutting, and a series of wood transformation techniques such as carbonization, distillation, pyrolysis, and torrefaction, as outlined by (Sadiya, 2022). Unsustainable wood harvesting leads to biodiversity loss, soil and water erosion, land degradation, increased flooding, and the release of greenhouse gases (GHGs), all of which negatively impact climate change across the global charcoal value chain, as demonstrated by Downward et al. (2018), Bamwesigye et al. (2020) and Udali et al. (2021). To combat the climate change issue stemming from deforestation and urbanization, achieving a cost-effective environmental balance in producing charcoal becomes imperative. Such endeavors necessitate the active participation of all stakeholders to enhance the efficiency of charcoal producers, thereby meeting consumers' energy needs. Charcoal produced from responsibly managed materials and advanced technologies boasts low net GHG emissions, making it an effective means to alleviate climate change, boost access to energy and income for all stakeholders, as expounded upon by Ahmad et al. (2022).

Approximately half of wood taken from global forests is directed towards energy generation, primarily for cooking and heating in developing nations, but also for energy production in developed countries. In Africa and Asia, harvested wood accounts for 90% and 60% of energy consumption, respectively, with 17% transformed into charcoal on a global scale, according to the FAO (2016). Given charcoal's market value, it is imperative to ascertain the inputs and expenditures involved in its production.

Charcoal, a traditional fuel with a history spanning centuries, provides a lifeline to the rapidly growing urban and rural populations in Africa. It has improved and sustained the livelihoods, income, and revenue of households, individuals, and governments in Africa and other developing countries. Charcoal is a cost-effective, reliable, convenient, and accessible energy source for many rural and urban poor families, as well as commercial kitchens. Increasing energy production and livelihood opportunities in the developing world has been a longstanding concern for national policymakers and international development agencies. In Sub-Saharan Africa (SSA), charcoal use is expected to double by 2030, with over 700 million Africans relying on it as a long-lasting, preferred, and low-cost source of energy, as highlighted by Drewello (2022) and Oyeniran and Isola (2023).

Despite its economic and social significance, CP remains predominantly traditional, with producers often unaware of more efficient contemporary methods. Unfortunately, this essential energy source has received little attention from policymakers and development agencies, as asserted by Adino et al. (2020). Recognizing the capacity of producing and marketing charcoal in Nigeria, it is imperative to gain a comprehensive understanding of its environmental, social, and economic implications, as emphasized by Ullah et al. (2021). Against this backdrop, this study embarks on an exploration of the profitability of CP and its impact in Sapele Local Government (SLG), Delta State, Nigeria.

This study endeavors to address the following research questions:

i. What are the socio-economic characteristics of charcoal producers in the study area?

ii. Is CP profitable?

iii. What is the effect of production on livelihood in Sapele?

iv. What is the perception of the inhabitants of the study area regarding the impact of CP on the environment?

v. What constraints are faced by charcoal producers?

The examined research hypotheses are as follows:

Hypothesis One

H0: There is no significant effect of the socioeconomic profile of respondents on income from CP.

2. Materials and Methods

The research was conducted in Sapele Local Government, Delta State, Nigeria, situated at coordinates 5˚54ˡN and 5˚40ˡE from the equator.

2.1. Sampling method and sample size

To gather data, a multistage sampling technique was employed to select twenty-two (22) charcoal producers from a chosen subset of five (5) out of the eight (8) communities within SLG. In total, one hundred ten (100) respondents were included in the study. A primary data collection instrument, in the form of a questionnaire, was used. This questionnaire was divided into three sections, each corresponding to inquiries concerning the socio-economic characteristics of the respondents, the impact of CP on their livelihoods, and its impact on the environment.

2.2. Data analysis

The data collected were analyzed using both descriptive and inferential statistics. Descriptive statistics were employed to examine socio-economic profiles of charcoal producers, while a cost and return analysis (Equation 1-4) was utilized to evaluate the profitability of their businesses. A 4-point scale was applied to gauge the level of CP's impact on livelihoods of respondents and environment. A mean score of 2.5 was used as the threshold for categorizing responses as either beneficial to livelihood or detrimental to environment (scores above 2.5 were deemed beneficial, and scores below were considered detrimental). To assess constraints faced by charcoal producers, a four-point Likert-type scale was employed, with options ranging from "strongly agreed" (4) to "strongly disagreed" (1). The mean value of 2.5 categorized responses as either agreed (scores above 2.5) or disagreed (scores below 2.5). Additionally, a multiple regression analysis (Equation 5) was conducted to test the hypothesis of how socioeconomic characteristics influenced charcoal producers income.

$$\text{Total Cost} = \text{Fixed Cost} + \text{Variable Cost} \quad \text{(Eq. 1)}$$

$$\text{Total Revenue} = \text{Price per unit of product x quantity of product sold} \quad \text{(Eq. 2)}$$

$$\text{Gross Margin} = \text{Total Revenue} - \text{Variable Cost} \quad \text{(Eq. 3)}$$

$$Return\ on\ Investment = \frac{\text{Total Revenue} - \text{Total Cost}}{Total\ Cost} \times 100 \quad \text{(Eq. 4)}$$

$$Z_i = U_0 + U_1X_1 + U_2X_2 + \ldots\ldots\ldots\ldots\ldots\ldots U_6X_6 + e \quad \text{(Eq. 5)}$$

Where;

Zi	=	Income (₦)
Uo	=	Intercept
e	=	Error term.
X_1	=	Age (years)
X_2	=	Marital status
X_3	=	Educational status
X_4	=	Household size
X_5	=	Production experience
X_6	=	Production size

This study was prepared within the scope of permission from the Department of Agricultural Economics Ethics Committee dated 09/08/23 and numbered AEDSU/090823/0020.

3. Results and Discussion

3.1. Socio-economic characteristics of charcoal producers

It is important to note that the majority (57.0%) of charcoal producers are male (*Table 1*). This gender distribution can be attributed to physically demanding nature of CP. This result aligns with previous research, as Ohwo and Ogoha (2017) also observed a male-dominated trend in the industry. Age profile of charcoal producers is noteworthy, with young producers averaging 41 years of age. This finding implies that individuals in their young and productive years dominate the CP business, which is consistent with the findings of Olasimbo and Olusola (2018). The prevalence of young producers is indicative of the vitality of the industry and underscores the importance of attracting and retaining youthful talent.

The marital status reveals that approximately 91.0% of charcoal producers are married. This statistic indicates that CP business serves as a means for these individuals to improve their standard of living. It is worth noting that society often views married individuals as more responsible, as highlighted by Ohwo et al. (2021) and Gbigbi (2021). These findings underscore CP role in contributing to family welfare. Charcoal producers education level is another significant aspect of the study, with 49.0% of respondents having completed secondary education. This suggests that a substantial proportion of charcoal producers are formally educated, as also noted by Gbigbi and Osun (2014). This educated workforce may be better equipped to adopt sustainable and environmentally friendly practices during production, contributing to the industry's overall development.

The household size of charcoal producers reveals that a majority (48.0%) have 5-6 persons in their families. This information highlights the potential impact of the industry on a relatively larger number of dependents, underlining its socio-economic importance. Most charcoal producers (49.0%) have between 10-19 years of production experience, with a mean of 17 years. Additionally, high percentages (99.0%) of respondents are well-informed about the CP process. These findings emphasize the long-standing expertise within the industry, which is crucial for maintaining quality and efficiency in production.

The CP volume is substantial, with 50.0% of producers manufacturing between 21-40 bags annually, averaging 34 bags per annum per producer (*Table 1*). This high level of production is indicative of the considerable demand for charcoal energy in Nigeria. Charcoal remains a popular and affordable source of energy for many families, in line with the convenient and cost-effective nature of this energy source (Drewello, 2022). The male-dominated workforce, the presence of young producers, the business role in supporting families, level of education among producers, and expertise in the industry collectively contribute to significance of CP in local and national context. Additionally, the substantial production volume underscores the ongoing demand for charcoal energy source. These findings can inform policy decisions, development strategies, and sustainability efforts within CP sector.

Table 1: Socio-economic characteristics of charcoal producers

Item	Frequency	Percentage	Mean /Mode
Gender			
Female	43	43.0	
Male	57	57.0	Male
Age			
20-29	5	5.0	
30-39	46	46.0	
40-49	22	22.0	41 years
50-59	5	5.0	
Marital status			
Single	4	4.0	
Married	91	91.0	Married
Divorced	2	2.0	
Widowed	3	3.0	
Educational status			
No formal education	14	14.0	
Primary	14	14.0	
Secondary	49	49.0	Secondary
Tertiary	22	22.0	
Size of household			
1-2	1	1.0	
3-4	24	24.0	5 persons
5-6	48	48.0	
Above 7	27	27.0	
Production experience			
1-9	16	16.0	
10-19	49	49.0	
20-29	35	35.0	17 years
Production awareness			
No	1	1	
Yes	99	99	
Production Size			
<20	24	24	
21-40	50	50	
41-60	12	12	34 bags
61-80	9	9	
81-100	5	5	

3.2. Charcoal production cost and return

Profitability analysis of CP reveals several key insights. The Total Cost (TC) of CP was ₦411.719.50, with Total Variable Cost (TVC) accounting for ₦394.736.50 of the overall production cost (*Table 2*). TVC components included labor (19.4%), transportation cost (11.1%), union dues (1.1%), levy (0.1%), kerosene (2.6%), raw material (wood) (52.5%), and rent (8.3%). The remaining costs, totaling ₦16.983.00, constituted the Total Fixed Cost of production, encompassing expenses related to wheelbarrows (3.1%) and rakes (1.0%). On the revenue side, CP generated a Total Revenue (TR) of ₦449.596.00. The net income, after accounting for all costs, amounted to ₦37.876.50, and a gross margin of ₦54.859.50. Additionally, the return on investment (ROI) for CP was calculated at ₦9.20. This signifies that for every ₦1 invested in CP, a profit of ₦9.20 was realized, indicating that CP is highly profitable in SLG. A substantial net profit suggests that the production process effectively manages its costs and delivers services that significantly exceed its expenses. These findings align with Ohwo and Ogoha's (2017) research, which reported return on investment figures of 46% to 55% for

sawnwood traders in SLG. Furthermore, the cost associated with wood as the raw material for CP corresponds to the findings of Ohwo et al. (2020), who estimated the cost of wood residues from sawmills for CP at ₦42.424.00 per cubic meter. In addition, Ohwo et al. (2021) documented a net income of ₦27,113.3 from the sales of *Aframomum melegueta* (bags) in Asaba. These parallels in profitability with other related businesses and industries underscore the economic viability and potential for growth within CP in SLG region. These results suggest that CP is a promising venture with a robust financial foundation, offering potential for expansion and growth. The profitability and returns on investment indicate that this industry is cost-effective and capable of generating substantial income, making it an attractive option for entrepreneurs and investors in SLG.

Table 2: Costs and return of charcoal production

Variables	Amount (₦)	% of total cost
Variable cost		
Labour	79.769.00	19.37
Transportation cost	45.635.00	11.08
Union dues	4.495.00	1.09
Levy	3.924.00	0.95
Kerosene	10.863.50	2.64
Wood	215.966.00	52.45
Rent	34.084.00	8.28
Total	394.736.50	
Fixed cost		
Wheelbarrow	12.818.00	3.11
Rake	41.65.00	1.01
Total	**16.983.00**	
Total cost	**411.719.50**	
Revenue		
CP	373.497.00	
Wood ash	76.099.00	
Total	**449.596.00**	
Gross margin	**54.859.5**	
Net Profit	**37.876.50**	
Return on Investment	**9.20%**	

3.3. Impact of charcoal production on livelihood of producers

3.3.1. Ability to save

The key finding of this study is that CP has a profound impact on producers' ability to save for their future needs. The mean score of 3.8, as obtained from the survey, indicates that majority of charcoal producers view their involvement in CP as positively affecting their savings behavior. Several factors contribute to this impact; CP provides a stable and reliable income source for many households. This income, in turn, allows producers to allocate a portion of their earnings to savings. The study found that households involved in CP have higher propensity to save from increased income levels. The CP often offers a flexible work schedule, allowing producers engage in other income-generating activities or work additional hours. This flexibility can contribute to higher savings, as individuals can allocate more resources to their savings goals. The study discovered that some producers had access to financial literacy programs and training through their involvement in the CP industry. This knowledge improved their ability to manage their finances and decisions about future saving. Charcoal producers often operate within close-knit communities, which can encourage a culture of saving. Savings groups or informal financial networks within these communities can facilitate better savings habits and provide safety net in times of need. The implications of these findings are significant. The CP, when managed sustainably and accompanied by support programs, can reduce poverty and economic development in regions where it is prevalent.

3.3.2. Payment of children's school fees

The results of this study reveal a mean score of 3.7, indicating a significant correlation between CP and payment of children's school fees. This statistic underscores the vital financial role played by charcoal industry, enabling families to afford education for their children. Such financial support has far-reaching implications, fostering a cycle of education and empowerment within these communities. CP acts as an economic driver, enabling families to break the cycle of poverty by investing in education. This empowerment leads to improved long term socio-economic conditions. The substantial contribution of CP to children's education implies that sustainable development initiatives should consider investing in educational infrastructure and resources. By enhancing educational facilities, scholarships, and vocational training programs, communities can further capitalize on financial stability generated by charcoal industry, fostering a skilled and knowledgeable workforce. The financial stability resulting from CP not only supports education but also enhances social cohesion within communities, fostering a sense of belonging and cooperation.

3.3.3. Enhanced asset acquisition and access to health services

Results of this study (*Table 3*) revealed a noteworthy trend among charcoal producers. On average, producers reported increased opportunities for acquiring assets and obtaining essential health services, with mean score of 3.6. This finding suggests that engagement in CP has a tangible and positive influence on lives of these individuals. The implications are manifold. Producers' improved access to assets signifies an enhanced quality of life, economic stability, and potential for further socio-economic development. This is particularly important in resource-scarce regions, where asset acquisition can be a pathway out of poverty. Increased access to essential health services is equally significant, as it results in better overall health, reduced mortality rates, and greater productivity among charcoal producers. These findings have critical implications for policymakers and stakeholders involved in resource management and sustainable development. It underscores the importance of promoting environmentally responsible CP practices that align with conservation efforts. Supporting such practices can further boost asset acquisition and health service access for producers. The producing communities can also reap the benefits of sustainable practices. An increased standard of living for producers can have a cascading effect on the entire community, leading to improved infrastructure, better healthcare facilities, and enhanced overall well-being. This study reveals that producers engaged in CP experience significant improvements in asset acquisition and access to essential health services. These findings emphasize the positive role of CP in enhancing lives of individuals in resource-constrained regions. Encouraging sustainable practices in the CP industry can yield substantial socio-economic benefits, not only for producers but also for the communities in which they operate. This research offers valuable insights for shaping policies and practices that foster more sustainable and prosperous future for these communities.

3.3.4. Support for food purchases

The mean score of 3.5 (*Table 3*) suggests a notable positive relationship between CP and households' capacity to purchase food. This implies that households engaged in CP are better positioned to secure a stable income source, thereby improving their food security status. The CP can significantly contribute to economic empowerment of households, particularly in resource-constrained areas. The ability to generate income from CP allows households have more consistent and reliable source of funds, which can be directed towards purchasing food. The findings underscore the vital role of CP in enhancing food security. Households engaged in CP are more likely to have safety net against food insecurity, as income generated from this activity provides a financial cushion to ensure regular access to food. This study recognized CP as a valuable economic activity, rather than solely a cause of deforestation. Promoting sustainable and responsible CP practices can contribute to both local economic development and food security. The mean score of 3.5 clearly demonstrates that CP plays a substantial role in enabling households to purchase food. This has significant implications for policymakers, development organizations, and local communities, as it emphasizes the need to consider and support CP as a means to enhance household food security and promote sustainable development in resource-constrained areas. By acknowledging the socioeconomic importance of CP, stakeholders can work towards finding a balance between environmental conservation and livelihoods of those engaged in this industry.

3.3.5. Aid in house rent payment

The result suggests that CP, with an average mean score of 3.4, significantly contributes to the financial well-being of these households, creating ripple effects on their socio-economic conditions and the environment. The CP significantly enhanced the ability of households to pay their rent, leading to more stable housing situations. This provides a sense of security for families, ensuring they have a roof over their heads and reducing risk of eviction or homelessness. The implications for these households are far-reaching, as they can now allocate their resources to other essential needs, such as education, healthcare, and food, leading to an improved quality of life. Beyond its direct impact on household rent payments, charcoal producing industry generates income for a substantial number of people. This boosts local and regional economies, creating jobs and promoting economic growth. The study underscores that by supporting the CP sector, governments and policymakers can bolster economic development in both rural and urban areas, ultimately reducing poverty and enhancing living standards. The mean score of 3.4 confirms that CP significantly contributes to household financial stability, socio-economic development, and employment opportunities. However, it also underscores the need for responsible and sustainable practices in the industry to mitigate environmental impacts. These findings provide a foundation for future research and policymaking, ultimately aiding in the development of strategies that promote economic sustainability, while protecting our environment for future generations.

3.3.6. Promotion of other business ventures and investment in agriculture

Notably, our research has illuminated the fact that producers, in addition to their primary agricultural activities, also diversify their resource allocation. Our findings indicate that these producers allocate resources to initiate other entrepreneurial ventures and make investments in the agriculture sector, with mean score of 3.3 (*Table 3*), as per our survey respondents. These findings hold profound implications for various stakeholders, including policymakers, entrepreneurs, and agricultural experts. The revelation that producers allocate resources to start other businesses and invest in agriculture underscores significance of supporting policies that facilitate entrepreneurship and agricultural investment. Policymakers can design initiatives and incentives to encourage diversification among producers, which can foster economic growth and resilience in rural communities. From an economic standpoint, the diversification of resource allocation by producers suggests an increased potential for income generation and wealth creation. Entrepreneurs and investors in various sectors can tap into the opportunities created by this resource allocation trend, contributing to economic development. The study's findings imply that producers are not just confined to their primary agricultural activities but are actively investing in the agriculture sector. This bodes well for sustainability of agricultural industry, as it reflects a commitment to its growth and development. Similarly, resource diversification can also serve as a risk mitigation strategy for producers. By engaging in various businesses and investment avenues, they are less vulnerable to the fluctuations and uncertainties of a single sector. This resilience can contribute to overall stability of rural livelihoods. The disclosure that producers allocate resources to start other businesses and invest in agriculture represents a pivotal discovery in agricultural economics. The implications stemming from this finding span a wide range of areas, from policy development to economic growth and sustainability. These insights can serve as a valuable foundation for research and contribute to more informed decision-making among various stakeholders in the agricultural sector.

Table 3: Charcoal production on livelihood of producers

Livelihood	Strongly disagree	Disagree	Agree	Strongly agree	Mean
Purchase food	0(0.0)	0(0.0)	47(47.0)	53(53.0)	3.5
House rent	0(0.0)	1(1.0)	51(51.0)	48(48.0)	3.4
Asset acquisition	1(1.0)	2(2.0)	55(55.0)	42(42.0)	3.6
Invest in agriculture	1(1.0)	2(2.0)	49(49.0)	48(48.0)	3.3
Start another business	3(3.0)	4(4.0)	46(46.0)	47(47.0)	3.3
Pay children's school fees	0(0.0)	0(0.0)	48(48.0)	52(52.0)	3.7
Obtain health service	1(1.0)	3(3.0)	39(39.0)	57(57.0)	3.6
Save for the future	1(1.0)	1(1.0)	31(31.0)	67(67.0)	3.8

The above contributions of this business to livelihood sustenance agree with the reports of Ohwo and Ogoha (2017). These authors reported that energy production locally contributes to rural economy; provide jobs and income to participants respectively. The utilization of funds from charcoal business to start up other business affirms the challenges of forestry development as funds generated from forest based activities are channeled to other sectors as reported by Ohwo et al. (2020).

3.4. Perception on impact of charcoal production on environment

The Perception on impact of CP on environment shows that CP impacts environment negatively. The producers agreed that CP impact environment from tree felling (3.6); increase erosion (3.1); increased temperature (3.0); weather gets drier (2.7); air pollution (2.6); absence of animal in bush and no positive impact on the environment (2.5) (*Table 4*). Sourcing for energy via tree feeling contributes to deforestation which negatively impact the environment and causes biodiversity loss as reported by Agunleye et al. (2020), Nyarko et al., (2021), Ohwo and Nzekwe-Ebonwu (2021) and Udali et al., (2021). Bamwesigye et al. (2020) observed that in Africa tree of *Dacryodes edulis* (Africa plum) and *Psidium guajava* are decreasing from their utilization for CP leading to a decline of the fruits for man's consumption.

Table 4: Impact of charcoal production on environment

Perception	Strongly disagree	Disagree	Agree	Strongly agree	Mean
Weather is getting drier	4(4.0)	36(36.0)	48(48.0)	12(12.0)	2.7
Tree felling is affecting the environment	3(3.0)	8(8.0)	12(12.0)	77(77.0)	3.6
Increase in erosion process	16(16.0)	16(16.0)	8(8.0)	60(60.0)	3.1
Increase in temperature	8(8.0)	12(12.0)	50(50.0)	30(30.0)	3.0
Introduction of air pollution	11(11.0)	32(32.0)	41(41.0)	16(16.0)	2.6
No animal in bush again	10(10.0)	32(32.0)	33(33.0)	25(25.0)	2.5
No positive impact	5(5.0)	27(27.0)	34(34.0)	34(34.0)	2.5

3.5. Constraints faced by actors in the value chain

The result of constraints faced by actors in the value chain is presented in *Table 5*. The availability of timber had mean of 3.1 which emerged as a primary constraint in charcoal value chain. The study identified that a scarcity of timber resources, which can be attributed to deforestation and biodiversity loss, significantly hinders the operations of various actors in the value chain. This constraint underscores the pressing need for sustainable timber sourcing and conservation efforts within the industry. The results align with previous research conducted by Bamwesigye et al. (2020) and Gbigbi and Achoja (2019), which similarly emphasized the issue of diminishing timber resources. The effective management of the production process had mean of 3.1 which was identified as another critical constraint. This finding suggests that there is a need for better process optimization, streamlining, and the implementation of best practices to enhance the overall efficiency and productivity within the charcoal value chain. The study also revealed that the furnace cooling time had a mean of 3.2 which represents a significant constraint. This factor indicates the importance of optimizing cooling processes, as delays can lead to inefficiencies and productivity losses. Abatement costs had mean of 3.1 which emerged as a substantial constraint, emphasizing the financial burden associated with environmental compliance and sustainability measures. This finding underscores the need for innovative solutions to mitigate these costs and promote eco-friendly practices.

The challenges associated with managing environmental licenses (3.1) were identified as a prominent constraint within the value chain. This highlights the importance of ensuring regulatory compliance and the need for more streamlined processes in obtaining and maintaining these licenses. Traceability had a mean of 3.4, a crucial factor for ensuring the sustainability and quality of CP, was also recognized as significant constraint. Improving traceability measures can enhance the transparency and accountability of charcoal value chain. The study identified constraints related to production flow which had a mean of 3.5, signifying potential bottlenecks and inefficiencies in the overall production process. Addressing these issues can initiate smoother and more productive operations. Timber quality had a mean of 3.7 which was identified as major constraint. Ensuring good

quality of raw material is crucial for producing high-quality charcoal. This constraint underscores need for better quality control measures and sustainable sourcing practices. Summarily, this study's findings underscore the complex nature of constraints faced by actors in charcoal value chain. These constraints not only impact the industry's operational efficiency but also have profound implications for environmental sustainability and resource conservation. It is crucial for stakeholders in charcoal value chain to address these constraints collaboratively and proactively to ensure a more sustainable and resilient future for charcoal industry. The alignment of these findings with prior research by Sari Gedik and Yilmaz, (2023), Bamwesigye et al. (2020) and Gbigbi and Achoja (2019) further reinforces the importance of addressing these issues for the betterment of the industry.

Table 5: Constraints faced by actors in charcoal value chain

Constraints	Strongly disagree	Disagree	Agree	Strongly agree	Mean
Availability of timber	0(0.0)	8(8.0)	75(75.0)	17(17.0)	3.1
Management of production process	1(1.0)	13(13.0)	64(64.0)	22(22.0)	3.1
Furnace cooling time	0(0.0)	7(7.0)	69(69.0)	24(24.0)	3.2
Abatement cost	0(0.0)	20(20.0)	53(53.0)	27(27.0)	3.1
Managing environmental licenses	0(0.0)	12(12.0)	63(63.0)	25(25.0)	3.1
Traceability	0(0.0)	4(4.0)	77(77.0)	19(19.0)	3.4
Production flow	0(0.0)	0(0.0)	84(84.0)	16(16.0)	3.5
Quality of timber	0(0.0)	4(4.0)	92(92.0)	4(4.0)	3.7

3.6. Relationship between socio-economic characteristic of respondents and income of charcoal producers

Socio-economic characteristics on income of charcoal producer have yielded insightful findings. The statistical model employed demonstrated a satisfactory level of explanatory power with an R-squared value of 0.593, signifying that 59.3% of variance in income can accurately be predicted by the selected independent variables ($p < 0.05$) (*Table 6*). This corroborates with Gbigbi (2022). This suggests that these variables hold substantial influence over the income generated by charcoal producers. Furthermore, the results of the linear multiple regression analysis shed light on the specific socio-economic characteristics that notably impacted income of charcoal producers within SLG. Notably, marital status, production size, and experience were identified as statistically significant predictors of charcoal producers' income. These findings corroborated Gbigbi (2017) and Açıkgöz (2017). These implications underscore the importance of considering socio-economic factors such as marital status, production scale, and experience when addressing income disparities among charcoal producers in SLG. By recognizing the significance of these variables, policymakers and stakeholders can develop more targeted and effective strategies to improve charcoal producers livelihoods and

Table 6: Socio-economic characteristics on income of charcoal producers

Model	Beta coefficient	Std. Error	T- value	Sig.	Collinearity Statistics	
					Tolerance	VIF
Constant	11.217	0.582	19.272	.000		
Age	-0.020	0.535	-0.148	0.833	0.922	1.084
Marital status	-0.388	0.187	-2.076	0.041**	0.908	1.102
Education	-0.172	0.091	-1.891	0.062	0.882	1.133
Household size	-0.082	0.135	-0.608	0.544	0.679	1.472
Production size	0.512	0.088	5.837	0.000 ***	0.458	2.186
Experience	0.216	0.254	2.585	0.011 **	0.453	2.208
R^2= 0.591 (59%)						
Adj.R^2 =0.566(57%)						
F-stat =22.556						

***,** & * represent significance at 1%,5% and 10% probability level respectively

promote economic development in Sapele. Moreover, the relatively high R-squared value suggests that there may be additional unexplored variables not accounted for in this study, warranting further research to enhance our understanding of income dynamics within this industry. With the Variance Inflation factor (VIF) less than 5, multicollinearity of variables in the model is absent.

4. Conclusions

This study has shed light on the resourceful nature of charcoal production as alternative energy source. Charcoal business is profitable and beneficial for livelihoods of those involved. However, we must acknowledge the stark negative environmental consequences associated with this industry, including deforestation and air pollution, both of which contribute to the pressing issue of climate change. One significant issue that has emerged from this research is the quality of timber intensifies the problem of wood scarcity, which ultimately exacerbates deforestation and its far-reaching environmental implications. Therefore, it is imperative that policymakers intervene in this matter, promoting the responsible and sustainable management of this valuable resource. To ensure the longevity and positive impact of the charcoal business on livelihoods and energy provision, regulatory measures must be put in place. These regulations should focus on promoting sustainable practices such as timber harvest regulation, monitoring charcoal production activities from the forest to the market, utilization of improved production approach that minimizes environmental degradation and reforestation efforts. By implementing all-inclusive policies and encouraging sustainable development in the charcoal sector, we can strike a critical balance between economic growth and environmental responsibility, ultimately safeguarding our planet for future generations.

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Ethical Statement

This study was prepared under the permission numbered ***AEDSU/090823/0020***, dated 09/08/23, from the Ethics Committee of Department of Agricultural Economics, Delta State University, Abraka, Delta State, Nigeria.

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Gbigbi, T. M.; Design: Gbigbi, T.M. and Ohwo, O.A.; Data Collection or Processing: Gbigbi, T.M., Ohwo, O.A., Okpoto, P. R.; Statistical Analysis: Gbigbi, T.M.; Literature Search: Gbigbi, T.M., Ohwo, O.A., Okpoto, P. R; Writing, Review and Editing: Gbigbi, T.M. and Ohwo, O.A.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Investigation on Characteristics of Natural Starch Based Coating as Potential Urea-Fertilizer Coating

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Abstract

The conventional fertilizer application oftentimes inefficient due to rapid release and leaching, which in turn caused pollution to the environment. The technique to control or slowing down the release of nutrients of the fertilizer in a controlled manner known as slow-release fertilizer (SRF). In sustainable agriculture, the utilization of natural starch as coating materials give alternative of the use of non-green materials. The abundance of natural starches may be serve as potential sources for sustainable fertilizer coatings. This study aims to investigate the properties of the urea fertilizer coated with several natural starch materials and to identify the most potent natural starch coating agents. The research was conducted as follows: 1) formulation of fertilizer coatings sourced from 7 natural starches (porang, gadong, sago, taro, sorghum, glutinous rice, and mung bean starches) and one synthetic materials (carboxymethoxyl cellulose, CMC); 2) granulation of urea fertilizer with coatings produced from the formulation, 3) manufacture of fertilizer coating from 7 natural starches. The SRF fertilizers were then tested for drip resistance and nutrient release. Formulation of fertilizer coatings was 2% w/v of natural starch with polyethylene glycol (PEG) and gum arabic. Granulation with coatings resulted in 73% of the granule produced met the desired size criteria (2.5-5 mm in size). Drip resistance test showed that CMC showed the highest durability, followed by gayong starch and sorghum starch, consecutively. Comparison of nitrogen nutrient release of urea-SRF on distilled water and 2% citric acid showed higher urea-SRF solubility in 2% citric acid. Natural starches—particularly gadong, glutinous rice, sorghum, sago, and porang—have shown potential as natural coating materials. However, since the observed parameters were limited to water hatches and nitrogen release, further research is needed to optimize the use of these starches as slow-release fertilizer (SRF) coatings across a broader range of parameters.

Keywords: Natural starch, Slow-release fertilizer, Coating, Drip resistance, Nutrient release, Urea

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1. Introduction

Growth and nutritional quality, including nutrient quantity are factors important for plant growth and development. Currently, nutrients application in the form of fertilizer still inefficient, which shows implications for nutrient loss and environmental pollution. Yearly estimation of fertilizer needed, including urea are approximately $2.5x10^6$ tons, and estimated to improve crop yields up to 56-58% and grain yields 31-32%. However, 40-60% of the fertilizer cannot be absorbed by plants (Chen et al., 2021). According to Karakuş et al. (2022), nitrogen is the most lost nutrient in agricultural soils. The loss of N nutrient from the soil can be caused by leaching (NO_3 and NO_2), evaporation (NH_3) and denitrification (N_2O and N_2) (Demirkiran, 2017). Leaching is a serious environmental issue as it can cause pollution, groundwater contamination and trigger eutrophication in the aquatic environment. On the one hand, nitrogen is the main macro nutrient that is needed by plants for their growth (Noviana et al., 2023). Thus, efforts are needed to overcome this problem and to increase fertilizer absorbance efficiency by plants.

To increase the efficiency of fertiliser absorption by plants, one technique that can be used is to control the release of fertilizer in the form of slow-release fertiliser (SRF) formulations. Slow-release fertilizer has a distinctive characteristic that the rate of release of nutrients is more controlled (Purnomo and Saputra, 2021). According to (Trenkel, 2010) the use of slow-release fertilisers can reduce nutrient losses by 20-30% compared to conventional fertiliser applications. The SRF method is considered more efficient because nutrients are released and available slowly into the soil, thereby reducing environmental pollution (Firmanda et al., 2022).

The solubility of SRF can be controlled by fertilizer coating technique which is a technique of coating fertilizer granules with various materials that can reduce their solubility rate. Generally, synthetic polymers are used as coating materials. However, they can not degrade easily in soil and can accumulate as plastic residue up to 50 kg $year^{-1}ha^{-1}$ (Fertahi et al., 2021; Lawrencia et al., 2021). On the other hand, natural materials are considered to be an alternative of sustainable coating materials as they are readily available, easily obtained and biodegradable. Reports on several natural coating materials and their modifications have been previously investigated, such as mixture of pectin, chitosan and sugarcane vinasse (Cerri et al., 2020), alginate (Fan et al., 2019), cassava starch (Tanan et al., 2021; Versino et al., 2019).

Starch as natural polysaccharide polymer are biodegradable, easily-available and eco-friendly, which regard as potential candidates for fertilizer coating materials (Naz and Sulaiman, 2017; Salimi et al., 2023). Moreover, starch-based hydrogel is known to significantly improve the soil's water-holding capacity owing to its hydrophilicity, network structure and the ability to form strong hydrogen bonds with water molecules (Fertahi et al., 2021). The use of natural starch as a wrapping material for SRF is possible because the lignin layer slows the release of urea and remains intact after submerging in water, indicating a high potential as a biopolymer for SRF fertiliser. Based on its plant source, starch can be obtained from sago starch, corn, cassava, and glutinous starch. Until now, starch types such as cassava starch, corn starch and sago starch have been used as materials to make slow-release urea fertilizer coatings (Chen et al, 2008; Sarwono et al, 2013; Suci and Astar, 2022). There are still numbers of potential starch to be use as coating agents. With the various types of starch available, it is necessary to select starch that has good ability as a slow-release fertilizer coating. Therefore, this study aims to compare the properties of urea fertilizer coated with several types of starch from natural materials and obtain the source and type of starch that has the potential as a slow-release fertilizer so that nutrients are expected to be absorbed efficiently by plants and not pollute the environment.

2. Materials and Methods

2.1. Natural starches coating formulation

The coating formulation sourced of several natural starches (*Table 1*). Coating solution formulation was made by mixing 2% (w/v) starch and 1 g polyethylene glycol (PEG) and gum Arabic. The mixture was then added with distilled water up to 30 mL and stirred until homogeneous at room temperature. The solution was then heated until all the starch was dissolved and color turned. The heating process was carried out to make the PEG solution as well as the starch thicken. In addition, the process of colouring the SRF fertiliser is done to distinguish the type of coating. Afterwards, the solution is then ready to use.

Table 1. Treatment code and composition of coating materials in the study

Treatment Code	Composition per 30 ml solution (w/v)
D1	2% porang starch
D2	2% gadong starch
D3	2% sago starch
D4	2% taro starch
D5	2% sorghum starch
D6	2% glutinous rice starch
D7	2% mung bean starch
D8	2% carboxymethyl cellulose

The coating process were carried out on a laboratory-scale pan granulator machine and sprayer. The coating solution was put in a sprayer and sprayed on the surface of the urea fertilizer granules on the rotating granulator pan (30 mL) per 100 g of urea fertilizer. After spraying the coating, the fertilizer was at 50^{o}C for 1 hour. Urea fertilizer that has been coated is then called urea-SRF.

2.2. Drip Resistance

The resistance to water droplet impact was tested by dripping distilled water on the fertilizer using a burette at a height of 20 cm until the fertilizer dissolved, and the time needed (in minutes) were then recorded

2.3. Nitrogen Nutrient Release

Nitrogen nutrient release test was conducted to measure the ability of 8 types of urea-SRF coating to control the release of nitrogen nutrient to the surrounding soil. The test was carried out in a shaker (type of equipment) using distilled water and 2% citric acid at shaking periods of 0, 15, 30, 45 and 60 minutes. The resulted released nitrogen nutrient was then measured using percolation test according to (Himmah et al., 2018). In shorts, a tube containing soil material of experimental site and urea-SRF coating formulation from various types of combinations and material ratios, which were conducted in triplicate. The resulting percolate was then analyzed for the soluble materials.

2.3. Statistical Analysis

The experimental was conducted using Randomised Complete Block Design with 4 replications. Research data were analyzed using SPSS software version 25. One way ANOVA (analysis of variance) was performed on the data to compare the effect of different treatments. The least significant difference (LSD) test was applied to the determine the significant difference. A p value of < 0.05 was considered statistically significant.

3. Results and Discussion

3.1. Fertilizer Characteristics

Granule Size of Granulated Fertilizer

The coating solution produced from the blending process has a paste-like shape, coarse texture, and high moisture content. The paste was then used to coat urea fertilizer using a pan granulator that was adjusted to parameters such as rotation speed, inclination angle and fertilizer moisture. The aim is to obtain fertilizer granules that meet the desired criteria based on the Indonesian national standard for urea fertiliser granule size between 1-2.25 mm. *Figure 1* shows the percentage of fertilizer granule sizes resulted from granulation process. As much as 73% urea-SRF sized 2.5-5 mm in size and this granule size was chosen as the finished fertilizer size as this size refers to urea-SRF commonly sold in the market which have been coated.

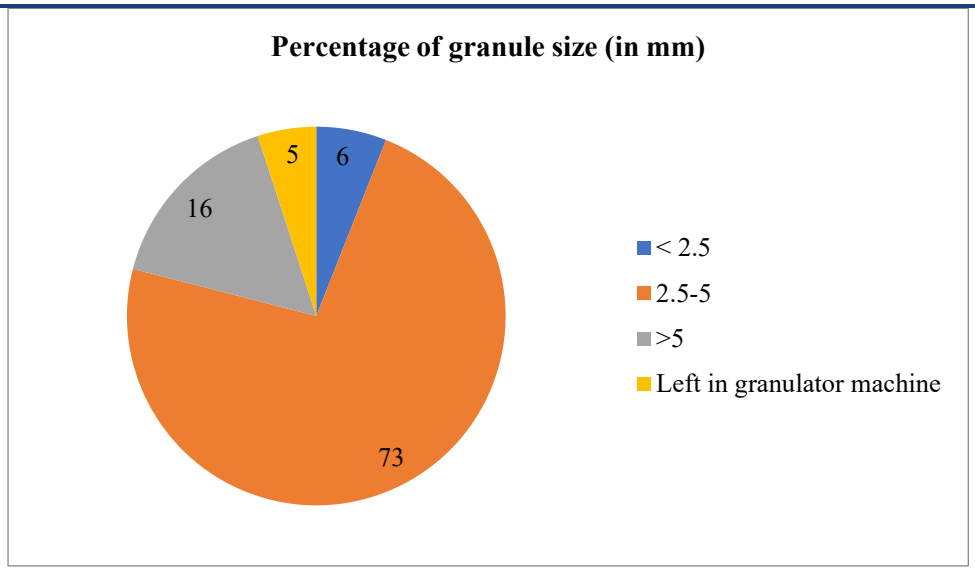

Figure 1: Size distribution of granulated urea-SRF from granulation process

3.2 Physical characteristics

Figure 2 shows the qualitative physical characteristics of the coated (SRF) fertilizer. SRF fertilizer is in the form of bright, light-coloured granules. The coating layer makes the SRF fertilizer appear shinier than its original colour. Coated SRF fertilizer has advantages in terms of quality and durability.

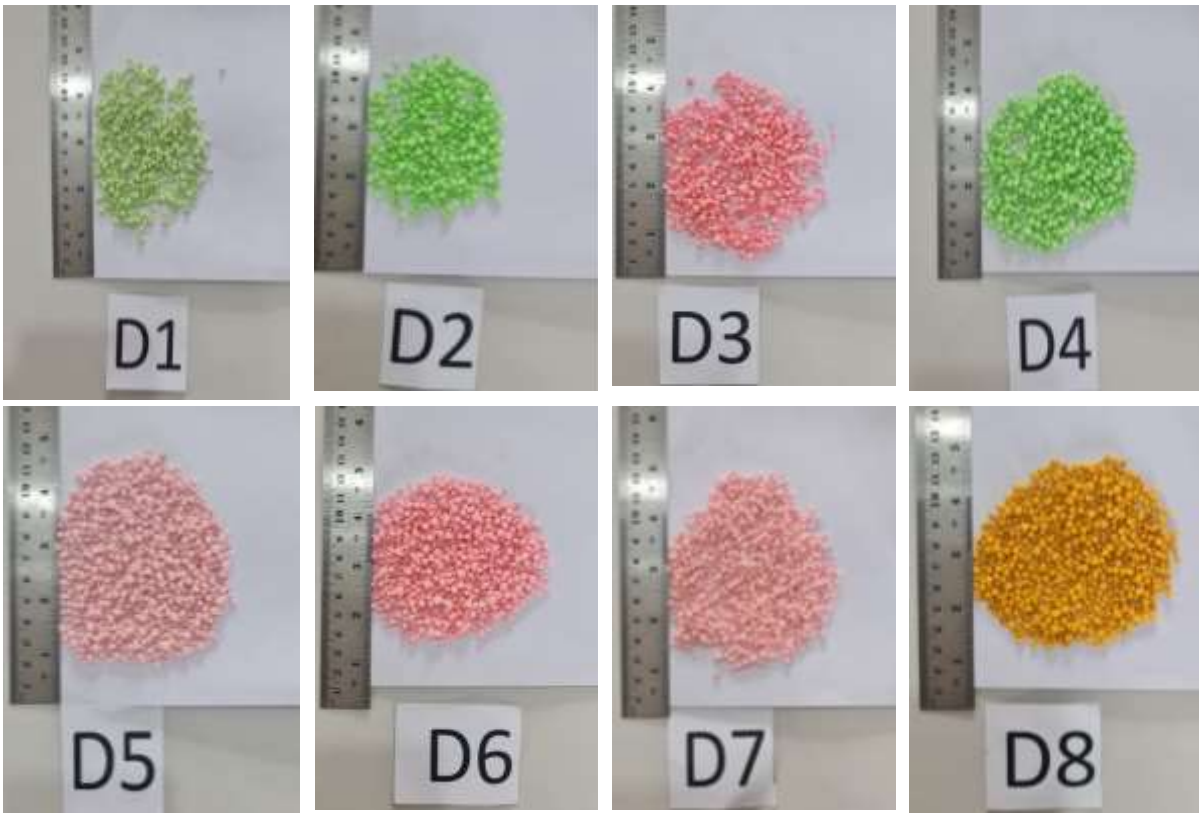

Figure 2 Physical appearances of urea-SRF formulation using various natural starches (D1 (Porang starch), D2 (Gadong starch), D3 (Sago starch), D4 (Taro starch), D5 (Sorghum starch), D6 (Glutinous rice starch), D7 (Mung bean starch), D8 (carboxymethyl cellulose (CMC)

Ningtias (2017) previously reported that commercial granulated urea fertilizer did not have a coating layer, so the surface was plain and smooth. However, in *Figure 2*, coated urea-SRF has a rough and diverse surface. This

is in line with the study of Lestari et al. (2020), which stated that urea-microcapsules were formed with rough and aggregated surface. Moreover, (Muslim et al., 2015) stated that the sago starch layer on the outside acts as a mass transfer inhibitor of urea, so as to reduce the rate of diffusion of water into the core as well as to reduce the diffusion of nitrogen out of the urea core.

3.3 Nutrient release in urea-SRF

Drip resistance

The durability of the fertilizer is measured by the number of water droplets required to make the fertilizer break. Urea-SRF fertilizers coated with natural and synthetic materials showed different resistance to water droplets (*Figure 3*). The one-way ANOVA results showed that the type of coating material significantly affected the durability of the fertilizer. Of the seven natural materials used, glutinous rice starch (D6) and mung bean starch (D7) had the lowest durability, needed only 35 water droplets to break; which were then followed by taro Starch (D4) with 43 droplets. These three materials fall into the category of weak coating materials. Meanwhile, porang starch (D1) and sago starch (D3) have better durability, at 60 and 64 droplets to break, consecutively. Finally, sorghum starch (D5) and ganyong starch (D2) were the strongest natural coating materials, lasting up to 72 and 74 drips, respectively. On the other hand, the synthetic material CMC (D8) had the highest durability of all the coating materials, at 100 drips. The order of drip durability is decrease as follows: D8>D2>D5>D3>D1>D4>D6=D7. Thus, it can be concluded that the coating materials affect the drip resistance of urea-SRF fertilizers.

Addition of ingredients such as gums are common in formulation of SRF, since the starch alone tend to have high solubility in water. In this study, the use of gum arabic was meant to increase the stability of the formulation. The use of other types of gum such carragenan, gellan, xanthan gives various results on stability of cassava starch film, as well as the solubility of the cassava starch matrices (Kim et al., 2015).

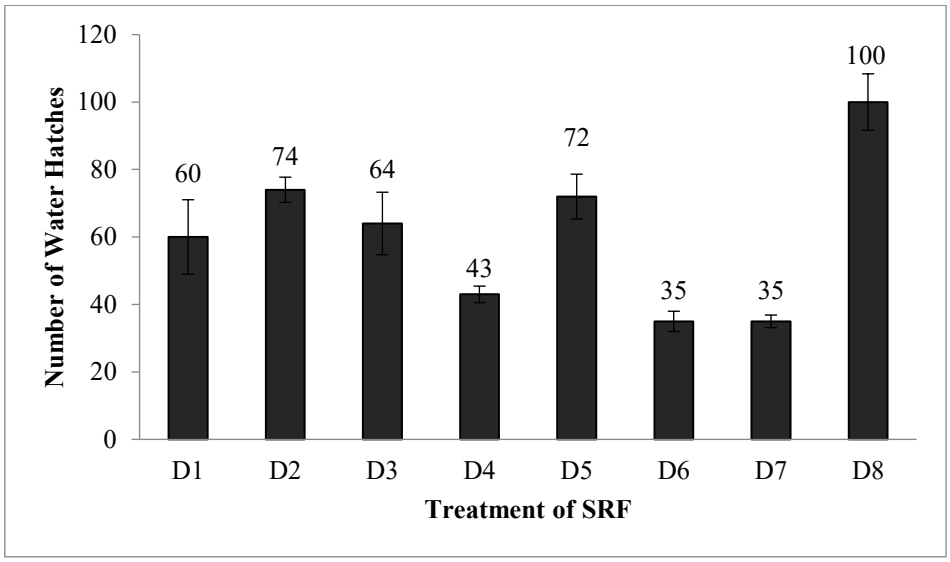

Figure 3. Resistance of SRF fertilizer to water droplets until the SRF fertilizer particles break. (D1 (Porang starch), D2 (Gadong starch), D3 (Sago starch), D4 (Taro starch), D5 (Sorghum starch), D6 (Glutinous rice starch), D7 (Mung bean starch), D8 (carboxymethyl cellulose (CMC)

Nitrogen nutrient release test with distilled water and 2% citric acid

Nitrogen nutrient release in this study were analyzed from the amount of nutrient leached in the form of percolate. The more nutrients leached from the percolate, the more nutrients released from fertilizer. Periods of shaking at 0, 15, 30, 45 and 60 minutes showed that urea-SRF nitrogen nutrient release had begun to occur, and 2% citric acid showed higher nitrogen release compared to distilled water. *Table 2* shows that nitrogen dissolved in urea-SRF fertilizer at 15, 30, and 60 minutes is increase with periods of shaking. D6 nitrogen solubility is higher (0.21%) compared to other treatments at 15 minutes of shaking, then at 30 minutes of shaking increased to 0.34%; the same value as D8. Similarly, nutrient release at 60 minutes shaking had the same trend as nutrient release at 30 minutes shaking. On the other hand, the lowest levels of N dissolved were observed gadong starch at 0.03%

and 0.15% at 0 and 15 minutes periods of shaking; sago starch at 0.24%, 0.24% and 0.30% at 30, 45 and 60 minutes shaking periods, respectively.

Table 2. Nitrogen nutrient release of urea-SRF in distilled water and 2% citric acid at various shaking periods. Different letters (a, b) indicate a significant difference within the column (One Way ANOVA, LSD test, $p < 0.05$)

Coating Treatment	Percentage of Nitrogen Nutrient Release of Urea -SRF									
	Distilled water					2% Citric acid				
	Shaking duration (minutes)					Shaking duration (minutes)				
	0	15	30	45	60	0	15	30	45	60
D1	0.03	0.16	0.25	0.28[a]	0.31	**0.13**	**0.24**	**0.28**	**0.30**	**0.34**
D2	0.03	0.15	0.27	0.27[a]	0.30	0.13	0.24	0.30	0.31	0.32
D3	0.03	0.15	0.24	0.24[a]	0.30	0.13	0.24	0.28	0.30	0.32
D4	0.03	0.18	0.26	0.29[a]	0.31	0.13	0.23	0.29	0.32	0.33
D5	0.03	0.21	0.33	0.32[a]	0.33	**0.13**	**0.25**	**0.34**	**0.37**	**0.34**
D6	**0.03**	**0.21**	**0.34**	**0.34[b]**	0.35	**0.14**	**0.24**	**0.35**	**0.38**	**0.35**
D7	0.04	0.19	0.28	0.31[a]	0.32	**0.14**	**0.25**	**0.33**	**0.34**	**0.34**
D8	**0.04**	**0.21**	**0.34**	**0.33[a]**	0.34	**0.14**	**0.29**	**0.35**	**0.35**	**0.35**
LSD 5%	**n.s**	**ns**	**n.s**	**0.09**	**ns**	**n.s**	**n.s**	**n.s**	**n.s**	**ns**

D1= porang starch, D2= gadong starch; D3= sago starch; D4= taro starch; D5=sorghum starch; D6=glutinous rice starch; D7= mung bean starch; D8= CMC (carboxymethyl cellulose); n.s= not significant

Furthermore, in shaking using 2% citric acid, there are no significant difference observed in all treatments (shaking duration of 0, 15, 30, 45, and 60 minutes) (*Table 2*). At 0 minutes of shaking, three types of coating showed the highest release of N nutrients eventhough there were no significant differences observed between other coating treatments. D6, D8 and D7 nitrogen nutrient release were as much as 0.14%, 0.14% and 0.14%, respectively, while D5, D1 and D4 were slightly lower at 0.13%, 013% and 0.13%, consecutively. The result is in correspondence with (Himmah et al., 2018), which pointed out the order of nitrogen nutrient release in the order of CMC>glutinous rice starch and sago starch. CMC is highly advantageous in reduction of water consumption and at the same time, improving soil's fertility. However, high production cost is one of its main drawback (Olad et al., 2018). Thus, several natural starches used as coating materials here showed promising initial result. On the other hand, the lowest release was recorded on D3 and D2 which were 0.13% and 0.13%, respectively. Furthermore, at 15 minutes shaking, the highest release of N nutrient in D8 was 0.29%, albeit not significantly different from other coating treatments, and the lowest was in D4 at 0.23%. Different results were found at 45 minutes shaking, where the highest release of nutrients was in the D6 treatment of 0.38%, significantly different from other coating treatments, and the lowest was in D3 of 0.30%.

Comparison between the results of shaking SRF fertilizer that has been coated with H_2O shaker material shows a clear difference with SRF fertilizer using 2% citric acid shaker. This is due to the fact that natural materials tend to have higher solubility in weak acids than in H_2O solution. This dissolution mechanism indicates that the use of SRF with natural material coating is more suitable for soils in Indonesia, which are generally acidic soils. The mixture of porang flour and chitosan is a blending biopolymer to improve physical properties due to the hydrogen bonding of starch in amylose and amylopectin. Compared to uncoated urea, which is subsequently converted to ammonium and goes through nitrification to form nitrate, coating on urea minimizes nitrogen loss by volatization. In terms of general benefits, SRF fertilizer results in savings in fertilizer quantity and labour in application frequency as only one application is required for the growing season. It also inhibits nutrient loss, seed toxicity, reduces emission hazards and improves soil quality.

4. Conclusions

Characteristics of natural starch as coatings materials for urea-SRF are greatly differ in relation with the properties of each of natural starch. The coating material used affected the drip resistance of the urea-SRF fertiliser. The drip resistance was sequentially obtained at D8>D2>D5>D3>D1>D4>D6=D7. Gadong, sorghum, sago and porang starches are potentials to be developed as coating materials in terms of dripping resistance. While glutinous rice starch, mung bean starch and sorghum starch showed comparable nitrogen nutrient release comparable to that of CMC. Further research is needed for better formulation of the natural starch to improve the quality as coating materials, including combination treatment of potential natural ingredients in this study, to facilitate the provision of ingredients on a wide scale.

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Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Halus Satriawan; Design: Halus Satriawan, Eka Rahmi; Data Collection or Processing: Mariana.; Statistical Analyses: Halus Satriawan.; Literature Search: Halus Satriawan, Ernawita; Writing, Review and Editing: Halus Satriawan, Ernawita.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Impact of Ultrasonic Pre-Treatments on Germination and Initial Seedling Growth of Common Vetch (*Vicia sativa* L.)

Ultrasonik Ön Uygulamaların Adi Fiğin (*Vicia sativa* L.) Çimlenme ve İlk Fide Gelişimi Üzerine Etkisi

Ramazan BEYAZ[1*], Abdullah BEYAZ[2]

Abstract

Although common vetch (*Vicia sativa* L.) is a very important forage legume plant, some varieties have a dormancy problem due to the hardness of the seed coat. So far, studies on breaking this dormancy seen in common vetch seeds have been quite limited. This research was carried out to determine the effects of ultrasonic pre-treatments applied to common vetch seeds under laboratory conditions on germination and initial seedling growth. Ultrasonic pre-treatment (US) was applied to common vetch seeds at a frequency of 47 kH for 0 -control-, 10, 20, 30 and 40 minutes, respectively. The experiment was designed according to a completely randomized plot trial design with 4 replications. In the research, germination percentage (GP-%-), mean germination time (MGT-day-), germination rate index (GRI-%-), shoot and root lengths (SL and RL-cm-), root-shoot ratio (R/S -%-), shoot and root fresh weights (SFW and RFW-mg per plant-), shoot and root dry weights (SDW and RDW-mg per plant-), shoot and root dry matter (SDM and RDM-% -), root/shoot dry matter ratio (R/S DM-%-), shoot and root water contents (SWC and RWC-%-) and seedling vigor index (SVI) parameters were measured. As a result of the research, it was determined that ultrasonic pre-treatments had statistically significant ($P \leq 0.05$) effects on germination parameters (GP, MGT and GRI). It has been determined that US_{10} and US_{40} treatments increase the GP by 11.11%. However, it was determined that US_{30} treatment shortened the MGT by 15.81% and increased the GRI and SL by 100.00% and 34.65%, respectively. In addition, it was determined that ultrasonic pre-treatments had statistically significant effects on growth parameters (RL, SL, R/S ratio, SFW, RFW, SDW, RDW, SDM, SDM and SVI). Compared to the control group, an increase of 42.95%, 51.35%, 17.75% and 21.00% in the RL, R/S ratio, SFW and RFW parameter values, respectively, was obtained from the US_{10} treatment. Additionally, US_{40} treatment caused an increase in RDW, SDM, RDM values by 51.51%, 33.83% and 33.87%, respectively. The highest increase in SVI was recorded in the US_{30} treatment with 30.56%. In conclusion, the data of this study showed that ultrasonic technology has a positive effect on breaking dormancy in common vetch seeds and thus on the initial seedling growth.

Keywords: Common vetch**,** Ultrasonic treatment, Dormancy, Seed germination, Initial seedling growth

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Öz

Adi fiğ (*Vicia sativa* L.), çok önemli bir baklagil yem bitkisi olmakla birlikte tohum kabuğunda karşılaşılan sertlik nedeniyle dormansi problemi görülmektedir. Şimdiye kadar, adi fiğ tohumlarında görülen bu dormansinin kırılmasına yönelik çalışmalar oldukça sınırlı kalmıştır. Bu araştırmada, laboratuvar koşulları altında yaygın fiğ tohumlarına uygulanan ultrasonik ön uygulamalarının çimlenme ve bununla birlikte ilk fide gelişimi üzerine etkilerinin belirlenmesi amacıyla yürütülmüştür. Ultrasonik ön uygulaması (UÖU) adi fiğ tohumlarına sırasıyla 0 -kontrol-, 10, 20, 30 ve 40 dakika buyunca 47 kH frekansında uygulanmıştır. Deneme 4 tekerrürlü olarak tamamen tesadüf blokları deneme desenine göre dizayn edilmiştir. Araştırmada, çimlenme yüzdesi (ÇY-%-), ortalama çimlenme süresi (OÇS-gün-), çimlenme hızı indeksi (ÇHİ-%-), sürgün ve kök uzunlukları (SU ve KU-cm-), kök-sürgün oranı (K/S-%-), sürgün ve kök taze ağırlıkları (STA ve KTA-mg bitki başına-), sürgün ve kök kuru ağırlıkları (SKA ve KKA-mg bitki başına-), sürgün ve kök kuru maddeleri (SKM ve KKM-%-), kök/gövde kuru madde oranı (K/S KM-%-), sürgün ve kök su içerikleri (SSİ ve KSİ-%-) ve fide güç indeksi (FGİ) parametreleri ölçülmüştür. Araştırma sonucunda, ultrasonik ön uygulamalarının çimlenme parametreleri (ÇY, OÇS ve ÇHİ) üzerine istatistiki açıdan önemli ($P \leq 0.05$) etkilerinin olduğu belirlenmiştir. $UÖU_{10}$ ve $UÖU_{40}$ uygulamalarının ÇY'yi %11.11 oranında artırdığı tespit edilmiştir. Bununla birlikte, $UÖU_{30}$ uygulaması OÇS'yi %15.81 kısalttığı, ÇHİ'yi ve SU'yu sırasıyla %100,00 ve %34,65 oranlarında artırdığı belirlenmiştir. Ayrıca, ultrasonik ön uygulamalarının büyüme parametreleri (KU, SU, K/S oranı, STA, KTA, SKA, KKA, SKM, KKM ve FGİ) üzerine de istatistiki açıdan önemli etkilerinin olduğu belirlenmiştir. Kontrol grubu ile kıyaslandığında, KU, K/S oranı, STA ve KTA parametre değerlerinde sırasıyla %42.95, %51,35, %17,75 ve %21,00 oranlarında bir artış $UÖU_{10}$ uygulamasından elde edilmiştir. İlave olarak $UÖU_{40}$ uygulaması KKA, SKM, KKM değerlerinde sırasıyla %51.51, %33.83 ve %33.87 oranlarında artışa neden olmuştur. FGİ'de ise en yüsek artış %30.56 ile $UÖU_{30}$ uygulamasında kayıt edilmiştir. Sonuç olarak bu araştırmanın verileri, ultrasonik teknolojisinin *adi fiğin* tohumlarındaki dormasinin kırılmasında ve bununla birlikte ilk fide gelişimi üzerine olumlu yönde etkisinin olduğunu göstermiştir.

Anahtar Kelimeler: Adi fiğ, Ultrasonik uygulama, Dormansi, Tohum çimlenmesi, İlk fide büyümesi

1. Introduction

Common vetch *(Vicia sativa* L.) is a grain legume crop that is highly valued for its protein level, fatty acid profile, and mineral composition. These nutritional characteristics make it an excellent choice for enhancing animal feed. Furthermore, significant pharmacological characteristics have been documented in human subjects. The common vetch, like other legumes, has the ability to perform nitrogen fixation, which is a vital characteristic for the development of sustainable agricultural systems. The aforementioned characteristics augment the use of vetch as a protective crop and its implementation in intercropping schemes (Nizam et al., 2022; Ramírez-Parra and De la Rosa, 2023). Despite all these important features of vetch, there is a problem of dormancy due to the hard seed coat (Büyükkartal et al., 2013). 'Hard seededness', or 'physical dormancy', is present in a few plant families, of which the *Leguminosae* are the largest (Paulsen et al., 2013).

Seed dormancy is a characteristic of plants that prevents seed germination in favorable conditions. This property has developed to increase the chances of seedling survival by preventing germination in unfavorable climatic conditions (Iwasaki et al., 2022). The reason of dormancy is seed coat and embryo (Yildiz et al., 2017). Although the hardseededness (physiological dormancy) increases the survival rate of seeds in the soil, especially in adverse environmental conditions, and helps prevent the extinction of species in nature, it prevents rapid germination and healthy seedling development in plant species, and may prevent the use of plant varieties or wild species relatives for agricultural or breeding purposes (Tiryaki and Topu, 2014; Yildiz et al., 2017; Altındal and Altındal, 2018). Physical dormancy, referred to as hardseededness or seed coat impermeability, is a situation wherein a seed's coat becomes impermeable, obstructing the ingress of water, gasses, and other external elements. This impermeability functions as a protective mechanism, postponing germination until optimal conditions are achieved. Factors affecting hard seed development are categorized into internal and external influences. Internal variables relate to plant-specific characteristics, including species and seed shape. Genetic differences and seed coat attributes influence the development of hard seeds. Environmental conditions also affect seed growth. Soil nutrient availability, water supply, humidity, temperature, and light conditions influence seed coat permeability and germination. The timing of seed maturity, drying, and storage conditions can influence the production of hard seeds. The interaction of these elements influences a plant's propensity to generate hard seeds (Ermis et al., 2024). There are some methods used for breaking seed coat dormancy such as scarification of seed coat by mechanical methods, temperature treatments, acid treatments, chemical treatments (Kinetin, GA3). Furthermore, a range of physical and extraterrestrial environmental elements, such as electromagnetic waves (EWs), magnetic fields (MFs), and ultrasonic sounds (US), have been documented as a potentially effective method for disrupting dormancy. The electromagnetic spectrum encompasses both ionizing and non-ionizing radiations. The spectrum of ionizing radiation is composed of X-rays and gamma rays, whereas non-ionizing radiation includes ultrasonic waves, magnetic fields, microwaves, and infrared light, among others (Alsuvaid and Demir, 2022; Bera et al., 2022).

In recent years, ultrasonic waves have been widely used as an effective method for disrupting seed dormancy and enhancing germination properties (Nazari and Eteghadipour, 2017). The application of ultrasonic waves to seeds is an environmentally friendly technology that shows potential for revolutionizing the food business. It improves the process of seed germination and seedling growth in various species by stimulating the absorption of water and oxygen, as well as boosting seed metabolism (Nogueira et al., 2023). The ultrasonic waving technique appears to be more convenient, safer, and healthier, while also being more time-efficient compared to conventional chemical and physical procedures (Sharififar et al., 2015). This therapy utilizes ultrasonic frequencies (20-100 kHz) to interact with material or seeds in either air or water (Memiş et al., 2022). It has been reported by many researchers so far that ultrasonic treatments break seed dormancy and positively affect germination and seedling growth in many plant species (Goussous et al., 2010; Nazari et al., 2014; Lahijanian and Nazari, 2017; Sharififar et al., 2015; Andriamparany and Buerkert, 2019; Babaei-Ghaghelestany et al., 2020; Wang et al., 2020; Alfalahi et al., 2022; Memiş et al., 2022; Babaei et al., 2023; Foschi et al., 2023). However, a thorough examination of previous studies revealed a lack of information regarding the assessment of ultrasound technology's efficacy in breaking the seed dormancy of common vetch. There are limited reports on breaking seed dormancy of common vetch in the literature (Samarah et al., 2004; Samarah, 2005; Uzun, 2012). Hence, the objective of this research was to employ ultrasound waves as a noninvasive, uncomplicated, and economical method to induce dormancy release and promote early seedling development in common vetch.

2. Materials and Methods

2.1. Seed Materials

The study utilized common vetch seeds, gathered in 2023, received from the Department of Field crops at Kırşehir Ahi Evran University in Türkiye. An *in vitro* experiment was conducted in 2023 at the Department of Agricultural Biotechnology, Faculty of Agriculture, Kırşehir Ahi Evran University in Türkiye.

2.2. Ultrasonic irradiation treatments

100 seeds for each treatment were treated with 47 kHz ultrasonication in 200 ml of distilled water for 0, 10, 20, 30, and 40 mininutes using a completely randomized design. During ultrasonic treatment, water temperature was kept at 21±2°C by adding ice from time to time. Ultrasonication treatments are labeled US_{10}, US_{20}, US_{30}, and US_{40}, respectively. During the ultrasonication process, the seeds are in contact with distilled. Therefore, in order to determine the effect of the soaking factor on germination and initial seedling growth paramaters, the seeds were soaked in water for 0, 10, 20, 30, and 40 minutes, just like in the ultrasonication process, and these treatments were labeled as -water soaking- WS_{10}, WS_{20}, WS_{30}, and WS_{40}, respectively. Soaking the seeds in water is considered hydro-priming. Seeds that were not exposed to water or ultrasonic treatments were used as controls.

2.2. Germination Assay and Growth Measurement

Test solution were prepared with distilled water. For each treatment, 25 seeds were sown between three rolls of filter paper in four replicates. At the beginning of the experiment, each subject was irrigated with 10 ml of test solution. Before planting, seeds were given a fungicide treatment (Thiram 80%). To prevent moisture loss, the rolled paper with seeds was placed in sealed, clear plastic bags. For 14 days, seeds were allowed to germinate at 20 ± 1ºC degrees in the dark in incubator (Memmert-In110). The radicles were deemed to have germinated when they reached a length of ~ 2 mm. For two days, the germination percentage was tracked every 24 hours (ISTA, 2003).

Germination Percentage(GP) = (Number of germinating seeds/ Total number of seeds) × 100

(Al-Enezi et al., 2012) (Eq. 1)

Equation 1 was used to calculate the proportion of seeds that germinated after being subjected to ultrasonic treatments. To assess the rate of germination, the mean germination time (MGT) was determined (Ellis and Roberts, 1980).

$$MGT=\sum Dn/\sum D \quad \text{(Eq. 2)}$$

where n is the number of freshly germinated seeds on day D, and D is the number of days since the start of the experiment.

The germination rate index (speed of germination) was calculated using the formula according to Maguire (1962).

$$GRI = \Sigma \text{ No of Germinated Seeds}/ \Sigma \text{ No of Days} \quad \text{(Eq. 3)}$$

Seedlings with stunted primary roots and short, thick, spiral-shaped hypocotyls were deemed to have aberrant germination. Initial seedling growth paramaters (shoot and root length, shoot and root fresh weights, shoot and root dry weights, shoot and root dry matter, shoot and root water content, and seedling vigor index) were measured after the 14th day (*Figure 1*). Samples were dried in an oven at 70°C for 48 hours before dry weights were calculated (Beyaz et al., 2011). The following parameters were used to calculate the growth parameters.

Water content (WC) = (fresh weight-dry weight)/fresh weight×100 (Zheng et al., 2008) (Eq. 4)

Dry matter (DM)= (dry weight/fresh weight) × 100 (Bres et al., 2022) (Eq. 5)

Seedling vigor index (SVI)= (average root length +average hypocotyl length) x germination percentage

(Abdul-Baki and Anderson, 1973) (Eq. 6)

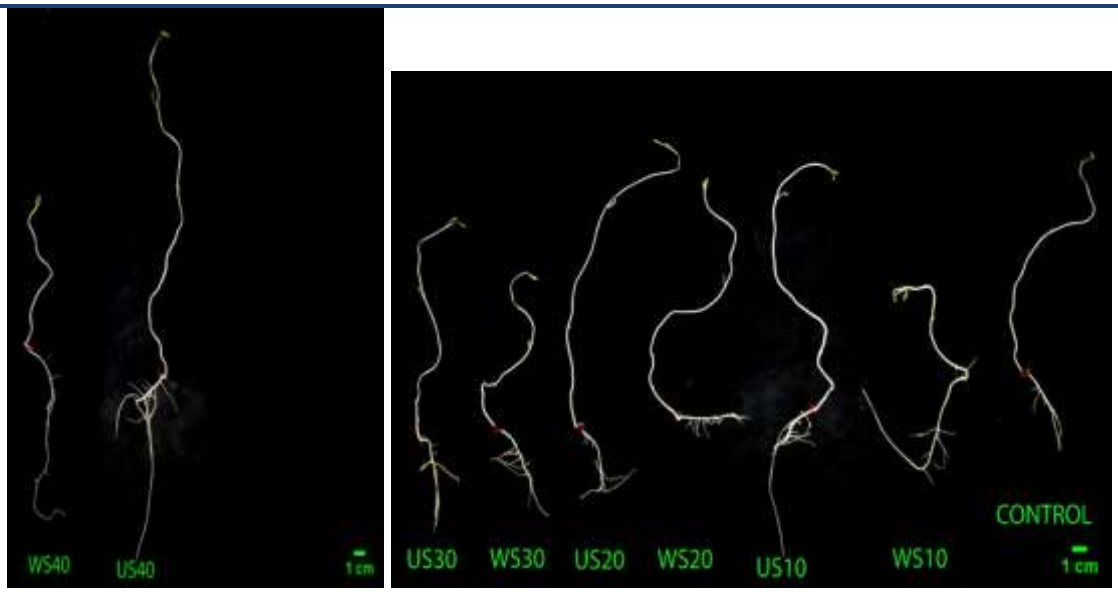

Figure 1. The morphology of common vetch seedlings after water soaking (WS) and ultrasound (US) treatments (after 14 days of germination)

Treatments*:

Control: Seeds that were neither soaked in distilled water nor exposed to ultrasonic treatments.

US_{10}, US_{20}, US_{30}, and US_{40}: Seeds exposed to ultrasonic (ultrasound) treatments for 10, 20, 30, and 40 minutes, respectively.

WS_{10}, WS_{20}, WS_{30}, and WS_{40}: Seeds soaked in distilled water for 10, 20, 30 and 40 minutes respectively. It is considered a hydropriming treatment.

2.2. Statistical Analysis

The gathered data were analyzed using a one-way Analysis of Variance (ANOVA) in the statistical software package SPSS 22. This analysis aimed to evaluate whether the treatments had a significant impact on the observed parameters. The statistical significance of the means was assessed using the Duncan Multiple Range Test (DMRT) at a significance level of $P \leq 0.05$. Before statistical analysis, the data in percentages were transformed using Arcsine transformation (Snedecor and Cochran, 1967).

3. Results and Discussion

3.1. Effects of ultrasonic pre-treatmens on germination of Common Vetch Seeds

The effect of different ultrasound (US) and water soaking (WS) treatments on the germination percentage (GP), germination rate index (GRI) and mean germination time (MGT) is given in *Table 1* and it was determined that there was a statistical difference between the ultrasound (US) and water (W) treatments in terms of GP ($P \leq 0.05$), GRI ($P \leq 0.05$), and MGT ($P \leq 0.01$). Water and US treatments caused an increase in GP compared to the control group. However, when water soaking (WS) and US treatments were compared, it was observed that the GP increase was greater in US treatments. The highest GP values of 100% were obtained from US_{10} and US_{40} treatments. The lowest GP value (90.00%) was recorded in the control group. The observed increase in GP due to increased ultrasound coincides with the findings of various researchers in other plants (Aladjadjiyan, 2002; Yaldagard et al., 2008; Goussous et al., 2010; Andriamparany and Buerkert, 2019; Babaei-Ghaghelestany et al., 2020; Alfalahi et al., 2022). The surface and architecture of the seed coat may potentially have an impact on the ultrasonic effect (Memiş et al., 2022). The primary effects of ultrasonic waves are mostly attributed to mechanical phenomena, such as acoustic cavitation and the disruption of plant cell walls. These processes ultimately lead to an enhanced uptake of water (Abd El-Sattar and Tawfk, 2023). The occurrence of cavitation during the sonication process was postulated as an additional potential factor that caused micro fissures on the seed coat. These fissures may have facilitated the absorption of moisture, leading to an accelerated germination rate (Yaldagard et al., 2008;

Table 1. Effects of ultrasound (US) and water soaking (WS) treatments on germination percentange (GP), mean germination time (MGT), germination rate index (GRI), shoot lenght (SL), root lenght (RL), root to shoot ratio (R/S) of 14 days-old common vetch seedling

Treatments	GP (%)	MGT (day)	GRI (%)	SL (cm)	RL (cm)	R/S (%)
0-control-	90.00±0.0^{c}	1.96±0.03^{a}	4.83±0.44^{d}	14.60±1.1^{b}	5.75±0.5^{bc}	0.37±0.04^{bc}
WS_{10}	96.66±3.3^{ab}	1.74±0.04^{c}	8.16±0.60^{ab}	13.70±0.3^{b}	6.13±0.4^{bc}	0.44±0.02^{ab}
US_{10}	100.00±0.0^{a}	1.73±0.04^{c}	8.66±0.88^{ab}	14.81±1.3^{b}	8.22±0.3^{a}	0.56±0.03^{a}
WS_{20}	93.33±3.3^{ab}	1.78±0.04^{ab}	7.33±0.60^{abc}	14.63±0.3^{b}	4.90±0.3^{c}	0.34±0.00^{bc}
US_{20}	96.66±3.3^{ab}	1.79±0.05^{ab}	7.50±0.86^{abc}	14.55±0.6^{b}	6.54±0.5^{abc}	0.44±0.02^{ab}
WS_{30}	93.33±3.3^{ab}	1.83±0.08^{ab}	6.66±1.01^{bcd}	14.33±1.1^{b}	4.92±0.4^{c}	0.35±0.06^{bc}
US_{30}	93.33±1.6^{c}	1.65±0.05^{c}	9.66±0.83^{a}	19.66±2.0^{a}	6.31±0.8^{abc}	0.32±0.01^{c}
WS_{40}	90.00±0.0^{c}	1.93±0.06^{a}	5.16±0.72^{cd}	16.56±0.4^{ab}	7.06±0.5^{ab}	0.42±0.04^{bc}
US_{40}	100.00±0.0^{a}	1.71±0.07^{c}	9.33±1.45^{ab}	16.32±1.4^{ab}	7.75±1.0^{ab}	0.47±0.03^{ab}
Summary of ANOVA						
Treatment	*	*	**	*	**	**

*significant at $P \leq 0.05$, **significant at $P \leq 0.01$. Different letters at the same column show significant differences at 0.05 level. ±: Standard errors.
Treatments*:
Different durations of two treatments: Seeds soaked in water (WS) or soaked in water in ultrasonic device (US).
Control: Seeds that were neither soaked in distilled water nor exposed to ultrasonic treatments.
US_{10}, US_{20}, US_{30}, and US_{40}: Seeds exposed to ultrasonic (ultrasound) treatments for 10, 20, 30, and 40 minutes, respectively.
WS_{10}, WS_{20}, WS_{30}, and WS_{40}: Seeds soaked in distilled water for 10, 20, 30 and 40 minutes respectively. It is considered a hydropriming treatment.

Abd El-Sattar and Tawfk, 2023). According to Bai et al. (2023), The ultrasound-germination therapy across the entire germination phase led to a notable increase in water content compared to the germination treatment alone in barley.

When compared to the control group, water soaking (WS) and US treatments caused a shortening of MGT. This shortening was recorded at higher values in ultrasound treatments (*Table1*). Considering the control group, the highest shortening was obtained from US_{30} and US_{40} treatments, with 15.81% and 14.61%, respectively. Memiş et al. (2022) reported that ultrasound treatment positively affects MGT and shorten its duration in vegetable species such as watermelon, melon, leek, pepper, carrot, tomato and aubergine. GRI increased in both water and US treatments when control was considered (*Table 1*). However, this increase was greater in US treatments. The highest increase was obtained from US_{40} treatment with 93.16 % compared to the control. Similar studies have reported that ultrasound treatments increase GRI in other plants (Goussous et al., 2010; Andriamparany and Buerkert, 2019; Namjoo et al., 2022; Parlak and Erken, 2023). The high germination index is considered to be a reliable sign of strong seed viability (Büyükyıldız et al., 2023). Consequently, based on the research findings, it can be concluded that US treatments enhance the seed vigor of vetch. Ultrasonic waves can accelerate the germination process of common bean seeds by producing tiny openings on the seed coat and reducing the stiffness of the cotyledon cell walls. This allows the seeds to absorb water more efficiently, leading to faster and more successful water uptake (Lahijanian and Nazari, 2017). Ultrasound improves the germination of specific seeds by stimulating the activity of different enzymes (Potolea et al., 2019).

3.2. Effects of ultrasonic pre-treatmens on morphological characters of Vicia sativa L. Seedlings

The effect of WS and US treatments on shoot lenght (SL), root length (RL), and root to shoot ratio are seen in *Table 1*. Statistically, the effect of both WS and US treatments on these parameters was found to be significant. For SL, statistically 0-control-, WS_{10}, US_{10}, WS_{20}, US_{20} remained in the same group. The highest SL (19.66cm) was obtained from the US_{30} treatment. It was calculated that there was a 34.65% increase in SL compared to the control group. However, it has been observed that WS (except, WS_{20} and WS_{30}) and US treatments increase RL. The highest RL value was recorded in US_{10} treatment with 8.22 cm. There was an increase of 42.95% between US_{10} and the 0-control- group. Considering R/S, the highest value was again obtained from US_{10} treatment with 0.56%. The increase here between the control group and US_{10} treatment was 51.35%. WS and US treatments affected SL, RL, and R/T parameters differently. In general, the results of the study showed that both treatments provided a general increase in these parameters, and this increase was greater in US treatments. Alfalahi et al. (2022) reported that ultrasonic exposure increased root and shoot lengths of the three soybean varieties. Zeng et al. (2023) reported that the application of ultrasonic treatment had a substantial impact on the growth of sugarcane shoots in all three cultivars. According to Huang et al. (2020), using lower levels of ultrasound over a prolonged period can promote cell division and maintain high-quality seedlings.

The results of WS and US treatments effects on shoot fresh weight (SFW), root fresh weight (SFW), shoot dry weight (SDW), and root dry weight (RDW) are shown in *Table 2*. SFW, RFW, SDW, and RDW were significantly affected by WS and US treatments. In general, SFW (except, WS_{20}, WS_{30}, US_{40}) and RDW (except, W_{30}) caused an increase in both applications. For SFW, the highest result (0.126 mg per plant) obtained from both US_{10} and WS_{10} treatments. However, for RFW, the highest value (0.144 mg per plant) was recorded at US_{10}. Considering RDW and RDW, the highest values were obtained from WS_{30} treatments with 0.0144 mg per plant and US_{40} treatments with 0.0300 mg per plant, respectively. The effects of ultrasonic assisted seeds priming (0 -cotnrol-,10, and 20 min) with a frequency of 40 kHz on seed enhancement of Fenugreek seeds were investigated by (Abd El-Sattar and Tawfk, 2023) who showed that SFW, RFW, SDW and RDW were signifcantly improved by using ultrasonic treatments.

Table 2 shows effects of the different durations of US treatment compared to WS on the shoot and root dry matter (SDM and RDM), root to shoot dry matter (R/S DM), shoot and root water contents (SWC and RWC), and seedling vigor index (SVI). For SDM, RDM, R/S DM, SWC, RWC and SVI, the means were statistically significant between the control, WS, and US treatment groups. Compared to the control, it was determined that WS and US treatments generally caused a decrease in SDM (except, WS_{40} and US_{40}) and an increase in RDM. However, it also caused an increase in R/SDM. The highest SDM and RDM values were obtained from US_{40} treatment with 14.36% and 22.05%, respectively. However, the highest value for R/S DM was obtained from WS_{30}

Table 2. Effects of ultrasound (US) and water soaking (WS) treatments on shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW), root dry weight (RDW), shoot dry matter (SDM), root dry matter (RDM) of 14 days-old common vetch seedling.

Treatments	SFW (mg/plant)	RFW (mg/plant)	SDW (mg/plant)	RDW (mg/plant)	SDM (%)	RDM (%)
0-control-	0.107±0.006^{b}	0.119±0.007^{bc}	0.0115±0.0008^{ab}	0.0198±0.005^{b}	10.73±0.15^{ab}	16.47±0.97^{b}
WS_{10}	0.126±0.003^{a}	0.137±0.007^{ab}	0.0110±0.0007^{ab}	0.0228±0.001^{b}	8.83±0.06^{bc}	16.77±0.98 ^{b}
US_{10}	0.126±0.006^{a}	0.144±0.007^{a}	0.0110±0.0004^{ab}	0.0250±0.006^{ab}	8.95±0.88^{bc}	17.16±1.63 ^{b}
WS_{20}	0.084±0.009^{c}	0.120±0.004^{bc}	0.0085±0.0009^{bc}	0.0213±0.002^{b}	10.45±0.15^{abc}	17.68±0.48 ^{b}
US_{20}	0.116±0.001^{ab}	0.128±0.003^{abc}	0.0114±0.0009^{ab}	0.0230±0.001^{b}	9.82±0.18^{abc}	18.01±0.55 ^{b}
WS_{30}	0.082±0.001^{c}	0.107±0.007^{c}	0.0067±0.0009^{c}	0.0197±0.002^{b}	8.16±0.13^{c}	18.34±0.31 ^{b}
US_{30}	0.109±0.006^{ab}	0.127±0.005^{abc}	0.0087±0.0004^{bc}	0.0220±0.003^{b}	8.04±0.65^{c}	17.28±0.80 ^{b}
WS_{40}	0.119±0.003^{ab}	0.123±0.002^{abc}	0.0144±0.0040^{a}	0.0231±0.002^{b}	12.19±2.25^{a}	18.71±0.45 ^{b}
US_{40}	0.107±0.004^{b}	0.137±0.010^{ab}	0.0137±0.0032^{a}	0.0300±0.001^{a}	14.36±0.14^{a}	22.05±1.87^{a}
Summary of ANOVA						
Treatment	**	*	**	*	**	*

*significant at $P \leq 0.05$, **significant at $P \leq 0.01$. Different letters at the same column show significant differences at 0.05 level. ±: Standard errors.
Treatments*:
Different durations of two treatments: Seeds soaked in water (WS) or soaked in water in ultrasonic device (US).
Control: Seeds that were neither soaked in distilled water nor exposed to ultrasonic treatments.
US_{10}, US_{20}, US_{30}, and US_{40}: Seeds exposed to ultrasonic (ultrasound) treatments for 10, 20, 30, and 40 minutes, respectively.
WS_{10}, WS_{20}, WS_{30}, and WS_{40}: Seeds soaked in distilled water for 10, 20, 30 and 40 minutes respectively. It is considered a hydropriming treatment.

Table 3. Effects of ultrasound (US) and water soaking (WS) treatments on shoot dry matter (R/S DM), shoot water content (SWC), root water cantent (RWC), seedling vigor index (SVI) of 14 days-old common vetch seedling.

Treatments	R/S DM (%)	SWC (%)	RWC (%)	SVI
0-control-	1.55±0.30^{b}	89.26±0.54^{ab}	83.52±0.97^{a}	1845±213^{c}
WS_{10}	1.91±0.04^{ab}	91.16±0.96^{a}	83.22±0.98 ^{a}	1912±20^{ab}
US_{10}	1.93±0.12 ^{ab}	91.04±0.88^{a}	82.83±1.63 ^{a}	2303±153^{ab}
WS_{20}	1.80±0.54 ^{ab}	89.54±1.86^{ab}	82.31±0.48 ^{a}	1826±114^{c}
US_{20}	1.83±0.03 ^{ab}	90.17±0.18^{ab}	81.98±0.55 ^{a}	2036±106^{ab}
WS_{30}	2.24±0.11^{a}	91.83±0.13^{a}	81.65±0.31 ^{a}	1791±21^{c}
US_{30}	2.16±0.20^{a}	91.95±0.65^{a}	82.71±0.80 ^{a}	2409±200^{a}
WS_{40}	1.62±0.06^{b}	87.80±0.63^{bc}	81.28±0.45 ^{a}	2124±118^{ab}
US_{40}	1.61±0.04^{b}	85.63±1.06^{c}	77.94±1.87^{b}	2407±248^{a}
Summary of ANOVA				
Treatment	*	**	*	*

*significant at $P \leq 0.05$, **significant at $P \leq 0.01$. Different letters at the same column show significant differences at 0.05 level. ±: Standard errors.
Treatments*:
Different durations of two treatments: Seeds soaked in water (WS) or soaked in water in ultrasonic device (US).
Control: Seeds that were neither soaked in distilled water nor exposed to ultrasonic treatments.
US_{10}, US_{20}, US_{30}, and US_{40}: Seeds exposed to ultrasonic (ultrasound) treatments for 10, 20, 30, and 40 minutes, respectively.
WS_{10}, WS_{20}, WS_{30}, and WS_{40}: Seeds soaked in distilled water for 10, 20, 30 and 40 minutes respectively. It is considered a hydropriming treatment.

treatment with 2.24%. Abd El-Sattar and Tawfk (2023) reported that US treatments (40 kHz, 10 and 20 min) increased seedling dry matter of fenugreek. Alfalahi et al. (2022) stated that ultrasonic exposure increased seedling dry matter of the three soybean varieties. In addition, Shekari et al. (2015) mentioned that sesame seedling dry matter was significantly affected by the priming sonication technique.

As shown in *Table 3*, the effects of WS and US treatments on shoot water content (SWC) and root water content (RWC) were different. While WS and US treatments generally caused an increase in SWC (except, WS_{40} and US_{40}), RWC caused a decrease. In terms of RWC, the root was found to be more negatively affected by US treatments. In terms of SWC, it was determined that the shoot was slightly positively affected by WS and US treatments, but it was observed that there was no statistical difference between WS and US treatments.

However, the 40-minute application period, which can be considered as a high WS and US treatment, has been observed to have a negative effect on SWC. Researchers report that US treatments can have a positive effect in the short term as well as a negative effect in the long term. Ran et al. (2015) reported that ultrasound increase wheat seedling leaf relative water content.

The vigor index is a numerical measure that represents the energy and efficiency of seeds during the process of germination and growth of seedlings (Uslu and Gedik, 2020; Abd El-Sattar and Tawfk, 2023). The result of both WS and US treatment affects on seedling vigor index (SVI) are given in *Table 3*. According to these results, both WS and US treatments increased SVI values. It has been observed that this increase is greater in US treatments. The highest SVI value (2409) was recorded in US_{30} treatment. SVI germination percentage was calculated along with shoot and root growth. It has been determined that US_{30} treatment significantly increases the values in terms of germination percentage, shoot and root development. Nazari and Eteghadipour (2017) found that quick germination and the appearance of seedlings are crucial for the effective establishment of plants and commodities. They also discovered that gentle sonication can enhance seedling development. The results given in this study align with the conclusions reached by other researchers (Machikowa et al., 2013; Risca et al., 2007; Yaldagard et al., 2008; Kouchebagh et al., 2014; Shekari et al., 2015; Alfalahi et al., 2022; Memiş et al., 2022; Abd El-Sattar and Tawfk, 2023).

4. Conclusions

The data collected study suggest that the hypothesis, which proposed that exposure to ultrasound pre-treatments would results in breaking dormacy and a increase initial seedling growth, was supported by the experimental results. In summary, the present study found that using an appropriate ultrasonic therapy (namely, a mixed frequency of 47 kHz for a duration of both 10 and 30 minutes) enhances the germination and growth of common vetch. In addition, it has been observed that water soaking (WS) treatments, also considered hydropriming, have a positive effect on germination and growth parameters in general. However, when WS and US treatments were compared, it was found that US treatments had more positive effects. It has been observed that the root is more positively affected by US treatment than the shoot. Overall, the research results show that ultrasound/ultrasonic pre-treatment can have positive effects on the cultivation of common vetch, but it also reveals the need for further studies on whether these effects are economical.

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Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Manisa İlinin Sarıgöl İlçesi Topraklarının Fiziko-Kimyasal Özellikleri, Bazı Verimlilik Özelliklerinin Tespiti ve Jeoistatistiksel Yöntemler Kullanılarak Haritalanması*

Determination of Physico-Chemical Properties, Some Productivity Characteristics and Mapping of Soils of Manisa Sarıgöl District by Using Geostatistical Methods

Gülay İYDİR[1*], Mehmet Ali ÖZDEMİR[2]

Öz

Bu çalışmanın amacı, Manisa ilinin Sarıgöl ilçesi sınırları içerisinde kalan tarım topraklarının fiziko-kimyasal özelliklerini, besin element kapsamı arasındaki ilişkileri belirlemek ve bu özelliklerin dağılım haritalarını üretmektir. Toprak analizlerinden elde edilen sonuçlara göre, çalışma alanı içerisinde yüzey topraklarının %82'si tınlı bünyede, %18'i killi-tınlı, pH değeri 6.6-8.73 aralığında, organik madde miktarı %0.06- 2.28 aralığında, toplam kireç içeriği genellikle düşük ve topraklar tuzsuzdur. Makro elementlerden azotun toprakların tamamında düşük olduğu tespit edilmiştir. Potasyum K_2O 10.94-204.75 kg da^{-1} aralığında yeter düzeyde, fosfor içeriği 0.76-31.6 kg da^{-1} ve değişken dağılımlı, kalsiyum 776-9000 mg kg^{-1}, genellikle yeterli, magnezyum 67.61-1144 mg kg^{-1} aralığında olup toprakların neredeyse tamamında yeterli bulunmuştur. Yüzey topraklarında, 4 mikro elementten birisi olan ve 0.61-5.4 mg kg^{-1} aralığındaki demir, toprakların %56'sında düşük, %41'inide orta, %3'ünde ise yüksektir. Bakır içeriği 0.03-3.99 mg kg^{-1} aralığında değer göstermekte, toprakların %68'i yeterli, %32'si yetersiz düzey bakır içermektedir. Çinko ise Türkiye'de en fazla eksikliği hissedilen mikro elementlerdendir. Sarıgöl toprakları ortalama 0.5 mg kg^{-1} düzeyinde ve daha düşük değerde çinko içermekte, yüzey topraklarının % 72'sinde, yüzey altı topraklarının % 98'inde çinko miktarı çok düşük düzeydedir. Mangan ise tüm sonuçlarda düşük miktarda bulunmuştur. Araştırma kapsamında en yüksek korelasyon organik madde ve azot arasında bulunmuştur. Değerlendirilen her bir toprak özniteliğinin konumsal dağılım haritaları için Spherical, Exponential ve Gaussian semivariogram modelleriyle, Kriging (ordinary, simple ve Universal) ve ters mesafe komşuluk benzerliği (IDW) 1, 2 ve 3 farklı güç seviyeleri enterpolasyon modelleri karşılaştırılmıştır. Enterpolasyon modellerinin başarı performansları hata kareler ortalaması karekökü (RMSE) parametresi kullanılarak belirlenmiştir. Çalışmada yer alan modellemeler elde edilen RMSE değerleri dikkate alınarak hazırlanmıştır.

Anahtar Kelimeler: Toprak, Mikro element, Sarıgöl, Jeoistatistik, RMSE

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*Bu Çalışma Gülay İYDİR'in Doktora tezinden üretilmiştir.

Abstract

The aim of this study is to determine physico-chemical properties of agricultural soils within the boundaries of Sarıgöl district in Manisa province, analyze the relationships between nutrient element contents, and produce distribution maps of these properties. Within the study area, 82% of the surface soils have a loamy texture, 18% have a clay-loamy texture, pH values range from 6.6 to 8.73, organic matter content varies between 0.06% and 2.28%, total lime content is generally low, and the soils are non-saline. Among the macro-elements, nitrogen was found to be low in all soils. Potassium K_2O ranges between 10.94-204.75 kg da^{-1} and is generally at a sufficient level, phosphorus content varies between 0.76-31.6 kg da^{-1} with variable distribution, calcium is generally sufficient in the range of 776-9000 mg kg^{-1}, magnesium is sufficient in almost all soils, ranging from 67.61-1144 mg kg^{-1}. In the surface soils, iron, one of the four micro-elements, ranges between 0.61-5.4 mg kg^{-1} and is low in 56% of the soils, moderate in 41% and high in 3%. Copper content shows a value in the range of 0.03-3.99 mg kg^{-1}, with 68% of the soils containing sufficient level and 32% containing insufficient levels of copper. Zinc is one of the most deficient micro-elements in Turkey. Sarıgöl soils contain an average of 0.5 mg kg^{-1} or lower levels of zinc, with zinc levels being very low in 72% of the surface soils and 98% of the sub-surface soils. Manganese is found in low amounts in all results. The highest correlation in the study was found between organic matter and nitrogen. For the spatial distribution maps of each evaluated soil attribute, Spherical, Exponential, and Gaussian semivariogram models, along with Kriging (ordinary, simple, and universal) and inverse distance weighting (IDW) interpolation models at 1, 2, and 3 different power levels, were compared. The performance of the interpolation models was determined using the root mean square error squared (RMSE) parameter. The models presented in the study were selected according to the obtained RMSE values.

Keywords: Soil, Microelements, Sarıgöl, Geostatistics, RMSE

1. Giriş

Sürekli artan nüfus, kıt bir doğal kaynak olan toprak üzerinde baskı oluşturmaktadır. Bir taraftan fazla ve kaliteli ürün elde etme baskısı ile yeni açılan tarım arazileri, diğer taraftan tarımsal arazilerin sanayi alanı veya yerleşim yeri olarak amaç dışı kullanımı, verimli toprakların giderek azalmasına yol açmaktadır. Tarımsal üretimde kullanılan aşırı ve plansız gübreleme sonucu tarım toprakları daha fazla heterojen bir yapı göstermektedir. Bu durum, arazinin kullanım şekli ve yoğunluğuna göre toprakların fiziko-kimyasal özelliklerinin konumsal değişkenliğini büyük oranda etkilemekte ve değiştirmektedir (Trangmar ve ark., 1985; Sürme ve ark., 2024).

Sürdürülebilir toprak yönetim için toprak kaynakları hakkında güvenilir ve kapsamlı veriye ihtiyaç bulunmaktadır. Toprakla ilgili oluşturulan veri tabanları ve toprağın değişken özelliklerinin konumsal dağılımlarının belirlenmesi ve bu özellikler ile ilgili iyi bir değerlendirme yapılması amacıyla CBS ve CBS yazılım sistemlerine entegre edilen jeoistatistik yöntemler ile hazırlanan toprağın verim özelliklerinin alansal değişkenliğine ait dağılım haritaları üretilebilmektedir. Arazide örnekleme noktaları arasındaki mesafeye bağlı ilişkiyi ve toprak özeliklerinin değişkenliğini belirlemek için jeoistatistik yaygın kullanılan bir yöntemdir (Unlu ve ark., 1990; Logsdon ve Jaynes, 1996). CBS ortamında konumsal enterpolasyon yöntemleri kullanılarak ölçülen coğrafi verilerin tüm alana dağıtılması ile alansal dağılım haritaları oluşturulmaktadır (Heuvelink, 2006). Jeoistatistikte işlemler metotlar iki aşamalıdır. İlk aşamada, incelemeye konu olan toprak özelliğinin ölçülen noktaları arasındaki otokorelasyonun veya doğal olarak bulunan yersel bağımlılığın derecesi belirlenmekte, ikinci aşamada ise ileri bir interpolasyon tekniği yardımıyla incelenen özelliğin örneklenmeyen nokta ve alanlardaki değerleri tahmin edilerek dağılım deseni belirlenmeye çalışılmaktadır. Semivariogramlar yersel bağımlılık derecesinin belirlenmesi ve kriging analizi ise interpolasyon aşamasında yaygın olarak kullanılan araçlardır (Öztaş, ve Ardahanlıoğlu, 1998).

Koordinatlı toprak örneği alınarak, toprak özniteliklerinin uzaysal değişkenliğini tespit eden çalışmalar mevcuttur (Koca ve ark., 2019; Sökmen ve ark., 2024). Foroughifar ve ark. (2013) toprakların bazı fizikokimyasal özelliklerinin uzaysal değişimlerini jeoistatistiksel metodlarla belirledikleri çalışmalarında, grid örnekleme sistemine göre 1000 m aralıklarla yüzeyden olmak üzere 98 toprak örneği almışlardır. Araştırma alanında jeoistatistiksel analizler neticesinde, pH, organik madde, katyon değişim kapasitesi, Zn, Cu, Fe, kil için spherical (küresel) modelin, P için exponential (üssel) modelin ve Mn için ise linear (doğrusal) modelin en uygun semivaryogram modeller olduğu, ayrıca incelenen parametrelerin varyogram modellerindeki etki mesafelerinin ise 1600-7364 m arasında değiştiği bildirilmiştir. Gözükara (2021) tarafından yapılan benzer araştırmada toprağın pH, EC, $CaCO_3$, kum, silt ve kil içerikleri değerlendirilmiş, çarpıklık değeri 0.5'den büyük olan toprak özellikleri EC, OM, $CaCO_3$ ve kilin normal dağılım göstermediği belirlenmiştir. Bu veri setlerine logaritmik dönüşüm uygulanmıştır. Toprak özelliklerinin farklı enterpolasyon yöntemleri ve yarıvariogram modellerine göre RMSE değerleri hesaplanmıştır. Tahmin performansı Ordinary ve Universal kriging enterpolasyon modellerinin Simple Kriging ve IDW enterpolasyon modellerine göre daha düşük RMSE değeri elde edilmiş, buna bağlı olarak daha başarılı entorpolasyon modelleri olduğu belirlenmiştir. Exponential yarıvariogram modelin, Sperical ve Gaussian yarıvariogram modellerine göre daha düşük RMSE değerine sahip olmasından dolayı en başarılı yarıvariogram modeli olarak belirlenmiştir. IDW enterpolasyon modelinde güç seviyesi artıkça kum ve kil gibi toprak özellikleri hariç diğer toprak özelliklerinde RMSE değerleri azalarak tahmin performansının arttığı ifade edilmiştir.

Sarıgöl sınırları içerisinde alüvyal topraklardan oluşan Sarıgöl ve Afşar ovaları yoğun olarak tarım yapılan alanlardır. Ovalara ek olarak eğimli yamaçlarda, Menderes Masifi'ne ait metamorfik kayaçların ana materyali oluşturduğu (Anonim, 2002) kireçsiz kahverengi topraklar ve kireçsiz kahverengi orman toprakları üzerinde var olan tarım arazileri yoğun olarak işlenmektedir. İlçede 18.960 hektar ekili dikili alanın % 57'sinde bağcılık yapılmakta, yıllık 155.000 ton yaş üzüm elde edilmektedir (Anonim, 2019a). Tarımsal faaliyetlerin önemli bir kısmını üzüm, diğerlerini zeytin, ceviz ve meyve bahçeleri ile hububat, endüstri bitkileri, yem bitkileri, sebze alanları oluşturmaktadır. İlçede yapılan tarımsal üretim Türkiye açısından önemli bir gelir sağlamakta iken, ilçe topraklarına ait koordinatlı veri yetersiz kalmakta ve bu durum tarımsal planlamalar için önemli bir eksiklik olarak kabul edilmektedir. Bu çalışmanın amacı, Manisa ilinin Sarıgöl ilçesi sınırları içerisinde kalan, benzer iklim ve farklı ana materyaller üzerinde oluşmuş tarım topraklarının fiziko-kimyasal özellikleri ve besin element kapsamı arasındaki ilişkileri belirlemek ve bu özelliklerin dağılım haritalarını üretmektir

2. Materyal ve Metot

2.1. Materyal

Çalışma alanını oluşturan Sarıgöl, Manisa iline bağlı olan bir ilçedir (*Şekil 1*). Ege Bölgesi'nin Ege ve İç Batı Anadolu bölümleri arasında Akdeniz ve karasal iklim geçiş sahasında yer almaktadır. Çalışma sahasında temeli oluşturan Menderes Masifi, Batı Anadolu'da geniş bir alanda yüzeylenen metamorfik kayaçlardan oluşmaktadır (Aslan, 2017). Maden Tetkik ve Arama Genel Müdürlüğü tarafından hazırlanan yapısal haritalara göre çalışma sahasında toprak ana materyalini oluşturan en fazla kayaç grubunun migmatit-gnays ve alüvyon olduğu görülmektedir. Ana materyalin % 50.35'ini Prekambriyen migmatit-gnays, gözlü gnays-metagranitoyit kayaç birimleri; % 34.65'ini Kuvaterner alüvyon, çakıl taşı-kumtaşı-kireçtaşı, traverten, yamaç molozu, birikinti konisi; % 12.21'ini Neojen çakıltaşı, kumtaşı, çamurtaşı; %12.79'unu ise Paleozoik metaporfiroyit- metaasidik kaya, mermer ve şistler meydana getirmektedir (Akkök, 1981; Koçman, 1989; Anonim, 2002). Neojen formasyonlar ve Kuvaterner yaşlı alüvyonlar Sarıgöl ile Afşar ovalarını doldurmuştur. Benzer şekilde Bozdağlar'ın kuzeyinde biriken sedimentler, Kuvaternerde meydana gelen tektonik faaliyetler sebebiyle yükselmiş, bugün hafif tepelik alan haline gelmiştir (Koçman, 1989). Bu araziler tarımın en çok yapıldığı, eğimin az ve orman örtüsünün bulunmadığı, toprağın 50 cm'den daha derin olduğu, I., II., III. ve IV. sınıf arazileri oluşturmaktadır. Metamorfik kayaçların toprak ana materyalini oluşturduğu alanlarda ise eğim nispeten fazla, toprak kalınlığı genellikle sığ, erozyon etkinliği fazla, orman örtüsü, fundalık, mera ve tarım arazisi olarak kullanılan, V., VI., VII., VIII. sınıf araziler bulunmaktadır (Anonim, 1974; İydir ve Özdemir, 2024).

İlçenin ova tabanlarında görülen iklim tipi Akdeniz iklimine benzemekte olup sıcaklık değerleri nadir olarak eksi derecelere düşmektedir. Çalışma sahasının içerisinde yer alan Sarıgöl ve Afşar ovaları, graben oluşumlu çöküntü alanları olmaları sebebiyle dağlık alanlarda yükselti birden artmakta; bu durum kısa mesafede sıcaklık ve yağış koşullarını değiştirmektedir. İlçede yükseltinin dağılışı 170-1338 metreler arasında değişmektedir. Temmuz ayı sıcaklık ortalaması 27.5 ℃, Ocak ayı sıcaklık ortalaması ise 6.9 ℃ 'dir. Sarıgöl'e kışın 150.5 mm, ilkbaharda 120.9 mm, yazın 59.46 mm, sonbaharda 81.92 mm yağış düşmektedir. Çalışma sahası ile benzer coğrafi koşullara sahip Alaşehir'de toprak sıcaklığı Temmuz ayında 5 cm derinlikte 33.2 ℃ iken, Ocak ayında 6.6 ℃'dir. 50 cm derinlikte ise sıcaklıklar Temmuz ayında 29.9℃, Ocak ayında 8.5 ℃'dir (Anonim, 2019b). Toprak taksonomisine göre yapılan değerlendirmede (Anonim, 1999) Sarıgöl'de Akdeniz iklimine benzer bir sıcaklık-yağış dağılımı olması, toprakların Xerik nem rejimine ve termik sıcaklık rejimine sahip olduğunu göstermektedir.

Figure 1. Study area Sarıgöl District

Şekil 1. Çalışma Alanı Sarıgöl İlçesi

2.2. Yöntem

Toprak Örneklemesi ve Analizler

Çalışma kapsamında Sarıgöl ilçesi sınırları içerisinden 1 -2 kg ağırlığında, 2 farklı derinlikten olmak üzere toplamda 78 adet bozulmuş toprak örneği serbest örnekleme yöntemi ile alınmıştır. Her örneklem noktasının coğrafi koordinatları Yer Konumlama Cihazı (Global Positioning System, GPS) ile kaydedilmiştir. Numune alınan noktaların çevresi fotoğraflanarak toprak tipi, yükselti ve lokasyonu, çevresinde yer alan bitki örtüsü, arazi kullanım modeli, taşlılık durumu, ana materyal, yer aldığı morfolojik ünite özellikleri not edilmiştir. Numune alma işlemi doğal ortam

koşullarının aynı olmasına, toprağın çok kuru veya çok ıslak olmamasına dikkat edilerek gerçekleştirilmiştir. Çalışma sahasında yer alan ana materyal özelliğine bağlı olarak örneklerin 25 tanesi alüvyal, 10 tanesi migmatit-gnays, 4 tanesi kumtaşı-kireçtaşı-çakıl ve çamur taşının oluşturduğu ana materyal üzerinde oluşmuş topraklardan alınmıştır. Çalışma sahasına ait yapısal harita üzerinde numune alınan noktalar *Şekil 2*'de, çalışma sahası fiziki coğrafya haritası *Şekil 3*'te verilmiştir.

Analize uygun miktar toprak üzerinde; toprak bünyesi saturasyon çamurunda Ülgen ve Yurtsever (1995) 'in bildirdiği şekilde belirlenmiştir. Toprak pH değerleri, Jackson (1967) ve Kacar (1995)'e göre saturasyon çamurunda pH metre ile, toplam eriyebilir tuz (%) ise saturasyon çamurunda elektriksel iletkenlik (EC) ölçer ile ölçülmüştür. Toplam kireç ($CaCO_3$) Çağlar (1949) tarafından tarif edildiği şekilde Scheibler kalsimetresinde işleme tabi tutularak, organik madde içeriği (OM) Walkey ve Black (1934) tarafından bildirildiği şekilde ıslak oksidasyon tekniği kullanılarak, toplam azot (N) Kjeldahl yöntemiyle (Jackson, 1967), alınabilir fosfor Olsen (1954)'e göre, değişebilir potasyum, magnezyum, kalsiyum Kacar (1995)'a göre 1 N amonyum asetat ile ekstraksiyon yoluyla belirlenmiştir. Mikro elementler ise (demir, mangan, çinko, bakır) 0.05 DTPA-TEA ekstraksiyon yoluyla AAS'da okunması sonucu tespit edilmiştir (Lindsay ve Norvell 1978).

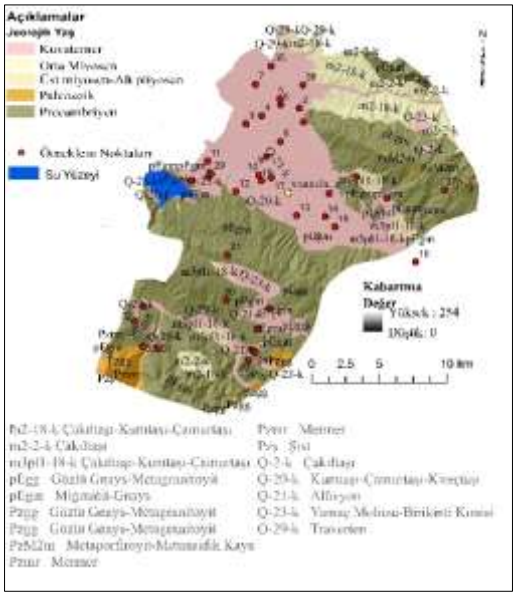


Figure 2. Lithological Map of the Study Area and Sampling Points

Şekil 2. Çalışma Sahasının Litolojik Haritası ve Örneklem Noktaları

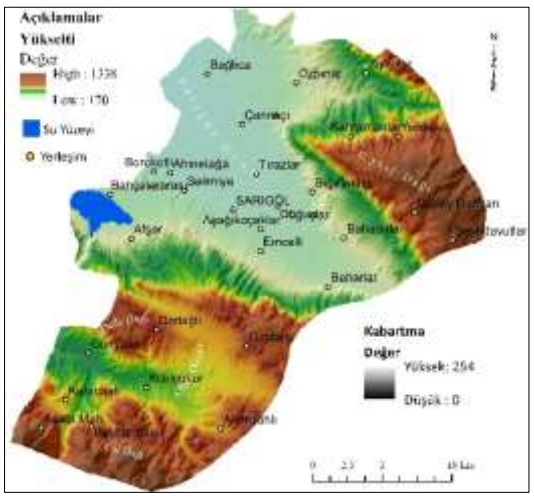


Figure 3. Study Area Physical Geography Map

Şekil 3. Çalışma Sahası Fiziki Coğrafya Haritası

Toprak Özelliklerin Enterpolasyon ile Haritalanması

Çalışma sahasında serbest örnekleme yöntemiyle 39 farklı noktadan alınan toplam 78 adet toprak örneğine ait 14 farklı özelliğin (Saturasyon, pH, tuz, OM, CaO_3, N, P_2O_5, K_2O, Ca, Mg, Cu, Fe, Zn, Mn) analiz sonuçları koordinat bilgisi yardımı ile ArcMAP 10.5 v. yazılımına öznitelik verisi olarak kaydedilmiştir. Toprak haritalarının oluşturulması için tek bir alanda yoğun toprak örneklemesi yapmak ekonomik bir yaklaşım olarak kabul edilmemektedir. Bu sebeple yapılan son araştırmalarda toprakların konumsal değişkenliğini belirlemek için jeoistatistiksel yöntemlerden sıklıkla yararlanılmaktadır (Özyazıcı ve ark., 2016; Ertaş ve Dengiz, 2024). Jeoistatistiksel teknikler, örneklenmemiş konumlar için özellikleri tahmin ederek, tahmin hatalarını ve maliyetleri azaltarak mekânsal dağılımı belirlemek için çok yararlıdır (Nielsen ve Wendroth, 2003; Saito ve ark., 2005). Toprak haritalamada kullanılan parametrelerin mekânsal dağılımlarını tahmin etmek için birçok enterpolasyon yöntemi bulunmaktadır. Bu araştırmada IDW, Ordinary, Simple ve Universal Kriging enterpolasyon teknikleri en az hata ile konumsal dağılım haritalarının üretilmesinde kullanılmış ve karşılaştırılmıştır. IDW enterpolasyon tekniği, enterpolasyon aşamasında matematiksel fonksiyonlar deterministik teknikler ile belirlenirken (Özyazıcı ve ark., 2016), stochastic (jeostatistiksel) yöntemler; tahmin işlemindeki belirsizlik ve hataları ortaya koyabilmek amacıyla hem matematiksel hem de istatistiksel fonksiyonları ortaya koymak amacıyla kullanılmaktadır (Çelik ve Dengiz, 2018). Kriging enterpolasyon tekniklerinin her birinde Spherical, Gaussian ve Exponential yarıvariogram (semivariogram) modelleri ve IDW de ise farklı güç seviyeleri (1, 2 ve 3) test edilmiştir. Jeoistatistikte konumsal değişken değerleri arasındaki farkın uzaklığa bağlı değişimleri variogram fonksiyonu ile ifade edilir. Variogram fonksiyonu, birbirinden h uzaklığındaki iki konumsal değişken arasındaki farkın varyansı olarak ifade edilir ve $2\gamma(h)$ ile gösterilir. Yarıvaryogram (semivariogram) ise variogramın yarısı olarak ifade edilir ve teorik olarak eşitlik 1'deki formül kullanılarak ifade edilir.

$$y(h) = \frac{1}{2n(h)}\sum_{i=1}^{n(h)}[Z(x_i) - Z(x_i + h)]^2 \qquad \text{(Eş. 1)}$$

Burada;

$\gamma(h)$= gecikme mesafesi (h) için yarıvaryogram değeri, n(h)= h mesafedeki nokta çiftleri sayısı, Z(x)= değişkenin değeri

Enterpolasyon teknikleri ve yarıvariogram modellerinde en başarılı modeli belirlemek için en düşük hata kareler ortalaması karekökü (RMSE) değerine sahip model tercih edilerek haritası üretilmiştir. RMSE için Eşitlik 2'deki formül kullanılmıştır (Ding, 2011).

$$\text{RMSE} = \sqrt{\frac{\Sigma(zi-z)^2}{n}} \qquad \text{(Eş. 2)}$$

Zi: Tahmini değer, Z: Gerçek değer, n: Gözlem sayısı

Toprakların bazı fiziko-kimyasal özellikleri ve yarayışlı besin element kapsamına ait verimlilik ilişkilerinin ortaya konulmasında yararlanılan bazı tanımsal istatistik ve korelasyon analizleri Microsoft Excel veri çözümleme eklentisi ile yapılmıştır.

2.Bulgular ve Tartışma

Çalışma Alanı Topraklarının Tanımlayıcı İstatistiksel Özellikleri

Çalışma alanından 0-30 ve 30-60 cm derinliklerden alınan toprak örneklerine ait en küçük, en büyük değerler, standart sapma, varyasyon katsayısı, ortalama, çarpıklık-basıklık gibi tanımlayıcı istatistiklerine ait analiz sonuçları *Tablo 1*'de verilmiştir. Toprak özelliklerindeki değişimin değerlendirilmesinde kullanılan varyasyon katsayısı düşük (% <15), orta (% 15-35) ve yüksek (% >35) olarak sınıflandırılmaktadır (Wilding, 1985). Değerlendirmeye göre iki farklı derinlikte değerlendirilen verimlilik parametreleri arasında en düşük değişkenlik gösteren özellik pH ve N iken, saturasyon değerleri orta düzey değişkenlik göstermiştir. Diğer tüm parametreler ise orta ve yüksek değişkenliğe sahiptir. En yüksek değişkenliğin görüldüğü $CaCO_3$ içeriği, 27 numaralı toprak örneğinin 0-30 cm derinliğinde, Tmolos depolarının yer yer kireçli sedimentlerden oluşan ana materyalin tarla sürümü ile araziye dağılmış olması sebebiyle ortaya çıkmıştır. Bu analiz sonucuna göre kireç üst toprakta 2 kat daha fazla görülmektedir. Benzer çalışmalarda Bayram ve ark. (2023) en az değişkenliği pH (CV=0.02), en yüksek değişkenliği P_2O_5 (CV=1.49), Saraçoğlu ve ark. (2014)'da pH (CV=1.34), P_2O_5 (CV=55.63) olarak belirlemişlerdir.

Tablo 1. Çalışma Alanı Topraklarına Ait Tanımlayıcı İstatistikler

Table 1. Descriptive Statistics of Study Area Soils

Parametreler	Derinlik	EDD	EYD	Ort.	SS	VK	Varyans	Çarpıklık	Basıklık
Saturasyon	0-30	31.46	63.8	44.88	6.91	15.40	47.79	0.65	0.39
	30-60	30.8	72.6	45.43	8.67	19.09	75.29	1.14	1.68
pH	0-30	6.6	8.73	7.72	0.38	5.01	0.14	-0.38	1.63
	30-60	6.36	8.31	7.69	0.45	5.93	0.20	-1.21	1.57
$CaCO_3$, %	0-30	0.81	47.78	3.84	7.81	203.04	61.07	5.07	27.86
	30-60	0.73	18.46	3.23	3.95	122.39	15.67	2.97	9.42
OM,%	0-30	0.06	2.28	0.63	0.47	75.03	0.22	1.77	3.45
	30-60	0.11	1.42	0.53	0.30	56.56	0.09	1.04	0.72
Tuz,%	0-30	0.01	0.49	0.11	0.08	75.22	0.007	2.48	9.05
	30-60	0.02	0.29	0.10	0.076	73.46	0.005	1.12	0.26
Azot (N),%	0-30	0.04	0.06	0.042	0.005	11.91	0.00002	1.61	1.87
	30-60	0.04	0.05	0.042	0.004	9.72	0.00001	1.51	0.32
Fosfor, (P_2O_5) kg da^{-1}	0-30	0.69	31.68	8.29	7.28	87.80	53.01	1.53	2.28
	30-60	0.02	31.05	4.78	5.25	109.85	27.62	3.47	16.22
Potasyum, (K_2O) kg da^{-1}	0-30	10.96	204.75	57.41	45.14	78.62	2037.88	1.50	2.46
	30-60	11.18	297.9	46.65	51.02	109.35	2603.34	3.52	15.50
Kalsiyum, mg kg^{-1}	0-30	776.3	9000	5281.16	3142.53	59.50	9875545.52	0.13	-1.76
	30-60	1185	9000	5112.81	3300.97	64.56	10896422.16	0.19	-1.83
Magnezyum, mg kg^{-1}	0-30	67.61	1144	492.28	224.88	45.68	50572.50	0.86	1.06
	30-60	88.69	1483	484.34	274.28	56.63	75232.54	1.48	3.40
Demir, mg kg^{-1}	0-30	0.61	5.49	2.49	1.05	42.06	1.10	0.60	0.44
	30-60	0.73	6.95	2.40	1.36	56.67	1.85	1.56	3.05
Bakır, mg kg^{-1}	0-30	0.03	3.99	0.71	0.83	115.85	0.69	2.32	6.67
	30-60	0.009	1.85	0.36	0.43	121.76	0.19	2.08	4.16
Çinko, mg kg^{-1}	0-30	0.01	0.91	0.14	0.16	112.08	0.02	2.84	11.61
	30-60	0.01	0.33	0.04	0.05	124.12	0.003	3.59	16.69
Mangan, mg kg^{-1}	0-30	0.03	3.29	1.117	0.83	74.45	0.69	0.73	-0.38
	30-60	0.11	3.62	0.95	0.80	83.42	0.64	1.45	2.41

Normal dağılımı test etmek için kullanılan çarpıklık ve basıklık katsayıları incelendiğinde; her iki katsayının da normal dağılımdan anlamlı düzeyde farklılık göstermemesi ve -1 ile +1 aralığında olması beklenmektedir (Pearson, 1900). Analiz sonuçlarına göre pH her iki derinlikte normal sınırlar içerisinde negatif çarpık, 0-30 cm derinliğinde saturasyon, Ca, Mg, Fe ve Mn normal sınırlar içerisinde pozitif çarpıklık göstermektedir. 30-60 cm derinliğinde ise yalnızca Ca normal sınırlar içerisinde pozitif çarpık iken, diğer veriler normale yakın pozitif dağılım göstermektedir. Toprakların Ca ve Mn dağılımlarında, eğri normale göre daha basık olarak belirlenmiştir. Yapılan benzer araştırmalarda topraklara ait analiz sonuçlarının istatistiki olarak farklılıkların ortaya çıkabileceği ortaya konulmuştur (Atalay, 1987; Alaboz ve ark., 2020; Ertaş ve Dengiz, 2024). Nitekim örneklem alanında toprakların oluşum süreçlerini etkileyen faktörler ve toprağa uygulanan muamele farklılık göstermekte, bu durum analiz sonuçlarında etkili olmaktadır.

Toprakların bazı fiziko-kimyasal verimlilik özellikleri

Çalışma alanından 0-30 ve 30-60 cm derinlikten alınan toprak örneklerinin bazı fiziko-kimyasal özelliklerinin değerlendirilmesi ve sınıflandırılması *Tablo 2* ve *Tablo 3*'te verilmiştir. Saturasyon sonuçlarına göre yüzey toprakları %31.46 ile %63.8 aralığında, yüzey altı toprakları ise %30.8- 72.6 aralığında değer göstermiştir. Ülgen ve Yurtsever (1995) tarafından önerilen değerlendirmeye göre çalışma sahasında toprakların %82 si tınlı bünyede, %18'i ise killi-tınlı bünyededir. Dağılış haritaları incelendiğinde Sarıgöl'ün kuzeyinde yer alan neojen killi-kireçli depoları ve bu metaryaden etkilenen alüvyal arazide kil içeriğinin arttığı görülmektedir. Menderes masifine ait temeli oluşturan kayaçların bulunduğu Sarıgöl'ün güneyinde yer alan Dede Dağı, Tmolos (etek döküntüleri) depoları ve Afşar Ovası ile çevresindeki arazilerde toprak bünyesi tınlı, tınlı-kumlu aralığında değişim göstermektedir. Toprağın fiziksel, kimyasal ve biyolojik özellikleri üzerinde etkili olan en önemli unsurlardan birisi de toprak pH'sıdır (Brady ve Weil, 2008). Toprak pH'sına bakılarak toprağın asit-alkalin aralığında olma durumuna göre eksik olabilecek bitki besin elementleri tespit edilebilmektedir (Eyüpoğlu, 1999).

Tablo 2. Toprakların Bazı Fiziko-Kimyasal Özelliklerinin Dağılımı ve Sınıflandırılması

Table 2. Distribution and classification of some physico-chemical properties of soils

Sınır Değeri		Değerlendirme	0-30 cm Örn. Sayısı	%	30-60 cm Örn. Sayısı	%
Saturasyon % (Ülgen ve Yurtsever, 1995)	<30	Kumlu	-	-	-	-
	31-50	Tınlı	32	82	32	82
	51-70	Killli-tın	7	18	6	15
	71-1 10	Killi	-	-	1	3
	>110	Ağır Killi	-	-	-	-
pH (Richards, 1954; Ülgen ve Yurtsever, 1995)	<4.5	Kuvvetli asit,	-	-	-	-
	4.5-5.5	Orta Asit	-	-	-	-
	5.5-6.5	Hafif Asit	-	-	2	5
	6.5-7.5	Nötr	10	26	9	24
	7.5-8.5	Hafif Alkalin	28	72	27	71
	>8.5	Kuvvetli Alkalin	1	2	-	-
$CaCO_3$ % (Hızalan ve Ünal, 1966)	0-2	Kireçsiz	24	62	25	63
	2-4	Az Kireçli	9	23	5	13
	4-8	Orta Kireçli	4	10	7	18
	8-1 5	Kireçli,	-		-	-
	15-50	Çok Kireçli,	2	5	2	5
	>50	ÇokFazlaKireçli	-			-
OM % (Charman ve Murphy, 2007; Emerson, 1991)	<0.70	Çok Aşırı Düşük	27	69	27	69
	0.71-1.00,	Çok Düşük	6	15	8	21
	1.01-1.70	Düşük	5	13	4	10
	1.71-3.00	Orta	1	3	-	-
	3.01-5.15	Yüksek	-	-	-	-
	>5.15	Çok Yüksek	-	-	-	-
Tuz % (Richards, 1954)	<0.15	Tuzsuz	31	79	29	74
	0.15-0.35	Hafif Tuzlu	7	18	10	26
	0.35-0.65	Orta Tuzlu,	1	3	-	-
	>0.65	Çok Tuzlu	-	-	-	-

Yüzey topraklarında pH değeri 6.6-8.73, yüzey altı topraklarında ise 6.36-8.31 aralığında değer göstermektedir. Önerilen değerlendirmeye göre (Richards, 1954; Ülgen ve Yurtsever, 1995) Sarıgöl'de yüzey topraklarının % 72'si hafif alkalin, % 26'sı nötr, % 2'si kuvvetli alkalin; yüzey altı topraklarının ise % 71'i hafif alkalin, % 24'ü nötr, % 5'i hafif asit reaksiyon göstermektedir. Sarıgöl Ovası ve çevresinde toprak alkaline dönmekte, dağlık sahalarda ise nispeten nötr karakter kazanmaktadır. Toprak organik madde miktarı yüzey topraklarında % 0.06- 2.28 aralığında; yüzey altı topraklarında ise % 0.11- 1.42 aralığında değer göstermiştir. Emerson (1991) ve Charman ve Murphy (2007) tarafından yapılan önerilen değerlendirme kriterlerine göre ilçe topraklarının organik madde miktarı düşüktür. Yüzey toprağında görülen küçük bir artış, yüzey altı toprağında bulunmamaktadır. Tarımsal faaliyetler ile toprağa eklenen biyolojik kökenli gübrelerin sonuçlar üzerinde ekili olduğu düşünülmektedir. Özden ve ark. (2022) tarafından Manisa ili topraklarında yapılan araştırmada tüm il topraklarının % 66'sının düşük düzeyde organik madde içerdiği, IDW yöntemi ile oluşturulan dağılım haritalarına göre Sarıgöl topraklarının % 1-2 arasında organik madde miktarına sahip olduğu görülmektedir. Toprak verimliliği üzerinde etkili olan bir diğer unsur topraktaki kireçtir. Nitekim toprakta kirecin yüksek olması başta P, Zn, Fe gibi besin elementlerinin bitkiler tarafından yarayışlılığını olumsuz yönde etkileyebilmektedir. Hızalan ve Ünal (1966) tarafından belirlenen değerlendirme kriterlerine göre yüzey toprakların % 62'si kireçsiz, % 23 'ü az kireçli, % 10'u orta ve % 5'i çok fazla kireçlidir. Yüzey altı topraklarında da benzer dağılım görülmektedir. Genel olarak ilçede topraklar kireçsizdir. Ancak, kireç içeriği yüksek olarak bulunan 28 numaralı örneklem noktasının 0-30 cm derinliğinde kireç % 48, 30-

60 cm derinliğinde ise % 17 olarak bulunmuştur. 30 numaralı örnekte ise iki derinlikte % 18 kireç bulunmuş, bu iki örneklem noktasında normalden fazla değere rastlanılmıştır. Bunun sebebi alüvyal arazi üzerinde yer yer bulunabilen kireçli ana materyaline bağlı olduğu düşünülmektedir.

Sarıgöl'de toprakların tuz içeriği düşüktür. Yüzey topraklarında % 0.01- 0.49 aralığında dağılım gösteren sonuçlar, yüzey altı toprağında % 0.02-0.29 aralığında bulunmuştur. Richards (1954) tarafından önerilen değerlendirmeye göre yüzey topraklarının % 79'u tuzsuz, % 18'i hafif tuzlu ve % 3'ü orta tuzludur. Orta tuzlu değer gösteren numune yüzey toprağında 19. numune iken, yüzey altı toprağında da en yüksek değer aynı noktaya ait olup hafif tuzlu değer tespit edilmiştir. Yüzey altı topraklarının % 76'sı tuzsuz, % 24'ü hafif tuzlu değer göstermiştir. Yeşiltepe, Doğuşlar, Sığırtmaçlı mahalleleri çevresinde ve eğimin azaldığı Sarıgöl Ovası'nın Tırazlar, Çanakçı mahalleleri çevresinde alüvyal arazide orta derece tuzluluk bulunduğu görülmüştür. Toprak-Su Genel Müdürlüğü (MÜLGA) tarafından Gediz Havzası toprakları üzerinde yapılan toprak envanter çalışmasında hafif drenaj sorunu tespit edilen alan ile, tarafımızdan yapılan dağılım haritalarında tuz artışı görülen alanlar ile uyumluluk göstermektedir.

Toprakların Besin Element kapsamı

Yapılan analizlere göre çalışma alanı topraklarının toplam azot içerikleri her iki derinlikte % 0.04–0.05 arasında değişmektedir. FAO (1990)'nun belirlediği sınır değerlerine göre; toprakların tamamının N içeriklerinin düşük olduğu tespit edilmiştir. Toprakta mevcut toplam azotun büyük bölümü (% 96-98) organik formdadır. Küçük bir bölümü ise amonyum, nitrat ve diğer inorganik formlarda bulunur (Brady ve Weil, 2008; Fageria ve ark., 2010). Azottan sonra bitkiler tarafından en fazla kullanılan element potasyumdur. Topraktaki potasyum içeriği ana materyalin özellikleriyle yakından ilgilidir. Menderes Masifi'ni oluşturan gnayslar; feldispat, kuvars, biyotit ve muskovit minerallerini içermektedir (Akkök, 1981). Potasyumlu mineralleri içeren kayaçların parçalanıp dağılması ile çeşitli oranlarda potasyum toprağa karışmaktadır (Sparks and Huang, 1985). Biyotit ayrıştığında açığa çıkan ise potasyum (K) ve magnezyumdur (Mg). Kuvars ayrışmaya son derece dirençlidir ve ayrıştığında demir (Fe) ile silisyum (Si) açığa çıkmaktadır. Muskovit ise ayrışmaya dirençlidir ancak ayrıştığında değişime uğrayarak kil ve kuvarsa dönüşmekte, iyon olarak potasyum (K) ve silis açığa çıkarmaktadır (Akalan, 1965). Toprakta bulunan potasyum primer mineraller ve kile bağlı olduğu için ince bünyeli topraklarda potasyum miktarı fazladır. Sıcak ve kurak iklime sahip bölgelerde oluşan kil içeriği yüksek toprakların potasyumca zengin olduğu bilinmektedir. Sarıgöl topraklarında Richards (1954) ve Tüzüner (1990) tarafından önerilen değerlendirmeye kriterlerine göre genellikle potasyumun yüksek ve çok yüksek düzeylerde dağılış sergilediği görülmektedir. Yüzey toprağında K_2O 10.94-204.75 kg da^{-1} aralığında bulunmuştur. Önerilen değerlendirmeye göre toprakların % 59'u fazla, % 23'ü az, % 13'ü orta ve % 5'i yeter düzey potasyum içermektedir. Yüzey altı topraklarında ise K_2O 11.18-297.9 kg da^{-1} aralığında bulunmuştur. Toprakların % 33'ü fazla, % 26'sı az, % 20'si orta ve % 21'i yeter düzey potasyum içermektedir. Analiz sonuçlarının derinliğe göre değişimi incelendiğinde 17 numaralı toprak örneği hariç, üst toprakta daha fazla potasyuma rastlanmıştır. Türkiye topraklarının % 87'si, Ege Bölgesi topraklarının ise % 79.56'sı potasyumca zengindir (Eyüpoğlu, 1999). Benzer araştırmalarda Sarıgöl'ün neredeyse tamamında tarımsal açıdan yeterli potasyum bulunduğu ifade edilmektedir (Ateş, 2022; Özden ve ark., 2022).

Yüzey topraklarının fosfor içeriği 0.76-31.6 kg da^{-1} aralığında tespit edilmiştir. Yüzey altı derinliğinde ise benzer aralıkta bulunan fosforun üst toprakta genel olarak daha fazla bulunduğu, derinliğe göre azaldığı tespit edilmiştir. Tarımsal açıdan değerlendirme yapılan haritalarda Sarıgöl ilçe merkezi çevresinde fosforun en yüksek değere ulaştığı görülmektedir. Ülgen ve Yurtsever (1995) tarafından önerilen değerlendirilmeye göre yüzey topraklarının % 23'ü çok az, % 33'ü az, % 10'u orta, % 21'i fazla, % 13'ü ise çok fazla fosfor içeriğine sahiptir. Yüzey altı topraklarının % 49'u çok az, % 20'si az, % 15'i orta, % 13'ü fazla, % 3'ü ise çok fazla fosfor içeriğine sahiptir. Fosfor; azot ve potasyumdan sonra bitkilerin en fazla ihtiyaç duydukları elementtir. Toprakta organik ve inorganik fosforun kaynağı kalsiyum fosfat minerallerinin parçalanmasıdır. Organik kısmını ise toprak flora ve faunasının kimyasal parçalanması ile oluşmaktadır (Kacar, 2016). Asit veya kalker içermeyen kayaçlardan oluşan topraklar daha az, kireçtaşı, marn gibi benzeri materyalden oluşan topraklar daha fazla fosfor içermektedir (Kacar, 1995). Ayrıca fosfor içeriklerindeki farklılığın nedeni tarım yapılan arazilerde çiftçilerin farklı miktarlarda fosfor içerikli gübre kullanmasıdır (Çelik ve Dengiz, 2018). Özellikle Sarıgöl'ün kuzey bölgesinde yer alan traverten deposu, Afşar Ovası'nda yer alan mermerler ve çevresi, Tmolos depolarında var olan kireçtaşı gibi kalker ana materyaller ve çevresinde bir miktar artış gösteren fosfor değerleri doğal olarak karşılanmaktadır. Yalnızca Sarıgöl

merkezi çevresinde fosfor değeri kabul edilebilir sınırın 3 katına çıkmaktadır. Benzer araştırmalarda bu değişken dağılım görülmektedir. Örneğin Eyüpoğlu (1999) Ege Bölgesi topraklarının % 19.72'sinin çok az, % 28.58'inin az % 20'sinin orta, % 11'inin yüksek ve yaklaşık % 30'unun çok yüksek fosfor içerdiğini tespit etmiştir.

Çalışma sahasında makro elementlerden olan kalsiyumun dağılımı değerlendirildiğinde yüzey toprağında en düşük 776 mg kg^{-1} , yüzey altı toprağında en düşük 1186 mg kg^{-1} olarak tespit edilmiştir. En yüksek değer ise iki derinlikte 9000 mg kg^{-1} olarak tüm ortaya çıkmıştır. Dağılım haritalarında kalsiyumun yüksek olduğu saha Sarıgöl Ovası ve Neojen depoları olduğu görülmektedir. Bu alanlarda yıllık yağış ortalaması yükselti de dikkate alındığında 400-650 mm civarındadır. Loue (1968) ve Pizer (1967) tarafından önerilen değerlendirmeye göre yüzey topraklarının % 64'ü yüksek, % 31'i orta ve % 5'i düşük düzey kalsiyum içermektedir. Yüzey altı topraklarında ise durum benzer olup topraklarının % 59'u yüksek, % 23'ü orta ve % 18'i düşük düzey kalsiyum içermektedir. Kalsiyumun yüksek olduğu alanlarda toprak reaksiyonu hafif alkalindir. Ateş (2022), Sarıgöl bağ alanlarında yaptığı çalışmada kalsiyum içeriğini 360.8-9000 ppm aralığında tespit etmiştir. Değerlendirmeye alınan bir başka makro elementte magnezyumdur. Magnezyum yüzey toprakları 67.61-1144 mg kg^{-1} aralığında değer göstermekte iken yüzey altı toprakları 88.69-1483 mg kg^{-1} aralığında değer göstermektedir. Magnezyumun derinlikle ilişkisinde iki derinlikte de benzer sonuçlar elde edilmiş olup önerilen değerlendirmeye göre (FAO, 1990) toprakların % 54'ü yeterli, % 44'ü fazla, %2'si az düzeyde magnezyuma sahiptir. Dağılım haritaları incelendiğinde, magnezyumun kritik derece yüksek olduğu sahalar Sarıgöl Ovası orta kısımları ve drenaj sorunu yaşanan alana denk gelmektedir. Ayrıca Karacaali yerleşmesi çevresinde de bir miktar artış olduğu görülmektedir. Toprakta magnezyum elementinin bulunması toprağın oluşumu esnasında magnezyum içeren minerallerin dağılıp parçalanma derecesiyle yakından ilgilidir. Silikat, mafik ve ultra mafik gibi derinlik kayaçları magnezyumun başlıca kaynağıdır (Atalay, 2006). Sarıgöl'e yakın bir lokasyon olan Manisa Selendi ilçesi topraklarında Sökmen ve ark. (2024) tarafından yapılan araştırmada toprakların % 44'ünde yeter, % 39'unda fazla düzey magnezyum tespit edilmiştir.

Araştırma kapsamında 4 mikro element (Fe, Cu, Zn, Mn) değerlendirilmiştir. Yüzey topraklarının demir içeriği 0.61-5.4 mg kg^{-1} aralığında değer göstermekte, önerilen değerlendirmeye göre (Lindsay ve Norvell, 1978) toprakların % 54'i düşük, % 41'i orta, % 3'ü ise yüksek düzey demir içermektedir. Yüzey altı topraklarının demir içeriği 0.73-6.95 mg kg^{-1} aralığında değer göstermekte toprakların % 54'ü düşük, % 44'ı orta, % 2'si ise yüksek düzey demir içermektedir. Kurak ve yarı kurak iklime sahip bölge topraklarında, toprakların fazla miktarda kireç içermesi ve yüksek pH'lara sahip olması demir eksikliğine sebep olduğu bildirilmektedir. Demir elementi dağılım haritaları incelendiğinde Sarıgöl Ovası'nda ilçe merkezi, Çanakçı, Tırazlar, Afşar ve Emcelli mahalleri arasında, yerel adı Üzüm Ovası olarak bilinen Dadağlı, Hacılar, Abdal yerleşmelerinin bulunduğu ve kısmen Dede Dağı yamaçlarını içine alan alanda demir elementinin yüksek değerlere ulaştığı görülmektedir. Analiz sonuçlarına göre yüzey topraklarının bakır içeriği 0.03-3.99 mg kg^{-1} aralığında değer göstermekte, yapılan sınıflandırmada (Follet, 1969) toprakların % 68'i yeterli, % 32'si yetersiz düzey bakır içermektedir. Bakır elementi dağılım haritasına göre elementin Sarıgöl Ovası'nda, ilçe merkezi çevresinde Ahmetağa, Çanakçı, Tırazlar ve Emcelli mahalleleri arasında en yüksek değerlere ulaştığı görülmektedir. Yüzey altı topraklarının bakır içeriği ise 0.09-1.85 mg kg^{-1} aralığında değer göstermekte, toprakların % 51'i yetersiz, % 49'u yeterli düzey bakır içermektedir. Değerlendirilen bir başka mikro element ise Türkiye'de en fazla eksikliği hissedilen mikro elementlerden çinkodur (Eyüpoğlu ve ark., 1998). Sarıgöl topraklarının ortalama 0.5 mg kg^{-1} düzeyinde ve daha düşük değerde çinko içerdikleri belirlenmiştir. Yalnızca 17 numaralı örneklemde 0.91 mg kg^{-1} değer görülmüştür. FAO (1990) tarafından önerilen değerlendirmeye göre yüzey topraklarının % 72'sinde, yüzey altı topraklarının % 98'inde çinko miktarı çok düşüktür. Reaksiyon değeri yüksek kireçli alkalin topraklarda bitkiye yarayışlı Zn miktarı yeterli düzeyde değildir (Datnoff ve ark., 2007; Fageria ve ark., 2010). Sarıgöl'de ve çevresi bitkilerde Zn noksanlığı oluşması muhtemeldir.

Toprakların mangan içeriğinin 0.03-3.29 mg kg^{-1} aralığında, yüzey altı topraklarının ise 0.11-3.62 mg kg^{-1} aralığında olduğu tespit edilmiştir. Mangan elementi <4 mg kg^{-1} çok düşük olarak kabul edilmektedir (FAO ,1990). Elde edilen analiz sonuçlarının tamamı bu sınır değerin altında olduğundan toprakların %100'ünde mangan değeri düşüktür. Mangan düzeyinin düşük olması çoğunlukla toprağın kireç miktarının yüksekliği ya da pH'sının yüksek olmasıyla ilişkilendirilmektedir (McCauley ve ark., 2009; Kacar ve Karkat, 2010).

Tablo 3. Toprakların Besin Element Kapsamı Dağılımı ve Sınıflandırılması

Table 3. Distribution and classification of nutrient content of soils

	Sınır Değeri	Değerlendirme	0-30 cm Örn.Sayısı	%	30-60 cm Örn. Sayısı	%
N % (FAO, 1990)	<0,05	Fakir	39	100	39	100
	0,05-0,10	Orta	-	-	-	-
	0,10-0,15,	İyi	-	-	-	-
	>0,15	Zengin	-	-	-	-
K_2O kg da^{-1} (Richarts,1954; Tüzüner, 1990)	0-20	Az	9	23	10	26
	20-30	Orta	5	13	8	20
	30-40	Yeter	2	5	8	21
	>40	Fazla	23	59	13	33
P_2O_5 kg da^{-1} (Ülgen ve Yurtsever, 1995)	<3	Çok Az	9	23	19	49
	3-6	Az	13	33	8	20
	6-9	Orta	4	10	6	15
	9-15	Fazla,	8	21	5	13
	>15	Çok Fazla.	5	13	1	3
Ca mg kg^{-1} (Loue, 1968; Pizer, 1967)	<714	Çok Düşük	-	-	-	-
	714-1430	Düşük	2	5	7	18
	1430-2860	Orta	12	31	9	23
	>2860	Yüksek	25	64	23	59
Mg mg kg^{-1} (FAO, 1990)	< 50	Çok Az	-		-	-
	50-160	Az	1	2	1	2
	160-480	Yeterli	21	54	21	54
	480- 1500	Fazla	17	44	17	44
	> 1500	Çok fazla	-		-	-
Fe mg kg^{-1} (Lindsay ve Norvell, 1978)	<2.5	Düşük	22	56	21	54
	2.5-4.5	Orta	16	41	17	44
	>4.5	Yüksek	1	3	1	2
Cu mg kg^{-1} (Follet, 1969)	< 0.2	Yetersiz	12	32	20	51
	>0.2	Yeterli	25	68	19	49
Zn mg kg^{-1} (FAO, 1990)	0,2	Çok Düşük	29	72	38	98
	0,2-0,7	Düşük	9	25	1	2
	0,7-2,4	Orta	1	3	-	-
	2,4-8,0	Yüksek	-	-	-	-
Mn mg kg^{-1} (FAO,1990)	<4	Çok Düşük	39	100	39	100
	4-14	Düşük	-	-	-	-
	14-50	Orta	-	-	-	-
	50-170	Yüksek	-	-	-	-
	>170	Çok Yüksek	-	-	-	-

Tespit Edilen Toprak Özelliklerinin Konumsal Dağılımları

Değerlendirilen her bir toprak özniteliği için Gaussian, Exponential ve Spherical semivariogram modelleri denenmiş elde edilen en düşük RMSE (Root Mean Square Error -Ortalama Hata Kareleri Toplamının Karekökü) ve RMSSE (Standardize Karekök Ortalama Hata-Root Mean Square Standardized Error) sonuçları *Tablo 4*'te verilmiştir. Toprak özellikleri değişkenliği yüksek verilerdir. Saturasyon, pH ve azotun her iki derinliği, demir ve çinkonun yüzey derinliği, Mn'nin yüzey altı derinliği hariç diğer tüm veri setlerine log dönüşümü uygulanarak daha düşük RMSE değeri elde edilmiştir. Ayrıca RMSSE değerleri dikkate alınmıştır. Nitekim RMSSE değeri 1'e

Tablo 4. Parametrelere Ait RMSE ve RMSSE Değerleri

Table 4. RMSE and RMSSE values of parameters

Toprak Özelliği	Yüzey			Yüzey altı		
	Yöntem	RMSE	RMSSE	Yöntem	RMSE	RMSSE
Sat.	Gaussian, Universal Kriging	6.366	1.068	Gaussian, Universal Kriging	7.781	0.912
pH	Gaussian, Simple Kriging	0.343	0.983	Spherical, Simple Kriging	0.397	0.881
$CaCo_3$	Exponential, Simple Kriging	6.476	1.027	Exponential, Simple Kriging	2.921	0.698
OM	Exponential, Simple Kriging	0.467	0.858	Gaussian, Ordinary Kriging	0.278	0.719
Tuz	Exponential, Simple Kriging	0.079	0.959	Spherical, Ordinary Kriging	0.065	0.870
N	Gaussian, Ordinary Kriging	0.005	1050	Gaussian, Ordinary Kriging	0.003	1.052
K_2O	Exponential, Ordinary Kriging	36.354	0.971	Exponential, Ordinary Kriging	47.113	0.997
P_2O_5	Spherical, Simple Kriging	7.019	0.751	Spherical, Simple Kriging	5.004	0.412
Ca	Exponential, Ordinary Kriging	2071.0	0.694	Exponential, Ordinary Kriging	2208.8	0.582
Mg	Exponential - Ordinary Kriging	218.5	0.904	Exponential, Ordinary Kriging	266.3	0.906
Fe	Exponential, Simple Kriging	1.036	0.999	Spherical, Simple Kriging	1.325	0.974
Cu	Spherical, Ordinary Kriging	0.654	0.802	Gaussian, Ordinary Kriging	0.364	0.849
Zn	Gaussian, Ordinary Kriging	0.122	0.944	Spherical, Ordinary Kriging	0.060	1.198
Mn	Spherical, Ordinary Kriging	0.564	0.743	Gaussian, Ordinary Kriging	0.600	0.951

ne kadar yakınsa enterpolasyon hatasının o denli az olduğu kabul edilmektedir. Yüzey topraklarında saturasyon için UK Gaussian (RMSSE: 1.068), pH için SK Gaussian (RMSSE :0.983), $CaCO_3$ (RMSSE: 1.027), OM (RMSSE:0.858) ve tuz (RMSSE: 0.959) için SK Exponantial uygun model olarak belirlenmiştir. Makro elementlerden azot için en uygun modelin OK Gaussian (RMSSE: 1050), potasyum için OK Exponential, fosfor için SK Spherical (RMSSE: 0.751), kalsiyum (RMSSE:0.694) ve magnezyum (RMSSE:0.904) için OK Exponential model olduğu ortaya çıkmıştır. Mikro elementlerde ise demir (RMSSE:0.999) için SK Exponential model uygun iken, bakır (RMSSE:0.802) ve mangan için (RMSSE:0.743) OK Spherical, çinko (RMSSE:0.944) için OK Gaussian modelin uygun olduğu sonucuna ulaşılmıştır. Yüzey altı topraklarında ise pH (RMSSE:0.881) SK Spherical, OM (RMSSE:0.719), Mn (RMSSE: 0.951) ve bakır (RMSSE:0.849) OK Gaussian, Tuz için ise (RMSSE: 0870) OK Spherical model uygun bulunmuştur. En yüksek doğrulukla tahmin edilen özellik potasyum, en yüksek hata yüzey altı toprağında fosfor veri setindedir. Yüzey topraklarına ait incelenen özeliklerin yersel otokorelasyon gösterdiği mesafeler en yüksek organik madde içeriğinde (21091 m) en düşük çinkoda (1960 m), yüzey altı topraklarında ise en yüksek organik madde (11974 m) en düşük ise kireç ve pH (1585 m) içeriği değerlerinde hesaplanmıştır. Hesaplanan değişim aralığı, bu aralığın dışındaki noktaların yersel olarak birbirlerinden bağımsız olduğu (Wang ve ark. 2008) ve değerlerin aynı zamanda o özellik için alınması gereken maksimum örnekleme aralığını da göstermektedir (Ağca ve Çoşar, 2023). Uludağ ve Ağca (2019) Hatay Arsuz Ovası'ndan 41 noktadan 0-30 ve 30-60 cm derinlikten rastgele örnekleme yöntemi ile aldıkları toplam 82 adet bozulmuş toprak örneğinin jeoistatistik değerlendirmesinde etki aralığı değerlerini ise 300 m ile 15300 m arasında, çok geniş sınırlar içinde değiştiğini tespit etmiştir. Yapılan değerlendirme sonucu oluşturulan haritalar *Şekil 4 ve Şekil 5*'te verilmiştir.

Değerlendirilen bir başka enterpolasyon modeli IDW'dir. IDW güç seviyesi arttıkça RMSE değeri K_2O, Ca, Cu, Mn'nin her iki derinliği ve Zn'nin yüzey derinliği hariç genellikle artış göstermiştir. Ayrıca Universal Kriging enterpolasyon yönteminde Zn, Cu, K_2O ve tuzun RMSE değerleri düşük bulunmuş ancak Standartlaştırılmış Ortalama Hata Kareleri Toplamının Karekökü (RMSSE) değeri 1'den çok uzaklaşmıştır. Bu sebeple doğru kabul edilmemiştir. Ertaş ve Dengiz (2024) tarafından Bafra Ovası'nda lahana yetiştirilen topraklar üzerinde yapılan araştırmada OK yönteminde küresel, üssel ve Gaussian semivariogram denenmiştir. Araştırma sonuçlarına göre

yüzey topraklarının kum, kil, silt, P, K ve Cu için küresel semivariogram model uygun olduğu belirlenirken, pH, EC, N ve Zn için üssel semivariogram model en düşük RMSE değerleri olduğu belirlenmiştir. Ayrıca kireç, OM, Ca, Mg, Fe, ve Mn için ise Gaussian model dağılım haritalarının oluşturulmasında uygun model olarak belirlenmiştir.

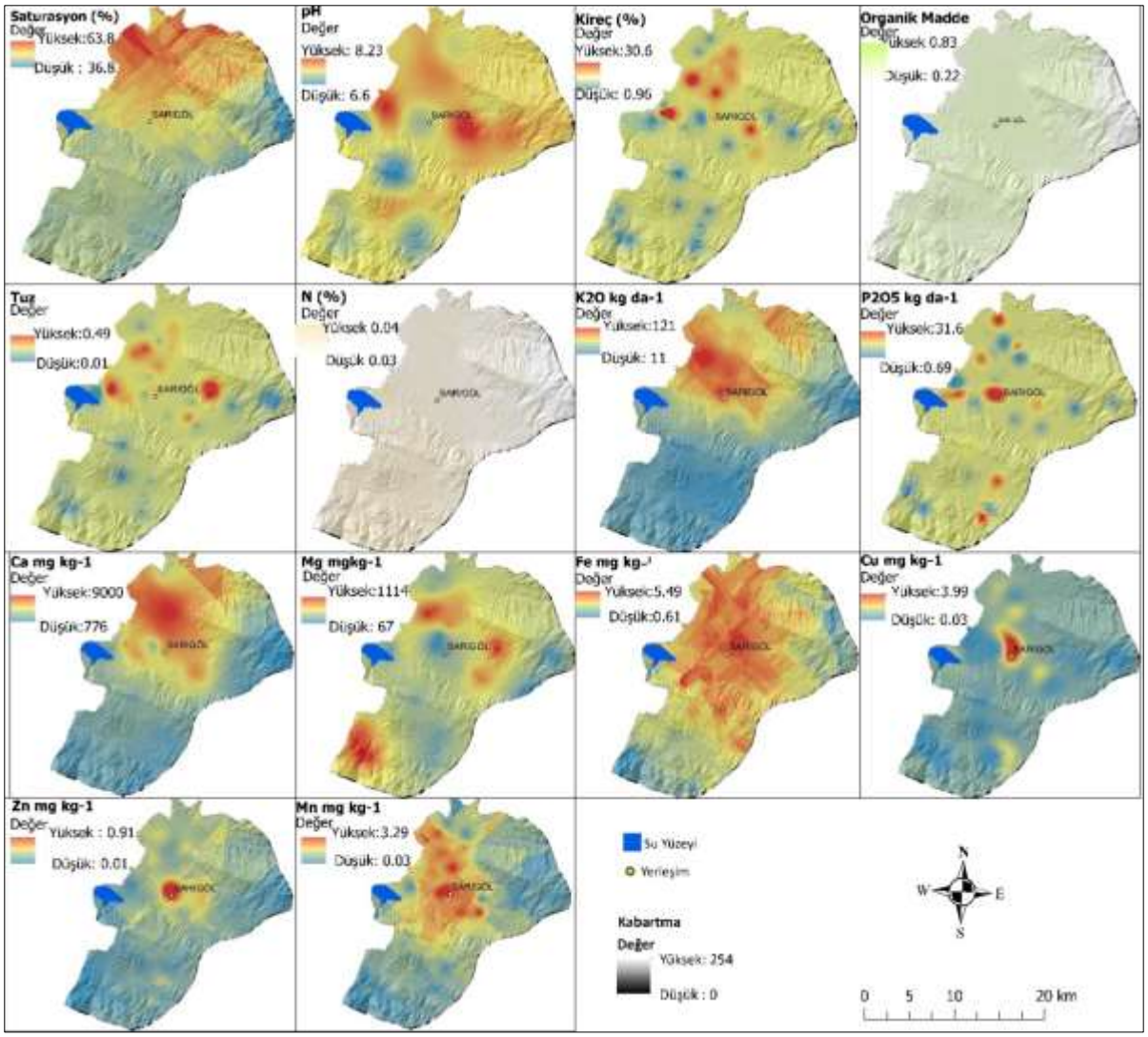


Figure 4. Distribution spatiale des paramètres physico-chimiques et de fertilité des sols de surface

Şekil 4. Yüzey Topraklarına Ait Fiziko-Kimyasal ve Verimlilik Parametrelerinin Alansal Dağılımları

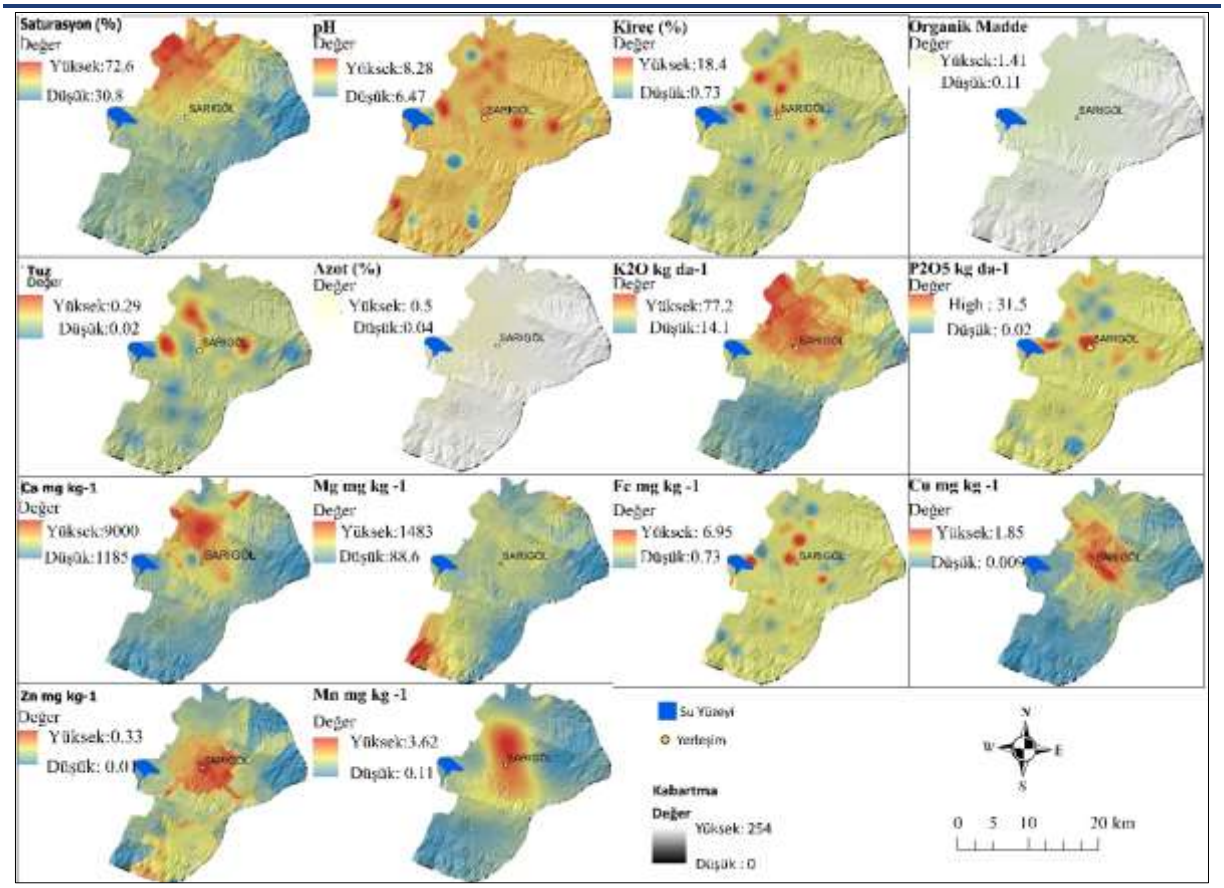
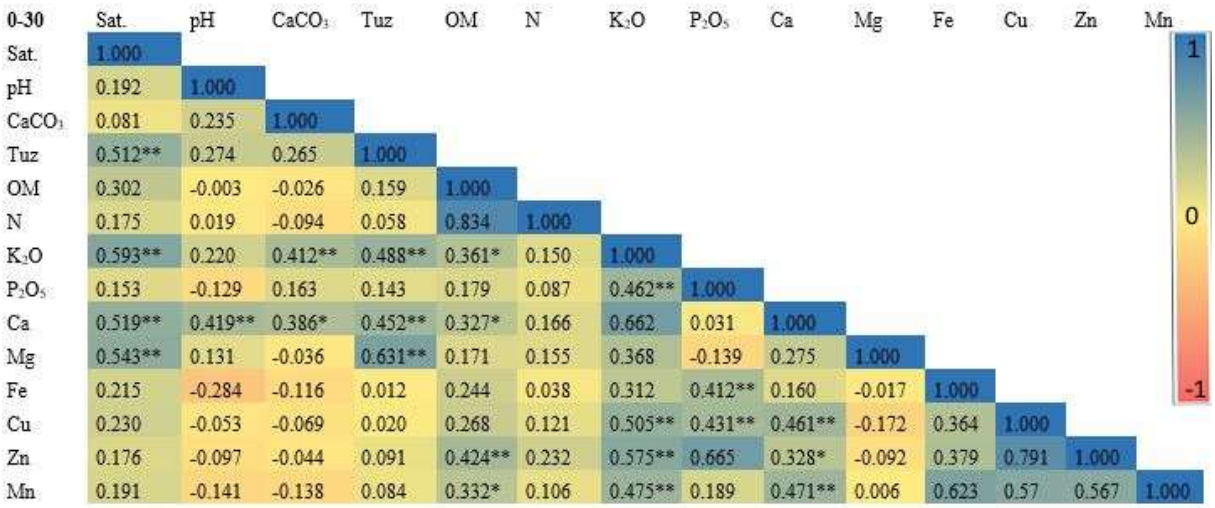


Figure 5. Distribution spatiale des paramètres physico-chimiques et de productivité des sols de subsurface

Şekil 5. Yüzey Altı Topraklarına Ait Fiziko-Kimyasal ve Verimlilik Parametrelerinin Alansal Dağılımları

Çalışma Alanı Topraklarının Korelasyon Analizi

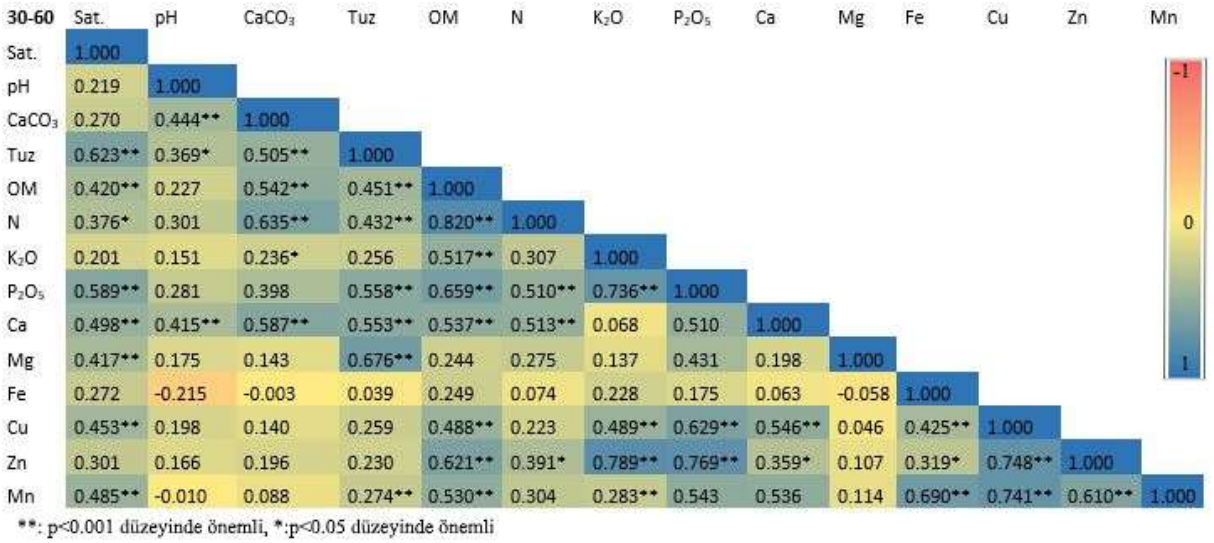
Çalışma alanı topraklarının korelasyon katsayıları *Şekil 6* ve *Şekil 7*'de verilmiştir. İki veri seti arasında korelasyon değeri +1'e yaklaştıkça pozitif yönlü, -1 'e yaklaştıkça negatif yönlü güçlü ilişki bulunmakta, değerler 0' ise iki veri arasında hiç ilişki olmadığı anlaşılmaktadır. İncelenen toprak özellikleri arasında $p< 0.05$ ve $p< 0.01$ düzeyinde önemli korelasyonların elde edildiği görülmektedir. Korelasyon analizi sonuçlarına göre yüzey topraklarında incelenen değişkenler (toprak özellikleri) arasında 25 toprak özelliğinin korelasyon katsayısı $p< 0,01$ önem düzeyinde önemli bulunmuştur. Eğer p-değeri küçükse (örneğin 0.05 veya daha az), bu sonuçları şans eseri elde etme olasılığının olmadığının göstergesi olarak kabul edilmektedir (Field, 2013). Yüzey topraklarının korelasyon ilişkisi değerlendirildiğinde saturasyonun; tuz (r:0.512**), K_2O (r:0,593**), Ca (r:0.519**), Mg (r:0.543**) ile orta düzey pozitif ilişki gösterdiği görülmektedir. Toprak reaksiyonu (pH) ise OM, P_20_5, Fe, Cu ve Zn ile zayıf negatif ilişki, Ca (r:0.499**) ile pozitif orta düzey ilişki göstermektedir. Kireç ($CaCO_3$) ile OM, N, Mg, Fe, Cu, Zn, ve Mn arasında negatif yönde zayıf ilişki bulunmakta iken, kireç ile K_2O (r:0.412**) arasında orta düzeyde pozitif önemli ve Ca (r:0.386*) arasında zayıf pozitif önemli ilişki bulunmaktadır. Eriyebilir tuz ile hiçbir değişken negatif ilişki göstermezken, K_2O (r:0.452**) ve Ca (r:0.452**) orta düzey pozitif ilişki ve Mg (r:0.631**) pozitif yönlü güçlü ilişki göstermektedir. Veri setinde OM ve N (r:0.834**) arasında çok güçlü ilişki, OM ile Zn (r:0.424**) arasında orta düzey pozitif yönlü ilişki görülmektedir. Değişebilir potasyum (K_2O); $P205$ (r:0.462**), Cu (r:0.575**), Zn (r:0.575**), Mn (r:0.475**) arasında pozitif yönlü orta, Ca (r:0.662**) ile pozitif yönlü güçlü ilişki bulunmaktadır. Alınabilir fosfor (P_2O_5); Fe (r:0.412**) ve Cu (r:0.431**) ile pozitif yönlü orta düzey ilişki göstermektedir. Değişebilir kalsiyum (Ca); Cu (r:0.461**) ve Mn (r:0.471**) arasında pozitif yönlü orta düzey korelasyon bulunmaktadır. Mikro elementlerden demir (Fe) ile Mn (r:0.623**) arasında, bakır (Cu) ile Zn (r:0.791**) arasında pozitif yönlü çok güçlü ilişki bulunmaktadır.



0-30	Sat.	pH	$CaCO_3$	Tuz	OM	N	K_2O	P_2O_5	Ca	Mg	Fe	Cu	Zn	Mn
Sat.	1.000													
pH	0.192	1.000												
$CaCO_3$	0.081	0.235	1.000											
Tuz	0.512**	0.274	0.265	1.000										
OM	0.302	-0.003	-0.026	0.159	1.000									
N	0.175	0.019	-0.094	0.058	0.834	1.000								
K_2O	0.593**	0.220	0.412**	0.488**	0.361*	0.150	1.000							
P_2O_5	0.153	-0.129	0.163	0.143	0.179	0.087	0.462**	1.000						
Ca	0.519**	0.419**	0.386*	0.452**	0.327*	0.166	0.662	0.031	1.000					
Mg	0.543**	0.131	-0.036	0.631**	0.171	0.155	0.368	-0.139	0.275	1.000				
Fe	0.215	-0.284	-0.116	0.012	0.244	0.038	0.312	0.412**	0.160	-0.017	1.000			
Cu	0.230	-0.053	-0.069	0.020	0.268	0.121	0.505**	0.431**	0.461**	-0.172	0.364	1.000		
Zn	0.176	-0.097	-0.044	0.091	0.424**	0.232	0.575**	0.665	0.328*	-0.092	0.379	0.791	1.000	
Mn	0.191	-0.141	-0.138	0.084	0.332*	0.106	0.475**	0.189	0.471**	0.006	0.623	0.57	0.567	1.000

Figure 6. Correlation coefficients (r) for the relationships between physico-chemical properties and nutrient element content of surface soils

Şekil 6. Yüzey topraklarının fiziko- kimyasal özellikleri ve besin element kapsamı arasındaki ilişkilere ait korelasyon katsayıları (r)



30-60	Sat.	pH	$CaCO_3$	Tuz	OM	N	K_2O	P_2O_5	Ca	Mg	Fe	Cu	Zn	Mn
Sat.	1.000													
pH	0.219	1.000												
$CaCO_3$	0.270	0.444**	1.000											
Tuz	0.623**	0.369*	0.505**	1.000										
OM	0.420**	0.227	0.542**	0.451**	1.000									
N	0.376*	0.301	0.635**	0.432**	0.820**	1.000								
K_2O	0.201	0.151	0.236*	0.256	0.517**	0.307	1.000							
P_2O_5	0.589**	0.281	0.398	0.558**	0.659**	0.510**	0.736**	1.000						
Ca	0.498**	0.415**	0.587**	0.553**	0.537**	0.513**	0.068	0.510	1.000					
Mg	0.417**	0.175	0.143	0.676**	0.244	0.275	0.137	0.431	0.198	1.000				
Fe	0.272	-0.215	-0.003	0.039	0.249	0.074	0.228	0.175	0.063	-0.058	1.000			
Cu	0.453**	0.198	0.140	0.259	0.488**	0.223	0.489**	0.629**	0.546**	0.046	0.425**	1.000		
Zn	0.301	0.166	0.196	0.230	0.621**	0.391*	0.789**	0.769**	0.359*	0.107	0.319*	0.748**	1.000	
Mn	0.485**	-0.010	0.088	0.274**	0.530**	0.304	0.283**	0.543	0.536	0.114	0.690**	0.741**	0.610**	1.000

**: p<0.001 düzeyinde önemli, *:p<0.05 düzeyinde önemli

Figure 7. Correlation coefficients (r) for the relationships between the physico-chemical properties and nutrient element content of subsurface soils

Şekil 7. Yüzey altı topraklarının fiziko-kimyasal özellikleri ve besin element kapsamı arasındaki ilişkilere ait korelasyon katsayıları (r)

Yüzey altı (30-60 cm) topraklarında incelenen değişkenler arasında korelasyon katsayısı p< 0,01 önem düzeyinde daha fazla veri bulunduğu görülmektedir. Nitekim yüzey altı topraklarında tarım kaynaklı değişim daha az ve veri değişkenliği daha düşüktür. Yüzey toprağında tespit edilen ilişkilere ek olarak yüzey altı topraklarında saturasyon ile OM (r: 0.420**), N (0.376*), Cu (r: 0.453**), Mn (r: 0.458*) arasında pozitif yönlü orta düzey ilişki tespit edilmiştir. Toprak reaksiyonu (pH) ile tuz (r: 0.369*), $CaCO_3$ (r: 0.444**) arasında orta düzey, kireç ile tuz (r: 0.505**), OM (r: 0.542**) arasında orta düzey ilişki bulunmaktadır. Organik madde ile K_2O (r: 0.517**), P_2O_5 (r: 0.569**) Ca (r: 0.537**) Cu (r: 0.488) arasında pozitif yönlü orta düzey, azot ile P_2O_5 (r: 0.510**) Ca (r: 0.513**) arasında pozitif yönlü orta düzey ilişki tespit edilmiştir.

4. Sonuç

Sarıgöl'de çoğunlukla tınlı bünyede tespit edilen topraklar, tuzsuz, hafif alkalin reaksiyonlu, alüvyal arazide yer yer bulunan kireçli ana materyal hariç kireçsiz, organik madde miktarı çok aşırı düşük düzeydedir. Makro elementlerden azotun tüm havzada noksanlığı görülmektedir. Ayrıca fosfor, potasyum, magnezyum ve kalsiyum değişken dağılım sergilemekte, genellikle yeterli ve fazla düzeylerde bulunmaktadır. Havzada çoğunlukla yapılan bağcılık sebebiyle toprağa muamelenin benzer olduğu ve fosfor, potasyum içerikli gübre kullanımının analiz sonuçlarında etkili olduğu görülmüştür. Bu sebeple toprak analizleri yapılarak gereksiz gübre kullanımından kaçınılmalıdır. Toprak verimliliği ve kalitesinin artırılması için organik madde ilavesi elzem görülmektedir. Yeşil gübreleme veya hayvansal kökenli gübreler tarım topraklarına ilave edilmelidir. Toprak reaksiyonu ve kireç mikro elementlerin etkinliğini azaltmaktadır. Tarımsal üretimde bitkilerde ortaya çıkabilecek besin noksanlıkların önüne geçilebilmesi için gübreleme esnasında mikro element içerikli gübreler kullanılmalıdır.

Her bir toprak özniteliğinin dağılım haritalarının oluşturulması için kullanılan semivariogram modelleri arasında yüzey topraklarında expotansial, yüzey altı topraklarında gaussian model ağırlıklı olarak başarılı sonuç vermiş, farklı enterpolasyon yöntemi ile uyumluluk göstermiştir. Semivariogram modellerinde ortaya çıkan etki mesafesi en düşük 1565 metre bulunmuştur. Daha sonra yapılacak besin elementleri ile ilgili çalışmalarda, ya en düşük etki mesafesi olan 1565 metre değerine göre, ya da iki farklı örnekleme aralığı belirlenerek örnek alınmalıdır. Toprak insan neslinin sağlıklı bir şekilde var olabilmesi için önem verilmesi gereken bir doğal kaynaktır. Bu sebeple üzerinde tarım yapılan toprak materyalini iyi tanımak, eldeki bilgilere göre toprağa muamele yapmak önemlidir. Elde edilen sonuçlar toprak özelliklerine ait yersel değişim haritalarının, havza bazında topraklar ile ilgili genel bir bilgi edinilebilmesi açısından son derece yararlı olduğunu göstermektedir. Besin element durumlarının düşük ve yüksek olduğu lokasyonların belirlenmesi tarımsal üretimde planlama yapan idarecilerin ve çiftçilerin karar almalarını kolaylaştırabilecektir.

Etik Kurul Onayı

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

Çıkar Çatışması Beyanı

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

Yazarlık Katkı Beyanı

Planlama: İydir, G., Özdemir, M. A.; Materyal ve Metot: İydir, G.; Veri toplama ve İşleme: İydir, G.; İstatistiki Analiz; İydir, G.; Literatür Tarama: İydir, G.; Makale Yazımı, İnceleme ve Düzenleme: İydir, G., Özdemir, M. A.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Impact of Deficit Irrigation on Forage Yield, Quality, and Drought Tolerance: A Comparative Study of Berseem and Persian Clover Genotypes in a Semi-Arid Region

Kısıtlı Sulamanın Yem Verimi, Kalitesi ve Kuraklığa Tolerans Üzerindeki Etkisi: Yarı Kurak Ekolojik Şartlarda İskenderiye ve İran Üçgülü Genotiplerinin Karşılaştırmalı Bir Çalışması

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Abstract

Clover is recognized as one of the most distinguished forage crops within the leguminous family, particularly suited for temperate and humid regions. Given clover's sensitivity to drought stress, its yield and quality in semi-arid and arid regions heavily depend on the irrigation regimen. Revising irrigation and irrigation strategies due to global climate change is vital in semi-arid ecologies. To determine forage crops and varieties with high water use efficiency will have a key role in animal production in the future. The plants include Berseem clover and Persian clover species that can be grown in semi-arid ecologies. A two-year experiment was carried out in a semi-arid area (Karaj) of Iran, to investigate the impact of shortages of irrigation on production, forage values, efficiency of water use, and drought stress indices across five Berseem and five Persian clover genotypes. There were two levels of irrigation considered: full irrigation (100% moisture requirement) and deficit irrigation (50% water requirement). Among the genotypes studied, Berseem-Win exhibited the highest fresh forage yield (104.48 Mg ha^{-1}) and dry matter yield (17.20 Mg ha^{-1}), Berseem-Ekinaton displayed the greatest plant height (69.63 cm) and leaf area index (2.17), Berseem-Karaj recorded the highest energy content (2.76 Mcal kg^{-1}) and digestible protein (13.69%), and Berseem-Alex showed superior energy efficiency in water use (4.88 Mcal m^{-3}) and digestible protein production (0.246 kg m^{-3}). The Berseem-Alex displayed the greatest drought tolerance. Persian clover genotypes exhibited lower drought tolerance compared to the Berseem genotypes, with the Harat emerging as the most tolerant among the Persian clovers. Overall, the findings suggest that Berseem clover genotypes possess greater potential for forage cultivation within semi-arid and arid areas than Persian clover.

Keywords: Digestible protein, Energy, Stress tolerance, Water-use efficiency

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Öz

Üçgül, baklagiller familyasının en önemli yem bitkilerinden biri olarak kabul edilir ve özellikle ılıman ve nemli bölgelere uygundur. Üçgüllerin kuraklık stresine karşı duyarlılığı göz önüne alındığında, kurak ve yarı kurak bölgelerdeki verimi ve kalitesi büyük ölçüde sulama rejimine bağlıdır. Küresel iklim değişikliği sebebiyle sulama ve sulama stratejilerinin yeniden gözden geçirilmesi yarı kurak iklime sahip ekolojilerde hayati öneme sahiptir. Su kullanım etkinliği yüksek olan yem bitkisi ve çeşit seçimi hayvansal üretimde kilit role sahip olacaktır. Bu bitkiler arasında yarı kurak ekolojilerde yetiştirilebilen İskenderiye üçgülü ve İran üçgülü türleri bulunmaktadır. İran'ın yarı kurak bir bölgesindeki (Karaj) beş adet İskenderiye ve beş adet İran üçgülü genotiplerinde kısıtlı sulamanın verim, yem kalitesi, su kullanım verimliliği ve kuraklık stres indeksleri üzerindeki etkilerini incelemek için iki yıllık deneme yapılmıştır. Denemede iki farklı sulama seviyesi dikkate alınmıştır: haftalık buharlaşma ve su ihtiyacının %100'ünü içeren tam sulama ve haftalık buharlaşma ve su ihtiyacının %50'sini oluşturan kısıtlı sulama. İncelenen genotipler arasında İskenderiye -Win en yüksek yaş ot verimini (104.48 Mg ha^{-1}) ve kuru madde verimini (17.20 Mg ha^{-1}), İskenderiye - Ekinaton en yüksek bitki boyunu (69.63 cm) ve yaprak alanı indeksini (2.17) sergilemiştir. Genotipler arasında İskenderiye - Karaj en yüksek enerji içeriğini (2.76 Mcal kg^{-1}) ve ham protein oranını (%13.69) sağlamıştır. İskenderiye - Alex, enerji (4.88 Mcal m^{-3}) ve sindirilebilir protein üretimi (0.246 kg m^{-3}) parametreleri açısından üstün su kullanım verimliliği göstermiştir. En fazla kuraklık toleransı İskenderiye - Alex genotipinde görülürken İran üçgülü genotipleri, İskenderiye üçgülü genotipleriyle karşılaştırıldığında daha düşük kuraklık toleransı sergilemiştir. Harat, İran üçgülü genotipleri arasında en toleranslı olanı olarak ortaya çıkmıştır. Genel olarak bulgular, İskenderiye üçgülü genotiplerinin kurak ve yarı kurak bölgelerde kaliteli kaba yem üretimi açısından İran üçgülüne göre daha fazla potansiyele sahip olduğunu göstermiştir.

Anahtar Kelimeler: Sindirilebilir protein, Enerji, Stres toleransı, Su kullanım etkinliği

1. Introduction

Recent data show increasing atmospheric CO_2 levels, leading to projected rises in global temperatures and more frequently severe climate occurrences include droughts and heat waves (Ateş, 2016; Staniak, 2019; Staniak et al., 2020). Heatwaves adversely affect plants, especially during critical growth stages, while droughts restrict plant growth due to water scarcity. Both phenomena can significantly reduce agricultural yields (Ateş, 2016; Baghdadi et al., 2023; Balazadeh et al., 2021). Consequently, there's an imperative need for agricultural adaptations to anticipated climate change scenarios, including the cultivation of drought-resistant crop varieties (Ghalkhani et al., 2023; Marshall et al., 2015). According to Gerten and Rost (2009), drought affects two-thirds of international food production. Drought stress has adverse effects on crop development and growth (Baghdadi et al., 2023; Balazadeh et al., 2021; Farhadi et al., 2022). Drought can affect not only forage crops but also many plant groups (Azder et al., 2020). It has been indicated that water stress could diminish plant yields by up to 50% (Lisar et al., 2012; Heydarzadeh et al., 2023). Given these challenges, it becomes paramount to develop forage grasses and legumes resilient to drought stress, especially within forage cropping systems (Marshall et al., 2015, Staniak et al., 2020).

Highly productive pastures with quality forage are essential for ruminant feeding (Liu et al., 2018). Clover stands out as a significant forage crop in temperate, humid zones and is prevalent in Southwest Asia (Balazadeh et al., 2021). However, forage cultivation relies on a sufficient supply of water (Liu et al., 2018), posing challenges in semi-arid regions, exacerbated by local climate change effects and increasing summer drought risks (Ghalkhami et al., 2023). Water deficiency restricts forage legume yields, it's impacts varying based on drought severity and duration (Balazadeh et al., 2021; Liu et al., 2018). Drought sensitivity varies among forage legumes, with white clover (*Trifolium repens* L.) being a notable example. While white clover had significant agricultural importance, it exhibits considerable sensitivity to drought stress (Marshall et al., 2001). Such stress adversely affects forage quality, leading to inconsistent crude protein concentrations in these legumes (Liu et al., 2018; Heydarzadeh et al., 2022). It has been observed varied drought responses across clover varieties (Balazadeh et al., 2021).

Persian clover (*Trifolium resupinatum* L.) is a winter annual plant and is used for grazing or mowing (Tekeli and Ateş, 2006). Drought stress affects autumn forage legumes like Persian clover (*Trifolium resupinatum* L.) depending on growth stages, impacting both dry matter and seed yields (Ateş, 2016). Abiotic stresses, including drought and high temperatures, restrict root growth, nodulation, and nitrogen fixation in legumes (Lipiec et al., 2013). Red clover, known for its high-water consumption, sees a 3 to 34% reduction in the production of dry matter during water shortage circumstances (Chmura et al., 2009). It has been observed changes in protein content, forage quality, and water-soluble carbohydrates in white clover and other legumes under water-deficit conditions (Kuchenmeister et al., 2013; Olszewka, 2004). Berseem clover (*Trifolium alexandrinum*), a key winter forage crop in regions like the Mediterranean and the Middle East, requires irrigation optimization for optimal production, especially in areas extending from Asia to regions like the Australia and United States (Balazadeh et al., 2021; Daneshnia et al., 2016).

The selection of drought-tolerant cultivars aims to identify varieties that exhibit superior stress tolerance compared to others, resulting in minimal yield losses under similar conditions (Ghalkhani et al., 2023). Such cultivars enhance water-use efficiency, allowing plants to optimize water utilization, especially when faced with limited water resources (Baghdadi et al., 2023). Accordingly, the current study aims to examine how different clover genotypes respond to drought stress, focusing on forage quality and stress tolerance indices.

2. Materials and Methods

During the 2017–18 and 2018–19 cropping seasons, the study was carried out at the Experimental Farm of the Seed and Plant Improvement Institute in Karaj, Iran. The experimental place experiences a semi-arid climate distinguished by warm, dry summers and cold, semi-arid winters. Long-term meteorological data from the region indicates an annual precipitation of 251 mm, an annual evaporated water of 2184 mm, an average temperature in the atmosphere of 13.5 °C, and a average temperature of the soil of 14.5 °C. The weather information recorded during the research period and the chemical and physical characteristics of the soil at the location of the experiment are presented in *Table 1* and *2*, respectively.

Table 1. Monthly data on relative humidity, water evaporation, total precipitation, mean, maximum, and minimum air temperatures at the study area for the planting seasons of 2017-18 and 2018-19

Month	Relative Humidity (%)		Evaporation (mm)		Rainfall (mm)		T_{Mean}(°C)		T_{Max} (°C)		T_{Min} (°C)	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
September	34	35	268	266	0	0.81	24	24	32	32	16	17
October	38	53	175	138	4.8	29.12	17	17	24	23	11	11
November	43	73	89	71	0.64	65.91	11	9	17	13	6	5
December	50	62	36	42	4.72	34.32	7	7	12	11	2	4
January	54	61	0	0	19.84	61.53	4	4	9	9	0	0
February	65	56	0	0	30.62	12.23	6	5	11	10	2	1
March	39	59	0	0	14.11	91.94	15	8	21	13	8	3
April	51	57	188	115	45.8	41.86	14	12	20	18	8	7
May	55	44	191	240	57.06	12.03	18	21	26	28	12	13
June	37	29	334	297	7.23	0.02	26	28	34	35	17	19

The research study used a split-plot arrangement in a randomized complete block design with 3 replications. The main plots experienced two measures: full irrigation (100%) and deficit irrigation (50%). The sub-plots comprised ten levels, encompassing five Berseem clover genotypes (Karaj, Ekinaton, Elite, Alex, and Win) and five Persian clover genotypes (Aleshtar, Pars, Zabol, Harat, and Eghlid). Before sowing, soil preparation involved ploughing and leveling. Based on soil analysis results (*Table 2*), We added 50 kg ha^{-1} of N and 150 kg ha^{-1} of P_20_5 chemical fertilizers to the soil (Balazadeh et al., 2021), followed by thorough plowing. Each plot comprised four rows, spaced 50 cm apart, row length of five meters. Planting was done manually on September 11 in both years at a 20 kg ha^{-1} seeding rate. Throughout the growth cycle, field operations including furrow irrigation, weeding, and crust-breaking were carefully carried out.

Table 2. Specific characteristics of the top soil (0–30 cm) at the study location

Year	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Organic matter (%)	EC (ds/m)	pH
2017	0.06	12.6	256	0.58	2.22	7.2
2018	0.05	12.1	248	0.56	2.20	7.2

The stress treatment was applied only after ensuring the plants had established well. In the first year, irrigation was applied at five distinct stages post-planting, while in the subsequent year, it occurred at six stages. Irrigation ceased in early November and resumed in late March of the following spring, with stress initiation beginning April 6th. Across all treatments, irrigation was carried out on a weekly basis. The needed water amount was calculated following the equation suggested by Chaichi et al., (2015):

$$In = 0.623 \times A \times Kc \times ET0 \times IE - 1 \quad \text{(Eq. 1)}$$

where, *In* is the volume of irrigation water in gallons, *0.623* is the constant of equation, *A* indicates the plot area in square feet, *Kc* indicates the crop coefficient, ET_0 reflects the weekly potential evapotranspiration in inches, and *IE* indicates the irrigation efficiency. The constant 0.623 ensures that the volume of irrigation water (In) is expressed in gallons, based on the plot area in square feet and the depth of potential evapotranspiration in inches. The Penman-Monteith approach was used to determine the ET_0 indicates (Allen, 1998). FAO indicates provided the Clover Kc values (Kirda, 2002). For precise measurement and control of water, a volumetric meter was employed. During the study's first year, the entire irrigation volume amounted to 10.125 m^3 for full irrigation and 5.063 m^3 for deficit irrigation. Similarly, in the subsequent year, these volumes were 11.985 m^3 and 5.993 m^3, respectively.

2.1. Measurements and data analysis

The clover was harvested when it reached the 10% flowering stage (Balazadeh et al., 2021), with a total of three cuts conducted annually. Under full irrigation conditions, the first, second, and third harvests took place on

May 19th, June 14th, and July 23rd, respectively. Conversely, in the deficit irrigation treatment, these dates were June 2nd, June 29th, and July 23rd. The two central lines of every plot were sampled to calculate the forage yield. Two-kilogram samples were chosen randomly, dried for 48 hours at 65°C in an oven, and after the first fresh weight was recorded, the material was weighed to determine the dry matter percentage. These dried samples were then ground and pass through a 1 mm sieve to determine the quality of the forage. A composite sample of milled forage from the three cuts was then prepared to evaluate the relative dry matter yield of the genotypes within each plot and cut. Forage quality attributes were assessed using standard chemical methods as outlined by AOAC (2020) and NRC (2007). Leaf Area Meter-LI 3100C was used to evaluate the leaf area index (LAI). Prior to statistical analysis, the Shapiro-Wilk test was conducted to assess data distribution, confirming normality. Bartlett's test was then applied to evaluate the homogeneity of experimental errors across the two study seasons, justifying the use of a combined analysis of variance. In this analysis, year was considered a random effect, while irrigation regime and genotype were treated as fixed effects. The combined analysis of variance was performed using SAS software, and mean comparisons were carried out with the LSD test at a significance level of $p \leq 0.05$. Additionally, drought stress indices, based on the genotypes' dry matter yield, were calculated using the iPASTIC software (Khalili et al., 2014).

3. Results and Discussion

3.1. Results

The ANOVA results revealed a significant triple interaction among year, irrigation regime, and genotype for both fresh forage yield and dry matter yield ($p \leq 0.01$). Additionally, dry matter yield was significantly influenced by the interaction between year and irrigation regime ($p \leq 0.05$) (*Table 3*). In all genotypes and seasons, deficit irrigation reduced both fresh forage and dry matter yields compared to full irrigation, though the genotypes exhibited varying sensitivities to water stress. Under full irrigation in the 2018-19 season, the highest fresh forage yield (104.48 Mg ha^{-1}) was recorded for the Berseem-Win genotype, 12% higher than its yield in the previous year under similar conditions and 162% greater than that of Berseem-Ekinaton under deficit irrigation in 2017-18 (*Figure 1a*). In the 2017-18 season, Berseem-Win and Berseem-Alex produced the highest fresh forage yields under full irrigation (93.72 and 93.62 Mg ha^{-1}, respectively), with Berseem-Elite following closely (88.22 Mg ha^{-1}). The lowest yield was from Persian-Zabol (65.88 Mg ha^{-1}) (*Figure 1a*). Dry matter yield mirrored this trend, with Berseem-Win and Berseem-Alex leading (14.73 and 14.33 Mg ha^{-1}, respectively), while Persian-Zabol again had the lowest (9.10 Mg ha^{-1}) (*Figure 1b*). Under deficit irrigation in 2017-18, Persian clover genotypes outperformed Berseem genotypes in fresh forage yield, with Persian-Pars (52.65 Mg ha^{-1}), Persian-Aleshtar (52.60 Mg ha^{-1}), and Persian-Eghlid (52.35 Mg ha^{-1}) achieving the highest values (*Figure 1a*). Dry matter yield also showed similar patterns, with the Persian clover genotypes generally outperforming the Berseem clover genotypes, except for Berseem-Alex, which produced 8.38 Mg ha^{-1} of dry matter (*Figure 1b*). In the 2018-19 season under full irrigation, most genotypes showed improved performance compared to the previous year. Berseem-Win again had the highest fresh forage yield (104.48 Mg ha^{-1}), followed by Persian-Zabol (103.33 Mg ha^{-1}) and Persian-Harat (99.97 Mg ha^{-1}). Berseem-Karaj also improved, reaching 96.65 Mg ha^{-1} (*Figure 1a*). Dry matter yield followed a similar pattern, with Berseem-Win producing the highest value (17.20 Mg ha^{-1}), followed by Berseem-Karaj and Berseem-Ekinaton (Figure 1b). Under deficit irrigation in 2018-19, genotype performance varied significantly. Berseem-Elite had the highest fresh forage yield (57.25 Mg ha^{-1}), while Berseem-Win performed poorly under water stress, yielding only 43.07 Mg ha^{-1} (Figure 1a). Dry matter yield was highest in Berseem-Elite plots (10.82 Mg ha^{-1}), while Berseem-Win had lowest with 8.21 Mg ha^{-1} (Figure 1b). Overall, Persian clover genotypes showed superior performance under deficit irrigation, highlighting their potential for water-limited environments. In contrast, Berseem genotypes such as Berseem-Win and Berseem-Alex excelled under full irrigation, making them more suitable for high-input systems.

Digestible energy and protein were significantly influenced by the main effect of genotype, as well as the interactions between year × irrigation regime and irrigation regime × genotype ($p \leq 0.01$) (*Table 3*). Under full irrigation, Berseem-Karaj had the highest digestible energy (2.76 Mcal kg^{-1}), outperforming all other genotypes except Berseem-Ekinaton (2.72 Mcal kg^{-1}) and Berseem-Alex (2.73 Mcal kg^{-1}). In contrast, Persian clover genotypes displayed lower digestible energy values (2.47-2.50 Mcal kg^{-1}) (*Figure 2a*). For digestible protein, Berseem-Karaj again had the highest protein content (11.71%), followed by Berseem-Alex (11.27%), Berseem-

Table 3. The analysis of variance for the influence of irrigation system and genotype on the fresh forage yield (FFY), dry matter yield (DMY), digestible energy (DE), irrigation water-use efficiency for DE ($IWUE_{DE}$), digestible protein (DP), irrigation water-use efficiency for DP ($IWUE_{DP}$), plant height (PH), and leaf area index (LAI) of clover

Source of Variation	D.F.	Mean Squares							
		FFY	DMY	DE	$IWUE_{DE}$	DP	$IWUE_{DP}$	PH	LAI
Year	1	306.7^{ns}	15.45^{ns}	0.0048^{ns}	0.061^{ns}	2.40^{ns}	0.0009^{ns}	23.9^{ns}	0.082^{ns}
Block (Year)	4	51.7^{*}	2.05^{*}	0.0007^{ns}	0.192^{ns}	0.24^{ns}	0.0005^{ns}	21.2^{**}	0.039^{ns}
Irrigation regime (I)	1	47000.1^{ns}	827.51^{ns}	0.0033^{ns}	15.703^{ns}	52.18^{ns}	0.0778^{ns}	3138.7^{ns}	13.566^{*}
Year × I	1	529.5^{**}	25.39^{**}	0.0155^{**}	0.213^{ns}	21.30^{**}	0.0012^{ns}	295.2^{**}	0.049^{ns}
I × Block (Year)	4	20.7^{ns}	0.61^{ns}	0.0005^{ns}	0.053^{ns}	0.17^{ns}	0.0001^{ns}	21.7^{**}	0.099^{*}
Genotype (G)	9	37.8^{ns}	7.65^{ns}	0.1743^{**}	1.794^{*}	15.31^{**}	0.0077^{**}	575.1^{**}	1.365^{**}
Year × G	9	94.5^{**}	3.11^{**}	0.0004^{ns}	0.455^{**}	0.21^{ns}	0.0011^{**}	49.0^{**}	0.073^{ns}
I × G	9	143.5^{ns}	3.51^{ns}	0.0010^{**}	0.188^{ns}	2.91^{**}	0.0008^{ns}	29.0^{*}	0.128^{*}
Year × I × G	9	148.3^{**}	2.50^{**}	0.0002^{ns}	0.371^{**}	0.11^{ns}	0.0010^{**}	6.3^{ns}	0.038^{ns}
Error	72	17.6	0.58	0.0013	0.081	0.89	0.0003	5.4	0.036

*, **, and ns: Significant at the probability levels of 0.05 and 0.01 and non-significant, respectively.

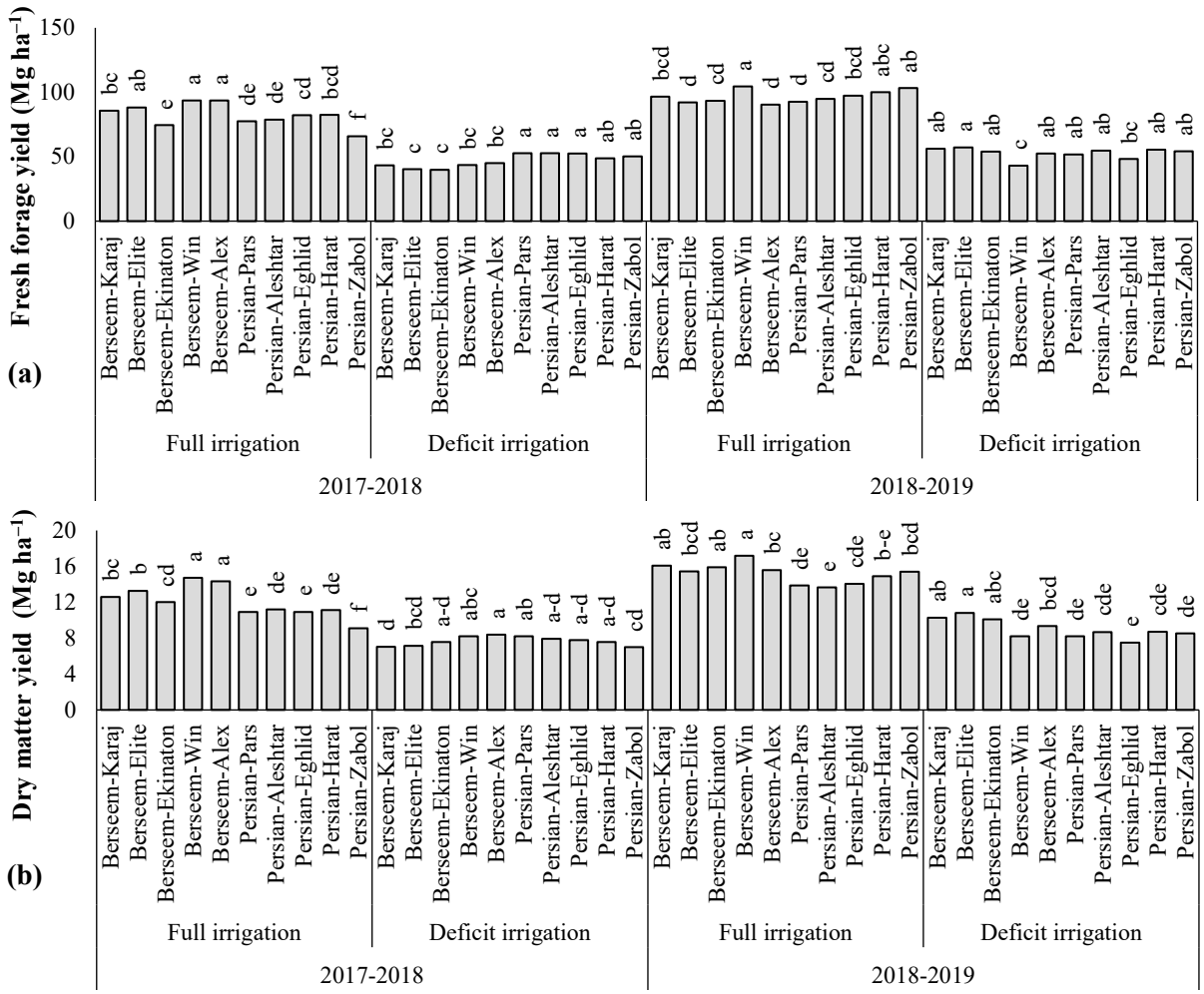

Figure 1. The effect of year × irrigation regime × genotype on fresh forage yield (a) and dry matter yield (b)

Ekinaton (11.06%), and Berseem-Elite (10.88%). Among the Persian clover genotypes, Persian-Pars showed the highest digestible protein content under both full and deficit irrigation conditions, while Persian-Aleshtar (9.72%) and Persian-Eghlid (9.78%) had the lowest protein levels under full irrigation (*Figure 2b*). Under deficit irrigation, Berseem-Karaj remained the top performer for digestible energy (2.72 Mcal kg^{-1}), though the performance gap

among genotypes narrowed, with Berseem-Elite, Berseem-Alex, and Berseem-Ekinaton all reaching 2.70 Mcal kg^{-1}. As with full irrigation, Persian clover genotypes exhibited lower digestible energy values, with Persian-Eghlid recording the lowest (2.46 Mcal kg^{-1}) (*Figure 2a*). All Berseem genotypes demonstrated higher digestible protein levels under deficit irrigation, with Berseem-Karaj (13.69%), Berseem-Alex (13.49%), and Berseem-Elite (13.44%) significantly outperforming the Persian genotypes. The lowest digestible protein content was again observed in Persian-Eghlid (9.97%) and Persian-Aleshtar (10.1%) (*Figure 2b*).

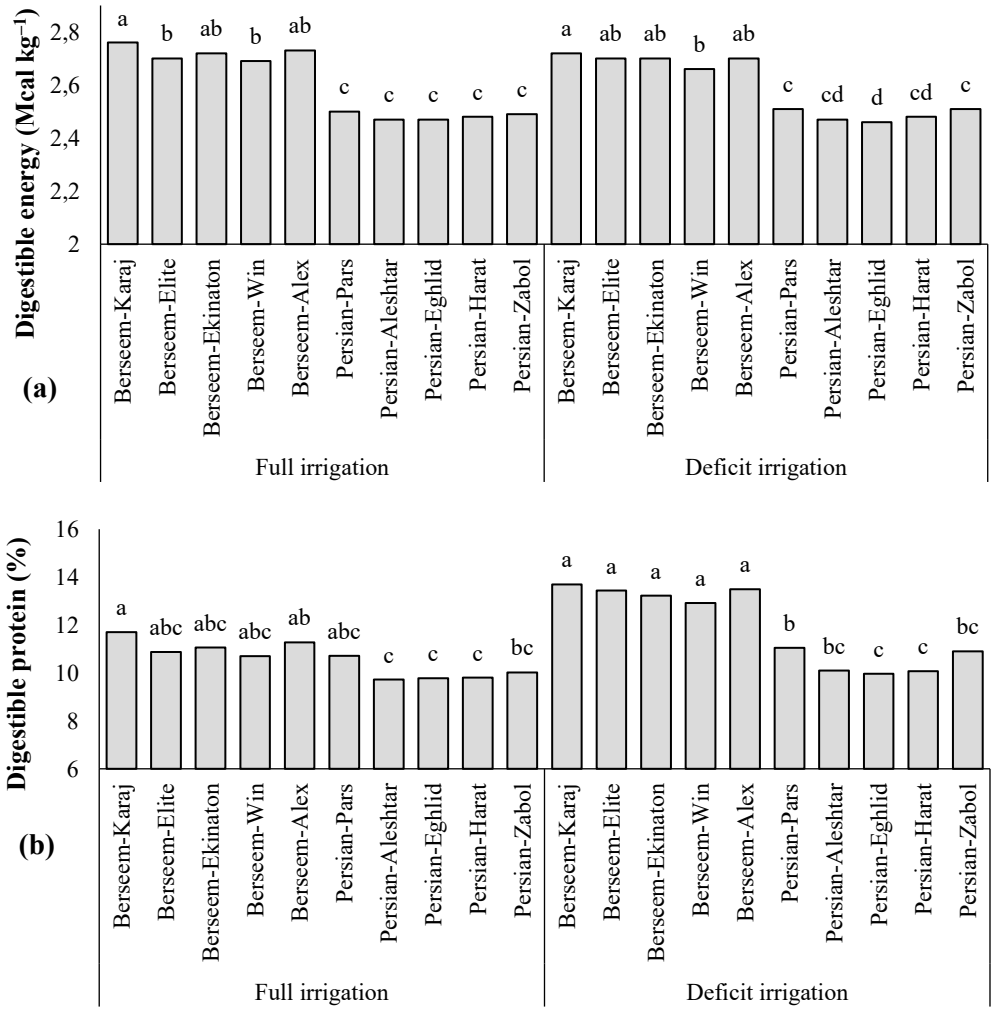

Figure 2. The effect of irrigation regime × genotype on digestible energy (a) and digestible protein (b)

The triple interaction of year, irrigation regime, and genotype significantly impacted irrigation water-use efficiency for digestible energy ($IWUE_{DE}$) and digestible protein ($IWUE_{DP}$) production ($p \leq 0.01$). Additionally, the main effect of genotype was significant for both $IWUE_{DE}$ ($p \leq 0.05$) and $IWUE_{DP}$ ($p \leq 0.01$) (*Table 3*). The highest $IWUE_{DE}$ and $IWUE_{DP}$ were observed in the Berseem-Elite genotype under deficit irrigation during the 2018-19 season, while Persian-Zabol under full irrigation in the 2017-18 season had the lowest values (*Figure 3a* and *3b*). Overall, as irrigation decreased, both $IWUE_{DE}$ and $IWUE_{DP}$ increased. The second cropping year showed a noticeable rise in $IWUE_{DP}$, peaking at 0.246 kg m^{-3} in Berseem-Elite under deficit irrigation during 2018-19, an 85% increase from the previous year under full irrigation. Compared to Berseem-Alex in the 2017-18 deficit irrigation season, this was a 9% improvement (*Figure 3b*). Under full irrigation during 2017-18, Berseem-Win and Berseem-Alex had the highest $IWUE_{DE}$ values, while Persian-Zabol and other Persian clover genotypes exhibited significantly lower values, ranging from 2.27 to 2.78 Mcal m^{-3} (*Figure 3a*). For $IWUE_{DP}$, Berseem-Alex ranked highest, followed closely by Berseem-Win and Berseem-Karaj, with Persian clover genotypes showing lower efficiency, especially Persian-Zabol and Persian-Eghlid (*Figure 3b*). Under deficit irrigation in 2017-18, $IWUE_{DE}$ improved overall, with Berseem-Alex, Berseem-Win, and Berseem-Ekinaton outperforming the Persian clover

genotypes. However, Persian-Pars demonstrated comparable $IWUE_{DE}$ to some Berseem genotypes (*Figure 3a*). In 2018-19, under full irrigation, Berseem-Win achieved the highest $IWUE_{DE}$ (3.81 Mcal m^{-3}), and Berseem-Karaj had the highest $IWUE_{DP}$ (0.146 kg m^{-3}). During deficit irrigation in the same season, Berseem-Elite recorded the maximum $IWUE_{DE}$ (4.88 Mcal m^{-3}) and $IWUE_{DP}$ (0.246 kg m^{-3}). Although the water-use efficiency of Persian clover genotypes improved under water stress, it remained lower than the Berseem clover genotypes (*Figure 3a* and *3b*).

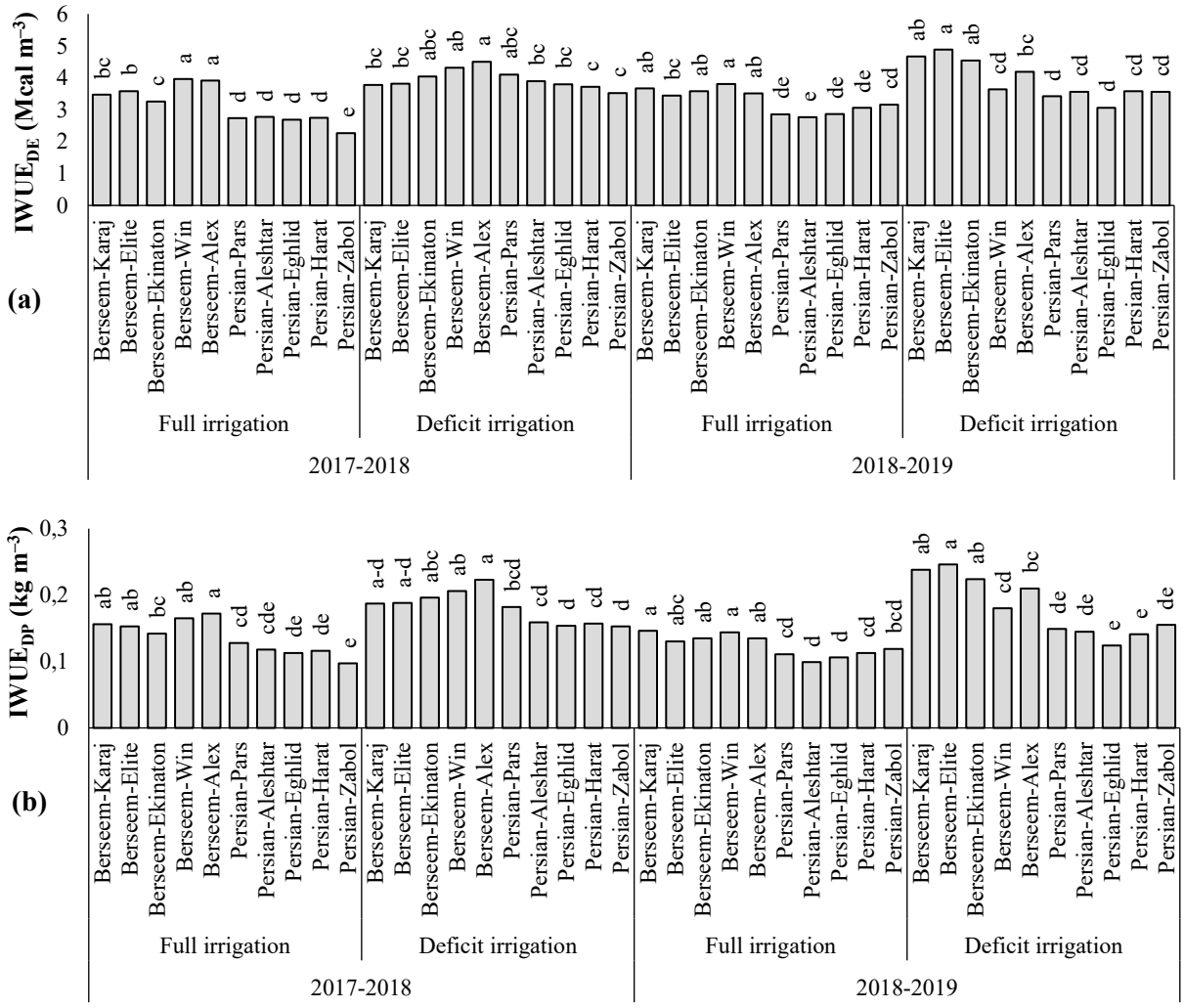

Figure 3. The effect of year × irrigation regime × genotype on irrigation water-use efficiency for digestible energy (a) and water-use efficiency for digestible protein (b)

Plant height was significantly affected by genotype and the interactions of year × genotype ($p \leq 0.01$), year × irrigation regime, and irrigation regime × genotype ($p \leq 0.05$) (*Table 3*). Plant height decreased as irrigation rates declined. Under full irrigation, Berseem-Ekinaton had the tallest plants (69.63 cm), standing 15 cm taller than under deficit irrigation and 29 cm taller than Persian-Zabol under the same water stress conditions (*Figure 4a*). Berseem-Karaj and Berseem-Win also exhibited relatively high plant heights (64.83 cm and 66.46 cm, respectively), which were statistically similar to each other but significantly higher than other genotypes. In contrast, Persian-Zabol had the shortest plants (46.71 cm), significantly shorter than all other genotypes (*Figure 4a*). Under deficit irrigation, Berseem-Ekinaton again had the tallest plants (54.60 cm), while Persian-Zabol had the lowest height (40.50 cm), significantly lower than all other genotypes (*Figure 4a*). The leaf area index (LAI) was significantly influenced by genotype ($p \leq 0.01$) and irrigation regime ($p \leq 0.05$), as well as their interaction ($p \leq 0.05$) (*Table 3*). Full irrigation resulted in a greater LAI compared to deficit irrigation. Berseem-Ekinaton had the highest LAI under full irrigation (2.17), which was 60% higher than its LAI under deficit irrigation. Moreover, its LAI was 2.8 times greater than Persian-Harat under deficit conditions (*Figure 4b*). Under deficit irrigation,

Berseem-Ekinaton still had the highest LAI (1.36), significantly higher than Berseem-Karaj and Berseem-Alex (*Figure 4b*).

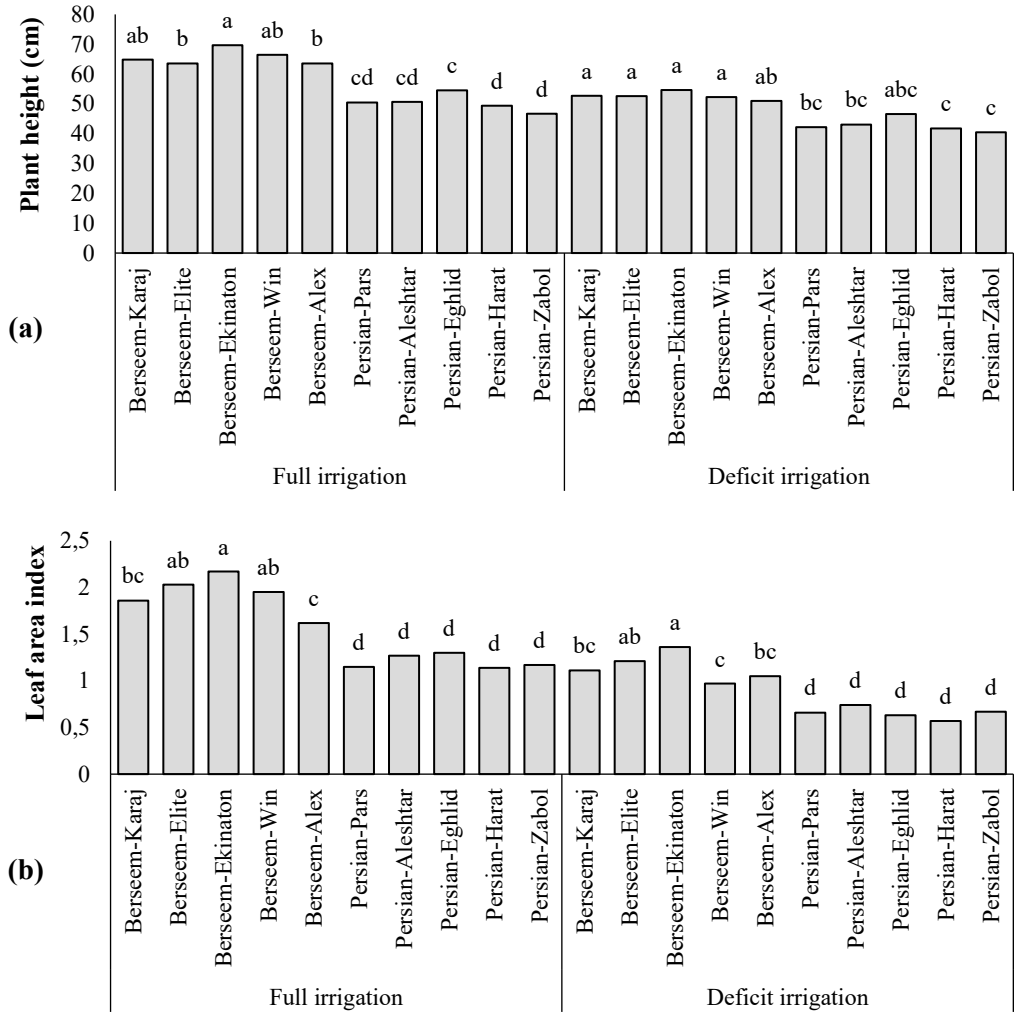

Figure 4. The effect of irrigation regime × genotype on plant height (a) and leaf area index (b)

Under full irrigation, fresh forage yield was positively correlated with dry matter yield, $IWUE_{DE}$, plant height ($p \leq 0.01$), and $IWUE_{DP}$ ($p \leq 0.05$), indicating that higher forage yields were associated with increased dry matter production and water-use efficiency. However, fresh forage yield was negatively correlated with digestible protein ($p \leq 0.01$), suggesting a trade-off between forage yield and protein content (*Table 4*). Dry matter yield exhibited strong positive correlations with $IWUE_{DE,}$ $IWUE_{DP,}$ and plant height ($p \leq 0.01$), indicating that higher dry matter production was aligned with taller plants and improved water-use efficiency. Digestible energy was positively correlated with digestible protein, $IWUE_{DE}$, $IWUE_{DP,}$ and leaf area index, highlighting that higher energy content was linked to better water-use efficiency and larger leaf areas (*Table 4*). Under deficit irrigation, fresh forage yield remained positively correlated with dry matter yield and $IWUE_{DE}$ but showed a negative correlation with digestible energy, indicating that higher forage yields were associated with lower digestible energy content under drought stress. Dry matter yield continued to show positive relationships with $IWUE_{DE}$ and $IWUE_{DP}$, reinforcing that efficient water use for both energy and protein production was crucial for maintaining yield under limited irrigation. Digestible energy remained strongly correlated with digestible protein and $IWUE_{DP}$, consistent with the trends observed under full irrigation, while digestible protein also showed positive associations with plant height and leaf area index, emphasizing the importance of plant structure in influencing protein content and water-use efficiency. Both full and deficit irrigation regimes demonstrated that water-use efficiency and plant morphological traits (plant height and leaf area index) play critical roles in determining forage yield and quality, with notable trade-offs between forage yield and protein content (*Table 4*).

Table 4. Pearson correlation analysis of the fresh forage yield (FFY), dry matter yield (DMY), digestible energy (DE), irrigation water-use efficiency for DE ($IWUE_{DE}$), digestible protein (DP), irrigation water-use efficiency for DP ($IWUE_{DP}$), plant height (PH), and leaf area index (LAI) of clover genotypes under full irrigation (the upper triangle) and deficit irrigation (the lower triangle) conditions

	FFY	DMY	DE	$IWUE_{DE}$	DP	$IWUE_{DP}$	PH	LAI
FFY	1	0.89^{**}	-0.03^{ns}	0.57^{**}	-0.37^{**}	0.26^{*}	0.37^{**}	0.04^{ns}
DMY	0.72^{**}	1	0.26^{*}	0.76^{**}	-0.27^{*}	0.41^{**}	0.65^{**}	0.27^{*}
DE	-0.32^{*}	0.26^{*}	1	0.61^{**}	0.68^{**}	0.81^{**}	0.70^{**}	0.77^{**}
$IWUE_{DE}$	0.37^{**}	0.78^{**}	0.74^{**}	1	0.29^{*}	0.85^{**}	0.75^{**}	0.67^{**}
DP	-0.24^{ns}	0.29^{*}	0.94^{**}	0.57^{**}	1	0.84^{**}	0.15^{ns}	0.44^{**}
$IWUE_{DP}$	0.16^{ns}	0.67^{**}	0.82^{**}	0.92^{**}	0.73^{**}	1	0.55^{**}	0.65^{**}
PH	0.18^{ns}	0.61^{**}	0.48^{**}	0.36^{**}	0.50^{**}	0.47^{**}	1	0.31^{*}
LAI	-0.16^{ns}	0.14^{ns}	0.75^{**}	0.48^{**}	0.66^{**}	0.60^{**}	0.66^{**}	1

*, **, and ns: Significant at the probability levels of 0.05 and 0.01 and non-significant, respectively.

Table 5. Average dry matter yield under full irrigation (Y_p), deficit irrigation (Y_s), mean productivity (MP), tolerance index (TOL), geometric mean productivity (GMP), stress susceptibility index (SSI), harmonic mean (HM), stress tolerance index (STI), yield stability index (YSI), yield index (YI), and relative stress index (RSI) in clover genotypes

Genotype	Yp[a]	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
Berseem-Karaj	14.33	8.66	5.67	11.50	11.14	10.80	1.03	0.67	1.04	0.60	0.98
Berseem-Elite	14.36	8.99	5.37	11.68	11.36	11.06	0.97	0.70	1.07	0.63	1.02
Berseem-Ekinaton	13.96	8.83	5.13	11.40	11.10	10.82	0.95	0.66	1.06	0.63	1.03
Berseem-Win	15.97	8.21	7.76	12.09	11.45	10.84	1.26	0.71	0.98	0.51	0.84
Berseem-Alex	14.96	8.86	6.10	11.91	11.51	11.13	1.06	0.71	1.06	0.59	0.96
Persian-Pars	12.40	8.22	4.18	10.31	10.10	9.89	0.87	0.55	0.98	0.66	1.08
Persian-Aleshtar	12.44	8.30	4.14	10.37	10.16	9.96	0.86	0.56	0.99	0.67	1.09
Persian-Eghlid	12.49	7.64	4.85	10.07	9.77	9.48	1.01	0.51	0.91	0.61	1.00
Persian-Harat	13.02	8.13	4.89	10.58	10.29	10.01	0.97	0.57	0.97	0.62	1.02
Persian-Zabol	12.25	7.82	4.43	10.04	9.79	9.55	0.94	0.52	0.93	0.64	1.04

Table 5 presents the results of nine stress-tolerance indices across genotypes. A Pearson correlation test was conducted to assess the relationships between these indices *(Figure 5*). Under deficit irrigation conditions, the indices MP, GMP, HM, STI, and YI exhibited significant positive correlations with dry matter yield. Under full irrigation, TOL, MP, GMP, HM, SSI, STI, and YI also showed significant positive correlations with dry matter yield, while YSI and RSI were negatively correlated. Notably, HM, STI, GMP, and MP displayed strong correlations with both yield under full irrigation (Yp) and yield under deficit irrigation (Ys) (Figure 1). Genotypes that performed well under both normal and water-deficit conditions demonstrated high STI, MP, GMP, and HM, reflecting their drought tolerance. Among Berseem clover genotypes, the highest and lowest HM values were recorded in Berseem-Alex and Berseem-Karaj, respectively. For Persian clover genotypes, Persian-Harat had the highest HM, while Persian-Eghlid had the lowest. Further analysis revealed that Berseem-Alex and Berseem-Win had the highest STI values among Berseem clovers, while Berseem-Ekinaton had the lowest. Among Persian clovers, Persian-Harat recorded the highest STI, and Persian-Eghlid the lowest. Berseem-Alex exhibited the highest GMP, while Berseem-Ekinaton had the lowest. Among Persian clovers, Persian-Harat had the highest GMP, with Persian-Eghlid at the lowest. In terms of MP, Berseem-Win recorded the highest value, while Berseem-Ekinaton had the lowest among Berseem clovers. For Persian clover genotypes, Persian-Harat had the highest MP, and Persian-Zabol the lowest (*Table 5*). To identify the top-performing genotypes, an average total rank was calculated, showing Berseem-Elite and Berseem-Alex as the most drought-tolerant varieties, with the lowest mean ranks (*Table 6*). Principal component analysis (PCA) of the relationship matrix revealed that two main components

Table 6. Ranking of genotypes for stress indices, average of ranks (AR), sum of ranks (SR), and standard deviation (SD).

Genotype	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	AR	SD
Berseem-Karaj	4	4	8	4	4	5	8	4	4	8	8	61	5.55	1.97
Berseem-Elite	3	1	7	3	3	2	5	3	1	5	5	38	3.45	1.86
Berseem-Ekinaton	5	3	6	5	5	4	4	5	3	4	4	48	4.36	0.92
Berseem-Win	1	7	10	1	2	3	10	2	7	10	10	63	5.73	3.95
Berseem-Alex	2	2	9	2	1	1	9	1	2	9	9	47	4.27	3.77
Persian-Pars	9	6	2	8	8	8	2	8	6	2	2	61	5.55	2.94
Persian-Aleshtar	8	5	1	7	7	7	1	7	5	1	1	50	4.55	2.94
Persian-Eghlid	7	10	4	9	10	10	7	10	10	7	7	91	8.27	2.00
Persian-Harat	6	8	5	6	6	6	6	6	8	6	6	69	6.27	0.90
Persian-Zabol	10	9	3	10	9	9	3	9	9	3	3	77	7.00	3.19

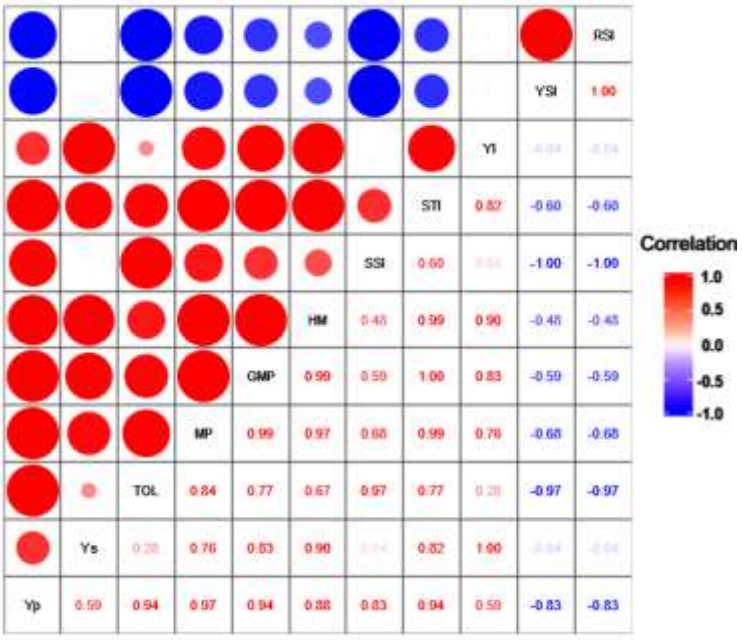

Figure 5. Correlation coefficients between dry matter yield under full irrigation (Yp), deficit irrigation (Ys), mean productivity (MP), tolerance index (TOL), geometric mean productivity (GMP), stress susceptibility index (SSI), harmonic mean (HM), stress tolerance index (STI), yield stability index (YSI), yield index (YI), and relative stress index (RSI) across ten clover genotypes

explained 99.93% of the variation in dry matter yield (*Figure 6*). The first principal component was strongly associated with yield under full irrigation (Yp) and the parameters MP, GMP, STI, and HM. The second principal component was significantly associated with yield under deficit irrigation (Ys), along with YSI, YI, and RSI (*Figure 6*). According to the PCA results, Berseem-Alex, Berseem-Elite, and Berseem-Win showed the highest levels of drought tolerance. While Persian clover genotypes exhibited lower drought tolerance compared to Berseem clover, the Persian-Harat genotype demonstrated the highest drought tolerance among the Persian clovers (*Figure 6*).

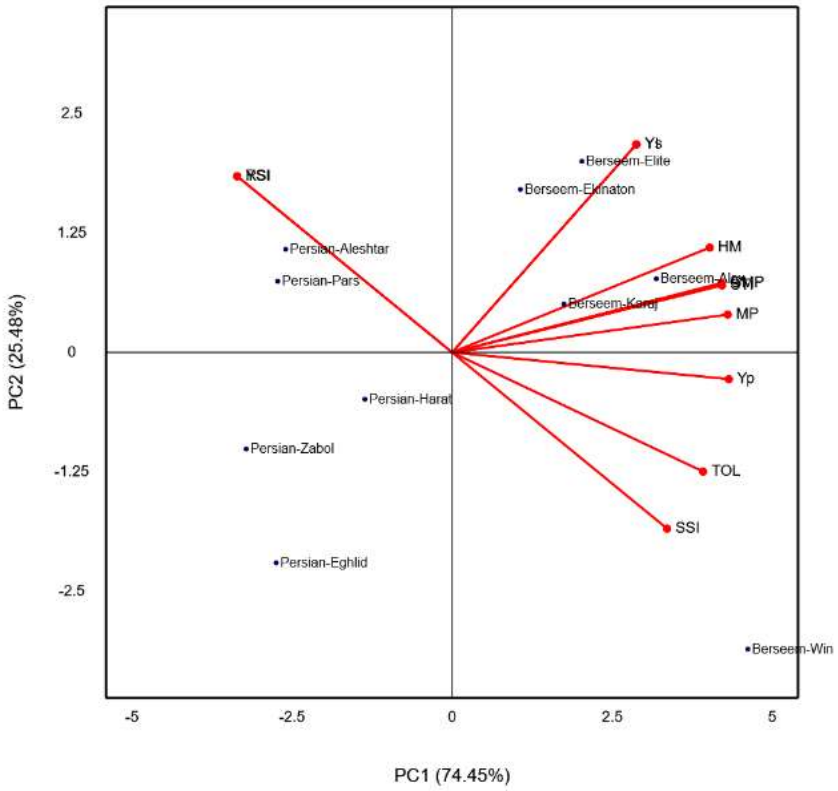

Figure 6. Principal components (PC) analysis based on the correlation matrix of dry matter yield under full irrigation (Yp) and deficit irrigation (Ys), mean productivity (MP), tolerance index (TOL), harmonic mean (HM), geometric mean productivity (GMP), stress susceptibility index (SSI), yield index (YI), stress tolerance index (STI), relative stress index (RSI) and yield stability index (YSI) in clover genotypes

3.2. Discussion

Climate change is anticipated to alter rainfall distribution patterns, potentially diminishing pasture efficiency (Balazadeh et al., 2021). Consequently, there's an escalating need to cultivate forage crops with heightened drought resilience (Baghdadi et al., 2023; Ghalkhani et al., 2023). Species typical of temperate grasslands, such as clovers, which primarily derive their agricultural yield from leaves and branches, are more susceptible to water stress than grains and legumes (Balazadeh et al., 2021). In this study, the Berseem-Win genotype outperformed other genotypes in terms of both fresh forage and dry matter yield across various irrigation regimes and years. Other research has similarly reported diminished plant performance during water stress conditions (Baghdadi et al., 2023; Pourali et al., 2023). The productivity of clovers in terms of forage and dry matter is intricately linked to stolon growth and leaf production within stolon nodules (Marshall et al., 2015). It has been observed a 40% reduction in leaf growth during drought conditions and noted a significant decline in leaf area, which adversely impacted dry matter yield (Belaygue et al., 1996). They posited that stolon and leaf area reductions were pivotal factors contributing to this decline. Additionally, diminished crop yield and efficiency of water-use across various cultivars have been documented by several researchers (Ahrar et al., 2020). In a study comparing white clover hybrids (*T. repens* L.) and Caucasians (*T. ambiguum* M. Bieb.) under drought stress, the Caucasian clover demonstrated superior drought resilience relative to white clover (Marshall et al., 2015). The researchers attributed this to the Caucasian clover's potential to preserve greater leaf relative water content and potential for water, even under moderate to severe drought conditions

The Berseem-Ekinaton genotype displayed the tallest plant height under full irrigation conditions, whereas the Persian-Zabol genotype exhibited the shortest height under deficit irrigation stress. This reduction in plant height can be attributed to diminished osmotic pressure, leading to reduced cell expansion and growth (Ghalkhani et al., 2023). Furthermore, deficit irrigation stress can cause internode shortening, most likely because of a decrease in light absorption (Hussein et al., 2015). Moreover, the Berseem-Ekinaton genotype achieved the highest leaf area

index under optimal irrigation conditions. Conversely, the Persian-Harat genotype recorded the lowest leaf area index under deficit irrigation-induced stress. The diminution in the area of leaves under water-stressed situations is a typical physiological response characterized by a reduction in cell numbers, diminished cell expansion, and reduced leaf budding (Ghalkhani et al., 2023). This reduction in leaf area serves as a drought-tolerance mechanism, optimizing water absorption and minimizing water loss through transpiration, thereby enhancing plant survival strategies (Gholamhoseini, 2020).

Total Digestible Nutrients (TDN) represent the nutritional value of livestock feed and are closely associated with the Acid Detergent Fiber (ADF) content in forage (Pourali et al., 2023). Given that the calculation of digestible energy relies on the TDN metric, any alteration in TDN content directly influences this energy index. An increase in ADF content corresponds to a reduction in TDN levels, thereby constraining the forage's nutritional utility for animals (Pourali et al., 2023). Interestingly, our findings suggest that digestible energy levels are higher under stress conditions than under full irrigation. The phenomenon is explained by a reduction in ADF production within plants experiencing stress. Such stress-induced changes in cell wall structure enable continued growth even under low water availability, thereby enhancing digestible energy content (Moore et al., 2008). Moreover, it has been posited that plants allocate a portion of their fixed carbon to fortify cell walls, bolstering osmoregulation mechanisms during water drought stress (Pecetti et al., 2017; Heydarzadeh et al., 2022). Additionally, it has been followed a decline in fiber content (specifically ADF) as drought stress intensifies (Ghalkhani et al., 2023).

To enhance protein nutrition in animal feed, crude protein is metabolized into its constituent parts, referred to as digestible protein. The quantity of digestible protein varies across different genotypes and under various irrigation conditions. Our findings indicate that digestible protein levels rise with increasing stress intensity. It has been noted that the concentration of crude protein in Berseem clover is influenced by varying degrees of drought stress, with peak levels observed at a 50% stress threshold (Daneshnia et al., 2016). In reaction to water stress, plants synthesize a range of proteins, including some that are water-soluble, aiding in stress tolerance mechanisms (Balazadeh et al., 2021; Farhadi et al., 2022). The content of crude protein significantly impacts the quality of forage crops (Bakhtiyari et al., 2020). Notably, the uptake of nitrogen, a critical component of crude protein, is predominantly influenced by water availability. Several studies have documented the correlation between water stress and nitrogen uptake. Specifically, it has been highlighted that under drought stress conditions, plants exhibit increased root population density and area on the surface, ameliorating enhanced nutrient absorption and subsequently elevating the available nitrogen for the crop (Liu et al., 2011; Liu et al., 2018).

Moreover, as stress intensity escalated, there was an observed increase in water-use efficiency for both energy and digestible protein. Within plant cultivation programs, water-use efficiency serves as a metric to gauge a crop's resilience to drought stress and its ability to adapt to water scarcity, encompassing various physiological traits (Inostroza and Acuna, 2010). The calculation of water-use efficiency can be undertaken at multiple levels: individual leaf level, canopy level, and field level (Bacon, 2009; Heydarzadeh et al., 2023). In research conducted by Lopez Olivari and Ortega-Klose (2021), the peak water-use efficiency across various red clover varieties, specifically to Sel SynII PRE III, was documented at 2.6 kg of dry matter per m^3 across all stress gradients. The findings suggested that advanced synthetic genotypes might exhibit enhanced capabilities in extracting soil moisture during periods of water scarcity compared to other red clover varieties. Similarly, in a research by Zhao et al., (2020), water-use efficiency in wheat was found to amplify under drought stress conditions. The researchers highlighted that even under reduced water utilization scenarios, wheat yield did not experience a significant decline. They further posited that wheat tends to optimize its water uptake when elemental concentrations are suboptimal, ensuring that the rate of water loss is outpaced by the rate of carbon assimilation.

The difference in dry matter production between strain and non-strain situations is known as the tolerance to stress factor. In the realm of plant cultivation, particularly concerning drought stress, stress tolerance emerges as a multifaceted trait characterized by intricate interactions between genotype and environment (Ghalkhani et al., 2023). This research found that the Persian-Aleshtar genotype endured the greatest tolerance, as demonstrated by its low SSI (0.86), high YSI (0.67), and RSI (1.09). Furthermore, the Berseem-Alex genotype demonstrated commendable performance across both strain and non-strain situations, registering peak values for GMP (11.51), MP (11.91), STI (0.71), and HM (11.13) indices. Consequently, the Berseem-Alex genotype is recognized for its robust stress tolerance capabilities. The SSI index specifically pinpoints genotypes that exhibit minimal reduction

under stressful conditions. In this context, the Berseem-Karaj, Berseem-Win, Berseem-Alex, and Berseem-Alex genotypes, with values greater than 1, are categorized as drought-sensitive genotypes. Moreover, parameters such as GMP, MP, STI, YI, and HM are closely linked to clover dry matter yield. On the other hand, YSI, YI, and RSI serve as indicators of genotype tolerance or sensitivity, making them valuable for stability assessments across strain and non-strain situations. These parameters have been applied across various crops, including sesame (Gholamhoseini, 2020), barley (Khalili et al., 2014), and safflower (Khalili et al., 2016). Consequently, farmers are advised to incorporate these indicators, tailoring their usage according to the specific stress intensity of the genotype in cultivation programs. Furthermore, PCA analysis offers insights into selecting different genotypes known for their drought tolerance, as emphasized in investigations by different scientists (Baghdadi et al., 2023; Ghalkhani et al., 2023).

4. Conclusions

Over the two-year cultivation period, notable differences emerged between the two irrigation methods and among the various genotypes. Specifically, the Berseem-Karaj, Berseem-Win, and Berseem-Ekinaton genotypes demonstrated superior performance, registering the highest values across the evaluated indices. In terms of drought tolerance, both the Berseem-Win and Berseem-Alex genotypes showcased remarkable resilience, exhibiting the least decline in dry matter yield. Notably, the Berseem-Win genotype excelled in water-use efficiency under both irrigation conditions. The genetic variability observed among these agricultural traits offers valuable resources for producers aiming to cultivate genotypes with enhanced drought resilience. The findings underscore the potential of integrating the Berseem-Win genotype into future agricultural strategies, given its commendable drought tolerance and consistent yield performance. This study underscores the importance of leveraging agricultural traits to optimize crop quality and yield.

Ethical Statement

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

Conflicts of Interest

The author declares that they have no conflict of interest.

Authorship Contribution Statement

Concept: Zamanian, M., Golzardi, F., Heydarzadeh, S.; Software: Zamanian, M., Heydarzadeh, S.; Validation: Golzardi, F.; Formal Analysis: Zamanian, M., Golzardi, F.; Investigation: Zamanian, M., Golzardi, F., Heydarzadeh, S.; Literature Research: Zamanian, M., Golzardi, F., Kara, E., Heydarzadeh, S.; Writing—Review and Editing: Zamanian, M., Golzardi, F., Kara, E., Heydarzadeh, S., Sürmen, M.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluating the Total Factor Productivity of Smallholder Cassava Farmers based on Socio-economic Variables, Cost and Revenue in Southwest, Nigeria

Oluwakemi ODUNTAN[1*]

Abstract

The nation's low productivity in producing food crops is a reflection of inefficiency and the use of antiquated technology, which further impedes attempts to make sustainable progress in food production and availability. This study used a structured questionnaire to gather cross-sectional data from 360 cassava-based farmers who were randomly selected using a multi-stage sampling method. The goal of the questionnaire was to estimate the Total Factor Productivity (TFP) of productive resources used in cassava-based farms in South-West Nigeria. Descriptive and inferential statistics, the gross margin and the total factor productivity index were used to assess the data. The results showed that the majority (82.2%) of cassava farmers were male and they were within the active age group given a mean of 47.9years with a mean household size of 6 persons. About 87.2% of the farmers were married and had an average farming experience of 13years while about 58.3% of them had secondary education. The cassava farmers had an average farm size of 3.4ha and many (72.2%) of them had no access to credit. According to the summary statistics on total factor productivity, 66.9% of farmers produced at high levels, with their total factor productivity indices being above the optimal range. It was discovered that a number of factors significantly influenced the productivity of cassava-based farmers, including age, gender, marital status, farming experience, farm size, access to financing, availability of extension agents, membership in a cooperative association, and total household income. It was also found that cassava-based production was a profitable enterprise and that the total variable cost, total cost, gross margin, profitability ratio, efficiency ratio, income expenditure ratio and return on investment were significant in determining the level of productivity of farmers. There was a significant difference between the socio-economic characteristics of farmers who had low productivity and farmers who had high productivity. As a result, the report advises that the government give farmers with subsidized inputs such as agrochemicals and fertilizer, as well as loan facilities, to help farmers raise their scale of output and productivity.

Keywords: Cassava-based, Factor-productivity, Profitability, Small-holder farmers, Southwest

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1. Introduction

Cassava (*Manihot esculenta*) is Sub-Saharan Africa's second most important staple food crop (Katz and Weaver, 2020). Sub-Saharan Africa has the largest per capita consumption, at over 800g per person/day, and it is the principal energy source for nearly 40% of the population (Adebayo, 2023). Because of its drought tolerance and capacity to produce even in unfavorable soil conditions, cassava is vital to Nigeria's rural economy. Nigeria's unique weather characteristics make it ideal for cassava cultivation (Ikuemonisan et al., 2020). Cassava is adaptable to a variety of agro-ecological zones, making it appropriate for both rain-fed and irrigated agriculture. The country's good environment reduces the hazards connected with weather swings, hence increasing cassava cultivation's resilience (Ogbuene et al., 2024). With a tolerance for low soil fertility, resistance to drought, pests, and diseases, as well as a high resistance to weeds, it adapts to climate change remarkably well (HarvestPlus, 2016).

Nigeria is the world's largest cassava grower, with 54.8 million MT produced in 2017, accounting for 20.4% of worldwide production; nonetheless, cassava yield in the country is low (FAOSTAT, 2019). Cassava farming provides a living for the majority of Nigeria's smallholder rural households, and it has the potential for bridging the food gap, because it has been discovered from research that famine rarely exists where cassava is widely grown (Olarinde et al., 2020). Cassava not only serves as a food reserve during famines, but it also boosts Nigeria's GDP and has transitioned from a staple to a commercial crop.

Despite a constant annual growth rate of more than 3% in global cassava production, African smallholder farming systems' crop yield falls short of optimal levels (Kintché et al., 2017; FAO, 2018). The country, which has an estimated 200 million people, is unable to meet the needs of its growing population, implying that it cannot meet global demand. This has resulted in a shift toward cassava cultivation, which has given a means of survival for millions of Nigerians and is now regarded highly by the government and foreign development groups as a target crop for agro-based industrialization and food security. To ensure the lowest-cost mix of inputs and outputs, increasing cassava output per unit of input consumption is the way to go (Osun et al., 2014).

The National Agricultural Development Programmes (ADPs), River Basin Development Authorities (RBDAs), the National Agricultural Land Development Authority (NALDA), the National Fadama Development Programme (NFDP), the National Agricultural Technology Support Project (NATSP), and the National Accelerated Industrial Crop Storage and Postharvest Technology Programme (NAICP) are a few of the initiatives that have been put into action. Even with ongoing government and donor financing intervention, changing strategies, and other measures, the situation of poverty has not significantly improved, and the full potential for cassava yield has not been realized (Eze and Nwobi, 2014). The trends in yield performance (output per hectare) in Nigeria remain low, as the majority of cassava farmers (approximately 95%) are smallholder farmers cultivating less than 2 ha, with just about 5% cultivating more than 5 ha. As a result, production has been low since farmers cultivate and process cassava on a subsistence basis, with no potential of commercializing the crop and competing with other cassava exporters throughout the world (Oluwafemi et al., 2019). Because it takes into account how much more can be produced with the limited and scarce resources available for production, boosting the productivity and efficiency of small farmers in rural areas is therefore essential for raising per capita income and achieving zero hunger (Bradshaw, 2006; Audu et al., 2013). To fulfill the country's growing population needs, Nigeria must improve cassava output while protecting future production variables (Sanusi et al., 2022). This demonstrates that total factor productivity must be tracked throughout time to reflect the nation's agricultural success (Thakur et al., 2014).

A number of studies on agricultural products' technical efficiency were conducted in Nigeria. Akhilomen et al., (2015); Ajayi and Olutumise (2018); Jimi et al., (2019); Oluwatayo and Taiwo (2019); Oyetunde-Usman and Olagunju (2019); Adebayo et al., (2020). Numerous studies (Audu et al., 2013; Eze and Nwibo, 2014; Oladeebo and Oluwaranti, 2014; Okebiorun et al., 2018; Okorie et al., 2021) have examined the productivity of cassava farmers in order to determine the reasons behind the differences in productivity. Many investigations (Thakur et al., 2014; Pilo, 2019; Ionescu, 2022; Nirere, 2022) have examined the yield of a range of crops grown in regions other than Africa. As a result, there is little empirical study on the profitability and total factor productivity of cassava farming in Southwest Nigeria. Due to this, the study evaluated the productivity level and the variables affecting the production level of cassava farmers in the research area. The specific objectives of this study are to

describe the socio-economic characteristics of respondents, determine the productivity of cassava farming and estimate the profitability of cassava production in the study area. The study's findings would help both farmers and policymakers understand the key variables required for increased cassava agricultural production and how to manage them. Hence, the findings will be beneficial in developing appropriate strategies to increase cassava output in the area and throughout the economy. Furthermore, the findings would be useful for future studies on cassava production.

2. Materials and Methods

2.1 Study area

Southwest Nigeria was the location of the study. Ogun, Osun, Ondo, Oyo, Lagos, and Ekiti are the six states that make up the region. According to Lawal et al. (2016), the region is situated between latitudes 6o 21' and 8o 37′ N of the Equator and longitudes 2o 31' and 6o 00′ East of the Greenwich Meridian. There are about 25.02 million people living there, spread across a total land area of 76,852 square kilometers (Adeolu, 2019). The area is renowned for having a lot of rain. The rainy season usually begins in March and lasts until mid-July. It then takes a short break in early August before returning in late August and continuing through October (Olujumoke et al., 2016). In the south of the region, annual rainfall varies from 2,000 mm to 1,150 mm. November marks the start of the dry season, which ends in February or March on average. All year long, the temperature stays between 210C and 290C with comparatively low humidity. With a high forest zone (rain forest) in the south and a sub-Savannah forest on the northern edge, the area boasts a diverse range of flora. The climate in the area is favorable for the growth of crops such as plantains, cocoa, yam, maize, millet, cassava, rice, and kola nuts (Olagunju, 2022).

2.2 Data collection

Primary data were collected for the purpose of the study with the aid of a structured questionnaire. Data were collected on their socio-economic characteristics, productivity of the respondents and cost and return of cassava production using a questionnaire with well-constructed open-ended and closed-ended questions, supported by the interview schedule. The questionnaire was designed by creating valid and reliable questions that address research objectives placing them in a useful order, and selecting an appropriate method for administration. The questionnaire was self- administered and researcher-administered in person and was presented on paper to gather specific information from the respondents.

2.3 Sampling technique and sample size

A multi-stage sampling procedure was used to choose the study participants. In the first stage, two states (Ondo and Osun) recognized for their cassava farming were specifically selected. This is because of their predominance in cassava farming in the areas. In the second stage, three Local Government Areas (LGAs) were randomly selected from each state. The third stage involved random selection of three communities from each local government area, while the last stage involved selection of twenty farmers from each community who specialized in cassava and were specifically chosen from a list provided by the Agricultural Development Program (ADP) office in each of the chosen States. This resulted in a total of 360 respondents for the study. The reference was 2021/2022 production year and all the estimates were based on the period. Ondo and Osun States are among the highest cassava producing States in Southwest, Nigeria (Ikuemonisan et al., 2020). The region (Southwest) contributes about 13.1% to the national cassava output and out of it, Ondo and Osun States account for about 4.8% (FAOSTAT, 2019).

The population size that was used for the study was 4000. Only 2,265 cassava farmers are registered with the Ondo State Agricultural Development programme and 1,735 cassava farmers are registered with the Osun State Agricultural Development programme from which the respondents (360) were selected.

Using the Yamane's formula to calculate the sample size,

$$n = \frac{N}{1+N(e)^2} \quad \text{(Eq.1).}$$

The variables in this formula are:

n = the sample size

N = the population of the study

e = the margin error in the calculation

Let's assume a desired margin of error of 5%

n = 4000/(1+4000*0.05^2) = 363.63

n = 364

2.4 Method of data analysis

The acquired data were examined using descriptive statistics such as frequency distribution and percentages. Profitability and financial ratios, gross margin ratio, income expenditure and return on investment were computed and discussed for the cassava farming businesses. Total factor productivity index was used in the categorization of the farmers into different groupings. Specifically, total factor productivity (TFP) indices were used to categorize the farmers into three levels of productivity of high, low and optimal. For a high productivity level farmer, the index was TFP >1. A TFP < 1 score indicated low productivity farmer while optimally producing farmer had a TFP equal to one (Sadiq et al., 2019). In similar vein, the second level of categorization was done using TFP indices based on socioeconomic characteristics. Eleven socio-economic characteristics computed for the analysis were age, gender, marital status, household size, level of education, farm size, access to credit, access to extension agents, access to healthcare, membership of cooperative association and total household income of the farmers. Each socioeconomic characteristic that had a TFP > 1 was rated high, TFP < 1 rated low, and TFP equal 1 was rated optimal. The last categorization of the farmers was done based on cost and returns of the cassava farmers. The variables of the cost and returns used included cost of labour, cost of cassava, cost of fertilizer, cost of agrochemicals, cost of depreciated fixed asset and cost of rent.

2.4.1 Total factor productivity (TFP)

This was used to calculate the productivity of cassava farmers. TFP can be expressed as the inverse of unit variable cost. This is because TFP is the ratio of the production to the total variable cost (TVC), as illustrated below.

$$TFP = \frac{Y}{\sum P_i X_i} \quad \text{(Eq. 2).}$$

Where Y is the quantity of cassava in kilograms, P is the unit price of the ith variable input, and X is the quantity of that variable input.

2.4.2 Gross margin (GM)

Gross Margin analysis was utilized to determine the costs and returns of cassava-based production in the research area (objective II).

$$GM = TR - TVC \quad \text{(Eq. 3).}$$

Where, GM = Gross Margin, TR = Total value of cassava output in/ ha, TVC = Total Variable Cost of cassava production/ ha. Ratios that were used included Profitability Ratio (GM/TVC), Efficiency Ratio (TR/TVC), Gross Margin Ratio (GM/TR), Income Expenditure Ratio (TR/TC), Return on Investment Ratio (Net Profit/Total Investment) (ROI) and Profitability Ratio (GM/TVC)

3. Results and Discussion

3.1 Socio-economic characteristics of the respondents

The descriptive analysis of the socio-economic characteristic of the respondents showed that most of the respondents were within the age bracket of 41-50 years with a mean age of 47.9 years (*Table 1*). This implies that majority of the cassava farmers were in their active age. The result showed that majority (82.2%) were male while 17.8% were female. This revealed that male gender dominated cassava production in the study area. About 87.2 percent of the respondents were married and most (58.3%) of the respondents had secondary school

Table 1. Distribution of respondents by socio-economic characteristics

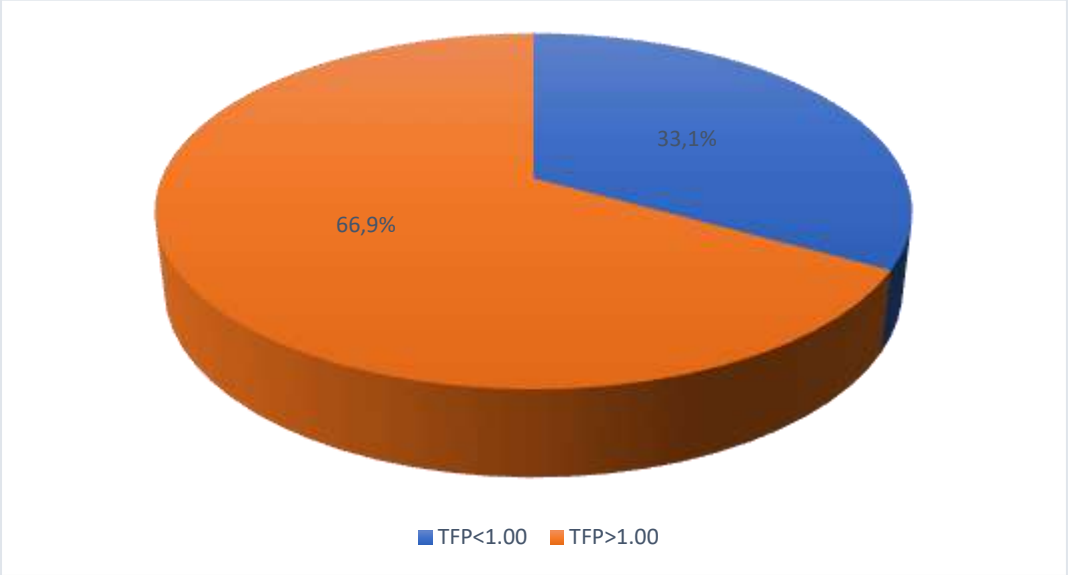
Variables	Frequency	Percentage
Age		
Mean = 47.9		
≤30	26	7.2
31-40	86	23.9
41-50	104	28.9
51-60	74	20.6
>60	70	19.4
Gender		
Male	296	82.2
Female	64	17.8
Marital status		
Single	18	5.0
Married	314	87.2
Widowed	18	5.0
Separated	10	2.8
Household size		
Mean = 5.6		
1-5	178	49.4
6-10	180	50.0
11-15	2	0.6
Level of Education		
No formal education	8	2.2
Adult education	34	9.5
Primary school	36	10.0
Secondary	210	58.3
Tertiary	72	20.0
Years of Farming Experience		
Mean = 12.7		
1-5	100	27.8
6-10	73	20.3
11-15	55	15.2
16-20	78	21.7
>20	54	15.0
Farm size		
Mean = 3.4		
1-5	324	90.0
6-10	32	8.9
>10	4	1.1
Credit Access		
Yes	100	27.8
No	260	72.2
Access to Extension Services		
Yes	88	24.4
No	272	75.6
Membership of Cooperative Society		
Yes	189	52.5
No	171	47.5

Source: Computed from Field Survey, 2022

education. The mean household size of the respondents was six persons. Oluwatoba et al. (2021) classified small scale farmers in terms of the size of their farm holdings. Small scale farms are farms under 6 hectares. Medium scale farms range between 6 and 9.99 hectares while large-scale farms are 10 hectares and above. The result indicated that majority (90%) of the respondents had farm size between 1-5 ha with a mean of 3.4 ha thereby, classifying them as small-scale farmers. This supports the assertion of Gbigbi (2021) that Nigerian farmers were small-scale farmers. The results further showed that the average farming experience of the farmers was 12.73 years. This indicates that cassava production is an age-long venture among the respondents, and farmers are equipped with the required skills. The result also revealed that 72.2% of respondents did not access credit while only 27.8% accessed credit. This could lower their level of investment in agricultural production as capital is an important factor in agricultural production activities (Mukaila et al., 2021; Falola et al., 2022). The result revealed that majority (75.6%) of respondents had no interaction with extension workers. This could affect the use of better cassava production technologies. According to membership of association, about 47.5% did not belong to any organization. This is likely to impact negatively on their level of their efficiencies.

3.2 Distribution of respondents by level of productivity

The summary statistics of total factor productivity in Figure 1 revealed that the majority of farmers (66.9%) had high levels of productivity because their total factor productivity indices were above the optimal scale, indicating good input mix allocation in the production process, while 33.1% had low levels of productivity because their total factor productivity indices were below the optimal scale. This means that more than half of the sampled population made effective use of their input resources. This is congruent with the findings of Sadiq et al. (2019), who discovered that more than half of the sampled farmers were productive in their utilization of input resources in the study area.



Computed from Field Survey, 2022

Figure 1: Distribution of Respondents by their Total Factor Productivity

3.3 Total factor productivity based on socio-economic variables

Table 2 shows that age, gender status, marital status, farming experience, farm size, access to credit, access to extension agents, membership in a cooperative association, and total household income had a significant impact on farmers' productivity at 1% or 5% level. These variables have given favorable results, implying that an increase in any of these factors could boost overall factor production in the study area. However, there is a substantial gap between farmers with low and high production in terms of socioeconomic factors. The average age of farmers who had high productivity was higher than that of farmers who had low productivity, implying that middle age farmers are more productive, possibly due to better experience that they have gained over the years in managing farming practices and utilizing productive resources. This is consistent with Adebayo et al. (2023) study, which found that middle age farmers were more productive. The majority of farmers who had high

levels of productivity were male. This may be due to gender differences in access to inputs, productive resources and services. Also, the majority of the farmers who had high levels of productivity were married, implying that marriage contributed to their output, which could have been owing to access to family labor. Farmers who had a high level of productivity had more years of farming experience, farm size, access to financing, access to extension agents, and total family income, which is consistent with the prior hypothesis that farmers with more of these would be more productive. This finding is congruent with that of Sadiq et al. (2019), who found that gender, farming experience, medicine, and income all had a favorable effect on the total factor productivity of broiler farmers in Niger State, Nigeria. This is also in line with the results of Gbigbi (2021), which stated that farm size had positive effect on efficiency among farmers in Delta State, Nigeria.

Table 2. Total factor productivity: The distribution of respondents based on socio-economic variables

Socio-economic Variables	Low Productivity (TFP<1.00) (Mean)	Std. Dev.	High Productivity (TFP>1.00) (Mean)	Std. Dev.	Mean Diff.	t-value
Age	42.50	10.88	50.69	13.07	-8.19	-5.90***
Gender	1.11	0.31	1.21	0.41	-.102	-2.40**
Male (freq.)	.891	.313	.788	.409	.102	2.40**
Female (freq.)	.109	.313	.212	.409	-.102	-2.40**
Marital Status	1.94	0.27	2.11	0.52	-.171	-3.39***
Single (freq.)	.067	.251	.041	.199	.026	1.05
Married (freq.)	.924	.266	.846	.361	.078	2.09**
Widowed (freq.)	.008	.092	.071	.257	-.062	-2.56**
Separated (freq.)	0	0	.041	.199	-.041	-2.26**
Household size	5.64	2.02	5.54	1.56	.095	0.49
Level of Education	3.93	0.66	3.80	1.03	.131	1.27
No formal education (freq.)	.008	.092	.029	.168	-.021	-1.25
Adult education (freq.)	.042	.201	.120	.326	-.078	-2.40**
Primary school education(freq.)	.076	.266	.112	.316	-.036	-1.08
Secondary school education (freq.)	.756	.431	.498	.501	.258	4.81***
Tertiary education (freq.)	.118	.324	.241	.428	-.123	-2.77***
Farming experience	9.69	6.71	14.24	9.30	-4.552	-4.76***
Farm size	3.10	2.12	3.57	2.15	-.472	-1.96**
Access to credits	0.12	0.32	0.38	0.54	-.264	-4.95***
Access to extension agents	0.11	0.31	0.31	0.46	-.202	-4.29***
Access to healthcare	0.77	0.42	0.87	0.34	-.094	-2.28**
Membership of cooperative association	0.49	0.50	0.54	0.49	-.044	-0.78
Total household income	302941.2	141872.2	455,020.7	184,535.7	-152079.6	-7.91***

Computed from Field Survey, 2022

** Significant at 5% level; *** Significant at 1% level

3.4 Total factor productivity based on cost and revenue

Results in *Table 3* showed that variable inputs such as labour, cassava stem and agrochemicals were significant in determining the level of productivity of farmers at 1% and 5% level respectively. Farmers who had high level of productivity incurred higher cost on labour and agrochemicals while farmers who had low

Table 3. Total factor productivity distribution of respondents based on cost and revenue: summary statistics for income of farmers

(A)Variable Cost	**Low Productivity (TFP<1.00) Mean**	**Std. Dev.**	**High Productivity (TFP>1.00) (Mean)**	**Std. Dev.**	**Mean Diff.**	**t-value**
Cost of labour	34848.74	56343.10	75663.90	89022.71	-40815.16	-4.57***
Cost of cassava stem	5362.19	4956.28	3541.08	1757.20	1821.11	5.09***
Cost of fertilizer	3331.09	2870.06	3427.80	2359.70	-96.71	-0.34
Cost of agrochemicals	4750.42	7389.38	6675.10	7170.25	-1924.68	-2.37**
Cost of transportation	18399.16	9995.89	19186.72	25680.75	-787.56	-0.32
Total Variable Cost (TVC)	66691.60	63916.77	108494.60	101202.20	-41803.01	-4.12***
(B) Fixed Cost						
Depreciated fixed assets	4107.42	626.71	4004.98	1637.61	102.44	0.66
Cost of rent	15126.05	156030.60	2626.56	6933.73	12499.49	1.24
Total Fixed Cost (TFC)	19233.47	156112.3	6631.54	7187.04	12601.93	1.25
Total Cost (TC)	85925.07	174680.80	115126.10	102032.90	-29201.08	-1.99**
Total Revenue (TR)	224369.80	168782.50	624045.60	291024.60	-399675.9	-13.87***
Gross Margin (GM) (TR-TVC)	157678.20	171151.30	515551	304552.20	-357872.9	-11.92***
Profitability Ratio (GM/TVC)	3.11	3.51	7.18	5.01	-4.07	-7.96***
Efficiency Ratio (TR/TVC)	4.11	3.51	8.18	5.01	-4.07	-7.96***
Gross Margin Ratio (GM/TR)	0.70	1.01	0.83	1.05	-0.13	0.86
Income Expenditure Ratio (TR/TC)	3.72	3.19	7.53	4.61	-3.81	-8.11***
Return on Investment Ratio (Net Profit/Total Investment) (ROI)	2.72	3.19	6.53	4.61	-3.81	-8.11***

Computed from Field Survey, 2022
** Significant at 5% level; *** Significant at 1% level

productivity incurred higher cost on cassava stem, fixed assets, and rent. However, farmers who had high productivity incurred higher cost on the input utilized and realized higher revenue than farmers who had low productivity.

Results further showed that the total variable cost, total cost, gross margin, profitability ratio, efficiency ratio, income expenditure ratio and return on investment were significant in determining the level of productivity of farmers at either 1% or 5% level. Farmers who had high level of productivity had a higher value in all these

ratios than farmers who had low productivity. Based on the return on investment, cassava production is a profitable enterprise and the farmers who had high productivity had higher profit than the farmers who had low productivity. This result is congruent with Mukaila et al. (2022). This is also consistent with a prior expectation that high productivity should translate into more profitability.

4. Conclusions

The summary statistics of total factor productivity revealed that more than half of the sampled population was productive in their use of input resources. However, a significant proportion of them performed below the ideal scale. Farmers with more years of farming experience, larger farm sizes, access to credit, extension agents, and total household income were more productive than their counterparts. Age, gender status, marital status, farming experience, farm size, access to credit, access to extension agents, membership in a cooperative association, and total household income were significant in determining the level of productivity of smallholder cassava farmers. Most of the farmers who had high level of productivity were male, mostly married and middle age. Results further showed that variable inputs such as labour, cassava stem and agrochemicals were significant in determining the level of productivity of farmers. Farmers who had high level of productivity incurred higher cost on labour and agrochemicals while farmers who had low productivity incurred higher cost on cassava stem, fixed assets, and rent. Farmers who had high production, on the other hand, paid a greater cost for their inputs and earned a bigger profit than those with poor productivity. The results also revealed that the total variable cost, total cost, gross margin, profitability ratio, efficiency ratio, income expenditure ratio, and return on investment all play an important role in influencing farmer productivity. Based on the return on investment, farmers who had high productivity had higher profitability than farmers who had poor productivity. The study therefore recommends that;

- Subsidies for agrochemicals and fertilizer should be provided by the government to farmers, as their high cost can impair profitability and production.
- The government should provide finance to farmers to boost production and productivity.
- The government should do better in empowering and equipping the extension agents to perform better in farmers' education, dissemination of relevant information and mobilization of farmers for training when the need arises.
- Encouraging and educating farmers to join cooperatives can help them form networks and generate beneficial relationships, which can benefit their operation.
- Farmers should be encouraged to engage rigorously in non-farm activities that can give them income. This income could be used to purchase all necessary farm inputs and increase their scale of production.

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Ethical Statement

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

Conflicts of Interest

I declare that there is no conflict of interest as the article author.

Authorship Contribution Statement

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

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Analysis of Production Efficiency Among Sesame (*Sesamum indicum*) Farmers in North West, Nigeria: A Stochastic Production Efficiency Frontier Approach

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Abstract

This research study analyzed production efficiency among sesame (*Sesamum indicum*) farmers in North West, Nigeria. Approximately, 150 sesame producers were selected among the villages utilizing a multi-stage sampling approach. Data used were of primary sources based on a well-structured questionnaire. The method employed econometric tools for analysis of data which include stochastic production efficiency frontier model (SPEFM) and principal component model (PCM). The result shows that the significant predictors influencing TE (Technical Efficiency) of sesame production include farm size, chemical, seed, fertilizer, and labour. The significant socio-economic factors increasing TE or decreasing technical inefficiency (TIE) of sesame production include education, age, years of farm experience, size of household, and extension contact. The calculated return to scale (RTS) was 1.4025, this signifies an increasing RTS. The gamma or variance ratio of 0.8038 implies that 80.38% of random variations in output of sesame is due to farmers' inefficiency, the remaining 19.62% of sesame output deviation from the potential level was because of random noises like unexpected rainfall, frost, and other natural disaster beyond the control of sesame producers. The minimum estimated technical efficiency is 0.06, the maximum is 0.98. The average TE score of sesame producer is 0.5430 leaving out an inefficiency gap of 0.4570 for improvement. The coefficient of total variance (σ^2) is 2.9221, this was significant at 1 percent probability level, which hypothesized that perfect goodness of fit of data with the Cobb-Douglas stochastic frontier model and also the assumption of the composite error term was properly specified. The 3 major constraints faced by sesame producers include lack of credit (1st), lack of improved quality seeds (2nd), and high cost of farm inputs(3rd). The study recommends based on the outcome of this research that farm inputs such as fertilizers, chemical. and improved quality seeds should be given to sesame producers at affordable prices and at appropriate time to increase productivity and efficiency.

Keywords: Production efficiency, Sesame farmers, Stochastic production efficiency, North west, Nigeria

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1. Introduction

Sesame (*Sesame indicum L*) is an ancient oilseed agricultural crops produced in the world. Sesame seed is cultivated in sub-tropical and tropical region (Bedigian, 2015). Sesame is reported to be a good source of healthy fat, plant protein, which can be used in place of animal fats and also animal protein in human diets. Sesame seed is also reported to be a good and major source of fibre, minerals, and vitamins (Elleuch et al., 2011). Sesame seeds are very nutritious and is used as food, edible oil, confectionary, medicinal ingredients, and can be processed into paste (Wacal et al., 2021). The health benefit of sesame seed include antioxidant, and also as an ingredient in pharmaceutical industry which have been reported to support the expansion of sesame seed international market. In Nigeria, sesame production in 2022 is about 450,000 metric tonnes (FAO, 2024). In Nigeria, the sesame area and sesame yield in 2022 are 365, 080 ha and 1232.9 Kg/ha respectively (FAO, 2024). According to FAO (2019), the world output of sesame seed exceeded 5.5 million tonnes in 2017, and about 57% of this was produced in developing Africa nations, and 40% was produced in Asia. The world production of sesame in 2021 and 2022 are 6,667,343.67 tonnes and 6,741,479.41 tonnes respectively (FAO, 2024). Sesame seeds is an important agricultural export commodity of Nigeria, currently sesame ranks second after cocoa among non-oil export agricultural commodities that can earn the country foreign exchange (Rukwe et al., 2019). According to FAO (2024), Nigeria exported 297,022 tonnes of sesame in 2022. The Nigeria sesame export value in 2022 worth 330.954 million USD (FAO, 2024). Also, Nigeria exported 154,716 tonnes of sesame in 2021, and the export value of Nigeria sesame in 2021 worth 190.862 million USD (FAO, 2024). Efficiency is used interchangeably and synonymous with productivity. According to report of Ogundele and Okoruwa (2006) efficiency measurement is an important measure of performance and an indicator by which production units are examined and also a method of identifying sources of production inefficiency. Farm productivity of stable and staple food crops in sub-Saharan nations including Nigeria is low, this is due to traditional ways or methods of farming, land fragmentation, poor irrigation facilities, misuse of modern agricultural technologies, poor irrigation facilities, less availability of credit and the impact of climate change (Chandio et al., 2017). The farmers cannot afford to purchase necessary farm inputs such as pesticides, fertilizers, improved seeds, which leads to low productivity. Efficiency according to Henderson (2003) can be defined as the ability or potentials of a producing unit to achieve maximum output (optimal) from a given value of inputs. Farm production efficiency can be defined as the ability or potentials of a farm to produce a certain level of agricultural produce with the minimum amount of factor input. The method used in producing an efficient an agricultural produce is the one which uses the lowest amount of factor input to get a given value of output (Ogunyinka and Ajibefun, 2003). A farm that operates on the production efficiency frontier is technically efficient, while a farm that operates below the production efficiency frontier is technically inefficient, but can be made to operate on the production efficiency frontier and become efficient by increasing its output of agricultural produce with the same factor input level or using fewer input level to produce the same agricultural output level (Rukwe et al., 2019). Technical efficiency (TE) measures the potentials or the ability of a sesame production unit to achieve the maximum possible agricultural output from a combination of production resource inputs or factors. The methods for estimating productive efficiency rely on the use of non-parametric approach (Data Envelopment Analysis, DEA) and the parametric approach using the SPEFM. Most empirical literatures show that the application of stochastic production frontier model in estimating efficiency of sesame production is still scarce in Nigeria.

1.1 Objectives of the study

The main objective is to analyze production efficiency among sesame (*Sesame indicum*) producers in North West, Nigeria: a stochastic production efficiency frontier (SPEFM) approach. The specific objectives are:

(i) determine the TE of sesame production,

(ii) evaluate the socio-economic factors influencing TIE of sesame production,

(iii) determine the TE scores of sesame producers, and

(iii) identify the constraints faced by sesame producers.

2. Methods

This work was conducted in Kano and Kaduna States, Nigeria. Kano State lies between Latitudes 12° 02|N and Longitudes 08° 30| E. The state has total land area of 20, 230 Km^2, the population of Kano State is 15,462, 200 people with annual population change of 3.2%. Kaduna State lies between Latitudes 09° 02| and 10° 36|North and Longitudes 06° 15| and 08° 50| East of the equator. Kaduna state has total land area of 4.5 million hectares. The mean rainfall is about 1,482mm. The population of Kaduna state is about 8.9 million people as at 2021. (NPC, 2022). The people of the 2 states engaged in farming activities. Multi-stage sampling technique was adopted, the fourth and last stage was the proportionate-random sampling of 150 sesame producers comprising of 75 sesame producers from Kano State and 75 sesame producers from Kaduna State. Primary sources of data were obtained by administering a structured and properly designed questionnaire to the respondent using agricultural extension officers that is adequately trained. The structured questionnaire was subjected to reliability and validity test. This research work utilized the formula established and advanced by Yamane (1967) in the calculation of the sample size. The formula is given as:

$$n = \frac{N}{1+N(e^2)} = 150 \quad \text{(Eq. 1)}$$

Where,

n = The Calculated Sample Size (Number)

N = The Sample Frame of Sesame Farmers (Number for the 2 States)

e =Maximum Margin of Error Acceptable as Estimated by the Researcher (5%)

Data were analyzed using the following econometric tools:

2.1 Stochastic production efficiency frontier model (SPEFM)

The non-parametric approach and the parametric approaches are often used in estimating the TE. If the production model can be expressed by a function with explicit parameters such as the Cobb-Douglas production function, the approach used is called a parametric (Houngue and Nonvide, 2020).

According to Alabi *et al*. (2022), the SPEFM is stated thus:

$$Y_i = f(X_i, \beta_i)e^{v_i - u_i} \quad \text{(Eq. 2)}$$

$$LnY_i = \beta_0 + \sum_{i=1}^{5} \beta_i \, LnX_i + \cdots \beta_n LnX_n + V - U_i \, . \quad \text{(Eq. 3)}$$

Technical efficiency (TE_i) would be estimated as follows:

$$TE_i = \frac{Y_i}{Y_i^*} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(Eq. 4)}$$

$$TE_{ij} = \frac{F(X_i,\beta)\exp(v_i - u_i)}{F(X_i,\beta)\exp(v_i)} \quad \text{(Eq. 5)}$$

$$TE_{ij} = \exp(-u_{ij}) \quad \text{(Eq. 6)}$$

Since the actual sesame seed production is usually less than the frontier production ($Y_i \leq Y_i^*$), the values for TE always lies between 0 and 1, with a TE of 1 suggesting that the actual production is equal to the frontier production and farm is said to be technically efficient (Ahmed and Melesse, 2018).

where,

Y_i = Output of Sesame (Kg)

Y_i^* = Unobserved Frontier Output of Sesame (Kg)

X_i = Vectors of Variable Inputs

β_i = Vectors of Estimated Parameters

V_i = Random Errors in Sesame Output

U_i= Error Term which is due to TIE

X_1 = Farm Size measured in Ha

X_2 = Chemical in Litre

X_3 = Seed (Kg)

X_4 = Fertilizer in Kg

X_5 = Labour (Mandays)

$$U_i = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_5 Z_5 \quad \text{(Eq. 7)}$$

where,

Z_1 = Level of Education (Years)

Z_2 = Age in Years

Z_3 = Years of Experience (Years)

Z_4 = Size of Household (Number)

Z_5 = Extension Contact (Number)

α_0 = Constant Term

$\alpha_1 - \alpha_5$ = Estimated Parameters

U_i= Error Term due to TIE

2.2 Principal component method (PCM)

The constraints faced by sesame producers was subjected to PCM or factor analysis. The PCM is stated thus:

$$\alpha_K = (\alpha_{1k}, \alpha_{2k}, \alpha_{3k}, \ldots \alpha_{pk}) \quad \text{(Eq. 8)}$$

$$\alpha_k^T X = \sum_{j=1}^{p} \alpha_{kj} X_j \quad \text{(Eq. 9)}$$

The variance of each of the principal components are:

$$Var[\alpha_k^T X] = \lambda_k \quad \text{(Eq. 10)}$$

$$S = \frac{1}{n-1} \sum_{i=1}^{n} (X_i - \overline{X_i}\,(X_i - \overline{X}_i)^{\mathrm{T}} \quad \text{(Eq. 11)}$$

Where,

X_i= Vector for p Random Variables

α_k =Components of P Vector

λ_K = Estimated Eigen Value

T = Stands for Transpose

S = Matrix of Covariance

3. Results and Discussion

3.1 Technical efficiency (TE) scores of sesame producers

Table 1 shows the summary statistics of TE scores of sesame farmers. The majority (74.00%) of sesame farmers were between 21 to 80 % efficiency levels. The average TE was 54.30 % leaving an inefficiency gap of 45.70 % for improvement. This means that the sesame farmers are able to obtain 54.30% of potential output from a given mixture of production inputs. This implies that an average sesame farmer is able to obtain 53.40% of the frontier output given the input used under existing technology. Thus, opportunity still exists for increasing sesame productivity and income through increased efficiency using available resources and by adopting new technologies

and techniques used by the best performing sesame farmers. Also, the minimum TE score was 6.00 %, while the best performing sesame farms had the maximum TE of 98.00%. If the mean sesame farmers were to obtain the level of TE like most of its efficient counterparts, then the mean sesame farmers could make 44.59 % cost savings estimated as $\left[\left[1-\frac{54.30}{98.00}\right]\times 100\right]$. The estimated value for the most TIE sesame producers reveals a cost savings of 93.87 % calculated as $\left[\left[1-\frac{6.00}{98.00}\right]\times 100\right]$. This result agrees with findings of Maurice (2004) who obtained an average TE score of 0.80 for cereal crops Fadama farmers in Adamawa State, Nigeria. This finding also agrees with Gbigbi (2021) who obtained mean TE of 0.67 for cassava farmers in Delta state, Nigeria.

Table 1. Summary statistics of TE scores of sesame farmers

Efficiency Score	Frequency	Percentage
0.00 to 0.20	18	12.00
0.21 to 0.40	19	12.67
0.41 to 0.60	50	33.33
0.61 to 0.80	42	28.00
0.81 to 1.00	21	14.00
Mean	0.5430	
Minimum	0.06	
Standard Deviation	0.2393	
Maximum	0.98	

Source: Field Survey (2024)

3.2 Determinants of technical efficiency (TE) of sesame production

Table 2 shows the Maximum Likelihood Estimates (MLEs) of determinants of TE using SPEFM is shown in *Table 1*. In the TE component, the factors included in the model were farm size, chemical, seed, fertilizer, and labour. All the variables included in the SPEFM had positive coefficient and were statistically significant. Farm size had positive coefficient of (0.3420) with TE of sesame production and was statistically significant at 1 percent probability level. A one % increase in farm size holding other predictors constant will give rise to 34.20% increase in TE of sesame production. Also, fertilizer input had positive coefficient of (0.2824) and was significant at (P < 0.10). A one % increase in fertilizer application holding other predictors constant will give rise to 28.24% increase in TE of sesame production.

The return to scale (RTS) is the addition of the elasticities of production for all the factors included in the TE component. The calculated RTS is 1.4025, this means an increasing RTS. The increase RTS implies that an increase in any of the factor inputs included in the TE components of sesame production keeping other predictors fixed will give rise to more than proportional increase in the output.

In the diagnostic statistics component, the coefficient of gamma or variance ratio(γ) is 0.8038, this means that 80.38% of variations in the agricultural output of sesame production were due to differences in TE. Furthermore, this means that 80.38% of random variation in the output of the sesame producers were due to the farmers' inefficiency. Therefore, reducing the effect of variance ratio will improve the yield and greatly enhance the TE of the farmers. The coefficient of total variance (σ^2) is 2.9221, which was significant at ($P < 0.01$). This signifies that the model is good and well fitted to the data. The LLF (Log-Likelihood Function) is -408.34. The result of this study agrees with Rukwe et al. (2019) who reported the quantity of seed, farm size, total labour input, quantity of herbicides and quantity of fertilizers were the significant predictors influencing TE of sesame production in Taraba State, Nigeria.

3.3 Socio-economic predictors influencing technical efficiency (TE) and inefficiency (TIE) of sesame production

Table 2 also presents the maximum likelihood results of socio-economic predictors influencing TE and inefficiency of sesame production using SPEFM. In the TIE component, the socio-economic factors included in the model include level of education, age, years of experience, household size, and extension contact. All the socio-economic factors in the TIE component had negative coefficient and were statistically significant. The negative

signs of coefficient of socio-economic predictors in the model decreases the TIE of sesame production, while the positive signs of coefficient of socio-economic predictors in the model increases the TIE of sesame production. The signs of the coefficients are in line with a priori expectations. The level of education had negative coefficient of (-0.3449) with TIE of sesame production and was significant at 5% probability level. A one % increase in level of education of sesame farmers holding other factors constant will give rise to 34.49% increase in TE (or decrease in TIE) of sesame production. Also, the years of experience had negative coefficient of (-0.2321) and was significant at 5 percent probability level. A 1% increase in years of experience of sesame farmers holding all other factors fixed will give rise to 23.21% increase in TE of sesame production. This result is in consonance with reports of Omolehin et al. (2010) who stated that about 85% of variations in sesame production in Jigawa State is due to inefficiency

Table 2. MLEs of the stochastic production efficiency frontier model

Variables	Parameters	Coefficient	Standard Error	t-Value
Constant	β_0	1.2351**	0.4319	2.86
Farm Size	β_1	0.3420***	0.0924	3.70
Chemical	β_2	0.4201***	0.1074	3.91
Seed Planted	β_3	0.1052**	0.0357	2.95
Fertilizer	β_4	0.2824*	0.1201	2.35
Labour	β_5	0.2528**	0.0890	2.84
RTS		**1.4025**		
Technical Inefficiency Component				
Constant	α_0	1.7102**	0.7038	2.43
Level of Education	α_1	-0.3449**	0.1493	-2.31
Age	α_2	- 0.2629**	0.1007	-2.61
Years of Experience	α_3	-0.2321**	0.0847	-2.74
Household Size	α_4	-0.3453***	0.0941	-3.67
Extension Contact	α_5	-0.3128**	0.1101	-2.84
Diagnostic Statistics				
Total Variance (Sigma Square)	σ^2	2.9221***		
Variance Ratio (Gamma)	γ	0.8038		
Log-Likelihood Function		-408.34		

Source: Data Analysis (2024) *-Significant at (P < 0.10), **-Significant at (P < 0.05), ***-Significant at (P < 0.01), MLEs-Maximum Likelihood Estimates

3.4 Constraints faced by sesame producers

The constraints faced by sesame producers were subjected to PCM and the result is presented in *Table 3*. Six (6) constraints were retained by the model based on the perceptions of sesame producers for those with Eigen-values that are greater than one. As can be observed, inadequate access to credit facilities with Eigen –value estimated at 1.9427 was ranked 1st and this actually explained 16.14% of all retained constraints in the PCM. Lack of improved seeds with Eigen-Value estimated at 1.8413 was ranked 2nd and it explained 15.19% of all retained constraints in the model. The high cost of farm input with Eigen-Value estimated at 1.4521 was ranked 3rd, and this also explained 17.23% of all retained constraints in the PCM. All constraints facing sesame farmers and retained by the principal component model jointly explained 81.05% of all constraints included in the analysis. The Kaiser-Meyer-Olkin estimates of sampling adequacy (KMO) of 0.8727 and Bartlett test of sphericity of 829.13 were statistically significant at 1 % probability level which demonstrated that the variables were feasible for principal component analysis. This result agrees with the findings of Alabi and Anekwe (2023), Aduba et al. (2013), Onuk et al. (2020), and Musa et al. (2019). This outcome also agrees with findings of Falola et al. (2022) who reported high cost of input as one of the constraints facing commercialization of pigeon pea production in Southwest, Nigeria.

Table 3. Principal component model of constraints faced by sesame farmers

Constraints	Eigen-Value	Difference	Proportion	Cumulative
Inadequate Access to Credit Input	1.9427	0.1014	0.1614	0.1614
Lack of Quality and Improved Seeds	1.8413	0.3892	0.1519	0.3133
High Cost of Sesame Farm Inputs	1.4521	0.0817	0.1723	0.4856
High Transportation Cost	1.3704	0.1192	0.1813	0.6669
High Cost of Fertilizers	1.2512	0.0408	0.1219	0.7888
Poor Storage Facilities	1.2104	0.0196	0.0217	0.8105
Bartlett Test of Sphericity				
χ Square	829.13***			
KMO	0.8727			
Rho	1.00000			

Source: Field Survey (2024), KMO – Kaiser-Meyer-Olken

4. Conclusions

This study has established the TE and inefficiencies of sesame production, the technical efficiency scores of sesame producers is estimated, in addition, the research study has identified the constraints facing sesame producers. The study employed the use of econometric tools such as SPEFM which is the parametric approach and principal component model in data analysis. The significant predictors influencing TE of sesame production were farm size, chemical, seed, fertilizer, and labour. The significant socio-economic factors influencing TIE of sesame production include education, age, years of experience, household size, and extension contact. The variance ratio or gamma of 0.8038, implies that 80.38% of random variations in output of sesame farmers were due to farmers' inefficiency. The total variance or sigma square of 2.9221 was statistical significant at 1 percent probability level which justified that the model stated is of good fit. The mean TE score of sesame farmers is 0.5430, this mean there exists an inefficiency gap of 0.4570. This means that an average sesame farmer is able to obtain 54.30% of the frontier output given the input used under existing technology. The major constraints facing sesame farmers include inadequate access to credit input (1st), lack of quality and improved seeds (2nd), and high cost of farm input (3rd). Based on the findings of this research study, the following recommendations were made:

(i) Farm inputs such as improved quality seeds, fertilizers, and chemical input should be given to sesame farmers at affordable prices and at appropriate time to increase productivity and efficiency.

(ii) Credit facilities for increased productivity and efficiency of sesame production should be made available for sesame producers at single digit interest rate with no collaterals and devoid of cumbersome administrative procedures.

(iii) Feeder roads should be constructed and more roads should be rehabilitated to facilitate easy access and movement of sesame produce to nearby market.

(iv) Extension officers should be deployed to disseminate and teach new agricultural research findings to sesame farmers.

(v) New farm technologies and techniques together with labour saving equipment's should be introduced to farmers to increase sesame farms efficiency and productivity.

Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Oladele, A. O., Aluwong, J. S., Maharazu, I., Alabi, O. O., Kareem, H. K., Ocheni, A, Design: Oladele, A. O., Aluwong, J. S., Maharazu, I., Alabi, O. O., Kareem, H. K., Ocheni, A, Data Collection or Processing: Oladele, A. O., Aluwong, J. S., Maharazu, I., Alabi, O. O., Kareem, H. K., Ocheni, A, Statistical Analyses: Oladele, A. O.,

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Bilyalı Kekik (*Origanum onites* L.) Uçucu Yağı Kullanılarak Üretilen Tavuk Sosislerin Genel Kimyasal Bileşimi ve Uçucu Bileşiminin İncelenmesi

Investigation of General Chemical Composition and Volatile Composition of Chicken Sausages Produced by Using Ball Thyme (*Origanum onites* L.) Essential Oil

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Öz

Kekik bitkisi ülkemizden ihracatı yapılan önemli türler arasındadır. İlk çağlardan itibaren farklı amaçlar için ilaç, gıda, kozmetik gibi alanlarda yaygın olarak kullanılmaktadır. Bu çalışmada Balıkesir Büyükşehir Belediyesi Çiftçi Eğitim Merkezi (BAÇEM) arazisinde yerli tohumlarla ilaçsız olarak yetiştirilmiş, hasat edilmiş ve damıtılmış bilyalı kekik (*Origanum onites* L.) türü kullanılmıştır. Bu türün uçucu yağ oranı ve bileşenlerini incelemek, farklı oranlarda tavuk sosis üretiminde kullanılmasıyla ürüne geçebilen bileşenleri görebilmek ve tavuk sosisin fizikokimyasal özellikleri üzerine etkilerini karşılaştırabilmek amacıyla deneysel çalışma yapılmıştır. Bu kapsamda BAÇEM'den tedarik edilen bilyalı kekik uçucu yağı %0.2, %0.1, %0.05 oranlarında tavuk sosis formülasyonuna eklenerek, ham yağ ve yağ ikameli sosis numunelerinde uçucu yağ bileşimi incelenmiştir. Bu amaçla 4 farklı deneme grubu için 1600 kg sosis üretimi gerçekleştirilmiştir. Buna ek olarak yağ ikamesi olmadan üretilen kontrol grubu sosisler ile yağ ikamesi olan ürünlerin fizikokimyasal (protein, yağ, toplam kül, nem) özellikleri karşılaştırılmıştır. Bilyalı kekik uçucu yağı incelendiğinde 44 adet uçucu bileşen tanımlanmıştır. En fazla yer alan bileşenlerin sırasıyla %37.46 karvakrol, %12.2 timol, %9.5 p-simen, %7.77 γ-terpinen olduğu görülmüştür. Uçucu yağ ilavesi yapılan sosis ürünlerinde ise 23 adet bileşenin tespiti yapılarak karvakrol ve timol sırası ile %0.77-2.83 ve %0.45-0.80 aralığında tespit edilmiştir. Örneklere en fazla geçen uçucu bileşimin ise %22.42-23.40 aralığında linalool olduğu bunu limonen ve terpinen-4-ol'ün takip ettiği görülmüştür. Tüm denemelerde protein ve toplam kül miktarlarının yağ ilavesi yapılmayan kontrol grubuna göre artış olduğu görülmüştür. %0.05 oranında kullanılan uçucu yağ bileşimli numunenin kontrol grubuyla karşılaştırıldığında ise toplam yağ analiz sonucunda farklılık görülmediği genel olarak fizikokimyasal analiz sonuçların birbirine çok yakın olduğu gözlemlenmiştir.

Anahtar Kelimeler: Uçucu bileşen, Kekik uçucu yağı, Tavuk sosis, *Origanum onites* L., Fizikokimyasal özellikler

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Abstract

Thyme plant is among the important species exported from our country. Since ancient times, it has been widely used for different purposes in areas such as medicine, food and cosmetics. In this study, balled oregano (*Origanum onites* L.) species grown, harvested and distilled without pesticides with local seeds in Balıkesir Metropolitan Municipality Farmer Training Centre (BAÇEM) land was used. An experimental study was carried out to investigate the essential oil ratio and components of this species, to see the components that can pass into the product when used in chicken sausage production at different ratios and to compare the effects on the physicochemical properties of chicken sausage. In this context, the essential oil composition of crude oil and oil-substituted sausage samples were analysed by adding 0.2%, 0.1%, 0.05% essential oil of ball thyme supplied from BAÇEM to chicken sausage formulation. For this purpose, 1600 kg sausage production was carried out for 4 different experimental groups. In addition, the physicochemical (protein, fat, total ash, moisture) properties of the control group sausages produced without oil substitution and the products with oil substitution were compared. When the essential oil of ball thyme was analysed, 44 volatile components were identified in ball thyme. The most common components were found to be 37.46% carvacrol, 12.2% thymol, 9.5% p-cymene, 7.77% γ-terpinene, respectively. In sausage products to which essential oil was added, 23 components were detected and carvacrol and thymol were detected in the range of 0.76-2.84% and 0.47-0.81%, respectively. It was observed that the highest volatile compound in the samples was linalool in the range of 22.5-23.34%, followed by limonene and terpinen-4-ol. In all trials, it was observed that the protein and total ash amounts increased compared to the control group without oil addition. When the sample with 0.05% essential oil composition was compared with the control group, it was observed that there was no difference in the total oil analysis result and in general the physicochemical analysis results were very close to each other.

Keywords: Volatile component, Thyme essential oil, Chicken sausage, *Origanum onites* L., Physicochemical properties

1. Giriş

Et ve et ürünleri bileşimindeki vitamin, mineral ve farklı değerli proteinler sebebiyle insan beslenmesinde önemli bir rol oynamaktadır (Geçgel ve ark., 2016; Ruiz-Hernández ve ark., 2023). Beslenme açısından önemi fazla olmasına karşın, et ürünleri mikrobiyal bozulma ve lipit oksidasyonuna karşı oldukça duyarlıdır. Bu nedenle birçok sentetik koruyucu ve sentetik antioksidan kullanılarak et ve et ürünlerinin raf ömürleri uzatılmaya çalışılmaktadır. Sentetik kaynaklı gıda katkı maddelerinin raf ömrünü arttırıcı etkisine karşın; doğal olmayan katkı maddelerine olan genel olumsuz yaklaşım tüketicilerin ağırlıklı olarak doğal katkı maddelerine yönelmesine sebep olmaktadır (Pateiro ve ark., 2018; Ribeiro-Santos ve ark., 2018; da Silva ve ark., 2021).

Yaygın tüketilen et ürünlerinden biri olan sosis; sığır, koyun, kanatlı etleri ve yağlarının emülsiyon formda kılıflara doldurularak akabinde ısıl işlem uygulanarak üretilmektedir. Kanatlı sektörü içerisinde en büyük pay tavuk eti üretimine ait olup tavuk eti ve ürünleri beslenme açısından önemi, kolay temini ve ekonomik olması gibi nedenlerden ötürü tüketiciler tarafından yaygın olarak tercih edilmektedir (Kayaardı ve ark., 1998; Yerlikaya ve Özkaya, 2020).

Uçucu yağlar, bitkilerin farklı kısımlarından (kök, gövde, yaprak, kabuk ve çiçek gibi) çeşitli yöntemler kullanılarak elde edilmekle birlikte genellikle su veya su buharı destilasyonu ile elde edilen uçucu ve kuvvetli kokulu olup, elde edildiği bitkinin karakteristik kokusunu veren birçok kimyasal bileşenden özellikle terpenlerden oluşan karışımlardır (Çalıkoğlu ve ark., 2006; Turek ve Stintzing, 2013). Uçucu yağlar, et ve et ürünlerinde yaygın olarak kullanılan doğal gıda katkı maddelerinden biridir. Et ve et ürünlerinde kullanılmasının en önemli nedeni antioksidan ve antimikrobiyal özellikler sergilemesi ve bunun yanında et ürünlerinde lezzeti geliştirmesinden kaynaklanmaktadır (Jayasena ve Jo, 2014; Pateiro ve ark., 2018).

Kekik, *Lamiaceae* familyasına ait bir bitki olup, Türkiye'de biyoçeşitlilik yönünden zengin bir türdür (Semerci ve Ken, 2024). Türkiye'de bilyalı kekik ismi ile bilinen *Origanum onites* L., uluslararası literatürde "Türk Kekiği" olarak yer almakta olup, Doğu Akdeniz ülkelerinde yaygın olarak yetişen önemli bir tıbbi bitkidir (Tepe ve ark., 2016; Canli ve ark., 2023). Uçucu yağ bileşimi ağırlıklı olarak terpenoitlerden oluşmakla birlikte bu yağın bileşiminde en fazla belirlenen bileşen karvakrol olmuştur (Tepe ve ark., 2016). *O. onites*'in uçucu yağın antimikrobiyal ve antioksidan özellikler göstermesi bileşiminde yer alan karvakrolden kaynaklanmaktadır (Andoğan ve ark., 2002; Özkan ve Erdoğan, 2011; Spyridopoulou ve ark., 2019). *Origanum* çeşidinin birçok türünün özellikle *O. vulgare* ve *O. majorana* uçucu yağlarının et ürünlerinde kullanımı üzerine literatürde birçok çalışmaya rastlanmakla birlikte, bu yağların sosis üretiminde kullanımının antioksidan ve antimikrobiyal etkileri üzerine literatürde sınırlı sayılı kaynağa ulaşmak mümkündür. Busatta ve ark. (2008), *O. majorana* uçucu yağını sosislerde kullanarak raf ömrü üzerine etkilerini araştırmışlardır. Yüksek konsantrasyonda uçucu yağ kullanımı ile antibakteriyel etki tespit edilirken, tat üzerine olumsuzluklar belirlenmiştir. *O. vulgare* uçucu yağı %0.3, %1 ve %1.5 (hacim/ağırlık) düzeyinde *Listeria monocytogenes* ve *Salmonella Enteritidis* ile inoküle edilen tavuk sosislerinde kullanılmış ve patojen mikroorganizmalara karşı etki gösterdiği belirlenmiştir (Barbosa ve ark., 2015). *O. majorana* uçucu yağı *in vitro* koşullarda gıda kaynaklı patojenlerden *Escherichia coli, Salmonella Enteritidis* ve *Listeria monocytogenes*'e karşı güçlü antimikrobiyel aktivite göstermiştir. Bunun yanında 0.50 µL g^{-1} ve 0.150 µL g^{-1} düzeyinde hindi sosislerinde kullanıldığında depolama süresince bakteriyel gelişimi baskılamış ve kontrol grubuna göre raf ömrünü uzatmıştır (Šojić ve ark., 2023).

Uçucu yağların sosis ürünlerinde kullanılmasına dair sunulmuş olan bu çalışmalara karşın; bilyalı kekik olarak bilinen *O. onites* uçucu yağının sosis üretimi uygulaması konusunda literatür çalışmasına rastlanmamıştır. Bunun yanında farklı *Origanum* türlerinin uçucu yağlarının kullanıldığı çalışmalarda, uçucu yağların antimikrobiyel etkileri genellikle konu edinilmiştir. Türkiye'de ihraç edilen kekiğin yaklaşık %80'i *O. onites* türüne aittir (Sancaktaroğlu ve Bayram, 2011). Bu çalışma ile elde edilecek sonuçların seri üretim şartlarında da kullanılabilmesi ve sektörde yaygınlaşabilmesi için; tedariğinde miktar sorunu gözlenmeyen bir uçucu yağ üzerinde çalışılması bu çalışmanın motivasyonunu oluşturmaktadır. Uçucu yağlardan hangi bileşenlerin sosise geçtiği konusunda şu ana kadar yapılan literatür çalışmalarına erişilememiştir. Bu çalışmada, farklı oranda *O. onites* uçucu yağının tavuk sosislerinde kullanımının genel bileşim ve bilyalı kekik uçucu bileşenlerinin sosise geçişi üzerine etkileri incelenmiştir.

2. Materyal ve Metot

Çalışmada kullanılan Bilyalı kekik (*Origanum onites* L.) uçucu yağ, Balıkesir Büyükşehir Belediyesi Çiftçi Eğitim Merkezi (BAÇEM) tarafından üretilen ürünlerden tedarik edilmiştir. Sosis üretiminde, baader kıyma ve göğüs eti HasTavuk firmasından tedarik edilmiştir.

Sosis üretimi Şekil 1'deki akış diyagramına uygun olarak üretilmiştir. Sosis formülasyonunun ana bileşeni %50 baader kıyma, %50 göğüs etinden oluşan et karışımı oluşturmaktadır. Karışıma; su, modifiye nişasta, baharat karışımı (beyazbiber, karabiber, sodyum trifosfat, sodyum polifosfat, tuz), sofra tuzu, nitritli tuz, tütsü aroması, doğal renklendirici (siyah havuç ve pancar kökü) ilave edilerek ürün formülasyonu tamamlanmıştır. Formülasyonda yer alan tüm girdiler tartıldıktan sonra miksere taşınarak karıştırılmış, ardından emülsifiyer yardımı ile emülsifiye edilmiştir. Emülsifiyer öncesinde %0.2, %0.1, %0.05 oranlarında bilyalı kekik uçucu yağı hamura ilave edilmiştir. Her deneme grubu için 400 kg sosis hamuru hazırlanmıştır. Sosislerin dolumunda ise 55 feet uzunluğunda rejenere selülozdan elde edilen kılıflar kullanılmıştır. Sosis için kullanılacak etler parçalama prosesinde ayrılarak 100 kg kapasiteli et taşıma aracı ile sosis üretim hattına taşınmıştır. İlgili süreçte mikser (INOTEC IM-1500 LT) 290 saniye sağ ve 290 saniye sol olmak üzere dönüş sağlayarak karışımı homojenize hale getirilmiştir. Mikser içerisinde su karışım süresinin başı, sonu ve ortası olacak şekilde üç parça halinde otomatik dozajlanmıştır. Hamur karışımı, hazırlandıktan sonra mikserin emülsifiyer bölümüne boşaltılarak emülsifiye edilmiş ve taşıma araçları ile dolum makinesine (VEMAG Vacuum filler HP10L) sevk edilmiştir. Dakikada 720 porsiyon sosis doldurulmuştur. Doldurulan sosisler askı arabalarına alınarak fırında pişirilmiştir.

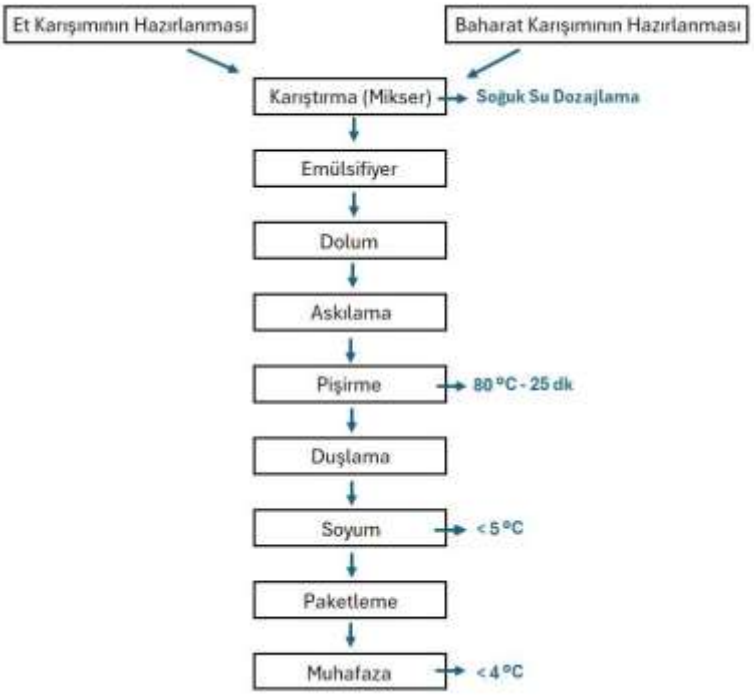

Figure 1. Process diagram of sausage production

Şekil 1. Sosis üretiminin akış diyagramı

Örneklerin fizikokimyasal analizlerinden nem tayini için TS ISO 1442 (TSE, 2023) ve kül tayini için TS 1746 ISO 936 (TSE, 2001) baz alınarak gerçekleştirilmiştir. Protein içeriğinin belirlenmesinde AOAC 960.52 metodu kullanılmıştır (AOAC, 1995). Kül ve protein miktarları kuru madde üzerinden g 100 g^{-1} olarak ifade edilmiştir. Yağ miktarı için TS 1744 (TSE, 1974) analiz metodu referans alınarak SOX-416 model (Gerhardt, Almanya) otomatik yağ tayin cihazı ile gerçekleştirilmiştir. Yağ miktarı, kuru madde üzerinden g 100 g^{-1} olarak hesaplanmıştır.

Sosis örneklerinin uçucu aroma bileşikleri tepe boşluğu katı faz mikro-ekstraksiyon (HS-SPME) ile ekstrakte edilerek, gaz kromatografisi-kütle spektrometresinde (GC/MS) bileşenlerin kalitatif ve kantitatif analizi gerçekleşmiştir. Homojen hale getirilen numunelerden SPME viallerine 3 g alınarak üzerlerine 3M 2 mL potasyum klorür (KCl) çözeltisi eklendikten sonra kapak kapatılmıştır. Ardından 24 saat oda sıcaklığında bekletilmiştir. Daha

sonra vialler 40°C'a ayarlı ısıtıcıda 15 dakika ön ısıtmaya tabi tutulmuştur. Uçucu bileşenleri yakalamak için DVB/CAR/PDMS fiber vialin tepe boşluğuna batırılmış ve burada 30 dakika adsorbe edilmiştir. Fiber uçta tutulan bileşikler, GC-MS enjeksiyon bloğuna enjekte edilerek desorbsiyon yapılması için 5 dakika beklenmiştir. Daha sonra uçucu bileşenlerin kalitatif ve kantitatif tayini için çalışma koşulları *Tablo 1*'deki gibi uygulanmıştır. Bilyalı kekik uçucu yağının bileşiminde de aynı metot kullanılmıştır.

Tablo 1. Uçucu bileşenlerin kalitatif ve kantitatif tayini için çalışma koşulları

Table 1. Experimental parameters of qualitative and quantitative analyses of volatile compounds

Parametreler	Değerler
Cihaz	Shimadzu QP2020NX GCMS
Enjeksiyon Miktarı	1 µL
Kolon	RTX Sil 5 MS (30 m x 0.25 mm iç kalınlığı, 0.25 µm film kalınlığı)
Sıcaklık Programı	40°C'da 5 dk beklet, 4°C dak^{-1} artışla 300°C'a çıkış ve bu sıcaklıkta 20 dakika beklet
Enjektör	250°C
Taşıyıcı Gaz	Helyum (1 ml dak^{-1})
Elektron Enerjisi	70 eV
Kütle Aralığı	m/z 29-425
Kütüphane	Wiley, NIST, FFNSC

Araştırma, Tam Şansa Bağlı Bloklar Deneme Planına göre 2 tekerrürlü olarak düzenlenmiştir. Araştırma sonuçları SPSS istatistik paket programı (v23, SPSS Inc., Chicago, IL) kullanılarak varyans analizine (ANOVA) tabi tutulmuş ve kontrol grubu dahil ortalamalar arası farklılık görülen gruplarda farkın önemli olup olmadığı Duncan çoklu karşılaştırma testiyle (p<0.05) analiz edilmiştir.

3. Araştırma Sonuçları ve Tartışma

3.1. Fizikokimyasal analizler

Sosis üretiminde kullanılan uçucu yağ miktarı çok düşük olmasına karşın üretilen ürünlerin fizikokimyasal analiz sonuçları *Tablo 2*'de sunulmuştur. Sosis örneklerinin protein, karbonhidrat, kül, yağ ve nem miktarları birbirine yakın değerler göstermiştir. Protein miktarı, kontrol örneğinde ortalama 14.75 g 100 g^{-1} iken uçucu yağ uygulamalı sosislerde 14.83-15.02 g 100 g^{-1} aralığında değişim sergilemiştir. Karbonhidrat miktarı, kontrol örneğinde 3.51 g 100 g^{-1} iken uçucu yağ uygulanan örneklerde ise 3.57-4.00 g 100 g^{-1} aralığında değişim göstermiştir. Üretilen sosis örneklerinde kül miktarı 2.28-2.31 g 100 g^{-1}, yağ miktarı 3.80-3.89 g 100 g^{-1} ve nem ise 74.87-75.44 g 100 g^{-1} aralığında değişim göstermiştir.

Tablo 2. Sosislerin fizikokimyasal özellikleri

Table 2. Physicochemical properties of sausages

Örnekler	Protein miktarı (g 100 g^{-1})	Toplam kül miktarı (g 100 g^{-1})	Yağ miktarı (g 100 g^{-1})	Nem miktarı (g 100 g^{-1})
Kontrol	14.75±0.49	2.26±0.04	3.80±0.10	75.44±0.57
BK1	14.99±0.50	2.31±0.04	3.86±0.10	74.95±0.57
BK2	15.02±0.50	2.28±0.04	3.89±0.10	75.01±0.57
BK3	14.83±0.50	2.29±0.04	3.80±0.10	74.87±0.57

Kontrol: uçucu yağ içermeyen sosis, BK1: % 0.2 uçucu yağ uygulanan sosis, BK2: % 0.1 uçucu yağ uygulanan sosis, BK3: % 0.05 uçucu yağ içeren sosis. Analizler üç paralel yapılmış olup sonuç ortalamaları ve standart sapmaları verilmiştir.

Polizer Rocha ve ark. (2019) yaptıkları çalışmada tavuk sosislerinde nem, kül, yağ ve protein oranını sırası ile %69.81, %2.95, %13.17 ve %12.53 olarak belirlemişlerdir. Munsu ve ark. (2021) yaptıkları çalışmada tavuk sosislerinde nem, kül, yağ ve protein oranını sırası ile %68.87, %0.64, %10.11 ve %19.23 olarak belirlemişlerdir. Tavuk göğsünün kullanıldığı Viyana yöresel sosislerinde nem, kül, yağ ve protein oranı sırası ile %56.44, %1.93, %22.91 ve %15.21 olarak belirlenmiştir (Kang ve ark., 2022). Araştırma sonuçları, protein açısından Polizer Rocha ve ark. (2019)'un sonuçlarından yüksek, Munsu ve ark. (2021)'in sonuçlarından düşük ve Kang ve ark. (2022)'nin sonuçları ile benzerlik göstermektedir. Nem içeriği, Polizer Rocha ve ark. (2019), Munsu ve ark. (2021) ve Kang ve ark. (2022)'nin sonuçlarından yüksek olmasına karşın, yağ miktarı ise

araştırmacıların sonuçlarından düşük bulunmuştur. Kül oranı ise Polizer Rocha ve ark. (2019)'un bildirdiği değerlerin altında, Munsu ve ark. (2021) ve Kang ve ark. (2022)'nin bildirdiği değerlerden yüksek bulunmuştur. Tavuk sosislerinde kullanılan formülasyonların farklı olması ve bunun yanında üretim koşullarındaki farklılıklardan dolayı araştırma sonuçları ile literatür değerleri arasında farklılıklar ortaya çıktığı düşünülmektedir.

Tablo 3. Bilyalı kekiğin (O. Onites) uçucu yağ bileşimi

Table 3. Composition of ball thyme (O. onites) essential oil

Sıra No	Alıkonma Süresi	Kovats İndeksi	Bileşen	Oran (%)
1	11.165	906	α-tujen	1.97
2	11.441	913	α-pinen	0.91
3	12.13	932	Kamfen	0.54
4	13.191	961	Sabinen	0.09
5	13.351	965	β-pinen	0.24
6	13.636	973	1-okten-3-ol	0.34
7	13.995	982	Mirsen	2.36
8	14.359	992	3-oktanol	0.08
9	14.625	999	α-fellandren	0.31
10	14.732	1002	Δ-3-karen	0.13
11	15.095	1011	α-terpinen	2.18
12	15.422	1019	p-simen	9.50
13	15.618	1024	Limonen	1.04
14	15.98	1034	cis-osimen	0.38
15	16.409	1044	Trans-osimen	0.21
16	16.854	1056	γ-terpinen	7.77
17	17.326	1068	cis-sabinen hidrat	0.60
18	17.955	1084	Terpinolen	0.30
19	18.583	1100	Linalool	3.37
20	21.337	1171	Borneol	2.45
21	21.663	1180	Terpinen-4-ol	1.95
22	22.052	1190	Pulegon	0.13
23	22.221	1195	α-terpineol	0.39
24	23.455	1228	Sitronellol	0.21
25	23.834	1239	Thimol metil eter	0.10
26	24.029	1244	Karvon	0.10
27	24.247	1250	Linalil asetat	1.30
28	24.33	1252	Geraniol	0.16
29	25.799	1293	Timol	12.20
30	26.139	1302	Karvakrol	37.46
31	30.036	1419	Trans-karyofillen	2.28
32	30.469	1432	α-bergamoten	0.17
33	30.64	1438	Aromadendren	0.08
34	31.171	1454	α-humulen	0.08
35	31.982	1480	Germasren D	0.73
36	32.311	1490	Viridifloren	0.17
37	32.438	1494	Bisiklogermasren	0.36
38	32.82	1507	β-bisabolen	5.69
39	33.143	1518	Δ-kadinen	0.21
40	33.291	1522	β-Seskifellandren	0.30
41	33.794	1539	α-bisabolen	0.10
42	34.402	1559	Nerolidol	0.19
43	34.88	1575	Spathulenol	0.13
44	35.034	1581	Karyofillen oksit	0.23

3.2. Uçucu bileşenler

Bilyalı kekiğin uçucu yağ bileşimi *Tablo 3*'de verilmiştir. Bilyalı kekik uçucu yağının bileşiminde 44 adet uçucu bileşen tanımlanmıştır. Bilyalı kekiğin bileşiminde en fazla yer alan bileşen %37.46 ile karvakroldür. Bunu %12.2 ile timol izlemektedir. p-simen ve γ-terpinen bileşenleri de bilyalı kekik uçucu yağ bileşiminde yer alan diğer önemli bileşenler olarak tespit edilmiştir (sırası ile %9.5 ve %7.77).

Kizil ve ark. (2009), *O. onites* uçucu yağında 26 bileşen belirlemiş olup, ana bileşen olarak karvakrol (%39.6-52.2) tespit edilmiştir. Bunun yanında timol (%10.7-18.6) ve linalool (%7.5-13.8) de temel bileşen olarak yer almaktadır. Toncer ve ark. (2009), *O. onites* uçucu yağında 26 uçucu bileşen tespit etmişlerdir. Bileşimde yer alan temel bileşen karvakrol olup, %24.66-52.58 aralığında değişim sergilemiştir. Karvakrolü, timol (%2.80-23.77), p-simen (%4.44-7.97) ve γ-terpinen (%7.02-11.16) izlemiştir. Demirci ve ark. (2022) tarafından yapılan çalışmada *O. onites* uçucu yağının bileşimini ağırlıklı olarak karvakrolün (%65.5-91) oluşturduğu, bu bileşeni linalool (%0.3-17.9), γ-terpinen (%2.8-4.6) ve timolün (%0.5-1.5) takip ettiği bildirilmiştir.

Araştırma sonuçları, Kizil ve ark. (2009), Toncer ve ark. (2009) ve Demirci ve ark. (2022)'nin *O. onites* uçucu yağı için tanımladıkları bileşenler ile uyumluluk sergilemektedir. Bunun yanında araştırma sonuçları ile yukarıda bahsi geçen literatürler arasında oransal farklılıklar mevcut olup, bu farklılıkların yetişme koşulları, hasat dönemi, ekstraksiyon işlemi ve lokasyon gibi faktörlerin farklı olmasından kaynaklanabileceği düşünülmektedir.

Tablo 4. Tavuk sosislerinde uçucu yağdan geçen bileşenlerin % olarak dağılım

Table 4. Percentage composition of compounds migrated from essential oil to chicken sausages

Sıra No	Bileşen	Kontrol	BK1	BK2	BK3
1	α-tujen	0.00±0.00^{c}	0.64±0.06^{b}	1.40±0.10^{a}	1.30±0.02^{a}
2	α-pinen	0.00±0.00^{d}	5.16±0.03^{a}	3.37±0.01^{c}	3.72±0.09^{b}
3	Kamfen	0.00±0.00^{d}	0.18±0.03^{c}	0.34±0.01^{a}	0.26±0.01^{b}
4	Sabinen	0.00±0.00^{c}	2.09±0.06^{b}	3.51±0.08^{a}	3.49±0.05^{a}
5	β-pinen	0.00±0.00^{c}	4.98±0.13^{b}	6.01±0.16^{a}	6.34±0.16^{a}
6	1-okten-3-ol	0.00±0.00^{d}	0.27±0.02^{c}	0.45±0.01^{a}	0.36±0.04^{b}
7	Mirsen	0.00±0.00^{c}	1.43±0.05^{b}	2.61±0.10^{a}	2.67±0.13^{a}
8	α-fellandren	0.00±0.00^{c}	1.01±0.03^{b}	1.21±0.04^{a}	1.27±0.04^{a}
9	Δ-3-karen	0.00±0.00^{c}	4.29±0.05^{b}	5.24±0.15^{a}	5.40±0.06^{a}
10	α-terpinen	0.00±0.00^{c}	1.49±0.10^{b}	2.81±0.07^{a}	2.72±0.07^{a}
11	p-simen	0.00±0.00^{d}	4.06±0.08^{c}	7.55±0.06^{a}	6.61±0.05^{b}
12	Limonen	0.00±0.00^{c}	15.60±0.04^{a}	11.26±0.08^{b}	11.38±0.05^{b}
13	γ-terpinen	0.00±0.00^{d}	5.67±0.05^{c}	6.64±0.05^{a}	6.16±0.06^{b}
14	cis-sabinen hidrat	0.00±0.00^{c}	1.46±0.01^{b}	1.63±0.10^{a}	1.64±0.06^{a}
15	Linalool	0.00±0.00^{c}	23.22±0.04^{a}	22.42±0.12^{b}	23.40±0.08^{a}
16	Borneol	0.00±0.00^{d}	1.16±0.02^{a}	0.90±0.02^{b}	0.72±0.04^{c}
17	Terpinen-4-ol	0.00±0.00^{d}	13.73±0.06^{a}	12.25±0.14^{c}	12.68±0.10^{b}
18	α-terpineol	0.00±0.00^{c}	6.36±0.01^{a}	1.79±0.12^{b}	1.85±0.02^{b}
19	Timol	0.00±0.00^{d}	0.45±0.03^{c}	0.80±0.02^{a}	0.73±0.01^{b}
20	Karvakrol	0.00±0.00^{d}	0.76±0.01^{c}	2.83±0.01^{a}	2.57±0.07^{b}
21	Trans-karyofillen	0.00±0.00^{c}	5.07±0.06^{a}	4.68±0.14^{b}	4.46±0.08^{b}
22	α-humulen	0.00±0.00^{c}	0.52±0.04^{a}	0.26±0.04^{b}	0.22±0.01^{b}
23	Karyofillen oksit	0.00±0.00^{c}	0.45±0.03^{a}	0.10±0.01^{b}	0.14±0.02^{b}

Kontrol: uçucu yağ içermeyen sosis, BK1: % 0.2 uçucu yağ uygulanan sosis, BK2: % 0.1 uçucu yağ uygulanan sosis, BK3: % 0.05 uçucu yağ içeren sosis. Analizler iki paralel yapılmış olup sonuç ortalamaları ve standart sapmaları verilmiştir. Aynı satırda farklı harfler taşıyan (a-d) ortalamalar arasındaki farklar önemlidir ($p<0.05$).

Tablo 4'de uçucu yağ uygulanan sosis örneklerinde bilyalı kekik uçucu yağından geçen bileşenler gösterilmektedir. Uçucu yağın kullanılarak yapıldığı sosis örneklerinde bilyalı kekik yağında mevcut olan 23 bileşenin tespiti yapılmıştır.

Bilyalı kekik uçucu yağında temel bileşenler olan ve sosis uçucu bileşiminde kekikten geçen bileşenler olarak karvakrol ve timol sırası ile %0.76-2.83 ve %0.45-0.80 aralığında tespit edilmiştir. Bu iki bileşen özellikle % 0.01 ve %0.05 yağ uygulanan sosislerde kontrol ve % 0.2 yağ uygulaması yapılan örneklere kıyasla daha yüksek oranda geçiş sağlamıştır (p<0.05). Bilyalı kekik yağı uygulanan örneklerin uçucu bileşiminde bilyalı kekik yağında var olan linalool en fazla oranda (%22.42-23.40) geçiş yapmıştır. Bunu limonen (%11.26-15.60) ve terpinen-4-ol (%12.25-13.73) izlemiştir. Uçucu bileşiminde bilyalı kekik yağında var olan 3-oktanol, aromadendren, bisiklogermasren, cis-osimen, cis-sabinen hidrat, geraniol, germasren d, karvon, linalil asetat, nerolidol, pulegon, sitronellol, spathulenol, terpinolen, thimol metil eter, trans-osimen, viridifloren, α-bergamoten, α-bisabolen, β-bisabolen, β-seskifellandren ve δ-kadinen bileşenlerinin Bilyalı kekik yağı uygulanan örneklere geçmediği görülmüştür.

Demirok Soncu ve ark. (2020) yaptıkları çalışmada kekik uçucu yağında timolü temel bileşen olarak belirlerken, sucuk üretiminde timolün çok az oranda geçiş yaptığı tespit etmişlerdir. Çalışma sonuçları Demirok Soncu ve ark. (2020)'nin bildirdiği sonuçlardaki gibi sucuk üretiminde uçucu yağ bileşiminde temel olarak yer alan bileşenlerin daha az oranda geçiş yaptığını göstermektedir.

4. Sonuç

Bu çalışma bilyalı kekik (*Origanum onites* L.) türünün uçucu yağ oranı ve bileşenlerini incelemek, bu yağın farklı oranlarda tavuk sosis üretiminde kullanılmasıyla ürüne geçebilen bileşenleri görebilmek ve tavuk sosisin fizikokimyasal özellikleri üzerine etkilerini karşılaştırabilmek amacıyla yapılmıştır. Bu doğrultuda; %0.2, %0.1, %0.05 oranlarında tavuk sosis formülasyonuna kekik uçucu yağı ilave edilmiştir, ayrıca uçucu yağ ilavesi yapılmayan bir kontrol grubu oluşturulmuştur. Uçucu yağda en fazla tespit edilen karvakrol ve timol bileşenlerinin, uçucu yağ ilave edilen numunelerde linalool ve limonen bileşenlerinden çok daha az ürüne geçtiği görülmüştür. Aynı zamanda uçucu yağda 44 adet uçucu bileşen tanımlanmışken, uçucu yağ ilave edilen numunelerde 23 adet uçucu bileşen tanımlanabilmiştir. Bu durum 21 adet bileşenin ürüne hiç geçmediğini ve ürüne geçen bileşenlerinde uçucu yağ içerisinde tespit edilen yoğunluklardan farklı olduğu görülmüştür. Bu çalışma ileri dönemlerde yapılacak uçucu yağlar kullanılarak yapay olmayan bir koruyuculuk amaçlayan çalışmalara temel sağlamak amacıyla yapılmıştır. Gelecek çalışma olarak, ürünün raf ömrü boyunca mikrobiyolojik izlemesi yapılarak uçucu yağın raf ömrüne etkilerinin değerlendirilmesi üzerine çalışılacaktır.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Doğal Bir Mera Alanında Uygulanan Farklı Islah Yöntemlerinin Çevresel Etkilerinin Yaşam Döngüsü Değerlendirmesi Kullanılarak Belirlenmesi

Determination of Environmental Impacts of Different Improvement Methods Applied in a Natural Rangeland Using Life Cycle Assessment

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Öz

Hayvancılık için büyük öneme sahip olmalarının yanı sıra meralar, ekosistem için de çok değerli doğal alanlardır. Bu tür alanlarda yürütülecek faaliyetlerin, çok yönlü değerlendirilerek planlanması ve yürütülmesi, sosyal, ekonomik ve ekolojik olarak sürdürülebilirliklerini sağlamamızı kolaylaştırabilir. Bununla birlikte, meralar karasal alanlar içerisinde oransal olarak önemli paya sahiptir. Bu derece büyük alanlarda yapılan ıslah uygulamaları da tüm ekosistem sağlığını ve sürdürülebilirliğini etkileyebilecek büyük çaplı faaliyetlerdir. Yaşam döngüsü değerlendirmesi, üretim süreci boyunca oluşan çevresel etkileri kümülatif olarak değerlendirmemize olanak sağlayan ve yaygın olarak kullanılan bir yöntemdir. Bu çalışmada, yaşam döngüsü değerlendirmesi ile Samsun ilinde 30 yıl önce sürülerek terk edilmiş bir mera alanında yapılan bir ıslah denemesi sonuçları esas alınarak, yapılan uygulamalarının çevresel etkilerinin belirlenmesi ve karşılaştırılması amaçlanmıştır. Havalandırma (H), ahır gübresi uygulaması (AG), suni gübre uygulaması (SG), havalandırma + ahır gübresi uygulaması (HAG) ve havalandırma + suni gübre uygulaması (HSG) işlemleri, bir ton kuru ot ve bir ton protein verimi fonksiyonel birimleri kullanılarak değerlendirilmiştir. Yaşam döngüsü değerlendirmesi neticesinde, bir ton kuru ot fonksiyonel biriminde, en yüksek çevresel yüke neden olan ıslah uygulamalarının sırasıyla SG ve HSG, en düşük çevresel yük oluşturan işlemlerin sırasıyla AG ve H işlemleri olduğu görülmüştür. Bir ton protein fonksiyonel birimi için en yüksek çevresel yükün, sırasıyla HSG ve SG, en düşük çevresel yükün ise sırasıyla AG ve H işlemlerinde gerçekleştiği belirlenmiştir. Mera ıslah uygulamalarında suni gübre kullanımının, birim çıktı başına çok fazla çevresel yük oluşturduğu, yapılacak ıslah işlemlerinde suni gübre kullanımının çok dikkatle değerlendirilmesi gerektiği sonucuna ulaşılmıştır. Islah için otlatma kontrolü, biçim, havalandırma gibi yöntemlerin öncelenmesi ve bitki besin maddesi eksikliklerinin ahır gübresi ile telafi edilmesinin daha uygun olacağı değerlendirilmiştir.

Anahtar Kelimeler: Mera ıslahı, Yaşam döngüsü değerlendirmesi, Çevresel etki, Kuru ot, Protein

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Abstract

Besides being of great importance for livestock, rangelands are also very valuable natural areas for the ecosystem. The planning and execution of activities to be carried out in such areas with a multidimensional evaluation can facilitate us to ensure their social, economic and ecological sustainability. However, rangelands have a proportionally significant share in terrestrial areas. Improvement practices in such large areas are also large-scale activities that can affect the health and sustainability of the entire ecosystem. Life cycle assessment is a widely used method that allows us to cumulatively assess the environmental impacts that occur throughout the production process. In this study, with life cycle assessment, it was aimed to determine and compare the environmental impacts of the practices based on the results of a improvement experiment conducted in a rangeland abandoned by plowing 30 years ago in Samsun province. The treatments of Aeration (H), barn manure application (AG), chemical fertilizer application (SG), aeration + barn manure application (HAG) and aeration + chemical fertilizer applications (HSG) were evaluated using functional units of one ton of hay and one ton of protein yield. As a result of the life cycle assessment, it was observed that for one ton of dry grass functional unit, the treatments causing the highest environmental burden were SG and HSG, while the treatments causing the lowest environmental burden were AG and H, respectively. It was determined that the highest environmental load for a ton of protein functional unit was HSG and SG, and the lowest environmental load was in AG and H, respectively. It was concluded that the use of chemical fertilizers in rangeland improvement practices caused a very high environmental load per unit output, and that the use of chemical fertilizers should be evaluated very carefully in the improvement processes to be carried out. It was evaluated that it would be more appropriate to prioritize methods such as grazing control, cutting, aeration for improvement, and to compensate for plant nutrient deficiencies with barn manure.

Keywords: Rangeland improvement, Life cycle assessment, Environmental impact, Dry hay, Protein

1. Giriş

Türkiye'de 25.02.1998 tarihinde çıkarılan 4342 sayılı Mera Kanunu ile hukuki statüsü netleştirilmiş olan mera alanları, kamu orta malı hükmünde olan, kadimden beri bu amaçla kullanılan veya sonradan mera olarak kullanılabileceği tespit edilerek tahsis edilen, otlatma hakkının tahsis edilmesi yolu ile hayvancılık yapan üreticilerin kullanmasına olanak sağlanan, doğal olarak veya ıslah tedbirleri ile oluşturulmuş kısa boylu, karışık bitki örtüsüne sahip, hayvan otlatma yolu ile faydalanılan arazilerdir.

Tarım alanları sürekli toprak işleme, tohum yatağı hazırlama, gübreleme ekim, hasat, vb. kültürel işlemlere ihtiyaç duyarken mera alanları, çok az müdahaleyle yönetilebilirler; çalılar ve ağaçlar tarafından işgal edilmesini önlemek için yılda bir kez biçmek yeterli olabilmektedir (Nemecek ve ark., 2011). Seydoşoğlu (2018), meralarda sürdürülebilirliğin devam etmesi bakımından, ilk olarak otlatmanın planlaması, sonrasında başta gübreleme ve yabancı ot savaşımı olmak üzere bazı bakım ve ıslah işlemlerinin uygulamaya konulması ve ayrıca uygulamaların da zaman zaman yenilenmesi gerektiğini ifade etmiştir. Gökkür ve Uysal (2020), çok fazla bozulmamış mera alanlarında, otlatmanın planlanması, gübreleme, yabancı otla mücadele, drenaj sistemi oluşturma gibi ıslah uygulamaları ile başarılı sonuçlar alınabileceğini belirtmişlerdir.

Ülkemizde mera ıslah çalışmaları, Kanunun çıktığı 1998 yılından itibaren, yükseköğretim kurumları ile Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğüne bağlı araştırma enstitülerinin danışmanlığında, Tarım ve Orman Bakanlığı taşra teşkilatlarınca yürütülmektedir. Ülke çapında 2000 yılı ile 2024 yılları arasında 22.012.970 dekar alanda, 2958 adet mera ıslah ve amenajman projesi uygulanmıştır (Anonim, 2024).

Cangir ve Boyraz (2008), Arazilerin doğal yapılarının, ekosistemin sürdürülebilirliğine yönelik olarak korunması için her türlü teknik ve yasal tedbirin alınması gerektiğini, Cevher ve ark. (2009), mera alanlarına yönelik ıslah ve düzenleme tekniklerinin uygulamaya konulabilmesinin, ancak mera üzerinde yapılacak uygulamaların, ekolojik ve ekonomik olarak sürdürülebilir, sosyal olarak kabul edilebilir olması ile mümkün olabileceğini belirtmişlerdir. Oysa mera ıslah çalışmaları yapılırken, çoğunlukla kaba yem veriminin arttırılmasına odaklanılmakta, planlanan veya yapılan uygulamaların çevresel etkileri ve ekolojik sürdürülebilirliği geri planda kalmaktadır. Öyle ki bu çalışma için yapılan literatür taramasında, ülkemizdeki mera ıslah uygulamalarının ekolojik sürdürülebilirliğinin ölçülmesine yönelik objektif ve bilimsel değerlendirmelerin yapılabileceği bir yöntem tavsiyesine rastlanılmamıştır.

Yaşam döngüsü değerlendirmesi (YDD), çevresel yüklerin analiz edilmesi amacıyla kullanılan, Dünyada geniş kabul görmüş bir yöntemdir. Tarımsal faaliyetlerin çevresel etkilerini tahmin etmek ve tarımsal ürünlerin üretiminin neden olduğu kaynak tükenmesi sorunları ve çevresel ve sağlık etkilerini değerlendirmek için de yaygın olarak kullanılmaktadır (Avadi ve ark., 2022, Van Der Werf ve ark., 2020).

Bu çalışmada YDD yöntemi ile mera ıslah uygulamalarının oluşturduğu çevresel etkilerin tespit edilmesi, farklı uygulamaların etkilerinin karşılaştırılması ve birim çıktı artışı başına en az çevresel yük oluşturan ıslah yönteminin belirlenmesi amaçlanmıştır.

2. Materyal ve Metot

2.1. Çalışma alanı ve yöntemi

Yaşam döngüsü analizi için ele alınan veriler, 2005 – 2008 yılları arasında Samsun ilinde Ondokuz Mayıs Üniversitesi Ziraat Fakültesi'ne ait, denemenin kurulmasından yaklaşık 30 yıl önce sürülüp terk edilmiş, doğal bir mera alanından elde edilmiştir. Çalışma zamanında devam eden herhangi bir otlatma faaliyeti bulunmamaktadır. Mera alanında tesadüf blokları deneme desenine göre 4 tekrarlamalı olarak yürütülen denemede, farklı ıslah yöntemlerinin verim, ot kalitesi ve bitki kompozisyonuna etkileri araştırılmıştır (Mut, 2009).

Çalışmanın yaşam döngüsü analizi için ele alınacak kısmında havalandırma, suni gübre uygulaması, ahır gübresi uygulaması, havalandırma + suni gübre, havalandırma + ahır gübresi uygulamalarının sonuçları değerlendirilmiş, bu işlemler sonucu elde edilen ve *Tablo 1*'de verilen kuru ot ve protein verimi değerlerinden yararlanılarak çevresel etki analizi yapılmıştır. Söz konusu işlemlerden olan havalandırma işlemi tırmık ile yaklaşık 5 – 6 cm derinliğinde olacak şekilde sonbaharda gerçekleştirilmiştir (Ayan ve Acar, 2008). Gübre uygulamalarında ise deneme alanının toprak analiz sonuçları ve botanik kompozisyonu dikkate alınarak, 3 yılın

sonunda toplam dekara 12 kg N ve 8 kg P_2O_5 olacak şekilde suni gübre ve dekara 5 kg N olacak şekilde tamamı sonbaharda ahır gübresi uygulaması yapılmıştır. Parsellerin biçim işlemi dominant bitkilerin çiçeklenme dönemi esas alınarak elle gerçekleştirilmiştir.

Tablo 1. YDD ile çevresel yükleri karşılaştırılan işlemler*

*Table 1. Processes comparing environmental loads with LCA**

İşlemler	Kuru Ot Verimi (kg/ha)	Protein Verimi (kg/ha)
Havalandırma (H)	3783	527
Suni gübre uygulaması (SG)	4649	604
Ahır gübresi uygulaması (AG)	4721	668
Havalandırma + suni gübre uygulaması (HSG)	5606	637
Havalandırma + ahır gübresi uygulaması (HAG)	4918	619

** Veriler Hanife Mut'un doktora tezinden alınmıştır.*

2.2. Yaşam Döngüsü Değerlendirmesi Metodolojisi

Mera ıslah yöntemlerinin çevresel etkilerinin değerlendirilmesi için yaşam döngüsü değerlendirmesi (YDD) yöntemi kullanılmıştır. YDD bir süreci karakterize eden malzeme ve enerjinin girdilerini ve çıktılarını, ilişkili çevresel etkiye dönüştürmek için sistematik bir prosedür seti kullanan bütünsel bir yaklaşımdır (Bacenetti ve ark., 2018). Bu yöntem ile ürün veya hizmetin tüm yaşam döngüsü süreci ve bağlantıları bütünsel olarak ele alınır, bu sayede süreç boyunca oluşan çevresel etkiler kümülatif olarak değerlendirilebilir, raporlanabilir ve karşılaştırılabilir (Burgu ve Mut, 2023). YDD temelde endüstriyel ürünlerin çevresel etkilerinin değerlendirilmesi amacıyla geliştirilmiş ve uygulamanın ilk zamanlarında endüstriyel ürünlere odaklanılmış olmasına rağmen, zamanla yapılan çalışmalar sayesinde tarımsal sistemlerin çevresel etkilerinin değerlendirilmesi için de değerli bir yöntem olduğu kanıtlanmıştır (Van der Werf ve Petit, 2002). Bu çalışmanın amacı da mera alanında uygulanan ıslah yöntemlerinin çevresel etkilerini tespit etmek ve yöntemler arasında karşılaştırma yapılması yolu ile birim çıktı artışı başına en az çevresel yük oluşturan ıslah yöntemini belirlemektir.

2.2.1. Sistem sınırları

Çalışma alanı doğal mera alanı olduğundan ve ıslah uygulamaları öncesi herhangi bir işlem içermediğinden, sistem sınırları ıslah uygulamaları ile başlamakta ve hasat ile son bulmaktadır. Bu hali ile kapıdan kapıya bir yaşam döngüsü değerlendirmesidir.

2.2.2. Fonksiyonel birim

Fonksiyonel birim (FB), matematiksel normalleştirme ile daha basit karşılaştırma ve ölçüme olanak sağlamak için belirlenir, ölçülen ve açıkça belirtilen pazarlanabilir bir ürünü yansıtır (ISO14040, 2006). Yem bitkilerinin yaşam döngüsü değerlendirmesine birçok araştırmacı fonksiyonel birim olarak 1 ton kuru otu esas almıştır (Nemecek ve ark., 2011, Ghaderpour ve ark., 2018, Bacenetti ve ark., 2018). Bu çalışmada da 1 ton kuru ot (60 ^{0}C'de sabit ağırlığa gelene kadar kurutulmuş ot) fonksiyonel birim belirlenmiştir. Bununla birlikte alternatif bir değerlendirme yapabilmek ve kuru ot fonksiyonel birimi ile elde edilen sonuçları karşılaştırabilmek için 1 ton protein verimi, ikinci bir fonksiyonel birim olarak (González-García ve ark., 2016) çalışmaya dahil edilmiştir.

2.2.3. Envanter

Çalışmada veriler deneme alanına uygulanan işlemlerden elde edilmiştir. Ahır gübresi ve suni gübre miktarları denemede uygulanan miktarın oranlanması ile elde edilmiştir.

$$Bir\ birim\ fonksiyonel\ birim\ başına\ gübre\ miktarı\ =\ Uygulanan\ gübre\ miktarı\ (kg/ha)\ /\ verim\ (ton/ha) \quad \text{(Eş. 1)}$$

Gübrelerin 1 hektar alana uygulanması ve havalandırma için tırmık çekilmesi işlemlerinde değerlendirme ise yapılacak işlemlerin 1 hektar alanda, hangi makine ve ekipmanlarla ve ne kadar zamanda yapılabileceği hususunun işletmeler düzeyinde araştırılması sonucu elde edilen veriler ışığında gerçekleştirilmiştir.

$$Bir\ birim\ fonksiyonel\ birim\ başına\ makine\ kullanımı = Çalışma\ süresi(\ dakika/ha)/verim(ton/ha) \quad \text{(Eş. 2)}$$

2.2.4. Yaşam döngüsü etki değerlendirmesi

Bu çalışmada, ILCD (Uluslararası Referans Yaşam Döngüsü Veri Sistemi) orta nokta yöntemi kullanılarak etki kategorileri değerlendirilmiştir (Wolf ve ark., 2011).

3. Araştırma Sonuçları ve Tartışma

3.1. Kuru ot verimi fonksiyonel birimine göre değerlendirme

Fonksiyonel birim 1 ton kuru ot alındığında işlemlerin hesaplanan çevresel etkileri *Tablo 2*'de verilmiştir.

Tablo 2. Fonksiyonel birim 1ton kuru ot olarak alındığında işlemlere ait etki değerlendirme sonuçları

Table 2. Impact assessment results of the processes when the functional unit is considered as 1 ton of dry grass

Gösterge	H	SG	AG	HSG	HAG
Asidifikasyon (molc H+ eq)	9.898e-2	1.095e+0	3.583e-1	9.749e-1	4.200e-1
İklim değişikliği (kg CO2 eq)	9.881e+0	2.185e+2	1.994e+1	1.878e+2	2.674e+1
Tatlısu Ekotoksisitesi (CTUe)	3.129e+1	7.286e+2	3.179e+1	6.253e+2	5.458e+1
Tatlısu Ötrofikasyonu (kg P eq)	8.193e-4	6.407e-2	1.105e-3	5.368e-2	1.691e-3
İnsan toksisitesi- kanser etkisi (CTUh)	2.827e-7	3.726e-6	3.591e-7	3.281e-6	5.622e-7
İnsan toksisitesi- kanser dışı etki (CTUh)	8.041e-6	2.556e-5	8.048e-6	2.663e-5	1.391e-5
İyonize radyasyon E (CTUe)	4.852e-6	1.999e-5	1.850e-6	1.986e-5	5.509e-6
İyonize radyasyon HH (kBq U235 eq)	9.657e-1	6.369e+0	3.268e-1	5.934e+0	1.056e+0
Alan kullanımı (kg C deficit)	1.324e+4	1.090e+4	1.062e+4	9.058e+3	1.021e+4
Deniz Ötrofikasyonu (kg N eq)	4.137e-2	1.266e-1	1.585e-2	1.329e-1	4.704e-2
Mineral ve fossil kaynak tüketimi (kg Sb eq)	1.061e-3	5.035e-3	6.782e-4	4.891e-3	1.467e-3
Ozon tüketimi (kg CFC-11 eq)	1.795e-6	1.392e-5	6.746e-7	1.275e-5	2.028e-6
Partikul madde kirliliği (kg PM2.5 eq)	6.626e-3	8.266e-2	3.859e-3	7.302e-2	8.801e-3
Fotokimyasal ozon oluşumu (kg NMVOC eq)	1.199e-1	2.395e-1	5.048e-2	2.794e-1	1.407e-1
Karasal Ötrofikasyon (molc N eq)	4.538e-1	2.742e+0	4.128e+0	2.580e+0	4.312e+0
Su kaynakları tüketimi (m3 water eq)	3.782e-3	9.865e-1	2.099e-6	8.206e-1	2.911e-3

H-Havalandırma SG- Suni gübre uygulaması AG-Ahır gübresi uygulaması HSG-Havalandırma ve suni gübre uygulaması HAG- Havalandırma ve ahır gübresi uygulaması

Mera ıslah yöntemlerinin, her 1 ton kuru ot verimi için oluşturduğu çevresel yükler karşılaştırıldığında, *SG* işleminin, incelenen 16 etki kategorisinden 11'inde (asidifikasyon, iklim değişikliği, tatlısı ekotoksisitesi, tatlısı ötrofikasyonu, İnsan toksisitesi-kanser etkisi iyonize radyasyon E, iyonize radyasyon HH, mineral ve fossil kaynak tüketimi, ozon tüketimi, partikul madde kirliliği ve su kaynakları tüketimi) en büyük çevresel yüke sebep olduğu belirlenmiştir. *HSG* işlemi 3 (insan toksisitesi-kanser dışı etki, deniz ötrofikasyonu, fotokimyasal ozon oluşumu), *HAG* işlemi 1 (karasal ötrofikasyon) ve *H* işlemi kalan bir etki kategorisinde (alan kullanımı) en yüksek çevresel yüke neden olmuştur (*Tablo 2*).

AG işleminin 8 (iyonize radyasyon E, iyonize radyasyon HH, deniz ötrofikasyonu, mineral ve fossil kaynak tüketimi, ozon tüketimi, partikul madde kirliliği, fotokimyasal ozon oluşumu, su kaynakları tüketimi), *H* işlemin 7 (asidifikasyon, iklim değişikliği, tatlısı ekotoksisitesi, tatlısı ötrofikasyonu, insan toksisitesi-kanser etkisi, insan toksisitesi-kanser dışı etki, karasal ötrofikasyon) etki kategorisinde en az çevresel yük oluşturdukları, *HSG* uygulamasının ise kalan 1 etki kategorisinde (alan kullanımı) en düşük çevresel yükü oluşturduğu belirlenmiştir (*Tablo 2*).

Şekil 1'de her bir etki kategorisinde en yüksek çevresel yükü oluşturan işlemin etkisi 100 birim kabul edilmiş ve diğer işlemlerin etkileri bu değere göre oranlanmıştır. Söz konusu grafikte, *H* ve *HAG* işleminin en yüksek çevresel etkiye neden olduğu alan kullanımı ve karasal ötrofikasyon kategorilerinde *SG* ve *HSG* işlemlerinin etkilerinin de %60-80 aralığında olduğu, *SG* ve *HSG* işlemlerinin en yüksek etkiyi oluşturduğu 14 etki kategorisinde ise diğer işlemlerin etkilerinin oldukça düşük olduğu görülebilmektedir.

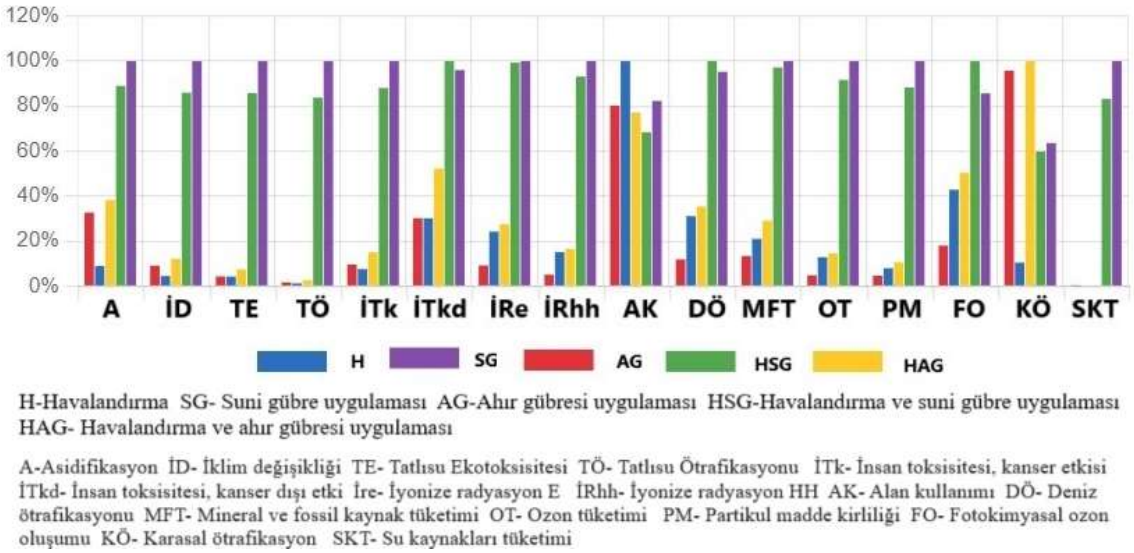


Figure 1. Graph showing the comparison of environmental impacts of processes when the functional unit is considered as 1 ton of protein

Şekil 1. Fonksiyonel birim 1 ton protein olarak alındığında işlemlere ait çevresel etkilerin karşılaştırmasını gösterir grafik

3.2. Protein verimi fonksiyonel birimine göre değerlendirme

Fonksiyonel verimin 1 ton protein alınarak yapılan değerlendirme sonucunda elde edilen veriler *Tablo 3*'te verilmiştir.

Tablo 3. Fonksiyonel birim 1 ton protein olarak alındığında işlemlere ait etki değerlendirme sonuçları

Table 3. Effect evaluation results of the procedures when the functional unit is considered as 1 ton of protein

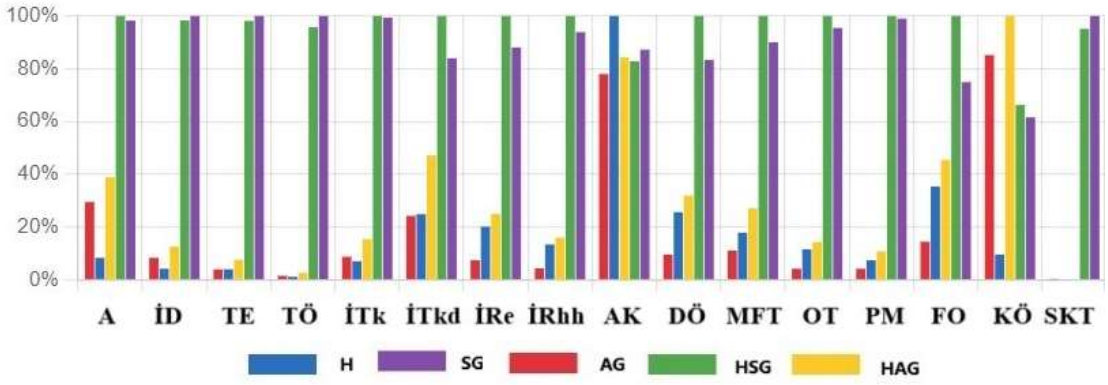
Gösterge	H	SG	AG	HSG	HAG
Asidifikasyon (molc H+ eq)	7.191e-1	8.428e+0	2.532e+0	8.579e+0	3.337e+0
İklim değişikliği (kg CO2 eq)	7.178e+1	1.682e+3	1.409e+2	1.653e+3	2.124e+2
Tatlısu Ekotoksisitesi (CTUe)	2.273e+2	5.607e+3	2.246e+2	5.503e+3	4.337e+2
Tatlısu Ötrofikasyonu (kg P eq)	5.952e-3	4.931e-1	7.808e-3	4.724e-1	1.343e-2
İnsan toksisitesi- kanser etkisi (CTUh)	2.054e-6	2.868e-5	2.538e-6	2.887e-5	4.467e-6
İnsan toksisitesi- kanser dışı etki (CTUh)	5.842e-5	1.968e-4	5.688e-5	2.343e-4	1.105e-4
İyonize radyasyon E (CTUe)	3.525e-5	1.539e-4	1.308e-5	1.748e-4	4.377e-5
İyonize radyasyon HH (kBq U235 eq)	7.016e+0	4.902e+1	2.305e+0	5.222e+1	8.390e+0
Alan kullanımı (kg C deficit)	9.621e+4	8.391e+4	7.505e+4	7.972e+4	8.114e+4
Deniz Ötrofikasyonu (kg N eq)	3.006e-1	9.746e-1	1.120e-1	1.170e+0	3.737e-1
Mineral ve fossil kaynak tüketimi (kg Sb eq)	7.707e-3	3.875e-2	4.793e-3	4.305e-2	1.166e-2
Ozon tüketimi (kg CFC-11 eq)	1.304e-5	1.071e-4	4.768e-6	1.122e-4	1.611e-5
Partikul madde kirliliği (kg PM2.5 eq)	4.814e-2	6.362e-1	2.727e-2	6.426e-1	6.992e-2
Fotokimyasal ozon oluşumu (kg NMVOC eq)	8.710e-1	1.843e+0	3.568e-1	2.459e+0	1.118e+0
Karasal Ötrofikasyon (molc N eq)	3.297e+0	2.110e+1	2.917e+1	2.271e+1	3.426e+1
Su kaynakları tüketimi (m3 water eq)	2.748e-2	7.593e+0	1.483e-5	7.222e+0	2.313e-2

H-Havalandırma SG- Suni gübre uygulaması AG-Ahır gübresi uygulaması HSG-Havalandırma ve suni gübre uygulaması HAG- Havalandırma ve ahır gübresi uygulaması

Mera ıslah yöntemlerinin her 1 ton protein verimi için oluşturduğu çevresel yükler karşılaştırıldığında, *HSG* işleminin, incelenen 16 etki kategorisinden 10'unda (asidifikasyon, insan toksisitesi-kanser etkisi, insan toksisitesi-kanser dışı etki, iyonize radyasyon E, iyonize radyasyon HH, deniz ötrofikasyonu, mineral ve fosil kaynak tüketimi, ozon tüketimi, partikül madde kirliliği, fotokimyasal ozon oluşumu) en büyük çevresel yüke sebep olduğu belirlenmiştir. *SG* işlemi 4 (iklim değişikliği, tatlısı ekotoksisitesi, tatlısı ötrofikasyonu, su kaynakları tüketimi), *HAG*

işlemi 1 (karasal ötrofikasyon) ve *H* işlemi ise kuru ot veriminde olduğu gibi yalnızca alan kullanımı etki kategorisinde en yüksek çevresel yükün oluştuğu görülmüştür (*Tablo 3*).

AG işleminin 11 (tatlısı ekotoksisitesi, tatlısı ötrofikasyonu, insan toksisitesi-kanser dışı etki, iyonize radyasyon E, iyonize radyasyon HH, alan kullanımı, deniz ötrofikasyonu, mineral ve fossil kaynak tüketimi, ozon tüketimi, partikul madde kirliliği, fotokimyasal ozon oluşumu, su kaynakları tüketimi) etki kategorisinde en az çevresel yük oluşturduğu, *H* uygulamasının ise diğer 5 etki kategorisinde (asidifikasyon, iklim değişikliği, insan toksisitesi-kanser etkisi, karasal ötrofikasyon) en düşük çevresel yükü oluşturduğu belirlenmiştir (*Tablo 3*).



H-Havalandırma SG- Suni gübre uygulaması AG-Ahır gübresi uygulaması HSG-Havalandırma ve suni gübre uygulaması HAG- Havalandırma ve ahır gübresi uygulaması

A-Asidifikasyon İD- İklim değişikliği TE- Tatlısu Ekotoksisitesi TÖ- Tatlısu Ötrafikasyonu İTk- İnsan toksisitesi, kanser etkisi İTkd- İnsan toksisitesi, kanser dışı etki İre- İyonize radyasyon E İRhh- İyonize radyasyon HH AK- Alan kullanımı DÖ- Deniz ötrafikasyonu MFT- Mineral ve fossil kaynak tüketimi OT- Ozon tüketimi PM- Partikul madde kirliliği FO- Fotokimyasal ozon oluşumu KÖ- Karasal ötrafikasyon SKT- Su kaynakları tüketimi

Figure 2. Graph showing the comparison of environmental impacts of processes when the functional unit is taken as 1 ton of dry grass

Şekil 2. Fonksiyonel birim 1 ton kuru ot olarak alındığında işlemlere ait çevresel etkilerin karşılaştırmasını gösterir grafik

Şekil 2'de bir ton protein verimi için, her bir etki kategorisinde en yüksek çevresel yükü oluşturan işlemin etkisi 100 birim kabul edilmiş ve diğer işlemlerin etkileri bu değere göre oranlanmıştır. Bu grafik sayesinde *H* işleminin en yüksek çevresel etkiye neden olduğu alan kullanımı etki kategorisinde, diğer işlemlerin etkilerinin %75-80 aralığında ve yakın olduğu, *SG* ve *HSG* işlemlerinin en yüksek etkiyi oluşturduğu 15 etki kategorisinde ise diğer işlemlerin oransal etkisinin çok düşük olduğu görülebilmektedir.

4. Sonuç

Bu çalışmanın hazırlanması sırasında yapılan literatür taramasında, ülkemizde mera ıslah yöntemlerinin veya yönetim modellerinin çevresel etkilerinin değerlendirildiği bir çalışmaya rastlanılmamıştır. Dünyada da bu konuda oldukça az sayıda çalışma bulunduğu görülmüştür.

Nemecek ve arkadaşları (2011), meralarda düşük yoğunluklu yönetimin çevresel etkiyi azalttığı ve biyoçeşitliliği arttırdığını ancak birim ürün başına net enerji laktasyonunu değerlendirerek, yem kalitesi de analiz edildiğinde yoğun yönetimin daha az çevresel etki oluşturduğunu belirlemişler ve tüm meraları düşük yoğunluklu bir şekilde yöneterek hayvanların niceliksel ve niteliksel yem ihtiyaçlarını karşılamanın da mümkün olmayacağını öne sürerek, yoğun ve az yoğun yönetilen parsellerin kombinasyonu ile çevresel ve ekonomik hedefler arasında bir uzlaşma sağlanmasını önermişlerdir.

Çalışmamızda değerlendirmeye alınan beş işlemden elde edilen sonuçlar her iki fonksiyonel birim bakımından karşılaştırılmış, 1 ton kuru ot ve 1 ton protein fonksiyonel birimlerinde elde edilen sonuçların uyumlu olduğu, aynı işlemleri işaret ettiği görülmüştür.

1 ton kuru ot fonksiyonel biriminde; en yüksek çevresel yükün *SG* işlemi (16 etki kategorisinin 11'inde) ve ikinci olarak HSG işlemi uygulamasında (16 etki kategorisinin 3'ünde), en düşük çevresel yükün ise *AG* (16 etki kategorisinin

8'inde) ve *H* (16 etki kategorisinin 7'sinde) işlemlerinin uygulamasında gerçekleştiği belirlenmiştir.

1 ton protein fonksiyonel biriminde; en yüksek çevresel yükün *HSG* işleminde (16 etki kategorisinin 10'unda) ve ikinci olarak SG işleminde (16 etki kategorisinin 4'ünde), en düşük çevresel yükün ise *AG* işleminde (16 etki kategorisinin 11'inde) ve ikinci olarak *H* işleminde (16 etki kategorisinin 5'inde) gerçekleştiği tespit edilmiştir.

Sonuç olarak; mera ıslah uygulamalarında suni gübre kullanımının birim ürün başına daha fazla çevresel yük oluşturduğu, önemli verim artışlarının garanti edilemeyeceği alanlarda ıslah uygulamalarında yer verilmemesi gerektiği, otlatma kontrolü, biçim, havalandırma gibi yöntemlerin tercih edilmesi ve bitki besin maddesi eksikliklerinin ahır gübresi ile telafi edilmesinin çevresel etki bakımında daha uygun olacağı değerlendirilmiştir. Gür ve Şen (2016), meraların korunması ve ağır otlatılmalarından kaçınılmasıyla, vejetasyonda kaliteli türlerin iyileştirilmesi ve uzun yıllar sürdürülebilirliklerinin kolaylıkla sağlanabileceğini bildirmişlerdir.

Weltz ve ark. (2003), Kırsal toplulukların refahı ile meraların sağlığı ve sürdürülebilirliği arasında denge kurmak için geliştirilmiş yöntemlere ihtiyaç duyulduğunu, mera ekosistemlerinin sürdürülebilirliği üzerinde yönetim uygulamalarının etkisini belirlemek için bilim temelli bir izleme sistemini geliştirmek ve çiftçilere ve mera yöneticilerine başarılı bir şekilde aktarmak için koordineli ulusal araştırmaların ve teknoloji transferinin gerektiğini belirtmişlerdir. Ülkemizde yapılan mera ıslah ve yönetim uygulamalarında da bilimsel temelli yeni izleme ve değerlendirme yöntemlerine ihtiyaç olduğu açıktır. YDD bu konuda etkin bir araç olabilir.

Farklı lokasyonlarda ve farklı vejetasyonlarda çevresel etki değerlendirmesine yönelik yeni çalışmaların yapılması gerektiği, çalışma sayısının artması ile daha net önerilerin sunulabileceği düşünülmektedir.

Etik Kurul Onayı

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

Çıkar Çatışması Beyanı

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

Yazarlık Katkı Beyanı

Planlama: Burgu, L., Mut, H., Ayan, İ.; Materyal ve Metot: Burgu, L., Mut, H., Ayan, İ.; Veri toplama ve İşleme: Burgu, L., Mut, H., Ayan, İ.; Literatür Tarama: Burgu, L., Mut, H., Ayan İ.; Makale Yazımı, İnceleme ve Düzenleme: Burgu, L., Mut, H., Ayan, İ.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Field Testing of Low-Cost PM Sensors in Animal Production Facilities

Düşük Maliyetli PM Sensörlerinin Hayvansal Üretim Tesislerinde Test Edilmesi

Seyit UGUZ[1], Pradeep KUMAR[2], Shalini TIWARI[3], Young CHANG[4], Xufei YANG[5]*

Abstract

The measurement of particulate matter (PM) in animal housing environments is crucial for ensuring the health and well-being of both animals and human workers. High concentrations of PM can lead to respiratory issues, reduced productivity, and compromised animal welfare. The affordability and compact design of low-cost PM sensors present an opportunity to enhance spatiotemporal resolution in PM measurements. However, these low-cost sensors have certain limitations and require characterization in dusty environments such as animal production facilities. This study examines eight low-cost PM sensors (PMS5003, PMS7003, OPC-R2, OPC-N3, Gravity, SDS011, GP2Y1010, and PPD42) for their performance in monitoring PM_1, $PM_{2.5}$, and PM_{10} concentrations in animal houses. It details sensor components, hardware integration, and field deployment, along with preliminary testing in farm office and production room environments. A GRIMM 11-D aerosol spectrometer was used as the reference monitor. The OPC-N3 sensor showed high linearity against the reference monitor in the office, with R^2 values higher than 0.97, but this correlation dropped to 0.40-0.59 in the production room due to increased particle concentration affecting sensor sensitivity. Meanwhile, the PMS7003 sensor excelled in PM_1 measurements with an R^2 value of 0.90, performing well in production settings, in contrast to its performance in the office. The SDS011 sensor also demonstrated good performance in production environments. Preliminary results suggest that while these sensors effectively measure PM levels under certain conditions, their performance varies significantly depending on environmental factors such as dust concentration, temperature, and relative humidity. The necessity for rigorous field testing and calibration is emphasized to enhance the reliability and accuracy of these sensors in monitoring indoor air quality in agricultural settings. Further research and field testing are essential to validate sensor performance and ensure their effectiveness across diverse environmental conditions.

Keywords: Particulate matter, Low-cost sensors, Air quality, Animal houses, Measurement

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Öz

Hayvan barınakları iç ortamında partikül maddelerin (PM) izlenmesi hem barındırılan hayvanların hem de çiftlik çalışanlarının sağlık ve refahının sağlanması için oldukça önemlidir. Yüksek düzeyde organic partiküllere ve kirletici gazlara maruz kalan çiftlik çalışanları, yaşlandıkça solunum yolu hastalıklarına daha duyarlı hale gelmektedirler. Düşük maliyetli sensörlerin ekonomikliği ve kompakt tasarımı, PM ölçümlerinde uzamsal-zamansal çözünürlüğü artırmak için bir fırsat sunmaktadır. Bu çalışmada, hayvan barınaklarından salınan PM_1, PM2.5 ve PM10 konsantrasyonlarının izlenmesi için düşük maliyetli PM sensörlerinin geliştirilmesi ve geliştirilen sistemin ön denemelerinin yapılması amaçlanmıştır. Çalışmada, düşük maliyetli 8 adet PM sensörlerinin (PMS5003, PMS7003, OPC-R2, OPC-N3, Gravity, SDS011, GP2Y1010, PPD42) donanım, sensör bileşenleri ve kurulum süreçlerinin yanı sıra hayvansal üretim tesislerinde ofis ve barınak ortamında ön testleri ve referans PM ölçer ile karşılaştırması yapılmıştır. OPC-N3 sensörü, ofis ortamında referans monitörle yüksek korelasyon göstermiştir (0.97-0.98) ancak bu korelasyon barınak iç ortamında 0.40-0.59 değerlerine düşmüştür. Bunun sebebi ise barınak iç ortamında artan partikül konsantrasyonlarının sensor hassasiyetini etkilediği düşünülmektedir. Bu arada PMS7003 sensörü PM_1 ölçümlerinde yüksek korelasyon değeri ile (R^2: 0.90) ile ofis ortamının aksine barınak iç ortamında daha iyi bir performans göstermiştir. SDS011 sensörü de barınak iç ortamında daha iyi performans göstermiştir. Ön sonuçlar, bu sensörlerin belirli çevre koşulları altında PM seviyelerini etkili bir şekilde ölçerken, performanslarının toz, sıcaklık ve bağıl nem gibi çevresel faktörlere bağlı olarak önemli ölçüde değiştiğini göstermektedir. Hayvansal üretim yapılarında iç mekân hava kalitesinin izlenmesinde bu sensörlerin güvenilirliğini ve doğruluğunu artırmak için detaylı saha testleri ve kalibrasyonunun gerekliliği vurgulanmaktadır. Düşük maliyetli PM sensörlerinin performansının doğrulanması ve farklı çevresel koşullarda etkinliklerinin arttırılması için daha fazla araştırma ve saha testi yapılması gerekmektedir.

Anahtar Kelimeler: Partiküler madde, Düşük maliyetli sensör, Hava kalitesi, Hayvan barınakları, Ölçme

1. Introduction

Indoor air quality in animal production facilities is a critical concern due to the potential health impacts on both animals and humans. Particulate matter (PM) emanating from animal husbandry, particularly in poultry and pig houses, poses significant challenges in maintaining air quality standards (Silva, 2023; Guo et al., 2022; Zhang et al., 2022). PM is categorized into three types based on particle size: PM_{10}, which consists of inhalable particles with diameters of 10 μm or smaller, $PM_{2.5}$, which comprises fine respirable particles with diameters of 2.5 μm and smaller, and PM_1, which includes extremely fine particles with diameters less than 1 μm (Lowther et al., 2019). These distinctions are essential for understanding the potential health impacts of various sizes of PM in the environment. Exposure to PM has been linked to an increased risk of lung cancer (Tsameret et al., 2024) and cardiovascular disease (Laltrello et al., 2022) and is associated with elevated daily mortality rates (Bist and Chai, 2022). In response to these health implications, regulatory bodies worldwide have implemented regulations and guidance to assess and control PM levels. Studies have emphasized the importance of measuring both PM number and mass concentrations within animal houses to develop effective reduction techniques and evaluate their actual performance (Cambra-López et al., 2011).

Past research highlights the need for real-time PM monitoring inside animal confinement buildings. However, professional instruments such as TEOM, DustTrak, and HAZ-DUST, while effective, come with several drawbacks. These include (1) high costs, which may be prohibitive for smaller farms; (2) operational complexity that requires specialized training; (3) the necessity for regular maintenance; and (4) limited accessibility. Additionally, these instruments may not offer real-time data at a desired temporal resolution, lack sufficient portability for field deployment, and are often designed for ambient PM monitoring with lower PM concentrations than typically found in animal houses. These factors limit their extensive use in commercial animal production facilities. Moreover, these instruments usually require intricate calibration and specific power conditions (Arulmozhi et al., 2024).

To overcome these challenges, low-cost sensors (LCSs) have garnered attention for their ability to facilitate personalized monitoring at a fraction of the cost of federal reference methods (FRMs) and federal equivalent methods (FEMs). LCSs offer flexibility in field deployment due to their compact size and minimal maintenance requirements. These sensors provide high-resolution data at minute or even second intervals, enabling the detection of transient PM emission events (Holstius et al., 2014; Gao et al., 2015; Li et al., 2018). Laboratory evaluations have demonstrated moderate to high correlations between LCSs and FRMs/FEMs, indicating their suitability for use across a wide range of concentrations and environmental conditions (Samad et al., 2021). LCSs have been proposed to estimate PM concentrations in broiler houses (Yasmeen et al., 2019), but no systematic assessments have been reported to date. Combined with advanced data processing technologies, LCSs may offer an affordable solution for assessing both animal and human exposure to PM and effectively mitigating PM pollution in animal houses.

LCSs have been increasingly deployed in both ambient and indoor settings, offering valuable insights into PM dynamics (Jayaratne et al., 2018). The evaluation and calibration of data collected by low-cost PM sensors in different environments have been a focus of recent research, aiming to enhance the accuracy and reliability of sensor measurements (Huang et al., 2022). The application of LCSs for PM measurements has been explored in various studies, including laboratory assessments (Manikonda et al., 2016), residential areas (Kortoçi et al., 2022; Mahajan and Kumar, 2020), and rural areas (Johnson et al., 2018). These studies highlight the versatility and potential of LCSs in diverse indoor environments. Several low-cost PM sensors, including models from Shinyei, Alphasense, and Plantower, have been tested in various environments and for different PM size fractions. However, gaps remain in the literature regarding their calibration and performance assessment, making it challenging to validate data quality across studies. For example, Delgado et al. (2020) faced challenges validating SDS011 sensors due to unsuitable testing environments. In contrast, Afroz et al. (2024) achieved an 80% accuracy with SDS011 sensors using a correction factor in a Canadian egg farm environment, though they noted decreased reliability at night. Yasmeen et al. (2019) used Dylos 1700 sensors in broiler houses, applying conversion factors to estimate PM concentrations. These findings highlight the ongoing need for evaluation and standardization of low-cost PM sensors to improve their accuracy and reliability across different research settings.

The effectiveness and accuracy of LCSs in animal houses, often hindered by dusty conditions, present significant challenges for maintaining sensor performance and ensuring reliable data. This research paper explores development and installation of low-cost PM sensors for measuring PM_1, $PM_{2.5}$, and PM_{10} concentrations for specific needs of confinement animal houses. Additionally, LCSs were rigorously tested and validated through preliminary tests and comparisons with a reference monitoring device. This study aims to foster animal welfare, the health of both animals and farmers, and the sustainable advancement of the agricultural sector by providing a cost-efficient, real-time PM monitoring solution for animal production facilities.

2. Materials and Methods

2.1. Sensor selection

Eight PM sensors were selected for field assessment, as listed in *Table 1*. Notably, although all these sensors are marketed as LCSs, they fall into two distinct price ranges. All sensors, with the exception of the OPC-N3 and OPC-R2 models, are priced below 50 USD each. OPC-N3 and OPC-R2 sensors are substantially more expensive but remain priced below 600 USD per unit. According to our discussions with animal producers in the United States, air quality sensors priced under 1000 USD are considered acceptable if they provide satisfactory field performance. In contrast, DustTrak, a professional instrument for real-time PM monitoring, costs over 7,000 USD per unit. All the selected LCSs use light scattering for PM detection. Based on the detection principle, these sensors can be classified into two categories: optical particle counter (OPC) and nephelometer. An OPC can count and allocate individual particles into multiple size ranges, allowing it to derive their mass concentrations; while a nephelometer estimates the mass concentration of all particles in an optical chamber based on their collective light scattering. Additional information on their detection principles can be found in Yang et al. (2022). A brief introduction to each of the tested sensors is given below:

- **Plantower PMS5003** is a widely used LCS for air quality monitoring, recognized for its capability to measure real-time PM_1, $PM_{2.5}$, and PM_{10} concentrations (Kobziar et al., 2019). It employs laser scattering to categorize airborne particles into six size bins: >0.3 µm, >0.5 µm, >1.0 µm, >2.5 µm, >5.0 µm, and >10 µm. The sensor then calculates PM concentrations for three size ranges: 0.3–1.0 µm, 1.0–2.5 µm, and 2.5–10 µm. The PMS5003 boasts high counting efficiency: 50% efficiency at 0.3 µm and 98% at 0.5 µm and larger sizes (Dobson et al., 2023). **Plantower PMS7003**, a newer model from the same manufacturer, features a smaller footprint and consumes less power compared to the PMS5003. It supports both binary and ASCII output modes, making it compatible with various data acquisition systems and microcontrollers (Badura et al., 2019).

- **Alphasense OPC-N3** classifies airborne particles with diameters ranging from 0.35 to 40 µm into 24 size bins, and calculates PM_1, $PM_{2.5}$, and PM_{10} concentrations based on particle counts in their respective size bins. **Alphasense OPC-R2** is a simplified version of the OPC-N3, featuring a more basic optical module and flow channel design. It classifies particles in a diameter range of 0.35 to 12 µm into 16 size bins. Both sensors are equipped with a fan to ensure consistent airflow through the optical chamber, which enhances the reliability of their measurements. These sensors are widely used in air quality monitoring applications due to their precision and robustness (Sousan et al., 2021; Correia et al., 2023; Raheja, 2023).

- **BJHike Gravity** is part of a series of environmental sensors designed for compatibility with Arduino and other microcontroller platforms. These sensors are typically used for air quality monitoring, detecting PM concentrations in the environment (Singh et. al., 2022). While specific details are not available, the sensor appears to use a design similar to the Plantower PMS5003, based on a visual inspection of their interiors.

- **Nova SDS011** is a PM sensor designed for air quality monitoring, capable of detecting both fine and coarse particles in the air. It measures $PM_{2.5}$ and PM_{10} levels using laser scattering technology, providing real-time and accurate assessments of PM concentrations. Known for its rapid response and stability within a compact design, the SDS011 is well-suited for use in portable devices or fixed air quality monitoring stations. It is commonly employed in both indoor and outdoor environments to evaluate air quality (Liu et al., 2019; Soms and Soms, 2021).

- **Sharp GP2Y1010** is an optical sensor designed to detect dust or smoke particles greater than 0.5 µm. It utilizes an infrared emitting diode (IRED) as the light source and a phototransistor to detect the light scattered by dust particles in the air. This sensor provides an analog output voltage that correlates to the density of dust particles,

enabling its use in air purifier systems and for monitoring air quality in indoor and semi-outdoor environments (Ghamari et al., 2022; Wang et al., 2015). **Shinyei PPD42**, also intended for dust or smoke particle detection, employs a similar design to the Sharp GP2Y1010 but has a more limited detection range (>1 μm; up to 28 particles/cm³). Both sensors are passive and do not include a fan to force air through the optical chamber.

Table 1. Low-cost PM sensors selected in this study

Manufacturer	Model	PM measured	Type	Unit price* (USD)
Plantower	PMS5003	PM_1, $PM_{2.5}$, PM_{10}	OPC	$30
Plantower	PMS7003	PM_1, $PM_{2.5}$, PM_{10}	OPC	$32
Alphasense	OPC-N3	PM_1, $PM_{2.5}$, PM_{10}	OPC	$550
Alphasense	OPC-R2	PM_1, $PM_{2.5}$, PM_{10}	OPC	$450
BJHike	Gravity	PM_1, $PM_{2.5}$, PM_{10}	Likely OPC	$45
Nova	SDS011	PM_1, $PM_{2.5}$, PM_{10}	Likely OPC	$35
Sharp	GP2Y1010	Total particles	Nephelometer	$15
Shinyei	PPD42	Total particles	Nephelometer	$14

* It is the price at which a sensor was acquired.

2.2. Test system construction

2.2.1. System Integration

Due to the significantly higher cost of the OPC-N3 and OPC-R2 compared to other sensors, separate test systems were constructed for each model (*Figure 1b*). Each system utilized an Arduino Mega 2560 R3 microcontroller to measure PM_1, $PM_{2.5}$, and PM_{10} concentrations from the OPC-N3 or OPC-R2 sensor. The PM concentration data, along with timestamp information from a real-time clock (RTC) module, were saved to a microSD card and simultaneously displayed on an LCD screen. Additionally, the system included a Wi-Fi module, which is currently unused but could enable real-time data submission to a cloud server in the future.

The remaining six PM sensors shared a common test system (*Figure 1a*). This system also used an Arduino Mega 2560 R3 microcontroller to collect PM concentration data from the sensors, which employed various communication protocols. An RTC module provided timestamp information. To simplify the setup, this system did not include a WI-FI module or an LCD screen. However, due to the higher power demands of the six sensors, a dedicated DC power supply board was employed to ensure an undisrupted power supply. *Figure 1* shows the system design of six sensors (a) and OPC-N3/OPC-R2 (b).

2.2.2. Packaging

Six sensors including PMS5003, PMS7003, GP2Y1010, Gravity, PPD42, and SDS011 sensors were enclosed inside a plastic box with a length, width, and height of 13 x 6 x7 cm, making the sensor compact and suitable to fit indoors and outdoors. The OPC-N3 and OPC-R2 sensors were enclosed inside a plastic box with the dimensions of 20 x 13 x 8 cm. This setup, housed in a waterproof box and powered by a DC power supply adapter or alternatively a 10.000 mAh standby battery, was collocated next to a reference monitor for testing.

The enclosure models to be printed were designed in the Autodesk AutoCAD 3D modeling software. The sensor enclosures were designed with two parts, the first one is the bottom part that holds the sensor, microcontroller, LCD screen, and battery. The second part is the enclosure cover, which is attached to the bottom part with screws. The 3D models, shape, and parameters of these parts are shown in *Figure 2.*

Then the designed model is exported in ".STL" format. STL, short for "stereolithography," is a file format developed by 3D Systems for its CAD software, widely adopted for 3D printing, rapid prototyping, and computer-aided manufacturing. The format predominantly captures the surface geometry of three-dimensional objects but lacks the capability to encode color, texture, or other common CAD model attributes (Hoque et al., 2018). The Flashforge CreatorPro 3-D Printer (FlashForge Creator Pro, FlashForge Corporation) was used for printing the sensor enclosures. The polylactic acid (PLA) 3D Printer Filament (Filament diameter: 1.75 mm) was used as the printing material. The sensors integrated into the printed enclosures are shown in *Figure 3*. *Figures 3a*, *3b*, and *3c* show the OPC-R2, OPC-N3, and six sensors, respectively.

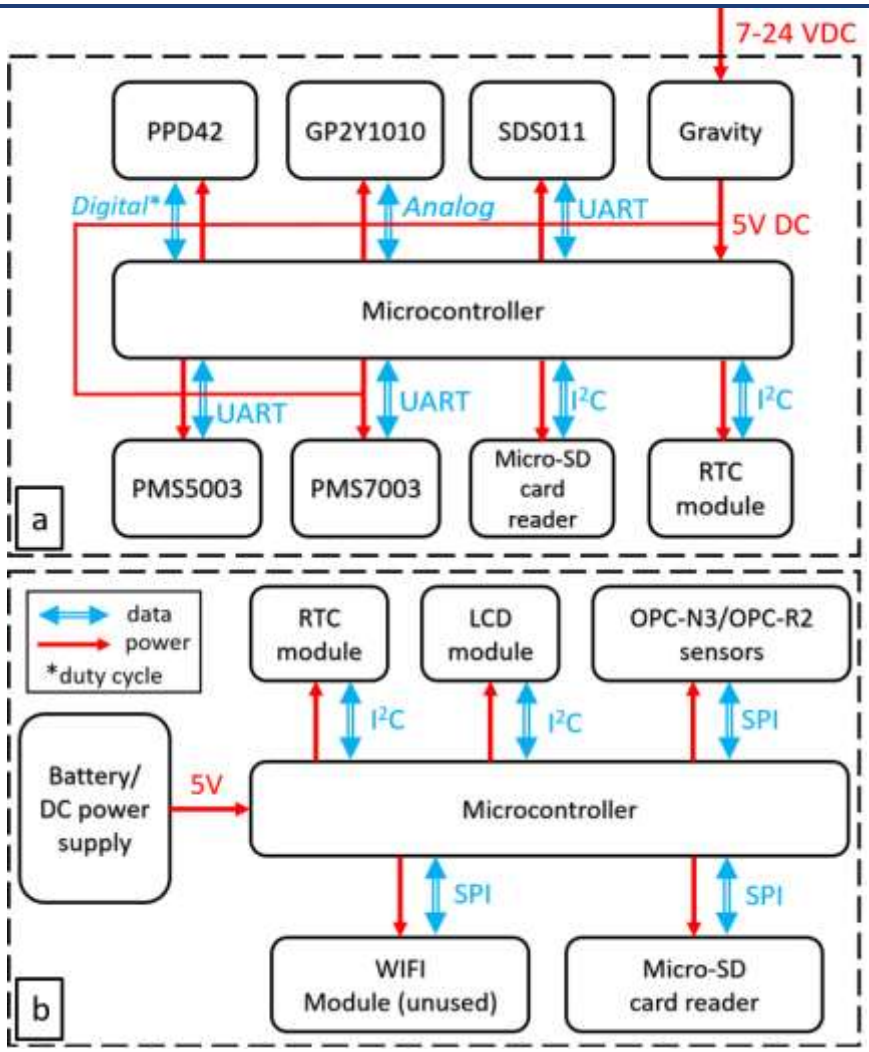

Figure 1. System design of six sensors (a) and OPC-N3/OPC-R2 (b)

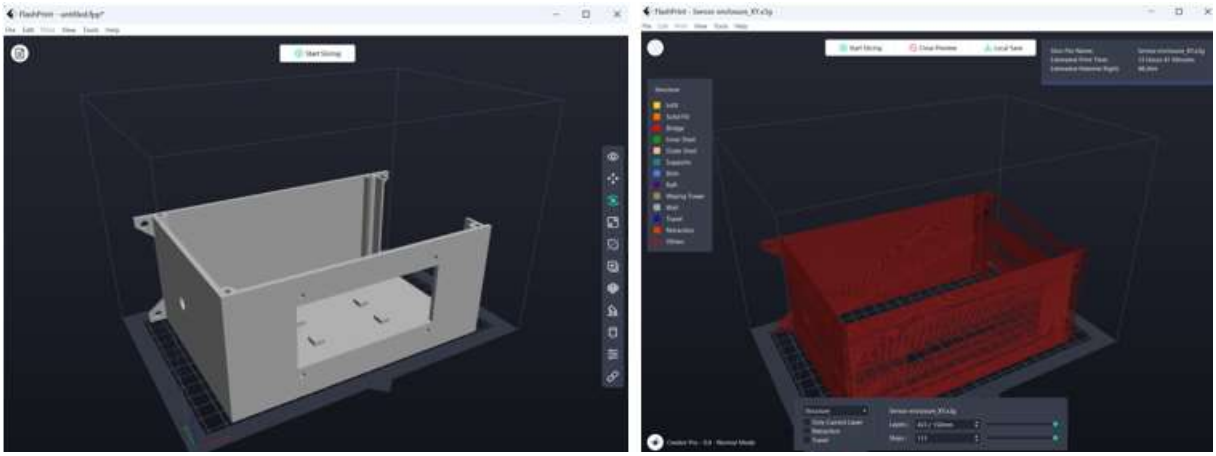

Figure 2. The designed 3D Model

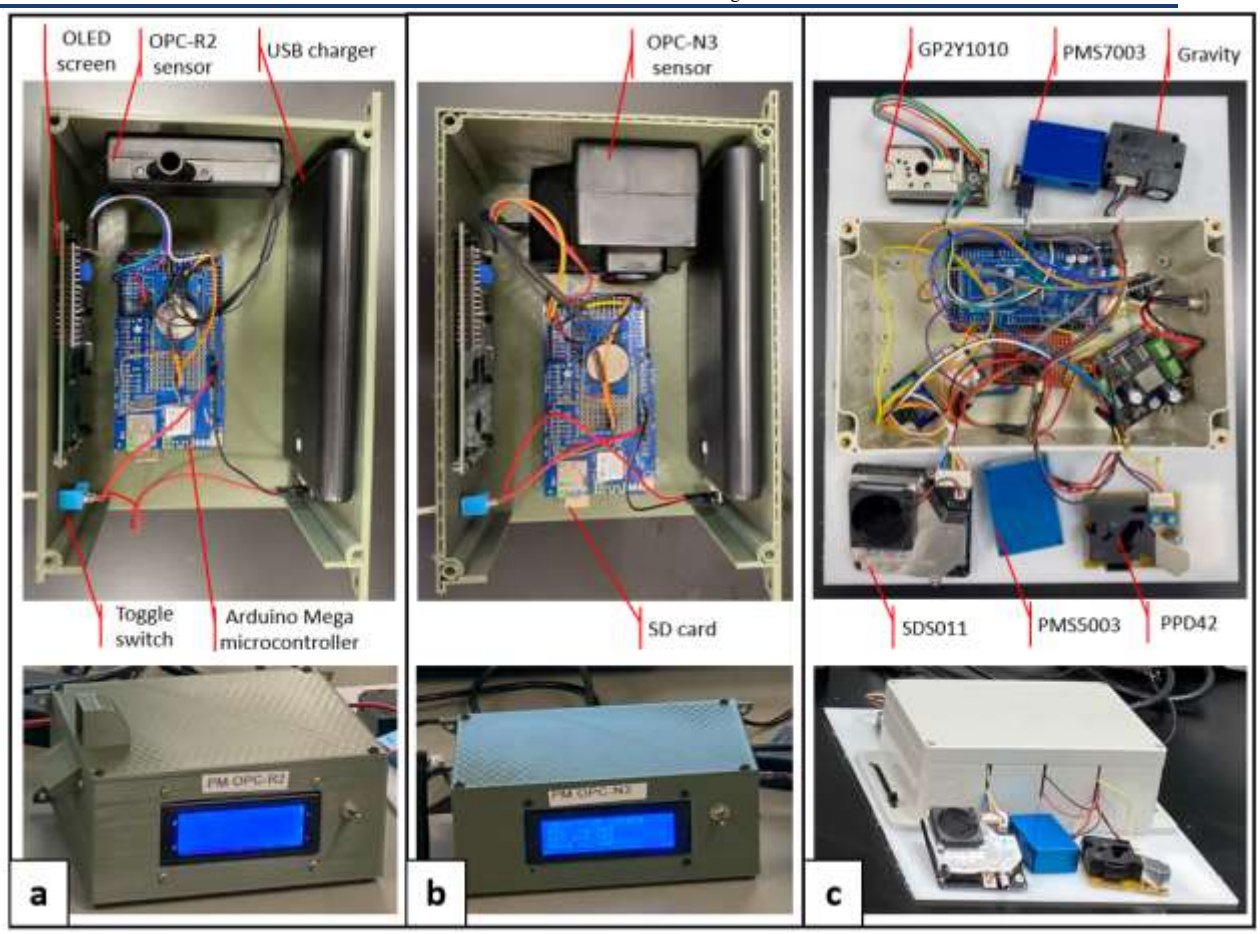

Figure 3. Interior view of the low-cost PM monitors

2.3. Preliminary test measurements

A preliminary test was initially conducted inside a barn office before moving to a wean-to-finish production room. This study developed low-cost PM sensors and validated them in a 1,200-head pig pen at South Dakota State University (SDSU). Field evaluations in both office and barn environments utilized the GRIMM and LCS to assess the sensors' performance. All devices measured PM_1, $PM_{2.5}$, and PM_{10} at the same location, while a temperature/humidity sensor monitored indoor conditions. Measurements were conducted at the Offsite Wean-to-Finish Production Barn, 12 miles south of the SDSU campus. The barn, which houses 1200 wean-to-finish pigs in two identical rooms of 52 pens each, is mechanically ventilated and features systems for remote monitoring and data logging. Sensors were positioned 1.2 m above ground level and about 3.5 m ft from the central exhaust fans. Eight different low-cost PM sensors were tested over seven days to evaluate their performance. Sensors recorded PM concentration every five minutes, and data were processed into hourly averages for comparison. Temperature and humidity were also monitored using a HOBO (MX1101, Onset) sensor. The field experiment setting is depicted in *Figure 4*, conducted at the SDSU Swine house in Brookings, SD, USA.

To analyze trends in PM concentration, the GRIMM 11-D aerosol spectrometer—a portable particle counter categorizing particles from 0.253 to 35.15 µm—served as the reference. It counts particles using a diode laser with a 30 mW output and 655 nm wavelength. Among various monitoring devices, the GRIMM monitor has emerged as a reliable tool for assessing PM levels in confined animal facilities. This device is particularly adept at measuring different PM size fractions, including PM_1, $PM_{2.5}$, and PM_{10}, which are critical for understanding the potential health risks associated with airborne particulates. The GRIMM monitor's effectiveness has been validated in various settings, including broiler farms and laboratory animal facilities, where it has been used to track PM concentrations and assess their impact on animal health (Fernández et al., 2018; Shen et al., 2018). The ability to continuously monitor PM levels allows for timely interventions to mitigate exposure risks, thereby enhancing the overall air quality in animal housing. As highlighted in recent studies, the integration of such monitoring systems is essential for developing comprehensive

strategies to manage indoor air quality and ensure the welfare of both animals and workers (Guo et al., 2022; Lovanh et al., 2016).

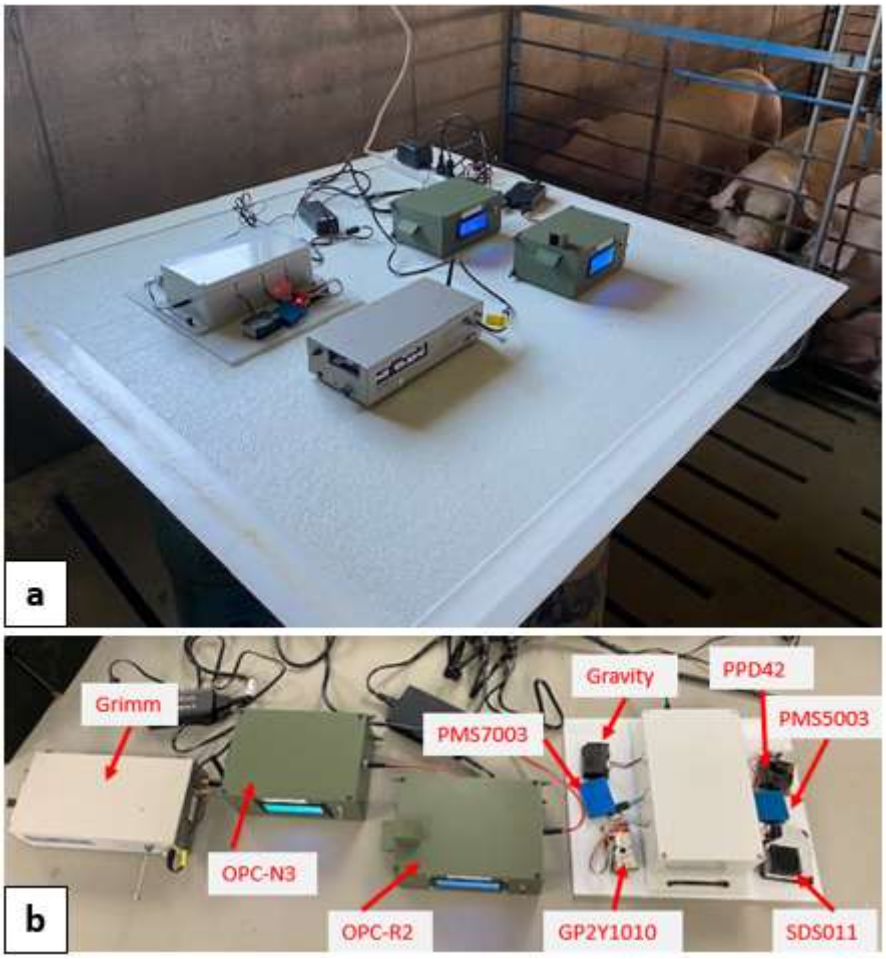

Figure 4. The experimental setup in the barn (a) and office (b) measurements

2.4. Data analysis

To analyze the data from the performance of LCSs against a reference instrument, several statistical metrics were employed, including coefficient of Variation (CV), Bias, R^2, and Root-Mean-Squared Error (RMSE). CV measures the dispersion of data points in a probability distribution relative to its mean. It is useful for comparing the degree of variation from one data series to another, even if the means are drastically different from each other. A higher CV indicates greater variability in sensor readings. Bias measures the average difference between the measurements recorded by the LCS and those recorded by the reference instrument. A positive bias indicates that the LCS typically overestimates the true value, while a negative bias indicates an underestimation.

$$Bias_t = \left(\frac{LCS_t}{GRIMM_t} - 1\right) \times 100 \quad \text{(Eq. 1)}$$

Where; LCSt is the low-cost sensor readings at time t and GRIMM is the reference concentration at time t for each of the hourly measurement points (Sayahi et al., 2019). R-squared (R^2) is a statistical measure representing the proportion of the variance for a dependent variable that can be explained by an independent variable or variables in a regression model. In this context, it indicates how well the LCS measurements correlate with those from the reference instrument. A higher R^2 value closer to 1 indicates that the LCS closely matches the reference instrument's readings. Root-Mean-Squared Error (RMSE) measures the average magnitude of the error by squaring the differences between predicted values and actual values. The RMSE will give a sense of how much error there is between the LCS measurements and those of the reference instrument. Each of these metrics provides insight into different aspects of the LCS performance, CV and RMSE provide a measure of reliability and precision. Bias

gives an indication of accuracy. R^2 offers a measure of the degree to which the LCS can reproduce the reference instrument's results.

3. Results and Discussion

3.1. Preliminary test in the field

Low-cost PM sensors are becoming increasingly popular for air quality assessments, but they are not designed for highly dusty environments. The performance of these sensors inside animal barns has not been well studied, with limited reports in the literature. This study developed eight different low-cost PM sensors specifically for use in barn environments and conducted preliminary tests in both an office and a production room. Initially, all sensors were tested in an office room for 48 hours to prepare them for the dusty conditions. Subsequently, they were tested in the production room for seven days. The two nephelometers including Sharp GP2Y1010 and Shinyei PPD42 were used to measure the total suspended particle (TSP) concentrations in the office and production room environments. *Figure 5* shows the comparison of total particle concentrations measured by the LCSs and the GRIMM. R^2 values for the comparison of GP2Y1010 and PPD42 sensors with the reference monitor were 0.059 and 0.001, respectively. The results show that the two nephelometers (Sharp GP2Y1010 and Shinyei PPD42) did not measure the total particle concentration properly. In practice, enhancing the performance of low-cost sensors such as the Sharp GP2Y1010 and Shinyei PPD42 is highly challenging, if not impossible. As outlined in *Table 1*, both sensors operate as nephelometers, estimating particulate matter (PM) concentrations based on the intensity of light scattered by PM at a fixed angle. However, unlike research-grade nephelometers, these sensors lack integrated fans or pumps. Instead, PM of varying sizes passively enters their optical sensing chambers through environmental or convective airflows. This passive sampling mechanism results in highly unpredictable efficiency in PM transfer to and deposition in the chambers, limiting their measurement accuracy and reliability. Additionally, these two sensors are most commonly used for smoke detection in built environments and are typically calibrated with smoke particles. However, the optical properties of smoke (e.g., size and refractive index) differ significantly from the particulate matter (PM) found in animal production facilities. As a result, it is not surprising that these sensors performed relatively poorly when measuring PM inside animal barns.

The other low-cost PM sensors are active devices, incorporating a fan or pump to drive airflow and improve PM transfer efficiency to the sensing chamber. However, variations in flow channel design can still lead to differences in PM transfer and deposition efficiencies. Sensors priced below $50 per unit, in particular, tend to show poor PM transfer and greater deposition. Furthermore, these inexpensive sensors are typically designed for ambient PM measurements, where particle sizes are considerably smaller than those found in animal production facilities. A recent study (Quimette et al., 2024) highlighted that these sensors often misclassify large PM as smaller particles, due to limitations in their optical particle counter (OPC) design and PM size retrieval algorithms.

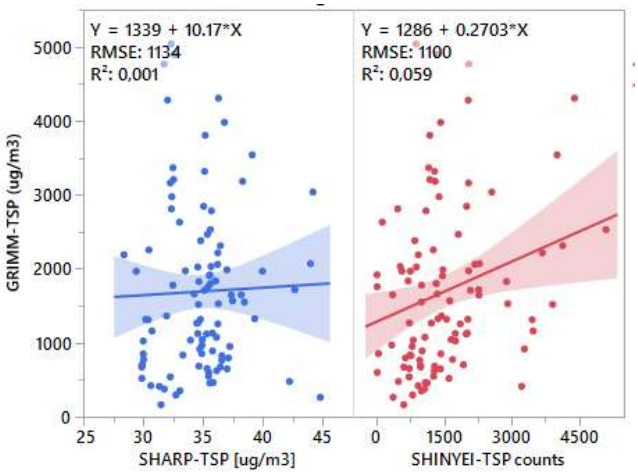

Figure 5. TSP concentrations of preliminary test in a barn environment

The PM_1, $PM_{2.5}$, and PM_{10} concentrations were measured with OPC-N3, OPC-R2, Gravity, PMS5003 and PMS7003 low-cost sensors, then compared the reference GRIMM monitor for the performance of the LCSs in the

office and barn environment. *Figure 6* shows the comparison of LCSs for different PM concentrations. *Table 2* shows the bias estimates of hourly PM concentration for the LCSs for all concentrations. The GRIMM data provided the reference concentrations for the bias determination (Eq. 1). *Table 2* shows the bias estimates of the LCSs for the office and production room measurements in this study. The lowest bias in the barn measurements was 13.7% for PM_{10} concentrations with OPC-N3 while PMS7003 showed the lowest bias (19.1%) for PM_{10} measurements in the office measurements.

For the PM_1 measurements, the PMS7003 showed the highest R^2 of 0.90, while the second highest R^2 of 0.586 was with the OPC-N3 sensor. The OPC-N3 also demonstrated the best correlation for $PM_{2.5}$ and PM_{10} measurements, with R^2 values of 0.423 and 0.406, respectively (*Table 2*). The findings indicated that the OPC-N3 sensor demonstrated decent performance for PM_1 in both environments, as well as for $PM_{2.5}$ in both settings. Additionally, the OPC-N3 outperformed other sensors for PM_{10}. However, the PMS7003 and Gravity sensors performed well in the production room but not in the office. The NOVA SDS011 sensor showed relatively good performance in the production room. Dubey et al. (2022) compared two particulate matter sensors, OPC N2 and PM Nova, using the Grimm instrument as a reference. The OPC-N2 excelled in measuring finer particles, achieving R^2 values from 0.54 to 0.93 for PM_1 and 0.31 to 0.95 for $PM_{2.5}$, but it was less effective for PM_{10} (R^2 = 0.19–0.89). Conversely, the PM Nova sensor performed well for both $PM_{2.5}$ (R2 = 0.1–0.96) and PM_{10} (R^2 = 0.19–0.78), showing a similar performance pattern to the OPC-N2. It should be noted that Dubey et al. (2022) conducted their study in ambient air conditions. In our study, the OPC-N3 sensor showed a high correlation with the reference monitor, achieving 0.97-0.98 in the office room. However, this correlation dropped to 0.40-0.59 in the production room due to increased particle density, which adversely affects the sensor's sensitivity.

Table 2. Low-cost PM sensors selected in this study

Location	Particulate matter	Parameters	OPC-N3	OPC-R2	Gravity	PMS5003	PMS7003	SDS011
Barn	PM_1	Mean Bias (%)	-72.7	95.0	-46.7	49.1	49.1	
		Obs.	98	98	98	98	98	
		RMSE	2.77	4.30	1.54	4.18	1.35	
		R^2	0.586	<0.001	0.872	0.060	0.901	
	$PM_{2.5}$	Mean Bias (%)	-44.9	-32.2	-65.2	-65.2	-65.2	-90.4
		Obs.	98	98	98	98	98	98
		RMSE	7.62	9.98	9.86	10.00	9.96	9.91
		R^2	0.423	0.009	0.034	0.005	0.014	0.023
	PM_{10}	Mean Bias (%)	13.7	-89.3	-91.8	-91.8	-86.2	-59.4
		Obs.	98	98	98	98	98	98
		RMSE	115.00	147.80	142.10	144.80	143.90	121.50
		R^2	0.406	0.020	0.093	0.059	0.07	0.337
Office	PM_1	Mean Bias (%)	-80.4	992.3	-62.3	1434.0	-68.2	
		Obs.	98	98	98	98	98	
		RMSE	0.35	3.29	3.30	3.30	3.30	
		R^2	0.989	0.009	0.003	0.002	0.001	
	$PM_{2.5}$	Mean Bias (%)	-70.3	779.1	-45.7	1011.7	-30.4	-113.3
		Obs.	98	98	98	98	98	98
		RMSE	1.30	13.04	13.03	12.99	13.04	13.05
		R^2	<0.001	0.002	0.003	0.010	0.001	<0.001
	PM_{10}	Mean Bias (%)	-31.4	635.6	-27.7	728.0	19.1	-287.8
		Obs.	98	98	98	98	98	98
		RMSE	10.20	62.20	62.10	61.40	62.10	62.00
		R^2	0.973	<0.001	0.003	0.026	0.002	0.007

The study highlighted that the performance of low-cost nephelometers in animal barns is often suboptimal due to several design limitations. Firstly, the passive and inadequately designed flow channels result in inconsistent

particle transfer efficiency from the sensor's inlet to its optical chamber. This variability affects the nephelometer's ability to accurately measure particle concentrations. Secondly, these devices typically use red photodiodes or laser diodes as light sources, operating at a wavelength of approximately 650 nm. This choice of wavelength leads to a poor response to the coarse particles that are commonly present inside barns, further compromising the sensor's effectiveness in these environments (Crilley et al., 2018).

The Grimm OPC differentiates itself from most low-cost OPC sensors through its sophisticated flow design. This design allows for the sequential release of particles through a nozzle, where they are immediately measured by light. This precise handling of particles mitigates issues commonly faced by lower-cost OPCs, which measure particles only once at the laser focal point. Such an approach often leads to inaccurate particle size estimations. For instance, a small particle positioned directly at the focal point and a larger particle situated nearby may emit similar optical signals under less precise conditions, leading algorithms in less advanced models to incorrectly classify both as small. This capability of the Grimm OPC to deliver more accurate measurements makes it superior in environments where such distinctions are critical.

The OPC-N3 sensor is distinguished from other low-cost optical particle counters due to its advanced features. One significant advantage of the OPC-N3 is its sophisticated optical design, which improves its response to coarse particles while reducing the chances of particle misclassification. This enhanced optical design enhances the sensor's capability to precisely detect and differentiate larger particles, thereby boosting its overall performance in particle measurement. Moreover, the OPC-N3's straight flow channel design significantly enhances particle transfer efficiency, especially for larger particles. The streamlined flow channel design facilitates better particle movement through the sensor, resulting in more precise and efficient particle concentration measurements. These design elements collectively establish the OPC-N3 as a dependable and efficient choice for measuring particulate matter concentrations in various settings.

Preliminary tests of low-cost PM sensors for animal houses are crucial for ensuring accurate and reliable monitoring of particulate matter levels in these environments. Low-cost sensors have the potential to provide valuable insights into indoor air quality (IAQ) in animal houses, aiding in the identification and mitigation of potential health risks associated with poor air quality. These sensors offer a cost-effective solution for continuous monitoring, allowing for real-time data collection and analysis to support decision-making processes aimed at improving the living conditions for animals and workers in these facilities. Laboratory evaluations, as highlighted in studies such as Bulot et al. (2023), play a vital role in assessing the performance of low-cost PM sensors under controlled conditions. These tests help determine key parameters such as lower limit of detection, response time, and the sensors' ability to detect transient pollution events. Additionally, field evaluations, as discussed in Huang et al. (2022), are essential for validating sensor performance in real-world scenarios, ensuring their accuracy and reliability in practical applications. Furthermore, Lowther et al. (2019) emphasize the importance of using low-cost sensors to provide personalized IAQ information, which can be particularly beneficial in animal houses where air quality can directly impact the health and well-being of both animals and workers. By leveraging the data collected from these sensors, stakeholders can implement targeted interventions to improve IAQ and create healthier environments for all occupants.

The study highlighted the need for extensive field testing of sensors across different concentrations and environmental conditions to fully evaluate the effectiveness of low-cost PM sensors (Mei et al., 2020). It also pointed out that the correlation between low-cost sensors and reference devices depends on operational conditions, aerosol characteristics, and the selection of reference instruments, which influences the calibration of the sensors (Zheng et al., 2018). Our research found that while some low-cost PM sensors performed reasonably well in animal production facilities, most failed to provide accurate PM concentration measurements. Setting aside technical details, a fundamental reason is that these sensors are typically designed for environments with significantly lower PM concentrations or smaller particle sizes than those found in animal production facilities. As a result, a thorough field assessment against reference monitors or methods is essential before deploying any low-cost PM sensors—or low-cost environmental sensors in general—in such settings. It is also important to note that environmental conditions, such as temperature and humidity, can impact sensor performance. We recommend concurrently measuring these variables to better interpret measurement results and potentially implement machine learning-based calibration methods to enhance sensor accuracy. Regarding the applicability of the OPC-N3 sensor in other livestock environments, based on our experience with poultry and cattle farms, the sensor is expected to perform reasonably well. However, a thorough field assessment remains necessary to calibrate the sensor and understand its limitations.

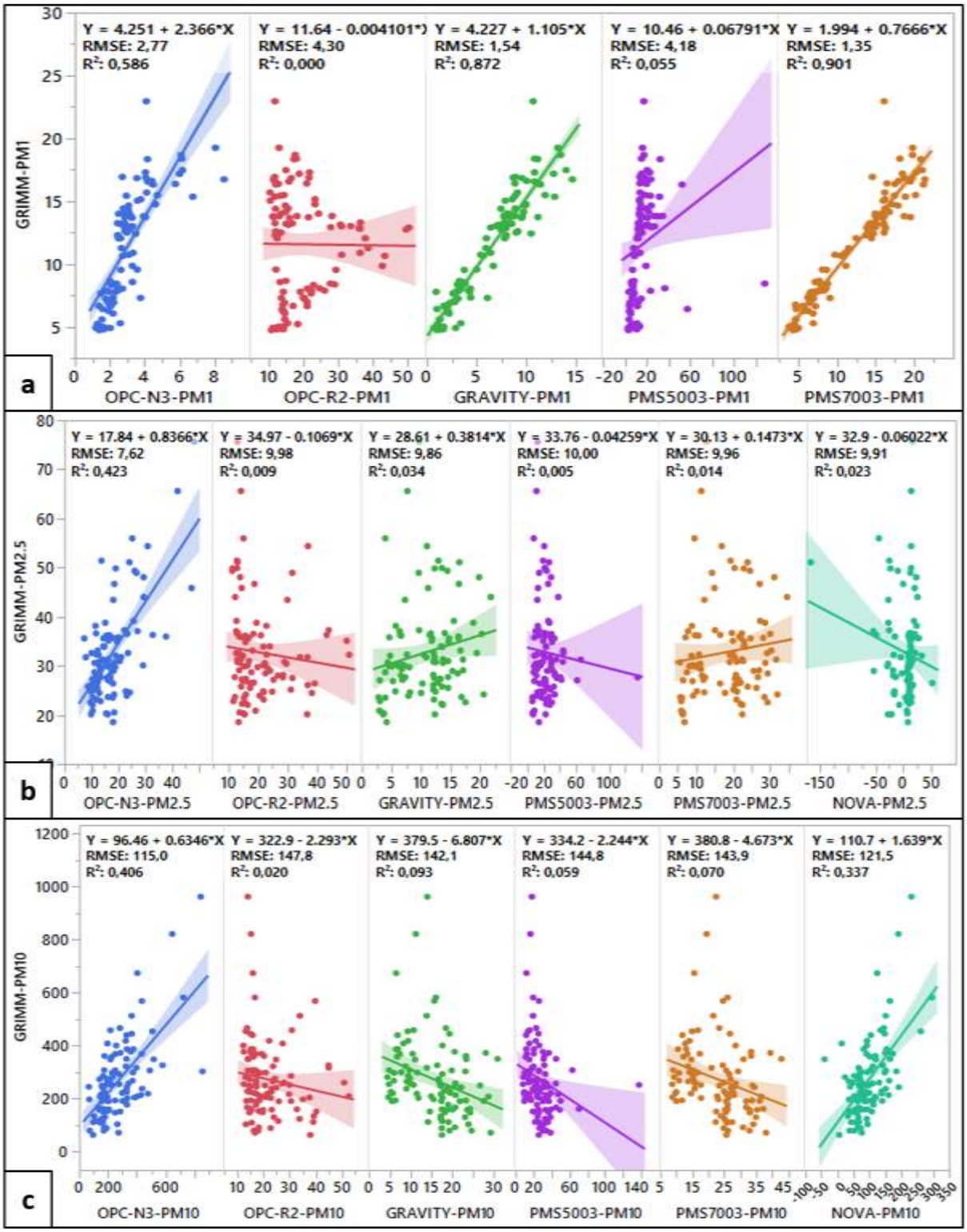

Figure 6. Comparison of low-cost sensors for measuring different PM size fractions in the barn environment

3.2. PM concentrations in the swine house

PM concentrations showed substantial variations in both the office and production room. In both environments, coarse particles (diameter > 2.5 µm) are dominant. *Figure 7* shows the hourly PM concentrations of office (a) and production room (b). The average PM concentrations in the swine house were as follows: TSP 1491.3 µg m^{-3}, PM_1 14.99 µg m^{-3}, $PM_{2.5}$ 34.4 µg m^{-3}, PM_{10} 240.8 µg m^{-3}. Analyzing the data relative to the particle size for the

production room revealed that PM_{10} accounted for 16.1% of the total PM concentration, while $PM_{2.5}$ accounted for 2.3%. This shows a higher proportion of particles around 10 µm in size. The PM concentrations for the office room were significantly lower than in the production room. The average TSP, PM_1, $PM_{2.5}$, and PM_{10} concentrations were 61.7, 1.44, 3.57, and 15.9 µg m^{-3}, respectively.

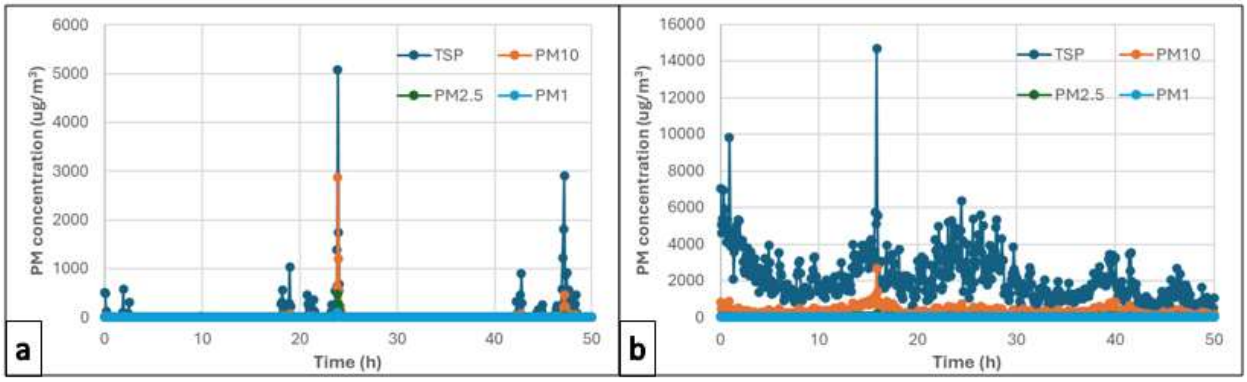

Figure 7. Hourly PM concentrations of office (a) and production room (b)

3.3. Environmental parameters in the swine house

The investigation of meteorological factors concerning the efficacy of the LCSs has been a subject of thorough examination, primarily due to the issues of overestimation or underestimation of particulate matter (PM) concentrations and the influence of temperature (T) and relative humidity (RH) on the response of the LCS (Macías-Hernández et al., 2023). The temperature and relative humidity in the barn environment were also monitored by using HOBO (MX1101, ONSET) sensor during the LCS experiment. *Figure 8* shows the hourly variation of temperature and relative humidity in the barn environment.

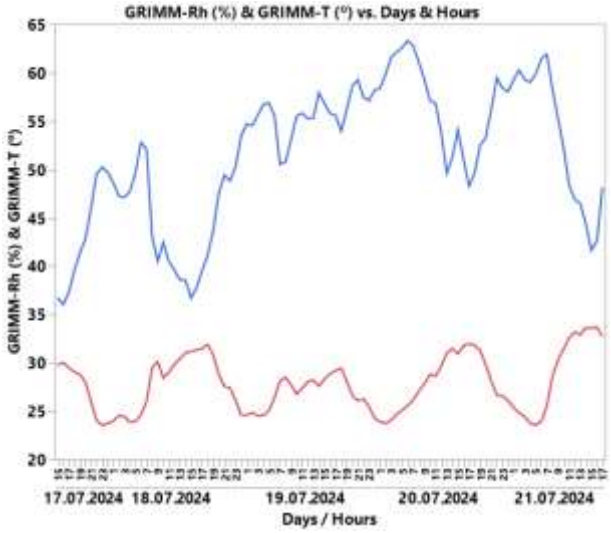

Figure 8. Hourly variation of temperature and relative humidity in the barn environment

Throughout the experiment, the temperature inside the barn ranged from 23.5ºC to 33.7ºC, with an average temperature of 28.04ºC. Relative humidity ranged from 36% to 63.3%, averaging 52.9%. Temperature impacts LCSs less than relative humidity, with minimal error values (–5 to 5 µg m^{-3}) even at low temperatures (–5 to 5°C). In calibration models for temperature, the error term is typically larger than the coefficient, indicating that temperature effects are negligible under normal conditions but not in extreme environments like deserts (Magi et al., 2020).

4. Conclusions

To conclude, LCSs have emerged as a cost-effective solution for personalized monitoring of PM levels in animal

houses. The preliminary tests in the field for low-cost PM sensors underscore their potential in animal houses despite challenges in dusty environments. Testing in both office and production settings revealed that while some sensors like the OPC-N3 performed well, others showed limitations due to design flaws affecting particle transfer efficiency. These findings highlight the need for ongoing evaluation and calibration to enhance sensor accuracy and reliability in real-world conditions. Continuous monitoring using these sensors could significantly improve air quality management in animal housing, contributing positively to both animal welfare and operational efficiencies. The integration of low-cost sensors for indoor air quality monitoring in animal houses presents a promising approach to address PM pollution. These sensors offer a cost-effective solution for continuous monitoring, enabling stakeholders to make informed decisions to improve air quality and create healthier environments for animals and workers. Ongoing research and field testing are essential to validate sensor performance and ensure their effectiveness in diverse environmental conditions.

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Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Uguz, S., Yang, X.; Design: Uguz, S., Yang, X.; Data Collection or Processing: Uguz, S., Kumar, P., Tiwari, S.; Analyses: Uguz, S., Kumar, P., Tiwari, S; Literature Search: Uguz, S., Kumar, P.; Writing, Review and Editing: Uguz, S., Kumar, P., Tiwari, S., Chang, Y., Yang, X.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Sütleğen (*Euphorbia macroclada* Boiss.) ve Yonca (*Medicago sativa* L.) Bitki Ekstraktlarının Sirken (*Chenopodium album* L.) Tohumlarının Çimlenmesi Üzerine Allelopatik Etkisi

Allelopathic Effects of Spurge (*Euphorbia macroclada* Boiss.) and Alfalfa (*Medicago sativa* L.) Plant Extracts on Germination of Lamb's Quarters (*Chenopodium album* L.) Seeds

Ayhan TAŞTAN[1], Enes FİDAN[2*]

Öz

Tarımsal alanlarda verim ve kaliteyi olumsuz etkileyen birçok yabancı ot türü bulunmaktadır. Yabancı otların mücadelesinde kullanılan yöntemlerin başında ise kimyasal mücadele gelmektedir. Ancak kimyasal ilaçların insan sağlığına ve çevreye olumsuz etkileri, çevre dostu mücadele yöntemlerinin gerekliliğini ortaya koymaktadır. Bu bağlamda, bazı bitki ekstraktlarının yabancı otların gelişimi üzerindeki olumsuz etkileri, kimyasal ilaçlara alternatif olabilecek umut verici sonuçlar sunmaktadır. Bu amaçla yapılan çalışmada, sütleğen (*Euphorbia macroclada* Boiss.) ve yonca (*Medicago sativa* L.) bitkilerinden elde edilen farklı çözücülerdeki (su ve etanol) bitki ekstratlarının farklı konsantrasyonlarda tarımsal alanlarda önemli verim kayıplarına neden olan sirken (*Chenopodium album* L.) bitkisinin tohum çimlenmesi üzerine allelopatik etkisi araştırılmıştır. Çalışma 2024 yılında Van Yüzüncü Yıl Üniversitesi Ziraat Fakültesi Bitki Koruma Bölümü Herboloji laboratuvarında yürütülmüştür. Hazırlanan su ve etanol ekstraktlarının %1, 2, 4, 8, 16 ve 32 konsantrasyonları, 9 cm çapındaki Petri kaplarına konulan sirken tohumlarına uygulanmıştır. Kontrol grubu için sadece saf su kullanılmıştır. Denemeler beş tekerrürlü ve her tekerrürde 50 adet sirken tohumu olacak şekilde yürütülmüştür. Bitkilerden elde edilen ekstraktların sirkenin çimlenmesi üzerinde uygulamalar arasında farklar istatistiksel olarak önemli bulunmuştur. Çalışma sonucunda, sütleğen ve yoncadan elde edilen hem su hem de etanol ekstaktlarının konsantrasyon artışıyla birlikte sirkenin çimlenme oranında azalma meydana geldiği tespit edilmiştir. Sütleğenden elde edilen etanol ekstraktının %8, 16 ve 32; yoncanın ise %16 ve 32 konsantrasyonlarında çimlenmenin tamamen engellendiği tespit edilmiştir. Ayrıca sütleğen ve yoncanın %32'lik su ekstraktlarında da çimlenmenin olmadığı gözlenmiştir. Yapılan bu çalışma, sütleğen ve yonca bitki ekstraktlarının sirkenin çimlenmesini engelleyerek tarımsal alanlarda verim ve kaliteyi etkileyen bu yabancı otla mücadelede alternatif bir yöntem olarak kullanılması açısından önemli olduğu düşünülmektedir.

Anahtar Kelimeler: Allelopati, Bitki ekstraktı, Çimlenme, Sirken, Yabancı ot

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Abstract

There are many weed species that negatively affect yield and quality in agricultural areas. Chemical control is the most common method used in weed management. However, the negative effects of chemical pesticides on human health and the environment reveal the importance of environmentally friendly control methods. In this context, the negative effects of some plant extracts on weed development offer promising results that can be an alternative to chemical pesticides. This study investigated the allelopathic effects of plant extracts obtained from spurge (*Euphorbia macroclada* Boiss.) and alfalfa (*Medicago sativa* L.) in various solvents (water and ethanol) and concentrations on the seed germination of lamb's quarters (*Chenopodium album* L.), a plant responsible for significant yield losses in agricultural fields. The research was conducted in 2024 at the Herbology Laboratory of the Department of Plant Protection, Faculty of Agriculture, Van Yüzüncü Yıl University. The prepared ethanol and water extracts at concentrations of 1%, 2, 4, 8, 16, and 32% were applied to lamb's quarters seeds put in Petri dishes of 9 cm diameter. The control group was treated with only pure water. The experiments were conducted with five replications, each containing 50 seeds. Statistically significant changes in seed germination were found between the treatments. The study showed that germination decreased when the concentrations of ethanol and water extracts obtained from spurge and alfalfa increased. Specifically, the ethanol extracts from spurge at concentrations of 8%, 16%, and 32%, and the from alfalfa at concentrations of 16% and 32% completely inhibited seed germination. In addition, no seed germination was observed with the water extracts from spurge and alfalfa at a concentration of 32%. This study is considered to be important in terms of using spurge and alfalfa extracts as an alternative method to control this weed, which affects yield and quality in agricultural areas by preventing the germination of lamb's quarters.

Keywords: Allelopathy, Plant extract, Germination, Lamb's quarters, Weed

1. Giriş

Tarım yapılan alanlarda, hastalık ve zararlılara ek olarak pek çok yabancı otla da karşılaşılmaktadır (Güncan, 2016). Tarımsal üretimin başlamasıyla birlikte yabancı otlar bir sorun haline gelmiş ve bu sorun günümüze kadar sürmüştür (Öten ve Tokat, 2024). Yabancı otlar, tüm dünyada tarım sistemlerinde gıda üretimini kısıtlayan ana faktörlerden biridir (Monteiro ve Santos, 2022). Bulundukları alanlarda doğrudan (bitki besin elementi, su, ışık, gibi rekabet unsurları) ve/veya dolaylı (hastalıklar ve zararlılara konukçuluk) sorunlara neden olarak önemli ürün ve ekonomik kayıplara neden olabilirler (Yazlık ve ark., 2019). Dünyada yabancı otların neden olduğu verim kayıplarının %34 oranında olduğu tahmin edilmektedir (Oerke, 2006). Bu yüzden tarım endüstrisinde, ürün verimini artırmak için çözülmesi gereken en önemli sorunlardan biri de yabancı ot kontrolüdür (Raja ve ark., 2020). Yabancı otların mücadelesinde birçok mücadele yöntemi olmasına rağmen üreticiler hızlı sonuç, kolay uygulama ve ekonomik olması nedeniyle kimyasal mücadele (herbisit) yöntemini tercih etmektedirler (Uludag ve ark., 2018). Ancak herbisitlerin insan ve çevre üzerinde olumsuz etkiler yarattığı, kalıntı problemleri oluşturduğu ve faydalı organizmalar üzerinde yan etkilere neden olduğu, bunun da besin zincirini etkilediği bir gerçektir (Ragsdale ve ark., 1993). Herbisit kullanımı sonucunda meydana gelen bu olumsuzluklar, yeni ve çevre dostu yöntemler geliştirmeyi zorunlu hale getirmektedir. Sadece herbisit kullanımını azaltmakla kalmayıp aynı zamanda çevre dostu olan ve tarımsal üretim maliyetini düşüren alternatif, sürdürülebilir ve yenilikçi yabancı ot yönetimi teknolojilerine olan küresel ilgi artmaktadır (Ghimire ve ark., 2019; Rişvanlı ve Fidan, 2024). Bu nedenle, doğada daha kolay parçalanan ve çevreyle uyumlu olan alternatif biyolojik mücadele yöntemlerine yönelik arayışlar hız kazanmıştır (Bond ve Grundy, 2001). Bu amaçla, çevreye ve insan sağlığına zarar vermeyen, kalıntı problemi olmayan ve kolayca elde edilebilen bitki ekstraktlarının kullanımına yönelik çalışmalar başlamıştır (Yavuz, 2010). Bitki kökenli kimyasal bileşiklerin, komşu bitkilerin büyümesini olumsuz yönde etkileyerek populasyon düzeyinde değişiklikler yaratma potansiyeline sahip olduğu düşünülmüş ve bu olaya allelopati adı verilmiştir (Willis, 2007).

Allelopatik etkiye sahip olan kimyasal maddeye allelokimyasal denilmektedir (Akgül, 2016). Allelokimyasalların etkileri türden türe farklılık gösterebilir (Karaman ve ark., 2021). Allelokimyasallar genellikle bitkiler tarafından sentezlenen bitki büyümesi ve gelişiminde doğrudan yer almayan ikincil bitki metabolitleridir. Bitkiler tarafından üretilen maddelerin allelopatik etkisi, tarımsal ortamda yabancı otların neden olduğu ekonomik zararları azaltacak ve doğal herbisitler olarak uygulanabilecek bileşiklerin ürün geliştirilmesi konusunda ilgi uyandırmıştır (Pereira ve ark., 2017). Günümüzde, allelopatik bitkiler, yabancı ot kontrolü ve doğal herbisit geliştirme amacıyla önemli bir potansiyel taşımaktadır. Bu yöntemle yapılan yabancı ot mücadelesi çevreyi ve biyolojik çeşitliliği koruyan yapısı, onu diğer mücadele yöntemlerinden daha popüler hale getirmiştir (Baziar ve ark., 2014; Sitthinoi ve ark., 2017). Allelokimyasal maddeler içeren bitkiler arasında sütleğen (*Euphorbia macroclada* Boiss.) ve yonca (*Medicago sativa* L.) da yer almaktadır.

Euphorbia cinsine ait birçok bitki, çevreye bazı kimyasallar salarak komşu bitkileri ve diğer organizmaları etkilemektedir (Liu ve ark., 2014). Bazı sütleğen türleri tahıl, sebze, yem bitkileri ve yağlı tohumlar üzerinde allelopatik aktivite gösterdiği bildirilmiştir (Deepti ve ark., 2023). Esansiyel yağlar *Euphorbia* cinsine ait bitkilerin temel bileşenlerinden biridir (Elshamy ve ark., 2019).

Kendisinden sonra ekilen kültür bitkilerinde görülen verim kayıpları nedeniyle yoncanın da allelopatik aktiviteye sahip bir bitki olduğu ilk kez Mishustin ve Nauvoma (1955) tarafından bildirilmiştir (Rizvi ve ark., 1992). Yoncanın çeşitli bitki fidelerine karşı inhibe edici özelliklere sahip fenolik bileşikler, saponinler ve medikarpin dahil olmak üzere çeşitli fitokimyasallar içerdiği bildirilmektedir (Dornbos ve Spencer, 1990). Daha sonra yapılan çalışmalar da bitkinin bünyesinde bulunan allelokimyasalların saptanması üzerine yoğunlaşılmış ve bu kimyasallar nedeniyle yoncanın farklı kültür bitkileri ile yabancı otlara, hatta kendi kendine de toksik etkiler gösterebildiği (ototoksisite) belirlenmiştir (Chung ve Miller, 1995).

Yaklaşık 25 *Chenopodium* türü dünyanın farklı yerlerinde yabancı ot olarak tanınmaktadır. Bu yabancı ot türlerinin en önemlilerinden bir tanesi de sirken (*Chenopodium album* L.)'dir. Çok sayıda tohum üretme kapasitesi, tohum bankasında uzun süre canlı kalması, farklı çevre koşullarına uyum sağlama yeteneği ve abiyotik stres toleransı gibi özellikleri, bu türün ciddi sorunlar oluşturmasına neden olmaktadır (Bajwa ve ark., 2019). Pek çok yabancı ot türüne kıyasla daha düşük sıcaklıklarda çimlenme özelliğine sahip olan bu tür, genellikle kültür bitkilerinin çıkışından önce çimlenerek erken dönemde rekabet avantajı elde eder (Weaver ve ark. 1988; Fischer

ve ark., 2004). Bu özellikler, *Chenopodium album*'un erken büyüme aşamalarından itibaren tarım ürünleriyle güçlü bir rekabet oluşturmasına yol açarak hem verim hem de kalite açısından önemli kayıplara neden olmaktadır (Damalas ve Koutroubas, 2022). Sirken, dünyanın farklı bölgelerinde soya fasulyesi (*Glycine max* (L.) Merr.), kolza (*Brassica napus* L.), mısır (*Zea mays* L.) ve buğday (*Triticum aestivum* L.) alanlarında yüksek rekabet gücüne sahip bir tür olarak doğal yayılış gösterdiği rapor edilmiştir (Guglielmini ve ark., 2017; Salonen ve ark., 2022).

Son yıllarda yoğun bir şekilde tarımsal alanlarda kullanılan kimyasalların insan ve çevre üzerindeki olumsuz etkileri düşünüldüğünde insan ve çevre dostu mücadele yöntemlerinin geliştirilmesi fikri önem kazanmıştır. Bu amaçla yapılan çalışmada, sütleğen ve yonca bitki ekstraktlarının farklı konsantrasyonlardaki (%1, 2, 4, 8, 16 ve 32) su ve etanol çözücülerinde elde edilen ekstraktlarının hem tarım hem de tarım dışı alanlarda ciddi problemlere yol açan sirken bitkisinin tohum çimlenmesine olan allelopatik etkisi araştırılmıştır. Dolayısıyla bu çalışma, tarımsal üretimde kimyasal herbisitlerin kullanımının çevre ve insan sağlığı üzerindeki olumsuz etkilerinin azaltılmasına katkı sağlamayı amaçlayarak, doğal kaynaklı herbisitlerin geliştirilmesi yönünde literatüre alternatif çözümler sunmayı hedeflemektedir.

2. Materyal ve Metot

2.1. Materyal

Çalışmada kullanılan Sütleğen (*Euphorbia macroclada* Boiss.) ve yonca (*Medicago sativa* L.) bitkilerinin toprak üstü kısımları 2023 yılında Van ilinde tarım arazilerinden toplanmış ve oda sıcaklığında kurutulmuştur. Denemeler Van Yüzüncü Yıl Üniversitesi Ziraat Fakültesi Bitki Koruma Bölümü Herboloji laboratuvarında yürütülmüştür.

2.2. Yöntem

Ekstraktların Hazırlanması

Oda sıcaklığında kurutulup toz haline getirilen bitkilerden 320 gr örneğin üzerine 1000 ml saf su eklenmiştir. Hazırlanan bu karışım 24 saat boyunca orbital çalkalayıcıda karıştırıldıktan sonra 2 katlı steril tülbentten geçirilmiştir. Tülbenten geçirilen eksrakt daha sonra 50 ml falkon tüplerine konularak 5000 devirde 10 dakika boyunca santrifüj edilmiştir. Elde edilen süpernatant daha sonra filtre kağıdından geçirilmiş ve su ekstraktı olarak kullanılmıştır (Türküsay ve Onoğur, 1998; Abbasi, 2012). Etanol ekstraktı, saf su yerine etanol kullanılarak ve santrifüj işlemine kadar aynı prosedür izlenerek yapılmıştır. Elde edilen süpernatant, rotary evaporatör yardımıyla 40°C'de etanolü uçurulduktan sonra kalan karışım ekstrakt olarak kullanılmıştır. Hazırlanan bu ekstraktlar +4 °C'de muhafaza edilmiş ve 24 saat içinde kullanılmıştır (Türküsay ve Onoğur, 1998; Abbasi, 2012; Taştan ve ark., 2024).

Çimlenme denemesinin kurulması

Çalışmada tabanına çift kat kurutma kâğıdı yerleştirilmiş 9 cm çaplı steril cam Petri kapları kullanılmıştır. Denemeler, tesadüf parselleri deneme desenine göre 5 tekerrürlü ve her tekerrürde (Petri kabında) 50 adet sirken tohumu kullanılmıştır. Zımpara yöntemi ile dormansileri kırılan sirken tohumları %1'lik sodyum hipokloritte 5 dakika bırakılıp beş defa saf su ile yıkandıktan sonra Petri kaplarına konulmuştur (Aydın ve Tursun, 2010; Efil, 2012; Turan ve Özkan, 2024). Elde edilen çözeltiden %1, 2, 4, 8, 16 ve 32 konsantrasyonlar hazırlanmıştır. Her Petri kabı için hazırlanan ekstraktlardan 5 ml eklenmiştir. Kontrol grubunda ise sadece saf su kullanılmıştır. Daha sonra Petri kapları parafilmle sarılmış, optimum çimlenme sıcaklıkları olan 25ºC de inkübatörlere bırakılmıştır (Üremiş ve Uygur, 1999). Bütün uygulamalar için 7 gün sonunda sayımlar yapılmış, 0,5 cm çim borucuğu oluşturan tohumlar çimlenmiş kabul edilmiştir (Efil, 2012).

2.3. İstatistiksel analizler

Denemeden elde edilen veriler, $p<0.05$ anlamlılık düzeyine göre SPSS istatistiksel paket programı ile analiz edilmiştir. Ortalamalar arasındaki farklar ise Duncan'ın çoklu karşılaştırma testi ile belirlenmiştir (SPSS, 2021).

3. Bulgular ve Tartışma

Sütleğen ve yonca bitkilerinden elden edilen su ve etanol ekstraktlarının sirken tohum çimlenmesi üzerindeki etkisinin araştırıldığı çalışmada istatistiksel olarak önemli farkların olduğu gözlenmiştir. ($p<0.05$) (*Tablo 1*). T*ablo*

1 incelendiğinde çözücü, konsantrasyon, bitki ekstraktı × çözücü, çözücü × konsantrasyon ve bitki ekstraktı × çözücü × konsantrasyon interaksiyonları önemli bulunmuştur.

Tablo 1. Sütleğen ve yonca bitkilerinin su ve etanol ekstraktlarının sirken tohumlarının çimlenmesi üzerine etkisi

Table 1. Effect of water and ethanol extracts of spurge and alfalfa on germination of lamb's quarters seeds

Ekstrakt (Bitki)	Çözücü	Konsantrasyon (%)	Çimlenen tohum sayısı (adet) (Ortalama ± SH)
Sütleğen	Su	Kontrol	40.20 ± 1.78 a
		1	22.80 ± 4.76 b
		2	13.20 ± 2.28 c
		4	11.20 ± 3.49 c
		8	4.80 ± 1.48 d
		16	1.00 ± 0.70 e
		32	0.00 ± 0.00 e
	Etanol	Kontrol	40.05 ± 1.30 a
		1	7.00 ± 1.22 b
		2	2.80 ± 1.09 c
		4	1.80 ± 0.83 c
		8	0.00 ± 0.00 d
		16	0.00 ± 0.00 d
		32	0.00 ± 0.00 d
Yonca	Su	Kontrol	40.30 ± 1.92 a
		1	24.80 ± 2.48 b
		2	18.40 ± 2.30 c
		4	11.80 ± 0.83 d
		8	6.20 ± 1.30 e
		16	0.20 ± 0.44 f
		32	0.00 ± 0.00 f
	Etanol	Kontrol	40.15 ± 0.83 a
		1	4.80 ± 1.48 b
		2	1.80 ± 0.83 c
		4	0.20 ± 0.44 d
		8	0.20 ± 0.44 d
		16	0.00 ± 0.00 d
		32	0.00 ± 0.00 d
Ekstrakt (Bitki)		**Sütleğen**	10.35 ± 13.92
		Yonca	10.62 ± 14.30
Çözücü		**Su**	13.91 ± 13.58 a
		Etanol	7.07 ± 13.79 b
p değerleri			
İnteraksiyonlar		$p^{Bitki(B)}$	0.322
		$p^{Çözücü(Ç)}$	0.000
		$p^{Konsantrasyon(K)}$	0.000
		$p^{B*Ç}$	0.001
		p^{B*K}	0.158
		$p^{Ç*K}$	0.000
		$p^{B*Ç*K}$	0.007

a, b, c : Aynı sütunda farklı harf ile gösterilen ortalamalar arasındaki fark istatistiksel olarak önemlidir ($p<0.05$). SH: Standart hata.

Her iki bitkiden elde edilen su ekstraktlarının sirken tohumları üzerindeki etkisi tüm uygulamalar arasındaki farklar istatistiksel olarak önemli bulunmuştur ($p<0.05$) (*Tablo 1*). Sütleğen ve yonca ile hazırlanan su

ekstraktlarının sirken tohumları çimlenmesini engellenme oranı doz artışına paralel olarak artmış ve çimlenen tohum sayılarının azaldığı gözlenmiştir. Sütleğen su ekstraktının uygulandığı sirken bitkisinde %2 ve 4'lük konsantrasyonların etkisi arasında istatistiksel olarak fark bulunmamıştır. Her iki bitkinin su ekstraktının %1'lik konsantrasyonu tüm test bitkilerinde çimlenme üzerinde en düşük etkiye sahip olmuştur. Çalışma sonucunda sütleğen su ekstraktının %1, 2, 4, 8 ve 16'lık konsantrasyonları sırasıyla %43, 67, 72, 88 ve 98 oranında, yonca ekstraktının ise %1, 2, 4, 8 ve 16'lık konsantrasyonları sırasıyla %38, 54, 71, 85 ve 99 oranında sirken tohum çimlenmesini azalttığı saptanmıştır. Sütleğen ve yoncadan elde edilen su ekstraktlarının %32'lik dozunda ise çimlenme tamamen engellenmiştir (*Şekil 1*).

Sütleğen ve yonca bitkilerinden elde edilen etanol ekstraktlarının sirken tohumları üzerinde yapılan çalışmada tüm uygulamalar arasındaki farklar istatistiksel olarak önemli bulunmuştur ($p<0.05$) (*Tablo 1*). Sütleğen etanol ekstraktının uygulandığı sirken bitkisinde %2 ve 4'lük konsantrasyonların etkisi arasında istatistiksel olarak fark bulunmamıştır. Çalışma sonucunda sütleğen etanol ekstraktının %1, 2 ve 4'lük konsatrasyonları sırasıyla %83, 93 ve 96 oranında, yonca ekstraktı ise %1, 2, 4 ve 8'lik konsatrasyonları sırasıyla %88, 96, 99 ve 99 oranında sirken tohum çimlenmesini azaltmıştır. Sütleğenden elde edilen etanol ekstraktlarının %8, 16 ve 32; yoncanın ise %16 ve 32 dozlarında sirkenin çimlenmesini tamamen engellediği saptanmıştır (*Şekil 1*).

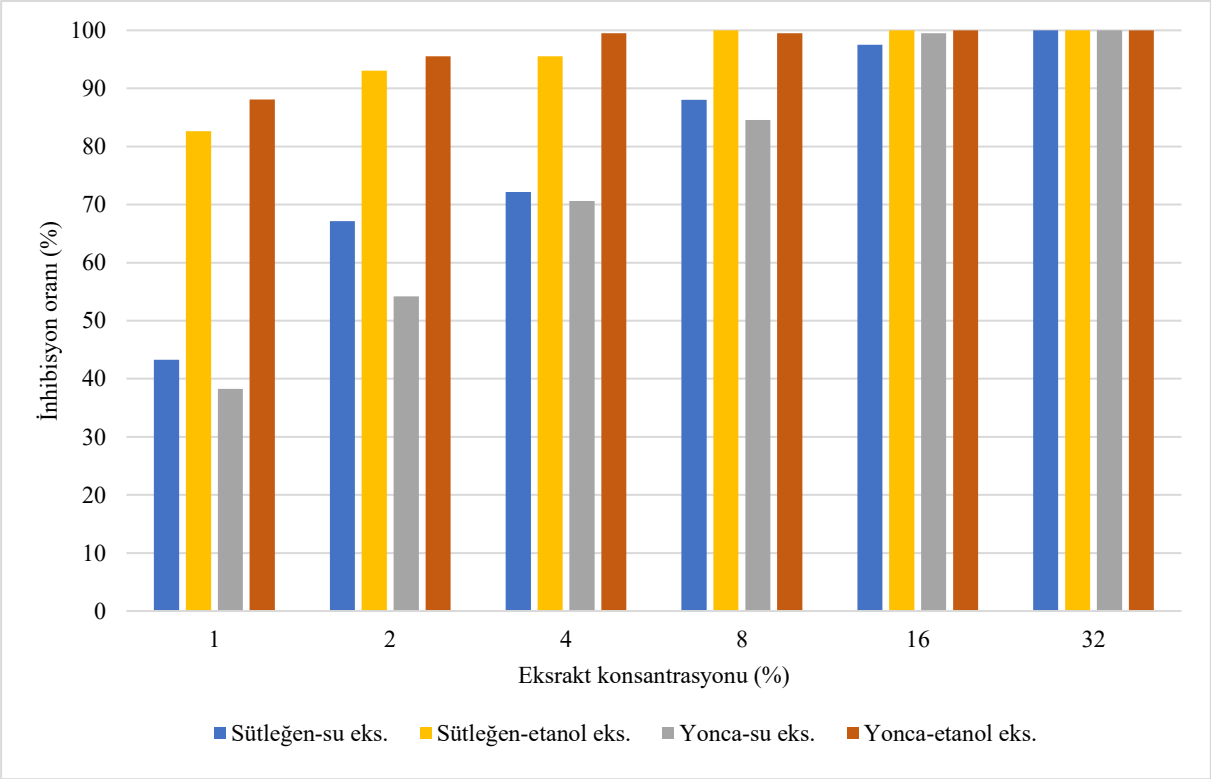

Figure 1. Effect of water and ethanol extracts of spurge and alfalfa plants on germination of lamb's quarters seeds

Şekil 1. Sütleğen ve yonca bitkilerinin su ve etanol ekstraktlarının sirken tohumlarının çimlenmesi üzerine etkisi

Bitki türleri, çevreye salındığında komşu türlerde morfolojik ve metabolik değişikliklere neden olan ikincil metabolizma ürünlerinin etkisiyle diğer türlerin gelişimini uyarabilir veya engelleyebilir (Fiorenza ve ark., 2016). Yapılan bu çalışma ile *Euphorbiaceae* familyasına ait sütleğen bitkisinin sirken tohum çimlenmesi üzerine allelopatik etkisinin olduğu belirlenmiştir. *Euphorbiaceae* familyasının bitkilerinde kimyasal bileşenlerinin çoğu saponin, triterpen, diterpenoid, flavonoid ve 4α-metil steroidlerini içerdiği bilinmektedir (Deepti ve ark., 2023). *Euphoria guyoniana* Boiss. & Reut.'un yaprak özündeki çeşitli bileşikleri (flavonoid, antosiyanin, fenol, tanen, steroid, saponin, serbest kinon, sterol, triterpen, karbonhidrat gibi) bulundurması sebebiyle önemli allelopatik etkileri olduğu bildirilmiştir (Otmani ve ark., 2022). Yapılan bir çalışmada, *Euphorbia granulata* Forssk.'nın farklı bitki türleri (hem yabancı otlar hem de kültür bitkileri) üzerindeki allelopatik etkisini bildirmiştir (Hussain, 1980).

Euphorbia guyoniana Boiss. & Reut. yaprak özütünün dört yabancı otun (*Bromus rubens* L., *Phalaris minor* Retz., *Plantago lagopus* L., ve *Ammi visnaga* L.) çimlenmesi üzerinde yüksek inhibisyon göstermiştir (Otmani ve ark., 2022). Sütleğenin (*Eupborbia esula* L.) allelopatik potansiyelinin araştırıldığı bir çalışmada, sütleğenden elde edilen bitki materyalinin *Agropyron repens* L. ve *Ambrosia artemisiifolia* L. populasyon yoğunluğunu azalttığı bildirilmiştir (Steenhagen ve Zimdahl, 1979). Başka bir çalışmada, *Euphorbia hypericifolia* L.'dan elde edilen ekstraktların domates, mısır, marul ve horoz ibiği bitkilerinin tohum çimlenmesini önemli derecede azalttığı bildirilmiştir (Ndam ve ark., 2021).

Fabaceae familyasına ait olan yoncanın (*Medicago sativa* L.) allelopatik etkileri olduğu bilinmektedir. Yonca bitkisinin saponin, glikozit, fitotoksik fenolik asitler, medikarpin, glukuronik asit, medikagenik asit, klorogenik asit gibi allelokimyasalları içerdiği rapor edilmiştir (Yılmaz ve Köse, 2021). Öten ve Tokat (2024) yaptıkları çalışmada, yoncadan elde edilen farklı çözücülerdeki (su, etanol ve metanol) ekstraktların yabani yulaf üzerinde allelopatik etkiye sahip olduğunu tespit etmişlerdir. Koloren (2007), yaptığı çalışmada yoncadan elde edilen farklı konsantrasyonlardaki (%5, 25 ve 50) su ekstraktları, *Amaranthus retroflexus, Lolium perenne, Ipomoea hederacea* ve *Portulaca oleracea* yabancı ot tohumlarının çimlenmesinde engelleyici etkiler gösterdiğini; %50 konsantrasyonun *A. retroflexus* dışında diğer üç yabancı otun çimlenmesini tamamen engellediğini bildirmiştir. Yapılan başka bir çalışmada yoncadan elde edilen ekstraktların *Acroptilon repens*'in çimlenmesini olumsuz etkilediği saptanmıştır (Sözeri, 2003). Ayrıca yonca bitkisinin ayçiçeği, buğday ve pamuk üzerinde allelopatik etkisi olduğu bildirilmiştir (Yılmaz ve Köse, 2021). Yapılan çalışmadan elde edilen veriler, sütleğen (*Euphorbia macroclada* Boiss.) ve yonca (*Medicago sativa* L.) bitkilerinden elde edilen ekstraktların allelopatik etki gösterdiğini ortaya koymakta olup, bu bulgular literatürde yer alan benzer çalışmaların sonuçlarıyla uyum göstermektedir.

4. Sonuç

Çalışma sonucunda, sütleğen (*Euphorbia macroclada* Boiss.) ve yonca (*Medicago sativa* L.) bitkilerinden elde edilen ekstraktların sirken tohumlarının çimlenmesi üzerinde allelopatik etkisi olduğu sonucuna varılmıştır. Her iki bitkiden elde edilen %32'lik su ekstraktı ile sütleğenin %8, 16 ve 32'lik etanol ekstraktları ve yoncanın %16 ve 32'lik etanol ekstraktları sirkenin çimlenmesini tamamen engellemiştir. Bu sonuçlar, her bir bitkiden elde edilen ekstraktların sirken tohumları üzerindeki inhibe edici etkilerini gösterirken, özellikle yüksek konsantrasyonların etkisinin daha belirgin olduğu saptanmıştır. Bitkilerden elde edilen etanol ekstraklarının, sirken tohumlarının çimlenmesini su ekstraktlarına kıyasla daha fazla engellediği belirlenmiştir. Etanol ekstraktlarının sirken tohumlarının çimlenmesini daha fazla engellemesinin nedeni, etanolün daha güçlü bir çözücü olması ile açıklanabilir. Başka bir ifadeyle etanol, bitkisel bileşenlerin daha etkin bir şekilde çözünmesini sağlar ve bu bileşiklerin tohum çimlenmesi üzerindeki inhibe edici etkilerini artırabilir. Bu sonuçlara göre sütleğen ve yonca bitkilerinin allelokimyasal özelliklerinden dolayı, sirkenin mücadelesinde alternatif bir mücadele yöntemi olarak kullanılması açısından önemli olduğu düşünülmektedir. Bu veriler ışığında, söz konusu bitkilerden elde edilen ekstraktların sirken mücadelesinde kullanılabilirliğinin değerlendirilmesi amacıyla sera veya tarla koşullarında da araştırılması gerektiği kanaatine varılmıştır.

Teşekkür

Bu çalışma TÜBİTAK Bilim İnsanı Destek Programları Başkanlığı (BİDEB) tarafından yürütülen, 2209-A Üniversite Öğrencileri Araştırma Projeleri Destekleme Programı 2023 yılı 1. dönem kapsamında 1919B012301807 numaralı proje ile desteklenmiştir.

Etik Kurul Onayı

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

Çıkar Çatışması Beyanı

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

Yazarlık Katkı Beyanı

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Assessment of Groundwater Quality of Anamur and Aydıncık Districts of Mersin, Türkiye in Terms of Irrigation Using Geographic Information System*

Coğrafi Bilgi Sistemi Kullanılarak Mersin İli Anamur ve Aydıncık İlçelerinin Yeraltısuyu Kalitesinin Sulama Açısından Değerlendirilmesi

Demet KÖSEOĞLU[1], Hakan ARSLAN[2]*

Abstract

Monitoring groundwater quality is very important in coastal areas with intensive irrigation. Excessive use of groundwater use coastal areas can lead to seawater intrusion. The quality of irrigation water significantly has a significant impact on a crop productivity and can cause soil salinization. This study was conducted to determine the quality of groundwater quality and assess its suitability for irrigation in the coastal regions of Anamur and Aydıncık districts in Mersin province. In August 2021, samples were taken from 51 groundwater wells used for greenhouse irrigations, and the values of pH, electrical conductivity (EC, Na, Mg, K, Cl, SO_4, HCO_3, and Ca were measured. To assess the suitability of the water for irrigation, values for %Na, PI, RSC, PS, MR, KI, and SAR were calculated. Additionally, spatial distribution maps were created for the water's chemical properties and irrigation water quality indices. The groundwater's EC values ranged from a minimum of 0.475 dS m^{-1} to a maximum of 1.13 dS m^{-1}. According to the spatial distribution map, it was determined that 92.03% of the region's groundwater quality is classified as Class 3 in terms of irrigation suitability. In 9.71% of the study area, magnesium (Mg) levels exceeded the acceptable threshold for irrigation water. Based on potential salinity (PS) values, 84.91% of the area falls within the medium class for irrigation suitability. The Permeability Index (PI) varies between 17.19 and 48.17, with an average value of 29.84. The potassium (K) values ranged from between 0.391 mg L^{-1} to 10.557 mg L^{-1}, with 68.3% of the groundwater samples in the region exceeding the threshold value which could pose a risk for irrigation. It was determined that there were no problems in terms of SAR, KI and RSC in the groundwater samples in the area. Groundwater quality is above the limit values in some regions. Due to the intensive agricultural activities in the study area and its proximity to the coastline, it was established that groundwater extraction in the area should be controlled.

Keywords: Groundwater quality, Geographic information system, Irrigation, Seawater intrusion

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Öz

Yoğun sulama yapılan kıyı bölgelerinde yeraltı suyu kalitesinin izlenmesi çok önemlidir. Kıyı bölgelerinde aşırı yeraltısuyu çekimi yapılması deniz suyu girişimine neden olabilmektedir. Sulama suyu kalitesi bitki verimini önemli derecede etkilemekte ve toprakta tuzlanmaya neden olabilmektedir. Bu çalışmada, Mersin ili Anamur ve Aydıncık ilçelerinin kıyı bölgelerindeki yeraltısuyu kalitesini belirlemek ve sulamada kullanıla birliğini incelemek amacıyla yürütülmüştür. Seraların sulanmasında kullanılan 51 adet yeraltısuyu kuyusundan Ağustos 2021 tarihinde örnek alınmış ve örneklerin pH, EC, Na, Mg, K, CI, SO_4, HCO_3, Ca değerleri tespit edilmiştir. Suların sulamaya uygunluğunu belirlemek için %Na, PI, RSC, PS, MR, KI, SAR değerleri belirlenmiştir. Suların kimyasal özellikleri ile sulama suyu kalite indekslerine ait değerlerin alansal dağılım haritaları hazırlanmıştır. Yeraltı sularının EC değeri en düşük 0.475 dS m^{-1} ve en yüksek ise 1.13 dS m^{-1} olarak ölçülmüş ve alansal dağılım haritasına göre bölgenin %92.03 lük kısmında yeraltısuyu kalitesinin sulamada açısından 3. Sınıf olduğu tespit edilmiştir. Çalışma alanının %9.71 lik kısmında ise Mg değerlerinin sulama suyu sınır değerinden yüksek olduğu belirlenmiştir. Potansiyel tuzluluk (PS) değerlerine göre ise alanının %84.91 sulama açısından orta sınıfta yer almıştır. Permeabilite İndeksi (PI) değerleri 17.19 ile 48.17 arasında değişmekte olup, ortalama değeri ise 29.84 olarak ölçülmüştür. Yersularından K değerleri 0.391 mg L^{-1} ile 10.557 mg L^{-1} arasında ölçülmüş ve bölgenin % 68.3' ündeki K değerlerinin sulama açısından sorun oluşturabilecek seviyenin üzerinde olduğu tespit edilmiştir. Alandaki yeraltısuyu örneklerinde SAR, KI ve RSC açısından herhangi bir sorun olmadığı belirlenmiştir. Yeraltısuyu kalitesi bazı bölgelerde sınır değerlerinin üzerindedir. Çalışma alanının yoğun tarım yapılan ve deniz kıyısına yakın bölgelerden oluşması nedeniyle, yeraltısuyu çekiminin kontrollü şekilde yapılması gerektiği belirlenmiştir.

Anahtar Kelimeler: Yeraltısuyu kalitesi, Coğrafi bilgi sistemleri, Sulama, Denizsuyu girişimi

1. Introduction

Groundwater is the most important water source in arid and semi-arid areas and is intensively used for irrigation (Arslan et al., 2017). Irrigation is critical for crop production, with low irrigation water quality affecting plant yield as much as its quantity. Uncontrolled use of groundwater can lead to deterioration in soil physical and chemical properties (Bhunia et al., 2018). Groundwater quality varies depending on physical, chemical, biological parameters, natural activities, anthropogenic activities, climate, geology, and irrigation practices significantly impact groundwater quality (Ramkumar et al., 2013).

Monitoring and assessing groundwater salinity are essential for mitigating its adverse effects. Mitigating the adverse effects of groundwater salinization will aid in preserving non-renewable soil and water resources while minimizing harm to crops and the environment (Abulibdeh et al., 2021). Each year, land across the globe is losing productivity as a result of salt buildup (Beyaz and Kazankaya, 2024). Groundwater salinization is a prevalent and serious environmental issue, particularly in densely populated coastal regions. This salinization can result from both natural factors and human activities (Cemek et al., 2022). Excessive groundwater usage, particularly in coastal regions, leads to seawater intrusion, increasing water salinity (Arslan et al., 2013). Numerous studies have been conducted globally using various modeling approaches to examine water salinity and seawater intrusion in various aquifer systems. High-salinity water increases the risk of soil salinity and reduces crop yield (Alkan and Meral, 2024). Many studies have been conducted worldwide and in Türkiye to assess the suitability of surface and groundwater for irrigation purposes (Abdelkarim et al., 2023; Kıy Şahin and Arslan, 2021; Maurya et al., 2023; Siddha and Sahu, 2023). Important parameters such as EC, pH, Na, K, Ca, Mg, HCO_3, and SO_4 hydrochemical properties are used to investigate water suitability for irrigation (Masoud et al., 2022). Different quality indices are commonly utilized to assess the suitability of water for irrigation, including sodium percentage (%Na), magnesium ratio (MR), Kelley's ratio index (KR), potential salinity (PS), Langelier saturation index (LSI), residual sodium carbonate (RSC), permeability index (PI), and sodium adsorption ratio (SAR) (Dhaou et al., 2023; Tasan, 2023).

Determining groundwater properties, spatial and temporal variation is crucial for managing water resources. Geographic Information System (GIS) is often used in groundwater quality studies (Duraisamy et al., 2019; Jha et al., 2020). Various interpolation methods are used to prepare spatial and temporal distribution maps. Many researchers have extensively utilized the Inverse Distance Weighting (IDW) technique to develop spatial and temporal maps illustrating the distribution of groundwater quality. (Abdessamed et al., 2023; Arumugam et al., 2023). Pappaka et al. (2024) gathered samples from 46 groundwater wells, calculating %Na, MR, KI, PS, RSC, and SAR values to assess the wells' suitability for irrigation. They also employed the IDW method to create spatial distribution maps of groundwater characteristics. The maps indicated that certain areas exhibited lower water quality in terms of irrigation suitability.

In this study, samples were taken from 51 different wells used for irrigation in the coastal regions of Anamur and Aydıncık districts in Mersin province. EC, pH, Na, Mg, K, Cl, SO_4, HCO_3, and Ca values were measured to determine the chemical properties of the wells. The %Na, PI, RSC, PS, MR, KI, and SAR values were calculated to examine the irrigation suitability of these wells. Spatial distribution maps were derived for hydrochemical properties and water quality parameters that are problematic for irrigation.

2. Materials and Methods

2.1. Study area

The study area is situated in the coastal regions of Anamur and Aydıncık districts in Mersin province (*Figure 1*). The lowest average temperature is in January at 11 °C, while the highest is in August at 29.3 °C. The annual average temperature is 19.3 °C, with a total annual precipitation of 921.6 mm. Intensive agricultural activities are carried out in the study area. Cucumbers, eggplants, tomatoes, and bananas are widely cultivated. Additionally, greenhouse cultivation is extensively practiced in the region.

2.2. Analysis of Groundwater Samples

As part of the study, samples were taken from 51 different groundwater wells in August 2021, primarily used for greenhouse irrigation (*Figure 1*). Before sampling, the wells were operated for 15 minutes, and samples were

collected in 2-liter plastic bottles. The samples were then stored in a refrigerator before analysis. The locations of the sampled wells were recorded using GPS.

The electrical conductivity (EC) and pH levels of the water samples were assessed on-site with a portable device (Horiba 300), while hydrochemical parameters such as HCO_3, SO_4, Cl, Na, Ca, K, and Mg were determined by ion chromatography.

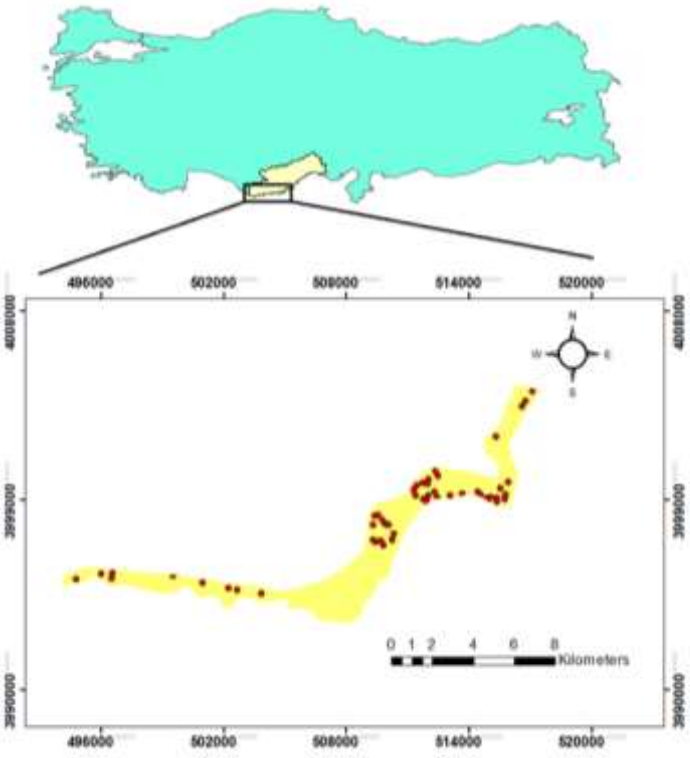

Figure 1. Study Area and Sampled Points

2.3. Irrigation Suitability of Groundwater

To determine the suitability of groundwater for irrigation, the values for SAR, %Na, RSC, KI, MR, PS were calculated. The following formulas were used in these calculations:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$ (Wilcox, 1955) (Eq. 1)

$$\%Na = \frac{Na}{(Ca+Mg+Na+K)} * 100$$ (Richards, 1954) (Eq. 2)

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$ (Eaton, 1950) (Eq.3)

$$KI = \frac{Na}{Ca+Mg}$$ (Kelly, 1940) (Eq.4)

$$MR = \frac{Mg}{Ca+Mg}$$ (Szabolcs, 1964) (Eq.5)

$$PS = Cl + \left(\frac{SO4}{2}\right)$$ (Delgado et al. 2010) (Eq.6)

$$Pl = \left[\frac{Na+\sqrt{HCO_3}}{Ca+Mg+Na}\right] x100$$ (Doneen 1964) (Eq.7)

2.4. Preparation of Spatial Distribution Maps

The spatial distribution maps of groundwater characteristics were prepared using the ArcGIS program. The IDW method was used as the interpolation method for creating these spatial distribution maps.

3. Results and Discussion

3.1. Hydrochemical Properties of Groundwater

The basic descriptive statistical values for the hydrochemical properties of the groundwater samples are presented in *Table 1*.

Table 1. Descriptive Characteristics of Groundwater Samples

Properties	Minimum	Maximum	Mean
pH	6.05	8.04	7.16
EC (dS m^{-1})	0.474	1.136	0.668
Na (mg L^{-1})	7.20	78.59	18.48
K (mg L^{-1})	0.39	10.56	2.58
Ca (mg L^{-1})	29.06	234.07	125.76
Mg (mg L^{-1})	7.29	99.55	47.47
HCO_3 (mg L^{-1})	70.76	593.53	355.70
Cl (mg L^{-1})	21.66	324.83	67.04
SO_4 (mg L^{-1})	12.13	432.89	181.96

The EC values area ranged from 0.475 dS m^{-1} to 1.136 dS m^{-1}, with an arithmetic mean of 0.668 dS m^{-1}. In terms of irrigation water classification, EC values less than 0.25 dS m^{-1} are classified as Class 1, between 0.25–0.75 dS m^{-1} are regarded as Class 2, between 0.75–2.25 dS m^{-1} are Class 3, and EC values greater than 2.25 dS m^{-1} are termed as Class 4 (USSL, 1994). The spatial distribution of EC values in the study area is presented in *Figure 2*, showing that 92.03% of the area has EC values between 0.25 and 0.75 dS m^{-1}. In 7.97% of the area, groundwater EC values range from 0.75 to 1.136 dS m^{-1}, classifying the water as Class 3 for irrigation. Due to the proximity of the area to the coastline, it is thought that there may be an increase in EC values in groundwater due to an interaction between groundwater and seawater.

The pH values ranged from 6.05 to 8.04. Water with pH values between 6.5 and 8.5 is considered safe for irrigation purposes (Ayers and Westcot, 1985). According to the spatial distribution map, 1.18% of the study area has pH values between 6.05 and 6.50, indicating that groundwater pH levels in this region fall below the permissible limits (*Figure 2*).

Water with potassium (K) values greater than 2 mg L^{-1} poses risks for plant irrigation (FAO, 1994). The K levels in the study area vary between 0.39 mg L^{-1} and 10.56 mg L^{-1} (*Table 1*). According to the spatial distribution map, 31.71% of the area, covering 1078 hectares, has K levels within permissible limits, while groundwater in other parts of the area is not suitable for irrigation in terms of K content (*Figure 2*). Elevated potassium concentrations in groundwater are frequently a result of the application of potassium-based fertilizers and the subsequent leaching into the soil (Gasmi et al., 2022).

Water with magnesium (Mg) levels exceeding 60 mg L^{-1} is unsuitable for irrigation (FAO, 1994). Mg levels in the groundwater of the region range from 7.29 mg L^{-1} to 99.55 mg L^{-1}, with an average of 47.47 mg L^{-1} (Table 1). In a 330-hectare section of the area, Mg levels exceed the permissible limit (*Figure 2*). High magnesium concentrations in groundwater are often attributed to the presence of minerals or the use of chemical fertilizers (Devic et al., 2014).

In the study area, groundwater calcium (Ca) levels range from 29.06 mg L^{-1} to 234.07 mg L^{-1}, while bicarbonate (HCO_3) levels vary between 70.76 mg L^{-1} and 593.53 mg L^{-1} (*Table 1*). Water with Ca levels below 400 mg L^{-1} and HCO_3 levels below 10 mg L^{-1} has no restrictions for irrigation use (FAO, 1994). Thus, there are no issues with Ca and HCO_3 levels in the region's groundwater.

For irrigation suitability, water with chloride levels below 105 mg L^{-1} is unsuitable, while levels between 105–350 mg L^{-1} indicate moderate suitability, and levels above 350 mg L^{-1} are unsuitable (Arslan and Gürler Çolak, 2023). Chloride levels in the groundwater range from 21.66 mg L^{-1} to 324.83 mg L^{-1} (*Table 1*). In 235 hectares of the study area, chloride levels pose no issues, while 3165 hectares fall into the moderate suitability category

(*Figure 2*). Higher chloride concentrations can result from industrial and domestic wastewater discharge or the mixing of salts from various sources into groundwater (Sundararaj et al., 2022).

The sulfate (SO_4) levels range from 12.13 mg L^{-1} to 432.90 mg L^{-1}, and sodium (Na) levels vary from 7.20 mg L^{-1} to 78.59 mg L^{-1}, with an average of 181.90 mg L^{-1}. SO_4 levels exceeding 960 mg L^{-1} and Na levels above 920 mg L^{-1} are undesirable for irrigation. Based on these values, groundwater in this area is safe in terms of SO_4 and Na content.

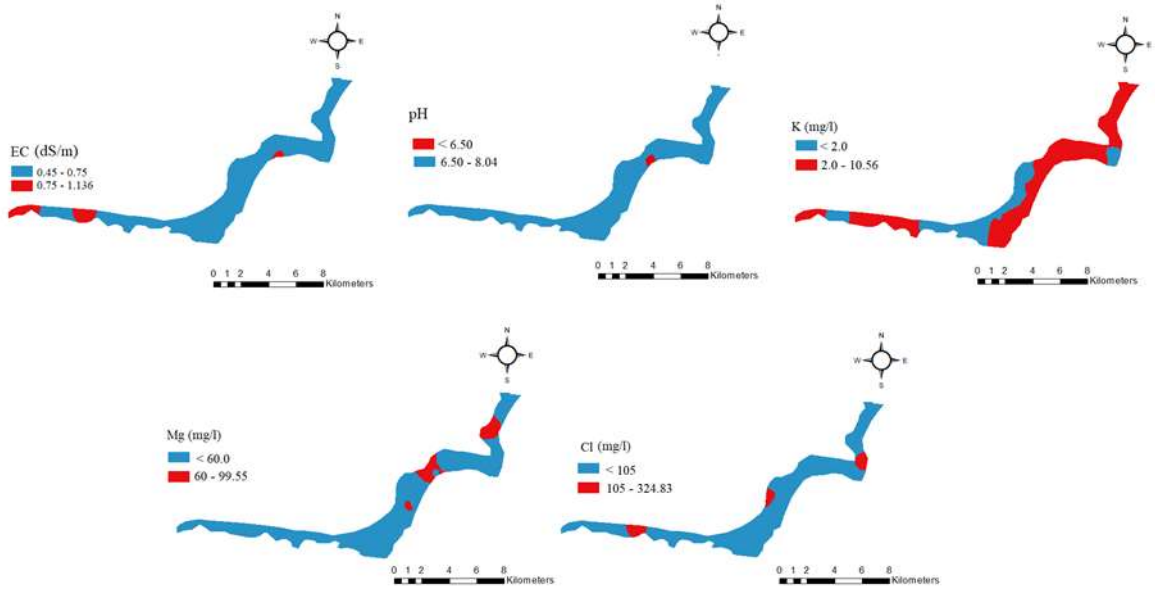

Figure 2. Spatial Distribution Maps of Hydrochemical Properties of Groundwater

3.2. Evaluation of Groundwater Suitability for Irrigation

The Sodium Adsorption Ratio (SAR), %Na, KI, MR, PS, RSC, and PI values were calculated to assess the suitability of groundwater for irrigation. The basic descriptive statistical values for the irrigation water quality indices of the 51 different groundwater samples are presented in *Table 2*. *Figure 3* shows the spatial distribution maps of groundwater quality criteria that could be a problem for irrigation.

The Percent Sodium (%Na) values in the study area fall between 2.19 and 26.52. Water with %Na values below 20 is considered excellent for irrigation, values between 20–40 are good, between 40–60 are permissible, between 60–80 are doubtful, and values above 80 are unsuitable (Wilcox, 1955). 7.27% of the area is classified as "good" for irrigation, while the remaining areas are classified as "excellent."

Table 2. Descriptive Characteristics of Irrigation Water Quality Indices

Irrigation water quality index	Minimum	Maximum	Mean
SAR	0.12	1.58	0.36
%Na	2.19	26.52	7.27
KI	0.02	0.36	0.08
MR	8.05	67.36	37.61
PS	1.38	11.01	3.76
RSC	-9.37	0.19	-4.35
PI	17.19	48.17	29.84

The Magnesium Ratio (MR) values in the groundwater samples vary from 8.05% to 67.36%. Water with MR values exceeding 50% is considered unsuitable for irrigation. Only 0.82% of the study area has MR values above this threshold. Additionally, 73.88% of the area has MR values between 30% and 50%, indicating a potential risk. High magnesium levels in water can greatly affect the physical properties of soil and raise soil alkalinity, ultimately diminishing agricultural productivity (Arslan, 2017).

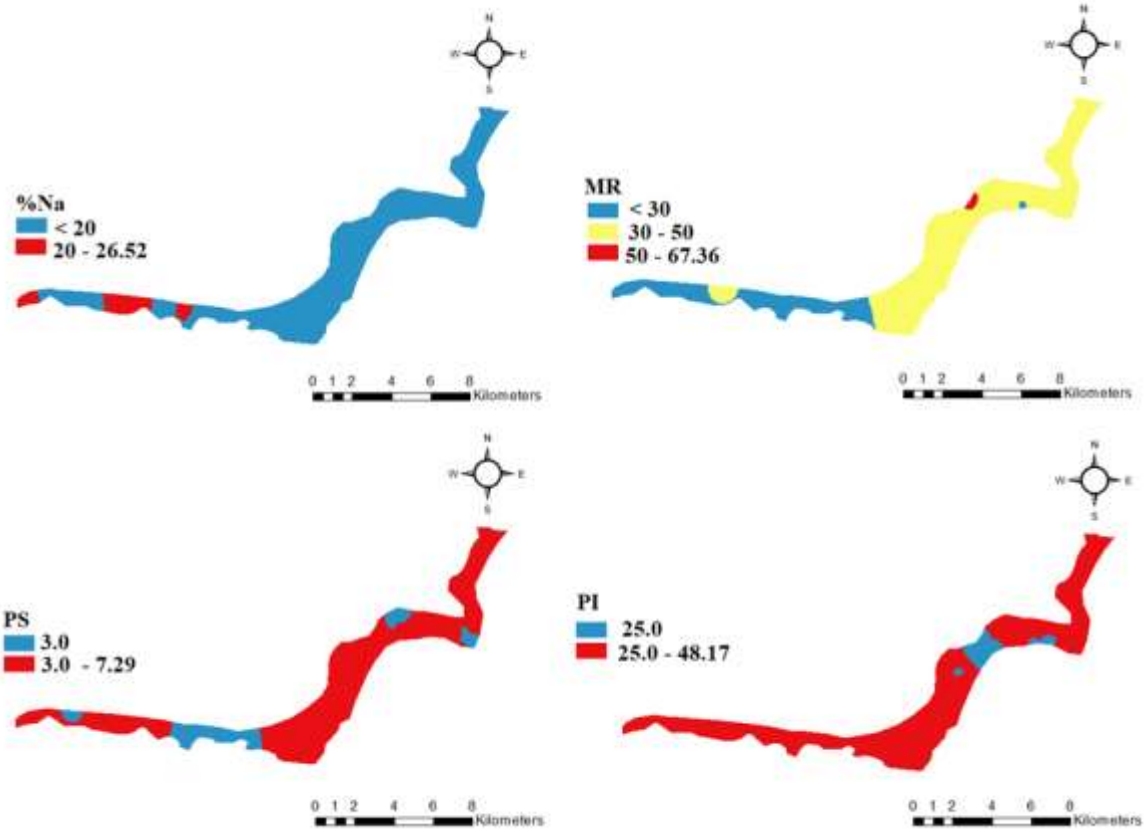

Figure 3. Spatial Distribution Maps of Irrigation water quality indexies

The Potential Salinity (PS) values ranged from 1.38 to 11.01, with an average of 3.76. PS values below 3 is considered unproblematic for irrigation, while those between 3 and 15 are in the moderate category. Water with PS values above 15 is unsuitable for irrigation. In the study area, 15.09% of the region has PS values below 3, while 84.91% has PS values between 3 and 15.

The Permeability Index (PI) ranges from 17.19 to 48.17, averaging 29.84. Water with PI values below 2 is unsuitable for irrigation, those between 25 and 75 are classified as questionable, and values above 75 are deemed suitable for irrigation (Donnen, 1962). The spatial distribution map indicates that 7% of the study area is suitable for irrigation, while 93% falls into the questionable category.

The Sodium Adsorption Ratio (SAR) ranged between 0.12 and 1.58, with a mean value of 0.36. SAR values of water below 10 are considered safe for irrigation (USSL, 1954). Based on the SAR data, there are no issues with the groundwater samples in the study area.

The Kelly Index (KI), another parameter for evaluating water suitability for irrigation, varied between 0.02 and 0.36, with an average of 0.08. Water with Kelly Index (KI) values below 1 is considered suitable for irrigation (Kelly, 1940). There are no KI related issues in the groundwater samples from the study area.

The Residual Sodium Carbonate (RSC) values ranged from -9.37 to 0.19. RSC values of water below 1.25 are considered safe for irrigation (Eaton, 1950). Based on these values, there are no RSC related issues in the groundwater samples from the study area.

In this study area, 39 groundwater wells (77%) are classified as C_2S_1, indicating moderate salinity and low sodium levels, while 12 wells (23%) fall into the C_3S_1 class, characterized by high salinity and low sodium levels.

4. Conclusions

Groundwater is frequently used for industrial and agricultural activities, particularly in coastal regions. Excessive extraction of groundwater in these areas can lead to salinization, adversely affecting plant growth and soil quality. The

aim of this study was to examine the hydro chemical characteristics of groundwater and evaluate its suitability for irrigation in the coastal areas of Anamur and Aydıncık districts in Mersin Province. A total of 51 groundwater wells were sampled, and different parameters such as EC, SAR, %Na, PI, MR, RSC, KI, and PS were evaluated to assess irrigation suitability. Spatial distribution maps of hydro chemical properties and irrigation water quality indices were prepared using GIS.

The EC values of the groundwater ranged from 0.475 dS m^{-1} to 1.136 dS m^{-1}, indicating that there is no well that belonged to the Class 1 irrigation water classification which is suitable for irrigation purposes, in the region. It was determined that in 7.97% of the study area, the groundwater should be carefully considered for irrigation purposes. In some parts of the region, the levels of K, Mg, Cl, and SO_4 in the groundwater were found to be very high, making it unsuitable for irrigation.

It has been concluded that groundwater in certain areas of the research region may pose problems for irrigation, and due to the coastal nature of the area, controlled use of groundwater should be implemented. Given the potential for seawater intrusion due to excessive groundwater extraction linked to climate change, there is a high likelihood of issues arising in the region.

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Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Arslan, H., Köseoğlu, D.; Design: Arslan, A.; Data Collection or Processing: Köseoğlu, D.; Statistical Analyses: Arslan, H., Köseoğlu, D..; Literature Search: Arslan, H., Köseoğlu, D.; Writing, Review and Editing: Arslan, H., Köseoğlu, D.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Drying Characteristics of Fresh Persimmons: Impacts on Color and Energy Consumption

Taze Hurmaların Kurutma Özellikleri: Renk ve Enerji Tüketimi Üzerindeki Etkileri

Emel ÇELİK[1*], Nezaket PARLAK[2]

Abstract

Persimmon *(Diospyros kaki)* constitutes a notable fruit in Türkiye. The fruit is consumed in its fresh state during specific periods of the year, which renders it of significant importance in the context of product preservation. Drying is the most commonly used method for preserving products. Drying requires significant energy consumption. The drying time and method employed have a direct impact on both energy consumption and product quality. Persimmon is a nutrient-dense fruit that needs to be dried for extended shelf life. This study investigated the drying behavior of persimmon slices having an initial moisture content of approximately %73.8 wet basis in a microwave oven. Moisture diffusion, shrinkage, color change and rehydration properties were investigated as a function of microwave power and slice thickness. Samples were prepared at two different thicknesses (5 mm and 9 mm) and tested at three microwave power levels (350 W, 460 W and 600 W). Curve fitting tools in the Matlab programmer were used to model the variation in moisture content over time. The study utilised six models: Lewis, Page, Henderson and Pabis, Logarithmic, Midilli, Wang and Singh. The logarithmic model has been demonstrated to provide the most accurate description of persimmon drying kinetics. The dried products' quality was evaluated through various parameters, including color metrics (L*, a*, b*), color difference (ΔE), browning index (BI), chroma, and hue angle, along with rehydration and shrinkage ratios. The effective diffusion coefficients of persimmon were found to range from 2.27×10^{-10} to 9.08×10^{-10} m²/s. Specific energy consumption ranged from 2.21 to 3.028 kWh/kg. The lowest ΔE value was observed in the samples dried at 460 W, suggesting that the highest power (460 W) effectively preserved the natural color of fresh persimmon and minimized browning reactions during the drying process. Results indicated that the applied microwave energy significantly influenced the drying process of the persimmon and the observed changes.

Keywords: Persimmon; Kinetic drying model, Shrinkage; Power, Color

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Öz

Trabzon hurması *(Diospyros kaki)* Türkiye'de önemli bir yere sahip meyvedir. Yılın belirli zamanlarında taze olarak tüketilen bir meyve olduğu için ürün muhafazası bakımından önemli bir potansiyele sahiptir. Kurutma, ürünleri muhafaza etmek için en yaygın kullanılan yöntemdir. Kurutma işlemlerinde önemli ölçüde enerji tüketimi gerektirir. Kurutma süresi ve kullanılan yöntem hem enerji tüketimi hem de ürün kalitesi üzerinde doğrudan bir etkiye sahiptir. Trabzon hurması, raf ömrünün uzatılması için kurutulması gereken besin değeri yüksek bir meyvedir. Bu çalışmada, yaklaşık olarak %73.8 yaş bazda ilk nem içeriğine sahip Trabzon hurması dilimlerinin mikrodalga fırında kurutma davranışı incelenmiştir. Nem difüzyonu, büzülme, renk değişimi ve rehidrasyon özellikleri mikrodalga gücünün ve dilim kalınlığının bir fonksiyonu olarak incelenmiştir. Örnekler iki farklı kalınlıkta (5 mm ve 9 mm) hazırlanmış ve üç mikrodalga güç seviyesinde (350 W, 460 W ve 600 W) test edilmiştir. Nem içeriğinin zaman içindeki değişimini modellemek için Matlab programındaki eğri uydurma araçları kullanılmıştır. Çalışmada altı model kullanılmıştır: Lewis, Page, Henderson ve Pabis, Logaritmik, Midilli, Wang ve Singh. Logaritmik model Trabzon hurması kurutma kinetiğini en iyi şekilde tanımlamaktadır. Kurutulmuş ürünlerin kalitesi, renk ölçümleri (L*, a*, b*), renk farkı (ΔE), kahverengileşme indeksi (BI), kroma ve ton açısı ile rehidrasyon ve büzülme oranları dahil olmak üzere çeşitli parametreler aracılığıyla değerlendirilmiştir. Trabzon hurmasının etkili difüzyon katsayılarının 2.27×10^{-10} ila 9.08×10^{-10} m²/s arasında değiştiği bulunmuştur. Spesifik enerji tüketimi 2.21 ila 3.028 kWh/kg arasında değişmiştir. En düşük ΔE değeri 460 W'da kurutulan örneklerde gözlenmiştir, bu da en yüksek gücün (460 W) taze Trabzon hurmasının doğal rengini etkili bir şekilde koruduğunu ve kurutma işlemi sırasında kahverengileşme reaksiyonlarını en aza indirdiğini göstermektedir. Sonuçlar, uygulanan mikrodalga enerjisinin Trabzon hurmasının kurutma sürecini ve gözlemlenen değişiklikleri önemli ölçüde etkilediğini göstermiştir.

Anahtar Kelimeler: Trabzon hurması; Kinetik kurutma modeli, Büzülme; Güç, Renk

1. Introduction

The persimmon is a member of the *Ebenaceae* family. It is cultivated in warm regions of the world (Senadeera et al., 2020). The persimmon is recognised as a nutrient-rich fruit (Jesus et al., 2023). Persimmon are typically consumed in their fresh state. However, since fresh persimmons consist of up to %80 water and are susceptible to softening and rotting following harvesting, they result in significant wastage (Qin et al., 2022). Nevertheless, the high moisture, sugar and polyphenol content of persimmon fruits renders them susceptible to decay and browning after harvesting (Jia et al., 2019).

The high yield of persimmons coupled with the brief period of harvest has resulted in a notable rise in postharvest losses, with estimates reaching up to %30 of total production (Cervera-Chiner et al., 2024). Consequently, one of the most pressing issues currently facing the persimmon industry is the need to identify strategies that enhance the value of the discarded fruit (González et al., 2021). Drying is a common postharvest preservation technique. The process reduces the likelihood of spoilage, extends the shelf life of harvested agricultural products, and reduces the bulk weight of the products during transportation. The application of heat during the drying of agricultural products inactivates enzymatic reactions, resulting in a reduction in the moisture content of the product (Khaled et al., 2020). However, excessive heat exposure may lead to a decline in quality attributes, highlighting the need for efficient drying methods to maintain the sensory and nutritional properties of fresh fruits (Jesus et al., 2023). The oldest traditional method is natural drying. Despite no energy requirements, this method has disadvantages. These include extensive drying areas, prolonged drying periods, a high demand for labour, and pests adhering to the product. To eliminate these and obtain higher quality, novel drying methods are used (Yildiz et al., 2024). Microwave heating is a new technology. In comparison to conventional heating methods, microwave heating is capable of utilizing energy more efficiently due to its accelerated rate of heat transfer (Wu et al., 2024). Karacabey et al. (2020) examined dried seedless grape samples at varying temperatures and power values, using the microwave and hot air methods without pretreatment. The study presented drying kinetics and energy consumption values, depending on the method employed. The process of microwave drying involves the simultaneous heating of the material from both the inside and outside, with a minimal overall temperature differential, a relatively brief heating duration, and the prevention of surface hardening. This leads to an enhanced quality of the final product (Łechtańska et al., 2015). Microwave drying is a common method for the drying of a variety of food products, such as fruits (Huang et al., 2022; Rodriguez et al., 2019; Taşova et al., 2023; Yildiz et al., 2023;), vegetables (Lapczynska-Kordon et al., 2019); Bi et al., 2023); Dursun et al., 2023) and meat (Kamiloğlu et al., 2023; Kipcak et al., 2021).

Mathematical modeling is important to extend the shelf life in fruit drying. Mathematical models are used to design and optimize industrial drying systems. (Brasiello et al., 2013). Mathematical models describe the drying process. Thin layer drying models can be grouped into theoretical, semi-theoretical and empirical models (Doymaz, 2012; McMinn, 2006). The literature review showed that studies have been done on the drying behavior of persimmon, (Cárcel et al., 2007; Tülek and Demiray, 2014), and even theoretical models for drying kinetics have been proposed, but no comprehensive study has been carried out, including energy, color analysis, and shrinkage. Drying models are important in the control of drying machines. There is a need for mathematical models that both save energy and ensure product quality. The objectives of this study were: To investigate the effect of microwave power and slice thickness on drying time, moisture, drying rate, shrinkage and rehydration rate, (b) to the experimental data to the mathematical model, (c) calculating the effective moisture diffusion, (d) power, (g) specific energy consumption and (e) color evaluations.

2. Materials and Methods

2.1. Raw Materials

The harvesting of persimmon was carried out in the Sakarya region of Turkey. Fruits with homogeneous characteristics (of the same size and color) were chosen, and distorted fruits are discarded. The weight of the persimmon fruit was 100 g on average, and the thickness was cut between 5 mm and 9 mm. Persimmon samples were selected to be uniform in size. The initial moisture content was approximately 73.8 (w.b) (± 2). After these preparations are completed, they will be subjected to drying. *Figure 1* shows the persimmon sample used in the experiment.

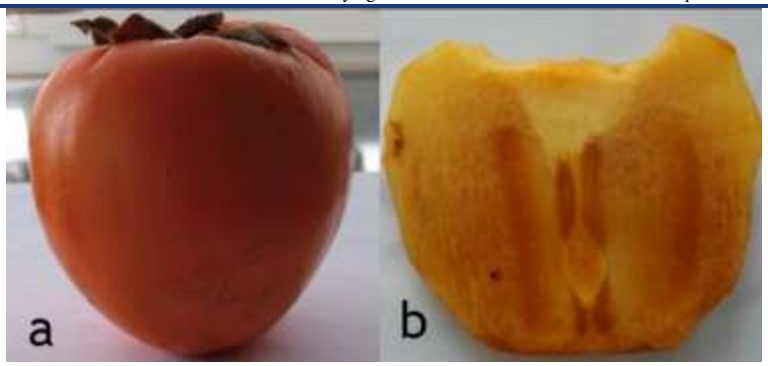

Figure 1. (a) All persimmon; (b) Internal see of the persimmon

Moisture measurements were conducted concurrently with the Sartorius MA30 device (Çelik et al., 2021). Persimmon samples were made at three different drying powers: 350 W, 460 W, and 600 W. In this study, persimmons (*Diospyros kaki*) with an initial moisture content of 73.8% (wetted base), an average length of 75 mm, an average width of 65 mm, and a thickness ranging between 5 and 9 mm were used.

2.2. Drying Processes

The experiments were performed using a precisely programmable microwave oven (Arçelik MD674 Microwave Oven). The microwave oven operates at 120, 350, 460, 540, 600, 700 and 900 W. The region of the microwave oven is 448 × 262 × 312 mm inner size. The samples were weighed manually throughout the drying process. The experiments were conducted in triplicate. See *Figure 2* for a schematic of the microwave drying procedure.

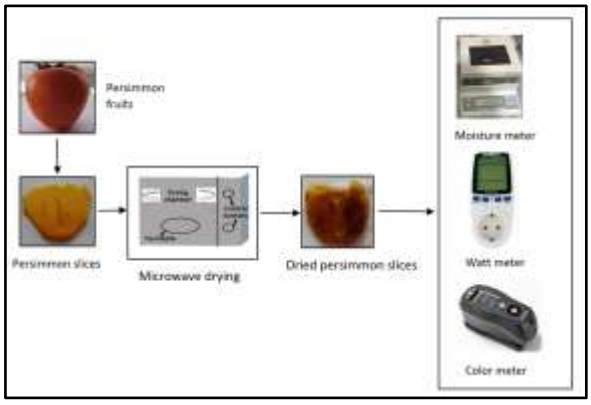

Figure 2. Microwave drying system cycle

Uncertainty analysis improves the precision of experiments used in modelling and design (Koç et al., 2008). Drying experiment discrepancies are usually due to measuring instruments, calibration, environmental conditions, observation and data interpretation (Koç et al., 2019). The general equation below expresses measurement uncertainty (Kaymak-Ertekin et al., 2005). The measurements were conducted with the following precision: ambient air temperature with an accuracy of ±0.2 °C, time ±0.1 minutes, mass ±0.05 grams, color ±0.01 nm, moisture content ±0.05 grams, and power ±0.02 kWh.

2.3. Mathematical Modeling of Hot Air Drying Kinetics

The moisture ratio (MR) for the persimmon was determined using the following equation, considering different microwave powers and thicknesses:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad \text{(Eq. 1)}$$

Here, M_t represents the moisture content (kg water kg^{-1} dry matter) at any given time t, while M_0 is the initial moisture content. M_e denotes the equilibrium moisture content, which remains constant during the hot air drying process (Karaaslan, 2014; Seremet et al., 2016; Zhao et al., 2021).

The drying rate (DR) of persimmon was calculated by the equation given below (Karaaslan, 2016);

$$DR = \frac{\Delta M}{\Delta t} = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad \text{(Eq. 2)}$$

Here, $M_{t+\Delta t}$ represents the moisture content at time t + Δt (kg water kg^{-1} dry matter), with Δt denoting the difference between the initial and final timescales. This study used experimental models to find the best way to define drying behavior (*Table 1*).

Table 1. Models used in modelling

Models	Model Equations	References
Lewis	$MR=exp(-kt)$	(Brooker et al., 1992)
Page	$MR=exp(-kt^n)$	(Hassan-Beygi et al., 2009)
Henderson and Pabis	$MR=a\ exp(-kt)$	(Ghodake et al., 2006)
Logarithmic	$MR=a\ exp(-kt)+b$	(Wang, 1978)
Midilli	$MR=a\ exp(-kt^n)+bt$	(Midilli et al., 2003)
Wang and Singh	$MR=a+bt+ct^2$	(Dağdeviren et al., 2023)

2.4. Effective Moisture Diffusivity

Efficient diffusion (D_{eff}) is considered a significant property of mass transfer along with the drying of agricultural products. The diffusion coefficient (D_{eff}) of persimmon was determined using Fick's second law, as represented by the following equation (Zhao et al., 2021):

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)}exp\left(\frac{-(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad \text{(Eq. 3)}$$

In this equation, L represents the half-thickness of the persimmon (m), t denotes the time required for air-drying (min), and n is an integer greater than or equal to 1.

Moreover, equation (3) was simplified to the following equation:

$$MR = \frac{8}{\pi^2}\left(e^{D_{eff}t\left(\frac{\pi}{2l}\right)^2}\right) \quad \text{(Eq. 4)}$$

The equation in its logarithmic form is as follows:

$$In(MR) = In\frac{8}{\pi^2} - D_{eff}\left(\frac{\pi}{2l}\right)^2 t \quad \text{(Eq. 5)}$$

2.5. Rehydration Ratio

The rehydration experiments were conducted by immersing approximately 25 grams of persimmon in 100 ml of purified water at ambient temperature for a 30-minute period. The examples were subjected to a process of removal, emptying and blotting in order to eliminate surface water, and were then subjected to a weighing procedure. The rehydration ratio (RR) was calculated using the equation from (Deng et al., 2008; Haneef et al., 2021; Jia et al., 2019).

$$RR = \frac{M_b}{M_a} \quad \text{(Eq. 6)}$$

The examples of the masses of the samples after and before rehydration(g), respectively, are labelled as M_b and M_a.

2.6. Shrinkage

The volume of persimmons was measured before and after drying using the toluene displacement technique (Dehghannya et al., 2019). The degree of shrinkage (S_b) of persimmon was calculated using the following equation, based on the measurement of primary and secondary volumes of material (Haneef et al., 2021; Kaveh et al., 2018; Miraei Ashtiani et al., 2018):

$$S_b = \frac{(\theta_o - \theta_f)}{\theta_o} \times 100 \quad \text{(Eq. 7)}$$

2.7. Power Consumption

Power consumption is calculated using the device output power and pass time. An overall calculation was conducted using the following formula:

$$P_t = P \times t \quad \text{(Eq. 8)}$$

Here, the variables are as follows: P_t represents power consumption, P denotes electronic output power (kW), and t is time (h) (Jia et al., 2019).

2.8. Energy Consumption Analysis

The specific energy consumed throughout the drying process, as defined by the equation (10), was calculated in order to represent the microwave drying method. This equation allows for the calculation of the amount of energy required to vaporize 1 kg of water from the crop (Jia et al., 2019; Taghinezhad et al., 2020):

$$SEC = \frac{P_t t}{m_w} \quad \text{(Eq. 9)}$$

The specific energy consumption (SEC) is represented by the microwave, and mw is mass of evaporated water (kg).

2.9. Color Evaluation

The color of persimmon samples was quantified using a tintometer. L*, a* and b* values are given for brightness, red, green and yellow. The L*, a*, and b* color parameters were measured for all samples. The hue angle (H°) represents the perceived color of a substance. The value in this instance was determined through the application of the following equation (Senadeera et al., 2020):

$$H = tan^{-1}\frac{b^*}{a^*} \quad \text{(Eq. 10)}$$

Furthermore, the browning index (BI) was determined in accordance with the formulary method described below(Karimi et al., 2021):

$$BI = \frac{100(x - 0.31)}{0.17} \quad \text{(Eq. 11)}$$

$$x = \frac{(a^* + 1.75\,L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad \text{(Eq. 12)}$$

A hue angle of over 90° yields green, while under 90° yields an orange-red.

Total color changes (ΔE) were computed using equation (13) (İlter et al., 2018; Kaveh et al., 2021):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2} \quad \text{(Eq. 13)}$$

In this equation, ΔL*, Δb*, and Δa* represent the differential values of the lightness, color parameter b, and color parameter a, respectively.

Chroma (C*) is a quantitative attribute that is used to quantify the colorfulness of a given hue. In order to ascertain the extent of the discrepancy between a specific hue and a grey color with an identical lightness, the C* value is utilized. C* is calculated using the following formula (Kayacan et al., 2020):

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad \text{(Eq. 14)}$$

3. Result and Discussion

The drying effect of persimmon with a microwave drying method at three different microwave power and two different thicknesses was investigated and compared with each other.

3.1. Drying Characteristics (Effect of microwave power and product thickness on drying time)

The initial moisture content of the persimmon samples used in the tests was between 73 and 75% and dried to 12% (w.b). *Figure 3* shows the moisture content variation of persimmon slices for different thicknesses during drying at various microwave powers.

Figure 3 demonstrates that an elevation in microwave power, coupled with a reduction in sample thickness, resulted in an accelerated rate of moisture loss. As the microwave power level was increased, a notable enhancement in the slope of the drying curve was observed during the initial time period of the process. Upon completion of the drying process, all curves demonstrated a proclivity towards flattening, indicative of a decline in the rate of moisture evaporation.

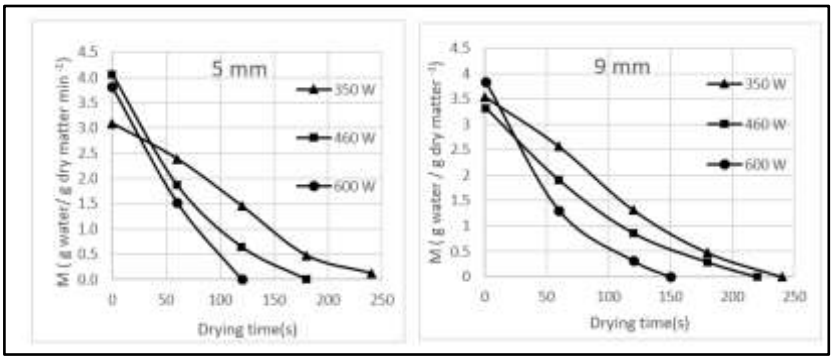

Figure 3. Moisture content (d.b) vs time a) for 5 mm thickness b) for 9 mm thickness

As the microwave power level increased, the drying time decreased in accordance with the expected relationship between these two variables. The maximum decrease in drying time was observed in the 5 mm thick persimmon samples, which showed a reduction of up to 50%. For 9 mm thick persimmon samples, the maximum decrease was found as 38 %. The mass and heat transfer are faster in higher microwave powers and thinner thicknesses. It is evident that elevated levels of power enhance both the kinetic energy and the energy absorbed, thus resulting in a greater disparity between the vapor pressures observed at the core and the external surface of the samples. This will, in turn, accelerate the rate of moisture elimination. Similarly Karaaslan (2014) observed a reduction in drying time as microwave power was increased.

Also, Jia et al. (2019) indicated that persimmon chips subjected to different drying air temperatures exhibited a notable influence on the evaporation and drying time. They showed that the moisture content decreased continuously until constant moisture content was reached. The drying rates of persimmon were evaluated at various time points, plotted against the moisture ratio for the second phase of the drying treatment, and illustrated in *Figure 4*.

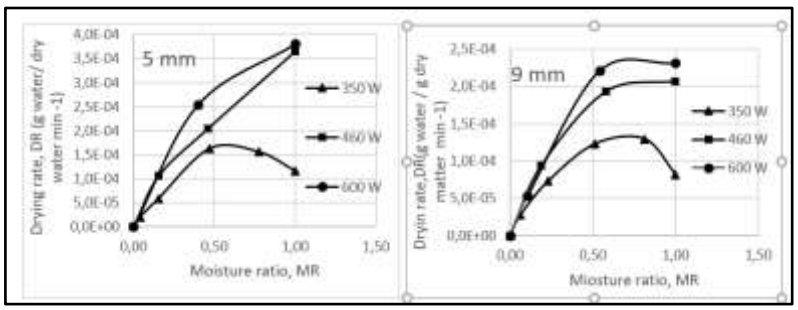

Figure 4. Drying rate vs Moisture ratio, a) for 5 mm thickness b) for 9 mm thickness at different microwave powers

Figure 4 shows the initial drying rate rises during drying. The samples' elevated moisture content causes them to absorb more energy at the surface. Moisture content and energy absorption decline, reducing drying rates. At a constant temperature, more microwave power means a faster drying rate, due to more energy being absorbed. The

maximum drying rate was observed at 600 W and 5-9 mm. The drying period exhibited a declining rate, which suggests that diffusion was the primary force influencing the removal of water. These results align with those of (Çelen, 2019). The drying rate was influenced by enhanced drying power, accelerated moisture loss and reduced drying time.

3.2. Mathematical Analysis of Drying Kinetics

A variety of mathematical models have been utilized in order to forecast the kinetic processes involved in the drying of agricultural products. The moisture content of the product is calculated through experimental means. Once the weight loss of the product has been determined over time, a graph is created based on the results of mathematical models. In the present study, a selection of six thin-layer models was made and adapted to the empirical data. The objective of this process was to determine the most suitable model for the purposes of the study. *Table 2* presents the results of the statistical analysis of the various models. The evaluation criteria that were used to ascertain each model's suitability are also included. As illustrated in *Table 2*, the values for the coefficient of determination (R^2), the root mean square error (RMSE), and the sum of squares due to error (SSE) are documented. The model that offers the optimal explanation of the thin-layer drying characteristics of whole persimmons was selected based on the criteria of achieving the highest possible R2 and the lowest possible RMSE and SSE. With regard to the complete experiments, the R^2, SSE, and RMSE data for the models exhibited values between 0.9901 and 0.998, 0.00027 and 0.00930, and 0.01671 and 0.9933, respectively. As demonstrated in *Table 3*, the logarithmic model exhibited the highest R^2 values and the lowest values of RMSE and SSE. However, it should be noted that the results of this study differ from those reported in the literature. The Midilli model has been demonstrated to be an appropriate fit for the empirical drying data of persimmon, as indicated by the findings of studies (Karaaslan, 2014; Doymaz, 2012; Sampaio et al., 2017). These findings are supported by the results of other empirical models.

Table 2. Statistical Comparison of Models for Thin-Layer Drying of Persimmon

Model	Thickness	R^2			X^2			RMSE		
		350 W	460 W	600 W	350 W	460 W	600 W	350 W	460 W	600 W
Lewis	5 mm	0.9538	0.9889	0.9718	0.04322	0.004782	0.01377	0.07858	0.03992	0.05867
	9 mm	0.9212	0.9107	0.998	0.04809	0.03918	0.00087	0.1096	0.1143	0.02097
Henderson and Pabis	5 mm	0.9491	0.9889	0.9733	0.04235	0.004764	0.01305	0.09204	0.04881	0.06596
	9 mm	0.9305	0.9142	0.948	0.04240	0.03764	0.00087	0.1189	0.1372	0.02955
Logarithmic	5 mm	0.9901	0.9908	0.9942	0.00930	0.008705	0.00454	0.04315	0.06597	0.0674
	9 mm	0.998	0.9994	0.9933	0.00028	0.000279	0.00379	0.01674	0.01671	0.9933
Page	5 mm	0.9972	0.9893	0.985	0.00192	0.004714	0.00734	0.01963	0.04855	0.04946
	9 mm	0.9988	0.9633	0.9927	0.00075	0.01609	0.00415	0.01591	0.08971	0.03721
Midilli	5 mm	0.9978	0.994	0.9852	0.00181	0.000876	0.00723	0.02459	0.0296	0.08503
	9 mm	0.9996	0.8707	0.9433	6.648e-05	0.05672	0.03802	0.00815	0.1375	0.06166
Wangh and Singh	5 mm	0.9871	0.9693	0.9846	0.0107	0.01782	0.00753	0.05172	0.09439	0.06137
	9 mm	0.9841	0.9911	0.9851	0.00486	0.00392	0.00422	0.04931	0.06261	0.04595

Senadeera et al. (2020) indicated that the Page model was the most appropriate for characterizing persimmon drying curves across a range of temperatures (45-65°C). The findings indicate that the Page and Midilli models can be employed, however, the logarithmic model is the most optimal among the models presented in *Table 2*.

3.3. Evolution of Effective Moisture Diffusivity

Effective moisture diffusion (D_{eff}) was calculated by slope method for different microwave power and different slice thicknesses. Effective diffusivity (D_{eff}) values were defined by Equation 4 and *Figure 5* shows effective diffusivity (D_{eff}) values.

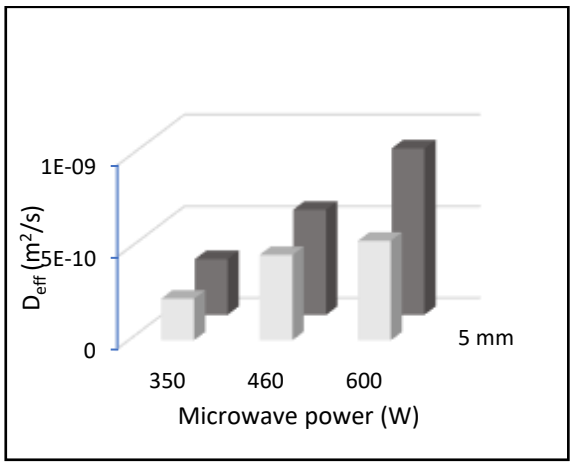

Figure 5. Effect of Microwave Power on Effective Moisture Diffusivity

Table 3. Comparison with results in the literature

Experiment conditions	Deff [m^2/s]	Reference
Convective dryer; 40,50 and 60 ˚C	**$7.05x10^{-11}$ to 2.34 x 10^{-10}**	(Doymaz, 2012)
Convective dryer; 55–75°C	9.24×10^{-10} and 10.40×10^{-10} (Blanched) **7.76×10^{-10} and 9.63×10^{-10} (Solution immersed)**	(Demiray and Tülek, 2017)
Freeze dryer; -55 ˚C	**2.57×10^{-12}**	(Dağdeviren et al. 2023)
Microwave drying; 120 W and 600W	**2.97×10^{-8} and 4.63×10^{-6}**	(Çelen, 2019)
Convective dryer 50, 55, and 60˚C	**1.04×10^{-6} , 1.40×10^{-6} , and 8.27×10^{-7}**	(Sampaio et al., 2017)

In the literature, the effective diffusivity coefficient is reported to range from 10^{-12} to 10^{-8} m²/s for food crops (Doymaz, 2012; Dağdeviren et al., 2023). *Figure 6* illustrates the rise in diffusion coefficients as the thickness of the persimmon slices is increased. It was noted that the D_{eff} values exhibited a marked increase with the elevation of slice thickness and microwave power. The application of a higher microwave power during the drying process resulted in an elevated level of heating energy, which in turn increased the activity of water molecules and consequently enhanced moisture diffusivity. Furthermore, persimmon slices with a thickness of 9mm had higher moisture diffusivity than 5mm across all microwave power levels. The thickness allows water to move towards the persimmon surface, increasing the effective moisture coefficient. The experiments demonstrated that the effective diffusion coefficients exhibited a dependence on both thickness and microwave power. The diffusion coefficients ranged between 2.26×10^{-10} and 9.07×10^{-9}. The findings were consistent with those in *Table 3*.

3.4. Rehydration Rate

The rehydration of dried products is a widely employed method for the evaluation of their quality. The data shows the changes in the samples during drying (Doymaz, 2012). Rehydration ratio values of persimmon calculated from Equation (6), are illustrated in *Figure 6*.

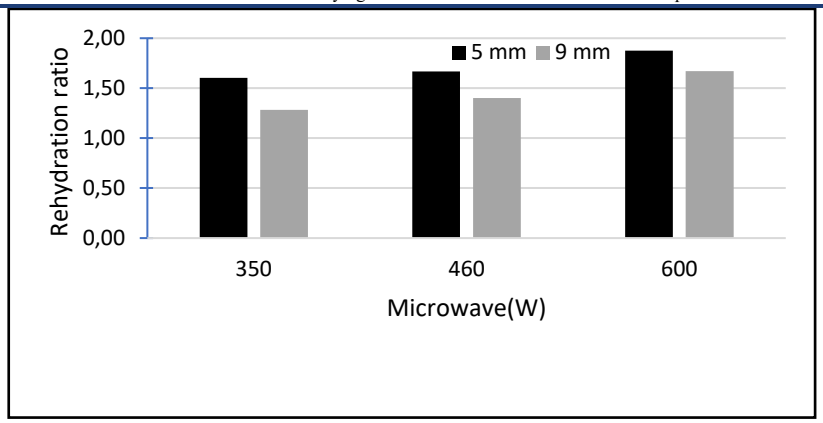

Figure 6. Rehydration graph for persimmon dried at 350, 460 and 600W

The rehydration rates of the 5 mm samples were higher than the 9 mm thick samples, which means that there is less structural damage and cell disruption during the drying process. The findings reported by Doymaz (2012); are comparable to , with rehydration ratios of persimmon reported to be between 2.3 and 3.1.

3.5. Shrinkage

Figure 7 illustrates the shrinkage percentage values for dried dates with varying strengths and two distinct thicknesses.

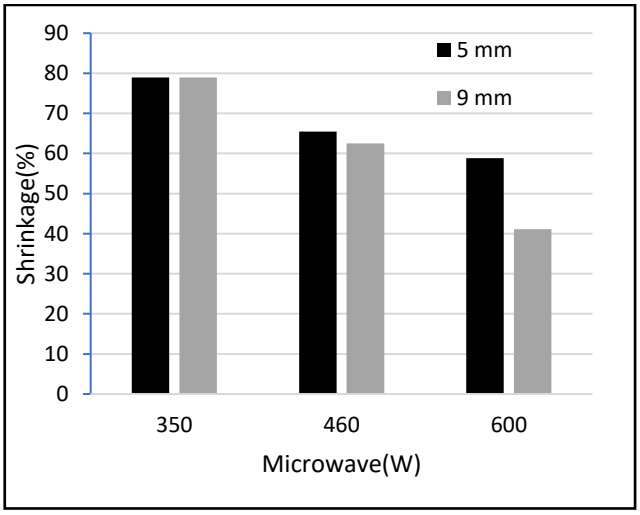

Figure 7. Shrinkage behavior of Persimmon samples

The shrinkage was observed to decrease at 5 and 9 mm slices with increasing drying power value. The lowest degree of shrinkage was observed at 600 W and a depth of 9 mm, while the highest degree of shrinkage was observed at 350 W and a depth of 5 and 9 mm.

3.6. Power

Energy consumption was measured with an energy counter. The graphic of persimmon power for microwave dryers is shown in *Figure 8*.

The energy consumption of a microwave oven was measured at different powers and slice thicknesses. At 5 mm, it was 0.05–0.23 kWh, at 9 mm, 0.05–0.46 kWh. 450 W and 9 mm may be the most energy-efficient. Çelen (2019), measured the system's energy consumption at 5 mm, 0.085 kWh; 7 mm, 0.1 kWh; and 9 mm, 0.09 kWh. Jia et al. 2019; said that persimmon chips were dried using a freeze-drying technique. Freeze-dried persimmon chips consumed 7-9 times more power than combined hot-air and hot-air microwave drying. The extended drying period necessitated by the freeze-drying process, which required approximately five times longer than that required

for the hot-air and combined hot-air-microwave methods, may have contributed to the result. The maintenance of a vacuum and low temperatures within the cold trap necessitated a greater input of energy.

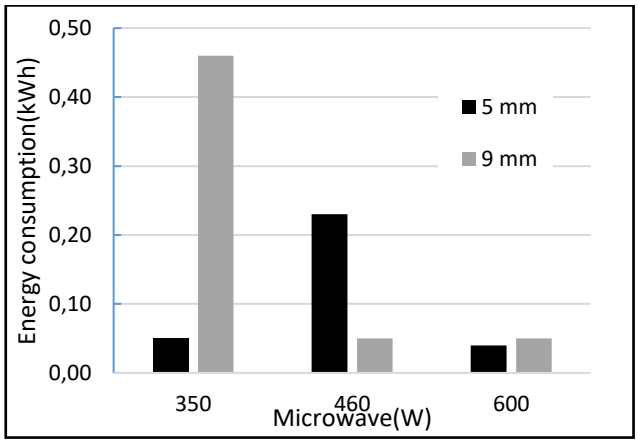

Figure 8. Energy consumption for drying of permission at different levels of microwave powers

3.7. Specific Energy Consumption (SEC)

Figure 9 demonstrates the values of the specific energy content (SEC) for two distinct persimmon slices (5 and 9 mm in thickness) subjected to microwave drying.

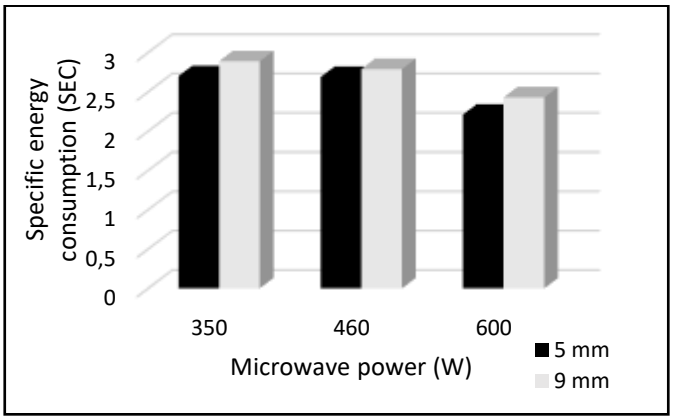

Figure 9. Specific energy consumption for microwave

This study found SEC ranged from 2.21 to 3.028 kWh/kg. *Figure 9* shows SEC declines with power. Kaveh et al. (2021) showed that drying pomegranate arils in a microwave dryer uses 35.42 kWh/kg at 270 W and 13.19 kWh/kg at 630 W. The ratio between the maximum and minimum values of SEC is 2.68. As MW power increases, SEC decreases significantly, reaching a value that is approximately three times less. The decrease in SEC is attributed to the impact of volumetrically heating, which reduces drying time. The reduction of drying times and the lowering of the specific energy consumption (SEC) are of significant importance in the process of improving microwave drying. Çelen 2019, reported that the maximum and minimum values of SEC were 14 and 28 MJ kg^{-1} at a microwave power range of 120–600 W.

3.8. Color

Food product color is important in marketing fresh and processed items, particularly in relation to quality. The microwave drying persimmon was determined for color changes depending on the time in the drying process. *Figure 10* shows the L*, a*, b* of dried persimmon for the microwave drying at different microwave power (350, 460, and 600W) and slice thickness. For the dried Persimmon, the lowest values of L*and b* were microwave power of 600 W but a* values are high.

Table 4. Comparative Colour Evaluation of Fresh and Dried Persimmon Samples

	Values						
Measured color values-5 mm	L*	a*	b*	C(Croma)	H(Hue)	ΔE	BI
Fresh	38.45	10.21	32.69	42.40	56.19		
350	37.80	10.39	21.24	23.78	50.71	31.23	73.59
460	33.50	10.92	15.80	19.27	52.34	19.66	79.02
600	31,15	11.17	16.03	19.70	50.49	21.19	86.00
Measured color values-9mm	L*	a*	b*	C(Croma)	H(Hue)	ΔE	BI
Fresh	43.15	13.20	34.85	37.27	69.26		
350	41.93	13.27	27.69	30.76	61.54	27.78	57.17
460	39.07	15.93	24.45	29.26	56.90	10.95	73.61
600	31,68	18.23	19.25	26.51	46.56	22.07	83.95

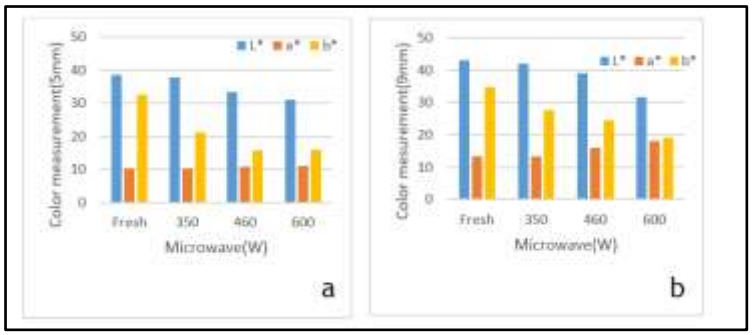

Figure 10. The color of persimmon, a) for 5 mm thickness b) for 9 mm thickness at different microwave powers

Çelen (2019) found that slice thickness has no effect on ΔL values. The impact of slice thickness on ΔE values was significant for samples sliced at 9 mm. The effects of microwave power levels on ΔL values were significant for samples dried at 600 W, while the effects on ΔE values were insignificant. The color alterations observed in the microwave power dryer are presented in *Table 4*.

The hue angle and total color variations from the Hunter values (L*, a*, and b*) provide a more nuanced representation of the color change in fresh and dried persimmons (Maskan, 2001). The optimal drying of persimmons is associated with minimal overall color change (ΔE), which plays a crucial factor in consumer approval (Senadeera et al., 2020). Moreover, the hue values of the dried samples differed from those of the fresh persimmons. Persimmon samples dried at 460 W with a thickness of 5 mm and at 350 W with a thickness of 9 mm showed a significant increase in hue angle values compared to other dried samples. The drying conditions notably influenced the total color differences of the dried samples. The lowest ΔE value was observed in the samples dried at 460 W, suggesting that the highest power (460 W) effectively preserved the natural color of fresh persimmon and minimized browning reactions during drying.

This result, which occurs in color change depending on the temperature, is also compatible with the general literature data. Yıldız Akbulut (2021) observed that in the microwave the L * (Brightness) value of Trabzon persimmon is increased. On the subject of a* (redness) and b* (yellowness) values, these values were observed to be decreased. Jia et al. (2024) observed a reduction in color with increased microwave power. The highest L* value and the lowest a*/b* value were observed at a power density level of 6.8 Wg^{-1}. Çelen (2019) observed a reduction in color change with increasing slice thickness. The lowest gloss and total color change were observed at 600 W and a slice thickness of 9 mm. The drying process results in oxidation, leading to a reduction in color intensity. Kaveh et al., (2021) indicated that the color changes in microwave dryers increased from 6.77 to 13.11 with the increase in microwave power from 270 to 630 W. Xu et al. (2020) emphasize that the alteration in pigment coloration can be attributed to the impact of elevated temperatures on heat-sensitive compounds, including

carbohydrates, proteins and vitamins. This phenomenon also leads to colour change during the drying process. Senadeera et al. (2020) report that no significant differences were observed in the L* values between fresh and all dried persimmon slabs. The a* values of the samples were found to be influenced by the drying conditions, specifically the temperature and time. With regard to the dehydrated samples, there was an increase in a* values following the drying process. No statistically significant differences were observed in the b* values of the dried persimmon slices. The dried samples exhibited distinct H° values in comparison to the fresh persimmon fruit. The persimmon samples that were dried at 65°C demonstrated a higher hue angle and ΔE values in comparison to the other dried samples. Kayacan et al. 2020 observed that the ΔE value of persimmon exhibited a range of 21.57 to 23.63, indicating a notable color change following hot air drying, with freeze-drying demonstrating a less pronounced effect. As power density increased, brightness decreased. Power density increases caused temperature and vapor pressure to rise. This was a consequence of the transfer of energy into the product.

4. Conclusions

This study examined the effects of microwave power and slice thickness on drying time, drying rate, shrinkage, color, and rehydration rate. A mathematical model was proposed, and diffusion coefficients and specific energy consumption values were calculated. The results of the experimental and theoretical study can be summarized as follows.

a) As expected, the 5 mm samples dried faster than the 9 mm ones. Drying time decreased with increased microwave power. 5 mm samples showed a higher rehydration ratio than 9 mm samples. Effective moisture values ranged from 9.08×10^{-10} to 2.27×10^{-10} $m^2 s^{-1}$, across tested power levels.

b) The drying process was not observed to occur at a constant drying rate; rather, it took place in a falling rate period

c) The Midilli model demonstrated the most accurate representation of drying data across all experimental conditions.

d) The 5 mm and 9 mm samples consumed between 0.05 and 0.23 kWh and 0.05 and 0.46 kWh, respectively. Thermodynamic analysis showed that increasing microwave power and sample thickness reduced specific energy consumption (SEC). The lowest and highest SEC values were 2.2 and 3.0 kWh/kg, and 10.5 and 25.9 MJ/kg of water, respectively.

e) The lowest shrinkage was at 600 W and 9 mm, while the highest was at 350 W and 9 mm.

f) The results of the color change indicate that a color change of 10.95 (ΔE) was observed in the samples with a 9 mm slice thickness at 460 W power. It was also observed that while the a* values are high at 600 W microwave power, the L* and b* values have the lowest values.

Ethical Statement

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

Conflicts of Interest

There is no conflict of interest between the article authors.

Authorship Contribution Statement

Concept: Parlak N., Çelik E., Design: Parlak N., Data Collection or Processing: Çelik E., Statistical Analyses: Parlak N., Literature Search: Çelik E., Writing, Review and Editing: Parlak N., Çelik E.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Developing A Field Test Method for Automatic Steering Systems

Otomatik Dümenleme Sistemleri için Bir Arazi Testi Yöntemi Geliştirme

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Abstract

Precision agriculture (PA) refers to planning and managing the processes from tillage to harvest using modern technology and techniques in order to increase the productivity of the cultivated crops. One of the most important components of PA equipment is the location determination and verification unit. Automatic steering systems, which have started to be included in developing agricultural machines, enable reaching the targeted locations with the least deviation from the determined route. These systems are provided accurately to navigate the fields, ensuring that crops are planted, fertilized, sprayed and harvested with precision. By reducing overlaps and skips in planting and other tasks, farmers can optimize their resources and maximize yields. The use of automatic steering systems in precision agriculture not only increases efficiency but also helps to minimize environmental impact by reducing the use of inputs such as fertilizer and pesticides. In this study, simple equipment that can be connected to the tractor's three-point linkage system was developed for pass-to-pass verification tests of the automatic steering systems in the field. For the field test, the narrowest and widest inter-row spacing that the automatic steering system was adjusted to have been taken into consideration. For the narrowest inter-row spacing, it was set to 3m; for the widest inter-row spacing, it was set to 18m. The automatic steering system was tested three times for each of the two different inter-row spacings. At the same time, the position information during the trial hours was compared with the records in the log files in the software part of the automatic steering system. Pass-to-pass tests were conducted based on ISO 12188-2:2012(EN) Tractors and Machinery for Agriculture and Forestry (Part 2). As a result of the evaluations, statistically significant difference wasn't found between the values obtained from the field trials with developed equipment and the results obtained from the log files of the automatic steering system. The results show that this developed equipment can be used practically in pass-to-pass tests in the field.

Keywords: Automatic steering system, Pass to pass test, Accuracy

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Öz

Hassas tarım (HT), yetiştirilen ürünün verimliliğini artırmak amacıyla modern teknoloji ve teknikler kullanarak ekimden hasada kadar olan gerçekleştirilen tarımsal işlemlerin planlanması ve yönetilmesi anlamına gelir. HT ekipmanlarının en önemli bileşenlerinden biri konum belirleme ve doğrulama birimidir. Gelişen tarım makinelerine dahil edilmeye başlanan otomatik dümenleme sistemleri, belirlenen rotadan en az sapma ile hedeflenen konumlara ulaşmayı sağlamaktadır. Bu sistemler, arazide doğru bir şekilde yönlendirme sağlamak için tasarlanmıştır ve yetiştirilecek ürünlerin hassas bir şekilde ekilmesini, gübrelenmesini, ilaçlanmasını ve hasat edilmesini amaçlamaktadır. Tarımsal faaliyetler sırasında aynı alanın tekrar işlenmesini veya işlenmeyen alanları azaltarak, çiftçilerin kaynaklarını optimize edebilir ve verimlerini artırabilirler. Otomatik dümenleme sistemlerinin hassas tarımda kullanımı sadece verimliliği artırmakla kalmaz, aynı zamanda gübre ve pestisit gibi girdilerin kullanımını azaltarak çevresel etkiyi de en aza indirir. Bu çalışmada, otomatik dümenleme sistemlerinin üst üste geçiş doğrulama testlerinin arazide yapılabilmesi için traktörün üç nokta askı düzenine bağlanabilen basit bir ekipman geliştirilmiştir. Arazide gerçekleştirilen test için otomatik dümenleme sisteminin ayarlanabildiği en dar ve en geniş sıra arası mesafeler göz önüne alınmıştır. En dar sıra arası mesafe için 3m; en geniş sıra arası mesafe için 18 m olarak otomatik dümenleme sistemi ayarlanmış; iki farklı sıra arası mesafe için üçer tekrarlı denemeler gerçekleştirilmiştir. Aynı zamanda, deneme saatleri boyunca konum bilgileri, otomatik yönlendirme sisteminin yazılım kısmındaki günlük dosyalarındaki kayıtlarla karşılaştırılmıştır. Üst üste geçiş testleri, ISO 12188-2:2012(EN) Tarım ve Orman için Traktörler ve Makineler (Bölüm 2) esas alınarak gerçekleştirilmiştir. Değerlendirmeler sonucunda, geliştirilen ekipmanla yapılan saha denemelerinden elde edilen değerler ile otomatik dümenleme sisteminin günlük kayıt dosyalarından elde edilen sonuçlar arasında istatistiksel olarak anlamlı bir fark bulunmamıştır. Sonuçlar, geliştirilen bu ekipmanın sahada üst üste geçiş testlerinde pratik olarak kullanılabileceğini göstermektedir.

Anahtar Kelimeler: Otomatik dümenleme sistemi, Üst üste geçiş testi, Doğruluk

1. Introduction

Precision Agriculture (PA) refers to planning and managing the processes from tillage to harvest using modern technology and techniques in order to increase the productivity of the grown product. PA technologies integrate control, electronics, computers, databases, and computational expertise to offer a sophisticated systems approach. Through the use of remote sensing technologies, geographic information systems, global positioning systems, and variable rate applications, PA technologies replace the traditional fixed-level application methods used across the field with a system that focuses on variable rate applications. This is accomplished by assessing soil and plant properties for much smaller portions of the field, such as soil moisture, plant nutrient levels, soil texture, crop conditions, yield, etc. The soil is tilled to varying depths, planting is done at varying norms, irrigation and drainage are applied at varying levels, and each portion receives the quantity of fertilizer or pesticide it requires. This approach, therefore, strives for more cost-effective and ecologically sustainable production (Özgüven and Türker, 2009).

One of the most important components of precision agriculture equipment is the location determination and verification unit. Automatic steering systems, which have started to be included in developing agricultural machines, enable reaching the targeted locations with the least deviation from the determined route. Effective using of agricultural inputs is possible with automated agricultural mechanization. With auto-steering tractors, rows can be tilled in parallel, and agricultural operations such as planting, fertilizing, and spraying can be performed more efficiently. These systems have been developing since the 1960s and it continues to evolve (Ming et. al., 2009). Li et al. (2019) introduced a cutting-edge navigation system designed for autonomous tracking of a guided vehicle, showcasing significant advancements in precision agriculture technology. The system comprises a master vehicle and a slave machine, working in tandem to execute autonomous navigation tasks effectively. The master vehicle can use an autopilot or be driven manually, while the slave vehicle adapts to its shape to carry out the navigational tasks automatically. A location unit, a steering controller, a wireless communication unit, and a vehicle terminal device make up the automatic navigation system, which uses a steering control method. The master-slave navigation system's vehicle terminal software is built to incorporate modules for controlling tracking, data connection, navigation, and positioning of agricultural machines. Experimental findings demonstrate reliable system performance and the ability of the slave to follow the master vehicle autonomously at a speed of 0.8 m s^{-1}.

Recent studies on automatic steering systems have noted improvements in response stability during critical time delays, increased time efficiency in headland turns, and reductions in lateral position deviations (Limpinski et al., 2016; Ye et al., 2020; Yang et al., 2022; Jing et al., 2023).

Automatic steering systems offer a multitude of benefits including reduced seed, fertilizer, and pesticide inputs, minimized machinery use, decreased operator stress, while enhancing work efficiency, fuel efficiency, and time management. Automatic guidance systems minimize stress and fatigue through permitting operators to focus on tasks outside steering (Burgers and Vanderwerff, 2022). Also, that is confirmed automatic steering systems provide many benefits and support the larger goal of agricultural production sustainability (D'Antonio et al., 2023). Topcueri et al., (2024) stated that automatic steering technology provides advantages in reducing differences in inter-row spacing between successive plants. Therefore, the automatic steering systems should be applied carefully with appropriate configurations to maximize advantages.

To provide these advantages, the system should have high operational accuracy in terms of overlapping or skipping. These values are supposed to be between 2-3 cm for automatic steering systems. Therefore, it is important to assess the system's performance, especially in field conditions together with tractor and equipment. Standard tests are available, especially for the global positioning systems (GPS), global navigation satellite system (GNSS), real-time kinematic (RTK), or real time extended (RTX) for positional accuracy at concrete or asphalt track level (ISO 12188-2:2012).

Point Test (Static test - Source of GNNS, GPS or RTK, RTX), Line Test and Pass to Pass Accuracy Test are carried out to assess the accuracy of automatic steering systems. The tests based on ISO 12188-2:2015 standard for testing the accuracy of automatic steering systems and deviation amounts claimed by the company are carried out on hard ground (asphalt, road, etc) and when any equipment is attached to the tractor. In addition to other tests in the standards, the tractor is tested according to the Reference Point (RVP) along the direction (XTE test) (during

these tests no forces appear). However, when determining these deviations, the compatibility of the tractor equipment combination in the field cannot be taken into account, especially during these tests and operations, lateral forces caused by the equipment behind, especially soil machines, can cause deviations in the tractor route, especially in the XTE line. This situation can reveal situations that the farmer can only realize after the operations and negatively affect his operations. If the first XTE line is not created properly, deviations that cause this skip or overlapping can occur in the next turn. In order to avoid these situations, especially to make quick adjustments in the field, to correct negative situations, this apparatus will allow the farmer to quickly see the deviation of the tractor equipment combination from the XTE line (in the first line) and it will be possible to correct this situation and adjust the settings at the beginning of the job. Therefore, this system is not an alternative to the tests of steering systems, but it has been developed only to provide additional support for the detection of deviations from the first straight line created in the field operation, which will also ensure the control of tractor and equipment compatibility.

Based on this idea, an apparatus unit has been developed in this study that contributes to the testing method of an automatic steering system that can be used in field trials. This apparatus was developed to practically determine the relative cross-track error (XTE) value in the field. An application of a method for determining the XTE value has been carried out.

2. Materials and Methods

2.1. Automatic steering system

The automatic steering system consists of a display screen, a receiving antenna that receives signals from the RTK-based CORS TUSAGA active system, a motorized steering wheel, and an angle sensor (*Figure 1*). The manufacturer states that the system's accuracy is ± 2 cm. The basic technical specifications of the system are provided in *Table 1*.

Table 1. Technical specifications of the tested automatic steering system

Constellations	GPS, GLONASS, Galileo, Beidou and QZSS
Ingress Protection	IP 67
Communication	Bluetooth, Wi-fi
Receiver	GNSS
Accuracy	± 2 cm
Screen width	25.6 cm
Steering	Electrical
Other features	Support for external camera Land registration Transaction path recording Ability to work with a SIM card Connection with RTK stations Possibility of remote control

2.2. Specification of test conditions

The automatic steering system was mounted on a 4WD agricultural tractor equipped with a 93 kW diesel engine. During the field trials, the tractor's forward speed was adjusted and maintained at a constant 2 m s^{-1}. The trial field was located Ankara, Kahramankazan province (40°04'23.3"N, 32°37'46.0"E) with a total area of 2 ha. The field surface was covered with stubble, and the slope ranged between 3–5%. The automatic steering system was tested on two selected working widths; 3 m referencing a tillage machine and 18 m referencing a sprayer.

2.3. Test procedure of automatic steering system

The field pass-to-pass tests were conducted in accordance with ISO 12188-2:2012(EN) Tractors and Machinery for Agriculture and Forestry (Part 2). Before the test, all elements of the automatic guidance system were properly installed. All settings were reset to factory defaults. The tests were carried out using correction signals provided by RTK TUSAGA. The reference line was established one hour before the first test. For a given rate of advance, each test was performed three times for two consecutive days with different arrays of GNSS satellites. The start time of each

test sequence was randomly assigned. The automated guided vehicle system was allowed at least 10 seconds in equilibrium operation before entering each designated test area. To ensure variability in GNSS positioning quality, consecutive test runs were spaced more than one hour apart. More than a 24-hour time period was allowed between the first and last test.

Figure 1. Automatic steering system used for trial (a: antenna, b: motorized steering wheel, c: display screen, d: angle sensor)

2.4. Designed apparatus for testing automatic steering systems

An apparatus was designed within the frame to determine the lines that are referencing the tractor's middle axis when the automatic steering system is working. The frame is manufactured according to the dimensions of the three-point linkage system (TS ISO 730, 2021) and then connected to the three-point linkage system. At the bottom of the frame, a plate was welded to the frame as its hole axis coincided with the center axis of the tractor. After the designed apparatus was connected to the tractor's three-point linkage, the arms that adjust the looseness of the lower links were tightened to minimize the sway of the tractor's three-point linkage lower links. Representative vehicle point (RVP) was created by aligning the centers of the holes that tractor drawbar and the plate included in the designed apparatus. *Figure 2* and *3* contain images from preliminary tests explaining the attachment of the designed apparatus to the tractor and the measurement method.

In the center of this frame, there was also a shaft with a roller on it. The first point was to assess the projection of the hole on the tractor drawbar line on the ground. When the tractor moves during the tests the pulley rotates and the rope on it determines the line followed by the tractor center axis. The second line was created by assigning the agricultural equipment width from the menu of the automatic steering system. Using tape measures, the distance intervals to be measured on the line were determined with the line starting points as reference. Subsequently, the distance of the two lines from each other was measured at the determined intervals (*Figure 3*).

Figure 2. Developed apparatus for automatic steering system testing

Figure 3. Measuring the width of lines for XTE test

The visuals related to the measurements of the designed apparatus and measurement method conducted in the field trials are provided in *Figure 4*.

Figure 4. Field experiments of designed apparatus

2.5. Determining lines from automatic steering system log files

In this method, the location data in the automatic steering system's log file was processed on the Google Earth program. The horizontal distance between the two lines was measured at intervals determined according to the reference point (*Figure 5*). Measurement values that are more than the set equipment width are called skip; values that are narrower than the set equipment width is called overlap. Overlap or skip conditions were determined according to the distance value between the lines determined in the automatic steering interface.

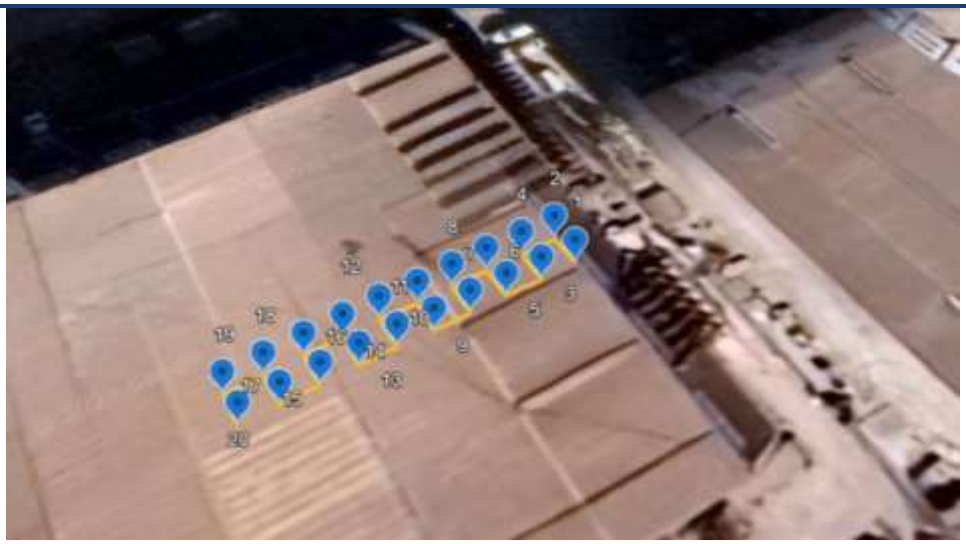

Figure 5. Determining line widths from log file

Measurements were taken every five meters to determine the relative cross-track error (XTE) values of parallel lines to compare both methods in this regard. Thus, deviations (overlap, skip) that could occur along the direction of movement were identified. The values obtained from the two different methods were compared with the results recorded in log files and field measurements.

2.6. Statistical analysis method of values

In terms of interval distance measurements taken every 5 m, whether there is a statistically significant difference between the values obtained from the memory of the automatic steering system and the developed method was determined using an independent samples t-test. Statistical analyses were performed using the MINITAB 16 software package.

3. Results

The work width of three meters in the table represents the working condition with a tillage implement and the work width of eighteen meters represents the working condition with a sprayer. The overlap or skip conditions can impact the efficiency and effectiveness of the equipment, as well as the overall quality of the work being done. It is important to monitor and adjust these settings to ensure optimal performance in the field. *Table 2* shows the measured distance of lines in the developed method column and calculated values from the automatic steering system log files column.

The values greater than 3000 and 18000 mm in the *Table 2* can be considered as overlap, while the values less than 3000 and 18000 mm can be considered as skip. This categorization helps define the dataset's values and understand the existing patterns. It can help in making preliminary assessments based on the values falling within these ranges. When the *Table 2* was examined, although one method was marked as overlap and the other as skip, it was observed that there were differences at the boundary of the ±20 mm error margin of the automatic steering system. Descriptive statistics related to the methods are provided in *Table 3*.

The differences between the values obtained from the memory unit of the automatic steering system and the measurements made using the developed method, both for the 3 m and 18 m row spacing distances, were not found to be statistically significant ($p>0.05$). Therefore, it can be said that both measurement methods yield the same results. Graphs showing the confidence intervals for both methods at 3 m and 18 m working widths are provided in *Figure 6* and *7*.

These values are also the narrowest and widest inter-row distances defined in the interface of the automatic steering system used to test the developed method. Additionally, the statistical analysis of measurements confirmed that there was no significant difference between the methods tested for both working widths. This suggests that the developed method can be confidently applied in practical field settings.

Table 2. Measured working width values during field tests

Working width values					
3m			18m		
Distance from reference point (m)	Developed Method (mm)	Log Files (mm)	Distance from reference point (m)	Developed Method (mm)	Log Files (mm)
5	2995	3003	5	17994	18003
5	3005	2998	5	18005	17997
5	3001	3007	5	18001	18007
10	3007	3000	10	18007	18000
10	3000	3004	10	18000	18004
10	3003	2999	10	18004	17998
15	2994	3002	15	17994	18002
15	3002	2998	15	18002	17998
15	3003	3007	15	18003	18007
20	3006	3001	20	18006	18001
20	3000	3004	20	18000	18004
20	3002	2999	20	18004	17999
25	2996	3004	25	17996	18004
25	3004	2999	25	18004	17999
25	3002	3008	25	18002	18008
30	3008	3002	30	18010	18002
30	3001	3005	30	18001	18005
30	3005	2999	30	18005	17997

Table 3. Descriptive statistics of methods

	Working width values					
	3 m			18 m		
Methods	**Mean±SEM[1]**	**Min**	**Max**	**Mean±SEM[1]**	**Min**	**Max**
Developed Method	3001.9±0.921	2994	3008	18002±1.01	17994	18010
Log files	3002.2±0.768	2998	3008	18002±0.834	17997	18008

[1]SEM: Standard error of mean

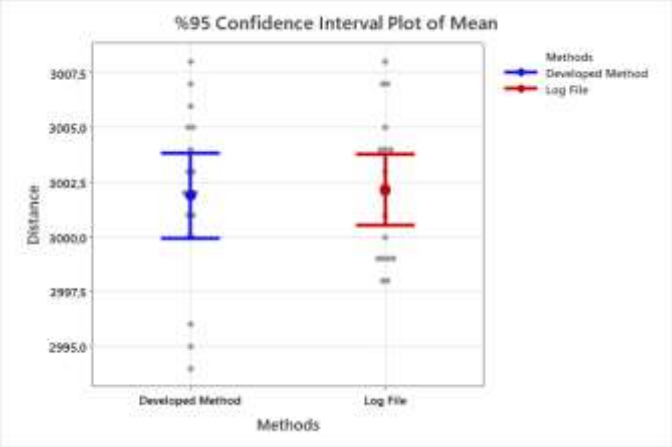

Figure 6. Confidence intervals for 3 m working width

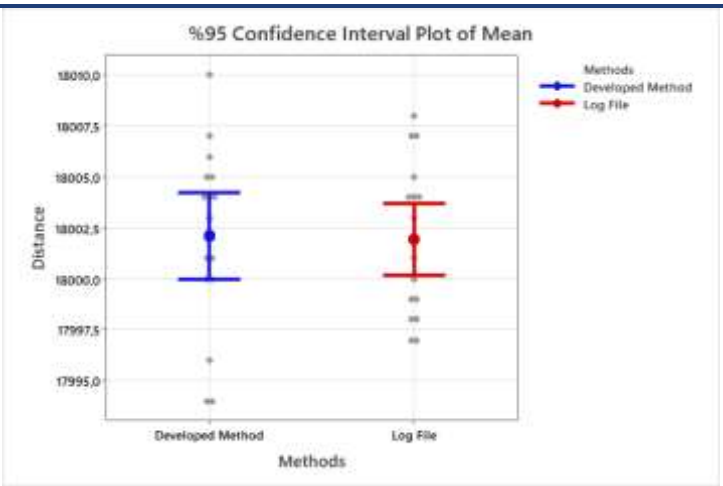

Figure 7. Confidence intervals for 18 m working width

4. Conclusions

This research introduced a novel method for assessing the accuracy and reliability of automatic steering systems in field trials. The method utilizes a specially designed apparatus.

When the values obtained during the field tests were compared, the difference between the methods was not found to be statistically significant. When looking at the study's results, the findings indicated that the equipment developed for testing automatic steering systems in the field gave results that were similar to the XTE tests done with the classical method for the smallest and largest row spacing distances of the automatic steering system that was used as the material. With this developed device, it is aimed to further develop the automatic steering system in the future in order to control the maintenance of the distance between the rows in the field after the normal standard tests. Especially tractors working with soil machines may cause the tractor to deviate from the working direction under the effect of lateral forces in the field. Since these deviations of the systems take a certain period of time, these deviations take effect and may cause the lines not to be formed properly in the next turn. In order to evaluate the reactions of a tractor equipped with an automatic steering system to the lateral forces it may encounter while working with soil machines, it is aimed to modify the designed device in the ongoing studies and use it together with soil tillage equipment.

With the designed apparatus and measurement method, it is aimed to practically perform the calibration and validation of the automatic steering system's XTE test under field conditions. Processing the position data obtained from the memory of automatic steering systems in a computer environment requires qualified operators and/or personnel. Therefore, this method has been developed to enable farmers and/or operators to perform practical control in the field. In the following studies, the apparatus developed will be suitable for working with tractors and equipment in the field. For future work, researchers aim to integrate to verify the reliability and sensitivity of the developed testing method using advanced technologies such as cameras and drones.

Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Eminoglu M.B., Türker., U.; Design: Türker, U., Eminoğlu, M.B.; Data Collection or Processing: Eminoglu M.B., Yegül, U., Türker., U.; Statistical Analyses: Eminoglu M.B.; Literature Search: Yegül, U., Eminoglu M.B.; Writing, Review and Editing: Eminoglu M.B., Yegül, U., Türker., U.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Combined Genotype Effects of PRLR and GH Polymorphisms on Litter Weight in Kilis Goats*

Kilis Keçilerinde PRLR ve GH Polimorfizmlerinin Kombine Genotip Etkilerinin Döl Ağırlığı Üzerine Etkisi

Zühal GÜNDÜZ[1*]

Abstract

This study investigates the relationship between polymorphisms in the PRLR, GH1, and GH2 genes and their impact on litter weight in Kilis goats, a native breed of significant economic importance in Türkiye. Within the scope of the research, a total of 198 goats were used under breeder conditions in Kilis Province. This study was conducted as part of the National Small Ruminant Breeding Project, coordinated by the Ministry of Agriculture and Forestry of the Republic of Türkiye and implemented by the General Directorate of Agricultural Research and Policies (TAGEM). Allele frequencies for the PRLR/RsaI, GH1/HaeIII, and GH2/HaeIII loci were analyzed, revealing that the C allele at PRLR/RsaI and the D allele at GH2/HaeIII were the most prevalent in this population. While no significant differences in litter weight were observed among PRLR genotypes ($P > 0.05$), significant associations were identified between the GH1 and GH2 loci and litter weight ($P \leq 0.05$). Specifically, Kilis goats with the AB genotype at GH1 and the CD genotype at GH2 exhibited significantly higher litter weights compared to other genotypes, highlight the potential influence of these genetic variations on reproductive performance. Furthermore, significant genotype interactions were observed, with the highest litter weight recorded in goats carrying the AB-CD genotype combination (7.613 ± 2.973 kg). These findings suggest that genetic variations at the GH1 and GH2 loci play a critical role in determining reproductive traits such as litter weight. Strategic breeding programs targeting these loci could enhance productivity in Kilis goats. Given the economic significance of litter weight in livestock production, these results provide a foundation for further research into the genetic basis of reproduction traits in goats. Additional studies across diverse breeds and environmental conditions are necessary to validate these findings and explore the broader implications for genetic selection in livestock breeding.

Keywords: Kilis goats, Litter weight, Polymorphism, Prolactin receptor, Growth hormone

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*This study was summarized from Zühal GÜNDÜZ's PhD thesis.

Öz

Bu çalışma, Türkiye'nin ekonomik açıdan önemli yerli ırklarından biri olan Kilis keçilerinde PRLR, GH1 ve GH2 genlerindeki polimorfizmler ile döl ağırlığı arasındaki ilişkiyi incelemeyi amaçlamaktadır. Araştırma kapsamında, Kilis ilinde yetiştirici koşullarında T.C. Tarım ve Orman Bakanlığı koordinatörlüğünde Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü (TAGEM) tarafından yürütülen Halk Elinde Küçükbaş Hayvan Islahı Ülkesel Projesi kapsamında elde edilen toplam 198 baş keçi kullanılmıştır. Bu hayvanlarda PRLR/RsaI, GH1/HaeIII ve GH2/HaeIII lokuslarına ait allel ve genotip frekansları hesaplanmış ve popülasyonun genetik yapısı analiz edilmiştir. Analiz sonuçları, PRLR/RsaI lokusunda C alelinin ve GH2/HaeIII lokusunda D alelinin popülasyonda en yaygın aleller olduğunu göstermiştir. PRLR genotipleri ile döl ağırlığı arasında anlamlı bir fark bulunmazken ($P > 0.05$), GH1ve GH2 lokuslarının döl ağırlığı üzerinde istatistiksel olarak önemli etkiler gösterdiği belirlenmiştir ($P \leq 0.05$). Özellikle, GH1 lokusunda AB genotipine ve GH2 lokusunda CD genotipine sahip Kilis keçilerinin, diğer genotiplere kıyasla istatistiksel olarak daha yüksek döl ağırlığına sahip olduğu tespit edilmiştir. Ayrıca, genotip kombinasyonları arasındaki etkileşimler incelenmiş ve AB-CD genotip kombinasyonuna sahip bireylerde en yüksek döl ağırlığı gözlenmiştir (7.613 ± 2.973 kg). Bu bulgular, GH1 ve GH2 lokuslarındaki genetik varyasyonların, Kilis keçilerinde döl ağırlığı gibi önemli üreme özelliklerinin belirlenmesinde kritik bir rol oynadığını ortaya koymaktadır. Ayrıca, bu genlerin stratejik olarak kullanılacağı genetik ıslah programlarının, Kilis keçilerinin ekonomik değerini artırma potansiyeline sahip olduğu vurgulanmıştır. Döl ağırlığının hayvansal üretimdeki ekonomik önemi göz önüne alındığında, bu çalışma, keçilerde üreme özelliklerinin genetik temellerine dair daha kapsamlı araştırmalar için bir temel oluşturmaktadır. Farklı ırklar ve çevresel koşullar altında yapılacak sonraki çalışmalar, bu bulguların doğrulanması ve genetik seleksiyonun etkilerinin daha detaylı incelenmesi açısından büyük önem taşımaktadır.

Anahtar Kelimeler: Kilis keçisi, Döl ağırlığı, Polimorfizm, Prolaktin reseptör, Büyüme hormonu

1. Introduction

With global distribution, goats are a vital livestock species, particularly in developing nations. They provide essential products such as meat, milk and fiber, which are crucial for communities living in arid and semi-arid regions (Gündüz and Biçer, 2023; Gül et al., 2018; Keskin et al., 2017). Goat farming in arid and semi-arid areas such as Türkiye requires a lower initial investment compared to other large livestock species. Their adaptability to harsh climatic conditions and remarkable resilience makes them an ideal choice for such ecosystems.

In Türkiye, goat farming plays a significant role in the agricultural economy, with an estimated population of approximately 10.3 million goats, as reported by the TUIK (Anonymous, 2023). Among the indigenous breeds, the Kilis goat is particularly significant due to its unique genetic identity, which has resulted from historical uncontrolled crossbreeding between Damascus and Hair goat populations (Karaköse, 2024; Gündüz and Biçer, 2023; Gül et al., 2020; Keskin et al., 2017). Well-adapted to the arid and semi-arid regions of Türkiye, the Kilis goat is renowned for its exceptional milk production and reproductive efficiency. Consequently, this breed offers promising opportunities for dairy farming and genetic improvement programs in the country. Moreover, previous studies have demonstrated that a combination of genetic and environmental factors—including age, lactation stage, parity, and management practices—significantly influences the reproductive and milk production traits of goats (Gündüz and Biçer, 2023; Daşkıran et al., 2022; Gül et al., 2022; Tilki and Keskin, 2021; Özdemir and Keskin, 2018; Keskin et al., 2016). These findings emphasizes the importance of genetic research in identifying valuable markers for improving goat productivity. Furthermore, investigating gene variations in native breeds through molecular markers is essential for preserving genetic diversity and developing sustainable utilization and improvement strategies (Togan et al., 2005).

Litter weight is a crucial trait in animal breeding, as it directly influences economic efficiency, reproductive performance, and offspring survival. Higher litter weights at birth and weaning are associated with increased neonatal viability, improved growth rates, and enhanced genetic selection for superior reproductive efficiency (Cobo et al., 2021). In pigs, greater litter weight correlates with higher weaning weights and reduced pre-weaning mortality, making it a key selection criterion for commercial breeding programs (Kiszlinger et al., 2015). Similarly, in sheep, genetic evaluations indicate that litter weight exhibits moderate heritability, making it a viable trait for improvement through selective breeding (Cobo et al., 2021). The ability to select for high litter weight using marker-assisted selection and genetic evaluation tools offers a powerful mechanism for improving herd efficiency, sustainability, and profitability in commercial livestock production.

Studies examining polymorphisms in the prolactin receptor (PRLR) and growth hormone (GH) genes suggest a significant impact on litter weight, primarily mediated by their effects on litter size, fetal growth, and milk production. PRLR is particularly relevant in swine and goats, where specific allelic variants are associated with higher litter weights and improved reproductive performance. For instance, research on Minpig and Landrace sows identified a Nae I polymorphism in PRLR, where sows with the BB genotype exhibited significantly higher litter weights at birth and greater piglet uniformity at weaning (Hu and Wang, 2006). Similarly, a study on Large White pigs revealed multiple single nucleotide polymorphisms (SNPs) in exon 10 of PRLR that correlated with an increased total number born and number born alive, ultimately leading to increased litter weight (Wu et al., 2023). Research on Mangalica pigs indicated that the AA genotype of the PRLR gene was associated with an increase of 1.11 piglets per litter compared to the BB genotype, suggesting a direct effect on litter weight (Tempfli et al., 2011). In goats, a specific single nucleotide polymorphism identified as g.173057T>C in PRLR was found to modify microRNA (miRNA) binding, thereby influencing PRLR expression and litter size (An et al., 2015). Regarding GH gene polymorphisms, although the literature on their direct influence on litter weight is limited, GH plays a crucial role in fetal growth, metabolic regulation, and milk yield, which indirectly affects litter weight (Hua et al., 2009). GH gene polymorphisms have been associated with improved growth traits and reproductive efficiency, suggesting that the selection of specific GH alleles may enhance PRLR-related improvements in litter weight.

The objective of this study was to identify polymorphisms in the PRLR and GH genes using restriction fragment length polymorphism (RFLP) analysis. Furthermore, the study aimed to investigate the potential association between the PRLR and GH genes, as well as their combined genotypes, and litter weight in Kilis goats.

This research enhances our understanding of the genetic mechanisms that influence litter weight and offers valuable insights for genetic selection programs aimed at improving reproductive efficiency in goats.

2. Materials and Methods

2.1. Procedure for Animal Selection and DNA Sampling Process

A total of 198 unrelated Kilis goats were obtained from the National Breeding Project for Kilis Goats, conducted under farm conditions. This project was support from by the General Directorate of Agricultural Research and Policy (TAGEM), under the Ministry of Agriculture and Forestry of the Republic of Türkiye and implemented in Kilis province. The study was conducted in accordance with the approval granted by the Hatay Mustafa Kemal University, the Animal Experiments Local Ethics Committee (approval date: 29/09/2016; approval number: 2016/8-1). Goats were selected from the 2nd and 3rd kidding season, matched for body weight at mating, and raised under identical management and feeding conditions. Approximately 9 mL of blood was collected from the jugular vein of each dairy goat using EDTA-coated vacutainer tubes (BD Vacutainer Systems, Plymouth, UK). Genomic DNA was extracted from white blood cells utilizing the high-salt technique described by Miller et al. (1988) and stored at -20°C for subsequent analysis.

2.2. PCR Reactions and Genotyping

For the targeted amplification of the PRLR, GH1, and GH2 genes, two sets of primers were designed specifically for this study. The nucleotide sequences of the primers and the fragment sizes of the PCR products are presented in *Table 1*.

Table 1. Primer sequences of target genes and PCR product sizes

Primers	Primer sequence	Gene Bank ID	Region	Product size
PRLR_F	5'-AGTGAGAGTTATGGAAGGATG-3'	KJ572972.1	3' UTR	443 bp
PRLR_R	5'-AAGGTTAAGCAACTGGTCTT-3'			
GH1_F	5'-CTCTGCCTGCCCTGGACT-3'	D00476.1	exon 2, intron 2, exon 3	422 bp
GH1_R	5'-GGAGAAGCAGAAGGCAACC-3'			
GH2_F	5'-TCAGCAGAGTCTTCACCA AC-3	D00476.1	exon 4	116 bp
GH2_R	5'-CAACAACGCCATCCTCAC-3'			

To amplify the target genes, PCR was performed using specific primers for PRLR, GH1, and GH2. The reaction mixture consisted of 1X PCR buffer, 2 mM $MgCl_2$, 200 µM of each deoxynucleotide triphosphate (dNTP), 1 µM of each forward and reverse primer, 1 unit of Taq DNA polymerase (Thermo Scientific, USA), and approximately 100 ng of genomic DNA in a total volume of 30 µL. PCR amplification was initiated with an initial denaturation step at 95°C for 5 minutes. This was followed by a specific number of cycles for each gene, consisting of denaturation at 94°C for 40 seconds, annealing at the optimal temperature (51.4°C for PRLR, 54°C for GH1, and 63°C for GH2) for 40 seconds, and extension at 72°C for 1 minute. A final extension step at 72°C for 5 minutes was included to ensure complete extension of the PCR products. PCR amplification was conducted using a Bio-Rad C1000 Touch™ Thermal Cycler. The PCR products of the PRLR and GH genes, 30 µL aliquots were digested with 10 units of RsaI (for PRLR) and HaeIII (for GH1 and GH2) restriction enzymes (Thermo Scientific, USA) for 2 hours at 37°C, following the manufacturer's protocol. The resulting restriction fragments were subsequently separated on a 2% agarose gel and visualized under ultraviolet (UV) light after being stained with ethidium bromide.

2.3. Statistical Analysis

The experimental animal population consisted of goats in their 2nd and 3rd parity. Additive correction factors were calculated using a general linear model to account for systematic variations due to parity and farm origin effects, ensuring a more accurate comparison across groups. Allelic and genotypic frequencies, and deviations from Hardy-Weinberg Equilibrium (HWE), were computed using GenAlex 6.5 (Peakall and Smouse, 2012) and PopGene 32 (Yeh et al., 2000) software packages. To examine the association between animal genotypes and litter weight, statistical analyses (Eq. 1) were performed using SPSS software (Kinnear and Gray, 1999). The following linear model was applied:

$$y_{ij} = \mu + a_i + e_{ij} \quad \text{(Eq. 1).}$$

Yij is the observed litter weight of the i j-th animal,
μ represents the overall population mean,
αi denotes the fixed effect of the ii-th genotype,
eij represents the random error associated with each observation.

3. Results and Discussion

3.1. Genotyping

Following the digestion of the goat PRLR gene with the RsaI restriction enzyme, the genotypes CC (383 bp, 60 bp), CT (443 bp, 383 bp, 60 bp), and TT (443 bp) were identified, using the GeneRuler 50 bp DNA Ladder (Thermo Scientific) as a reference (Hou et al., 2014). However, visualizing the 60 bp fragment on a 2% agarose gel posed a significant challenge. In contrast, the larger fragments, measuring 443 bp and 383 bp, displayed strong clarity, enabling reliable differentiation between the genotypes.

The digestion of the goat GH1 and GH2 genes with the HaeIII restriction enzyme revealed distinct genotypic patterns, using GeneRuler DNA Ladders (Thermo Scientific) as references. For the GH1 gene, the identified genotypes were AA (366 bp, 56 bp), AB (422 bp, 366 bp, 56 bp), and BB (422 bp). For the GH2 gene, the observed genotypes were CC (88 bp, 28 bp), CD (116 bp, 88 bp, 28 bp), and DD (116 bp) (Hua et al., 2009). In both cases, the smallest fragments—56 bp for GH1 and 28 bp for GH2—were difficult to resolve on a 2% agarose gel, rendering some fragments indistinguishable during visual inspection. Despite these limitations, the larger fragments—422 bp and 366 bp for GH1, and 116 bp and 88 bp for GH2—were clearly visible, enabling for accurate differentiation of the genotypes (*Figure 1*).

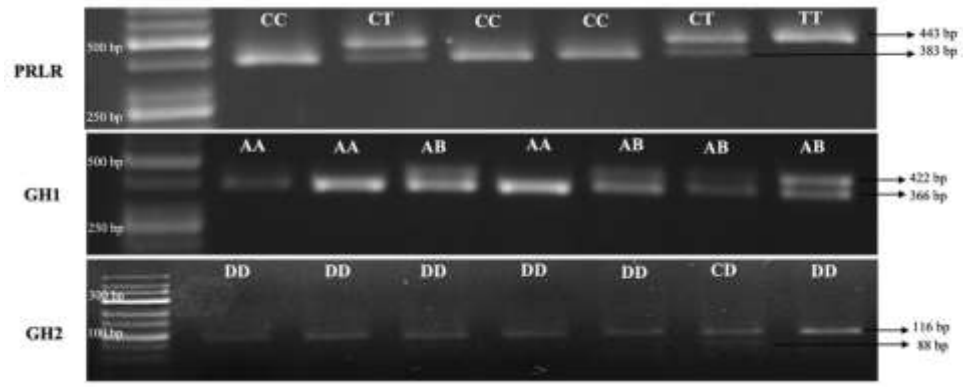

Figure 1. Electrophoretic profile for the PRLR, GH1 and GH2 fragments

3.2. Distribution of Allelic and Genotypic Fragments in Genes

In this study, the PCR-RFLP method was employed to investigate the allelic and genotypic frequencies of specific genes in goat genomic DNA. The findings, shown in *Table 2*, highlight the frequency distribution of alleles for each locus investigated.

Table 2. Allelic and genotyping frequencies of the PRLR, GH1 and GH2

Locus	Allele Frequencies		Genotype Frequencies			Ho	He	$\chi 2$
	C	**T**	**CC**	**CT**	**TT**	0.258	0.253	0.000286^{ns}
PRLR	0.851	0.149	0.722	0.258	0.020			
	A	**B**	**AA**	**AB**	**BB**	0.854	0.488	0.373^{ns}
GH1	0.573	0.427	0.146	0.854	-			
	C	**D**	**CC**	**CD**	**DD**	0.020	0.019	0.0001^{ns}
GH2	0.010	0.990	-	0.020	0.980			

Observed (Ho) and Expected (He) Heterozygosity and Chi-Square Statistic ($\chi 2$); ns: non-significant

The allele frequencies for the PRLR/RsaI locus were calculated to be 0.851 for the C allele and 0.149 for the T allele. Similarly, at the GH1/HaeIII locus, the frequencies of the A and B alleles were 0.573 and 0.427, respectively, with no occurrence of the BB genotype. For the GH2/HaeIII locus, the frequency of the C allele was

0.010, while the frequency of the D allele was 0.990, and the CC genotype was not detected. Additionally, the genotype distributions for all analyzed loci were consistent with Hardy-Weinberg equilibrium.

Nei's method was utilized to calculate the observed heterozygosity (Ho) and expected heterozygosity (He) for each locus. At the PRLR/RsaI locus, the Ho and He values were determined to be 0.258 and 0.253, respectively. For the GH1/HaeIII locus, the values were found to be 0.854 for Ho and 0.488 for He. Meanwhile, the GH2/HaeIII locus exhibited Ho and He values of 0.020 and 0.019, respectively.

3.2. The Relationship Between Genetic Variability and Litter Weight in Goats

As shown in *Table 3*, no statistically significant differences were observed in litter weight among the PRLR genotypes in Kilis goats ($P > 0.05$). The mean litter weights were 5.537 ± 2.238 kg for CC genotype, 4.954 ± 1.915 kg for CT genotype, and 6.900 ± 3.536 kg for TT genotype. In contrast, significant genotypic variations were detected at the GH1 and GH2 loci ($P \leq 0.05$). At the GH1 locus, the AB genotype demonstrated a significantly higher mean litter weight of 5.541 ± 2.232 kg compared to 4.677 ± 1.874 kg for the AA genotype. Similarly, at the GH2 locus, the CD genotype exhibited a significantly greater mean litter weight of 7.612 ± 2.972 kg compared to 5.369 ± 2.169 kg for the DD genotype.

Table 3. Effect of the PRLR, GH1 and GH2 polymorphisms on litter weight

Genotypes		**LW ± SD**
PRLR	**N**	**P=0.11**
CC	143	5.537 ± 2.238
CT	51	4.954 ± 1.915
TT	4	6.900 ± 3.536
Mean	198	5.415 ± 2.200
GH1	**N**	**P=0.05**
AA	29	4.677 ± 1.874[a]
AB	169	5.541 ± 2.232[b]
Mean	198	5.414 ± 2.200
GH2	**N**	**P=0.04**
CD	4	7.612 ± 2.972[a]
DD	194	5.369 ± 2.169[b]
Mean	198	5.415 ± 2.200

N: Number of animals; LW: Litter weight (kg); SD: Standard deviation.
Different letters in the same column indicate significant differences

Studies conducted across various species have demonstrated that polymorphisms in the PRLR gene significantly influence traits such as litter weight and birth weight (Yang et al., 2023; van Rens and van der Lende, 2002), and litter size (Wu et al., 2023; El-Shorbagy et al., 2022; Zhang et al., 2020; Guo et al., 2017; An et al., 2015; Xing-Ping et al., 2008). The absence of significant differences in litter weight among PRLR genotypes suggests that this gene may not directly influence litter weight in Kilis goats. This finding is consistent with previous studies, such as Sankhyan et al., (2019) and Terman (2005), which reported no significant association between PRLR polymorphisms and reproductive traits in goats. Furthermore, research conducted by An et al. (2015) suggests that while certain variants of the PRLR gene may be associated with reproductive efficiency in some goat breeds. Direct evidence supporting their influence on litter weight is still limited. Although PRLR is recognized for its role in lactogenesis and maternal behavior (Hou et al., 2014), its contribution to variations in litter weight is still not well established. Additional research involving larger sample sizes, diverse goat populations, and controlled environmental factors is required to clarify its precise role in reproductive performance. In studies conducted on goats, sheep, and cattle, the influence of GH polymorphism on birth weight has been reported as statistically insignificant (Kumar et al., 2024; Muniasamy et al., 2023; Sedykh et al., 2020; Gholamhoseinzadeh et al., 2018; Hua et al., 2009). However, other researches have demonstrated a significant effect of GH polymorphism on both birth weight and litter size (Buranakarl et al., 2024; Zhang et al., 2011). In the current study, the findings reveal that the two distinct GH loci examined exhibit a statistically significant influence on litter weight. These results contribute to the expanding body of evidence underscoring the potential role of genetic variation in growth hormone (GH) in modulating reproductive traits, particularly litter weight, in livestock. Further research is required

to investigate the underlying mechanisms and confirm these effects across diverse breeds and environmental conditions.

Table 4 and *Table 5* present an evaluation of the combined effects of PRLR and GH genotypes on litter weight (LW) in Kilis goats.

Table 4. Combined genotype effects of PRLR-GH1 and PRLR-GH2 on litter weight

PRLR-GH1			PRLR-GH2		
P=0.057			P=0.042		
Genotypes	**N**	**LW ± SD**	**Genotypes**	N	**LW ± SD**
CC-AA	26	4.752±1.969	CC-DD	139	5.478±2.199^{ab}
CC-AB	117	5.712±2.265	CC-CD	4	7.616±2.973^{b}
CT-AA	3	4.033±0.115	CT-DD	51	4.954±1.915^{a}
CT-AB	48	5.011±1.960	TT-DD	4	6.900±3.536^{ab}
TT-AB	4	6.900±3.536			
Mean = 5.415 ± 2.201 (N=198)					

N: Number of animals; LW: Litter weight (kg); SD: Standard deviation.
Different letters in the same column indicate significant differences.

No statistically significant differences in litter weight were observed among the combined PRLR-GH1 genotypes (P > 0.05). However, the highest mean litter weight was observed in goats with the TT-AB genotype (6.900±3.536 kg), whereas the lowest mean litter weight was recorded for the CT-AA genotype (4.033±0.115 kg). Significant differences in litter weight were observed among the combined PRLR-GH2 genotypes (P<0.05). The CC-CD genotype demonstrated the highest litter weight (7.616±2.973 kg), significantly exceeding that of the CC-DD genotype (5.478±2.199 kg), which exhibited the lowest mean value.The combined GH1 and GH2 genotypes exhibited statistically significant effects on litter weight (P<0.05). The AB-CD genotype showed the highest mean litter weight (7.613±2.973 kg), significantly exceeding that of the AA-DD genotype, which had the lowest mean litter weight of 4.678±1.874 kg. Our findings align with those of Hua et al. (2009), who reported that while the individual effects of polymorphisms at two distinct growth hormone loci were statistically insignificant for birth weight, their combined effect was significant. The observed increase in litter weight associated with specific GH1 and GH2 genotypes suggests a potential genetic advantage that could be exploited in breeding programs to enhance reproductive efficiency in Kilis goats. This observation supports the hypothesis that gene-gene interactions at multiple loci can influence complex traits, such as litter weight. Similar results have been reported in other livestock species, where interactions between growth-related genes contribute to variations in reproductive and production traits (Chen et al., 2001; He et al., 2014; Hou et al., 2013).

Table 5. Combined genotype effects of GH1-GH2 and PRLR-GH1-GH2 on litter weight

GH1-GH2			PRLR-GH1-GH2		
P=0.023			P=0.030		
Genotypes	**N**	**LW ± SD**	**Genotypes**	N	**LW ± SD**
AA-DD	29	4.678±1.874^{a}	CC-AA-DD	26	4.752±1.969^{ab}
AB-DD	165	5.491±2.199^{a}	CC-AB-DD	113	5.645±2.223^{abc}
AB-CD	4	7.613±2.973^{b}	CC-AB-CD	4	7.613±2.973^{c}
			CT-AA-DD	3	4.033±0.115^{a}
			CT-AB-DD	48	5.011±1.960^{ab}
			TT-AB-DD	4	6.900±3.536^{bc}
Mean = 5.415 ± 2.201 (N=198)					

N: Number of animals; LW: Litter weight (kg); SD: Standard deviation.
Different letters in the same column indicate significant differences.

The interaction among all three loci (PRLR-GH1-GH2) revealed statistically significant differences in litter weight (P<0.05). The CC-AB-CD genotype exhibited the highest mean litter weight (7.613±2.973 kg), whereas the CT-AA-DD genotype displayed the lowest mean value (4.033±0.115 kg). Intermediate values were observed for genotypes such as CC-AB-DD (5.645±2.223 kg) and TT-AB-DD (6.900±3.536 kg).The findings demonstrate

that specific combinations of PRLR, GH1, and GH2 genotypes exert a significant influence on litter weight in Kilis goats. Notably, the most favorable genotype combinations associated with enhanced litter weight include the CD allele at the GH2 locus and the AB genotype at the GH1 locus. These results highlight the potential role of genetic interaction in modulating this economically important trait.

4. Conclusions

This study provides genetic variations at the GH1 and GH2 loci significantly influence litter weight in Kilis goats, highlighting their potential as key genetic determinants of this economically important trait. Although no direct association was found between the PRLR gene and litter weight, the findings emphasize the complex genetic interactions between GH1 and GH2, which could have important implications for breeding strategies aimed at enhancing reproductive efficiency. Notably, the identification of specific genotype combinations, such as AB-CD, associated with increased litter weight offers valuable insights for targeted genetic selection. These results contribute to a deeper understanding of the genetic architecture underlying reproductive traits in Kilis goats and may facilitate the development of precision breeding approaches to optimize productivity in small ruminant populations. Further studies with larger sample sizes, diverse goat populations, and controlled environmental conditions are necessary to better define its exact role in reproductive performance.

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Ethical Statement

This study was prepared under the permission numbered 2016/8-1, dated 29/09/2016, from the Ethics Committee of Hatay Mustafa Kemal University.

Conflicts of Interest

There is no conflict of interest between the article authors.

Authorship Contribution Statement

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

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Digital Marketing Opportunities in Cooperatives and Consumers' Preference*

Kooperatiflerde Dijital Pazarlama Olanakları ve Tüketicilerin Tercihi

Gülen ÖZDEMİR[1*], Yaren KOCA[2]

Abstract

Cooperatives and other businesses to e-commerce, beginning with the phenomenon of consumption has gained a new dimension to the concept of consumption and traditional coming to the breaking point, the size of online consumption has been exceeded. Cooperatives and consumers, branding and e-commerce to prefer cooperative economic development is important for their brand. Electronic trade, one of the key pillars of the new economy and its reflection on the commercial space; can be defined as electronically processing and transmitting numbered data of individuals and institutions in the form of text, audio, and images over on or off networks. With the development of technology, information technologies have also shown rapid development. It has taken its share of this development in E-commerce after the internet came into our lives and has grown rapidly. The e-commerce market continues to grow rapidly in our country as it does in the world. The most important factor in the rise of the e-commerce market in our country is the Covid-19 pandemic. Increased online spending through the Covid-19 pandemic has also impacted on e-commerce and digital ad investments. Due to changing consumer behavior, cooperatives' digital marketing opportunities and consumers' perspective on cooperative branded products constitute the main purpose of this study. Agricultural Credit Cooperatives from cooperative enterprises have made progress in marketing their products on digital platforms and their products are more affordable on most used digital platforms in Turkey compared to other products in the same segment, becoming more preferred by consumers and the awareness of Agricultural Credit Cooperative branded products has increased with digitalization. Women's cooperatives in digital marketing have recently begun to be supported by the Ministry of Commerce and digital sales platforms, and women's cooperative products have been offered for sale on e-commerce sites, enabling women to participate in social life and increase their economic power. In this study, the consumers in the province of Edirne, e-commerce, Cooperatives, Consumer Preferences, their products were investigated. In this context, the findings from the center of Edirne province were obtained from consumer surveys 130. In the study, t-test by conducting Cooperative Consumers prefer branded products to condition and tested the relationship between demographic variables from digital platforms. Using Anova analysis, the cooperative to prefer branded products with cases for age, education level, income, definition of the relationship between the cooperative and the status of knowledge tested.

Key Words: Digitization, E-commerce, Cooperative, Brand, Consumer preferences

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Öz

Kooperatiflerin ve diğer işletmelerin e-ticaret yapmaya başlamasıyla birlikte tüketim kavramı yeni bir boyut kazanmış ve geleneksel tüketim olgusu kırılma noktasına gelerek, online tüketim boyutuna geçilmiştir. Kooperatiflerin markalaşması ve tüketicilerin e-ticaret yapan kooperatif markalarını tercih etmeleri ekonomik kalkınma açısından önem arz etmektedir. Yeni ekonominin temel direklerinden biri olan ve ticari alana yansıması olan elektronik ticaret; bireylerin ve kurumların metin, ses ve görüntü şeklinde numaralandırılmış verilerinin elektronik ortamda ağlar üzerinden veya ağlar dışında işlenmesi ve iletilmesi olarak tanımlanabilir. Teknolojinin gelişmesiyle birlikte bilişim teknolojileri de hızlı bir gelişim göstermiştir. İnternetin hayatımıza girmesiyle E-ticarette bu gelişimden nasibini almış ve hızla büyümüştür. E-ticaret pazarı dünyada olduğu gibi ülkemizde de hızla büyümeye devam etmektedir. Ülkemizde e-ticaret pazarının yükselişindeki en önemli etken Covid-19 pandemisidir. Covid-19 pandemisi ile birlikte artan online harcamalar e-ticareti ve dijital reklam yatırımlarını da etkilemiştir. Değişen tüketici davranışları nedeniyle kooperatiflerin dijital pazarlama olanakları ve tüketicilerin kooperatif markalı ürünlere bakışı bu çalışmanın ana amacını oluşturmaktadır. Kooperatif işletmelerinden Tarım Kredi Kooperatifleri ürünlerini dijital platformlarda pazarlamada ilerleme kaydetmiş ve Türkiye'de en çok kullanılan dijital platformlarda aynı segmentteki diğer ürünlere göre ürünleri daha uygun fiyatlı hale gelmiş, tüketiciler tarafından daha çok tercih edilir hale gelmiş ve dijitalleşmeyle birlikte Tarım Kredi Kooperatifi markalı ürünlerinin bilinirliği artmıştır. Dijital pazarlamada kadın kooperatifleri son zamanlarda Ticaret Bakanlığı ve dijital satış platformları tarafından desteklenmeye başlanmış olup, kadın kooperatif ürünleri e-ticaret sitelerinde satışa sunularak kadınların sosyal hayata katılımları ve ekonomik güçlerinin artması sağlanmıştır. Bu araştırmada Edirne il merkezindeki tüketicilerin, e-ticaret yapan kooperatif ürünlerini tüketim tercihleri incelenmiştir. Bu bağlamda bulgular, Edirne il merkezinden 130 tüketici ile yapılan anketlerden elde edilmiştir. Araştırmada t-testi yapılarak tüketicilerin dijital platformlardan kooperatif markalı ürün tercih etme durumları ile demografik değişkenler arasındaki ilişki test edilmiştir. Anova analizi kullanılarak ise, kooperatif markalı ürünleri tercih etme durumları ile yaş, eğitim düzeyi, gelir ve kooperatif tanımını bilme durumları arasındaki ilişki test edilmiştir.

Anahtar Kelimeler: Dijitalleşme, E-ticaret, Kooperatif, Marka, Tüketici tercihleri

1. Introduction

The involvement of cooperatives in marketing protects the interests of both producers and consumers. Cooperatives, community development, to increase employment, although it has contributed to the rise in incomes of small producers, it also one of the important activities from the partners are marketing the products. Creating branding and marketing cooperatives in the price to take the role of the channel is shortened. Increases the incomes of producers and consumers through marketing contracts pay less to buy the product. Thus, it contributes to the development of the local economy. Therefore, branding is important to their brand and consumers prefer cooperative of cooperatives (Everest et al., 2018).

The use of trademark comprehensive cooperative brands and emerging retail brands that are evaluated in the most appropriate way consumers ' purchasing decisions and those decisions and to know the factors that influence their strategic moves in this direction should throw (Baş and Göral, 2017). However, in today's world, the rapid expansion of computers and the internet, has led to the birth of electronic commerce, understanding that surpasses the traditional trade. Unlike traditional consumption of the day, at any time, any place products available online while in (Akçi and Annaç Göv, 2015).

Nowadays technology with the development together, digitization, every area penetrates to begin. Smart agricultural practices with agricultural productivity increase and Agriculture of the digitalization provide to cooperatives of the digitalization large degree of importance. The digitalization of agricultural cooperatives and unions increases their international competitiveness and turns their opportunities into advantages. Digitalization increases efficiency for companies of all sizes and makes businesses more competitive. (Yılmaz Altuntaş, 2018). Cooperatives in the digital transformation of a part to be Joint Information Systems (OBS) and resource planning , such as with applications, the manufacturer with its partners communication establish , facilitate and traditional boundaries break down to business processes re - shape will be required to (Sarstedt, et al., 2014). The production and use of technology when it comes to women's entrepreneurship, digital literacy, digital economy, such as the main themes come to mind. Digital literacy, especially in terms of women's cooperatives in the use of technology is one of the most important areas that need to be improved because digital marketing, marketing communication and sales channels is also important for consumers cooperatives and very strong player (Koçak Alan et al., 2018). Digital innovations undertaken by cooperatives; painting highlights the importance of consumer perception. Economic life in different spheres of the growing digital-to-use, increase the quality of social life on the one hand, on the other hand, consumer behavior, preferences and attitudes revealed differences in (Kayapınar, et al., 2017). Synthesis and subsequent purchase behavior of consumers with the study of emerging market divided into sections, revealed the importance of gender differences, and Sunday has become the target female consumers. Accordingly, businesses, arose the need to have more information about female consumers, and the studies in the direction of the direction being given to the identified strategies (Özdemir, 2005). Model to be utilized in the development of the economy of women, it is concluded that the most important (Özdemir et al., 2018).

Thanks to the developing technology, the global market size can reach consumers and manufacturers. In addition, with the internet, is changing the habits of consumers. In Turkey, especially Covid-19 pandemic period in recent years, with an important contribution to economic growth and employment cooperatives in order to provide the level of e-commerce, we are working to increase the volume. E - commerce and the continuous expansion of the network in the future will have a much bigger place, considering it is becoming important awareness on the situation of entrepreneurs and cooperatives in Turkey (Özdemir, 2019).

Literature review conducted numerous studies that have pointed out the importance of cooperatives in the branding of consumers, despite a limited number of branded products were found in the study investigating the cooperative approach (Baş and Göral, 2017; Güler and Bozacı, 2015). In this study, the factors affecting consumers' purchasing of cooperative branded products in digital marketplaces, access tools and perspectives on cooperative products were determined.

2. Materials and Methods

2.1. Material

The main material of the study, located in the Central District of Edirne province, were obtained from collected

from the consumers. The universe of this study, located in the Central District of Edirne province, constitute the consumers. Online selected with random sampling method the sample of this study using a questionnaire, data collected with different demographic characteristics constitute consumer 130. It is assumed that the sample will represent the universe. A total of 130 have been made to the consumer survey in June 2022. In the form of that survey; demographic information on consumers, consumers shopping online, reasons to prefer branded products cooperatives.

The purpose of the study questionnaire, in the Central District of Edirne province, located in the Consumers ' Cooperative of reason to prefer branded products, the importance is to reveal whether there is a significant difference between gender and marital status.

2.2. Method

Agricultural economics research populations are often limited in the populations examined (Çiçek and Erkan, 1996). A particular feature of known or estimated carrier rate (p) for sampling situations according to the proportional from the formula for calculating the volume of sample available (Miran, 2010). Therefore, the proportional sampling method was used in the sampling phase of the study.

$$n = \frac{\mathrm{n\ p(1-p)}}{(\mathrm{N-1})\sigma^2_{\mathrm{px}} + \mathrm{p(1-p)}} \qquad \text{(Eq. 1)}$$

The Central District of Edirne province in Turkish Statistical Institute (TurkStat) according to 45.225,25 based on data from households (TUIK, 2021). The formula for 95% confidence interval brought with 8.5% margin of error and the sample in order to achieve maximum volume, p=q=0.5 was taken to be. Analysis SPSS (version 25.0) was used. The difference between the groups was examined by using the Mann Whitney U test.

3. Research Results

In this section, we survey the statistical package SPSS analysis and interpretation of data obtained from consumers program reviewed. When we conduct a survey with consumers who are actively shopping from the digital souks were interviewed. The results were evaluated and the results of research presented in the form of tables.

3.1 Demographic characteristics of consumers

The scope of the research discussed in the consumer mainstream (*Table 1*) demographic findings presented. Accordingly, the respondents 56.9% women, 43.1% were male, 61.5% married, 38.5% percent are single. 40.0% of the respondents have no children, 25.4% have one child, and 24.6% have two children. Participants in the age group of 28-37% to 30.8 constitute the largest part with. Respondents in the age group of 38-47 %29.2 then follow it with. When looking at the state of education, the highest part 46.9% with participants constitute a bachelor degree. 73.9% of the survey participants know what a cooperative is.

(*Table 2*) 40% of the participants, work in the private sector, 19.2% working in the public sector of 15.4% percent is functioning, if not %and 13.8% working in free of profession, 6.9 percent as a student, %4.6% retired. 40 % of the participants stated that they earned a monthly income of 3000-5000 TL, 33.8% 8001 and above and 26.2% 5001-8000 TL.

Reasons to prefer branded products from the souks of the Consumers Cooperative in (*Table 3*) digital severity levels according to gender and marital status of statistically 95% confidence level it could be argued that this did not show a significant difference (p=0.133, p=0.614 >0,05 p). Therefore, participants' perspectives on cooperative branded products in digital markets did not differ according to gender (4.09 women's 3.93 men) and marital status (3.99 singles 4.04 married).

Reasons to prefer branded products from the souks in (*Table 4*) of the Consumers Cooperative of severity of the digital age, education level, income level and statistically knew cooperatives according to the situation to know what 95% confidence level it could be argued that this did not show a significant difference (p=0.870, p=0.202, p=0.512, p=0.217 > 0.05 p). Knowing their status on cooperatives "yes," he responds structures 4.05 the importance level of an average of, "partially" 4.07 it is observed that the average importance level of participants

who have replied. Therefore, participants' perspectives on cooperative branded products in digital markets did not differ according to the age, level of education, income and knew cooperatives according to the situation to know.

Table 1. The distributions of demographic characteristics of the participants

Demographic variables	For the groups in the	Frequency (F)	Percent (%)
Gender	Female	74	56.9
	Male	56	43.1
Marital Status	Married	80	61.5
	Single	50	38.5
The Number of Children	No	52	40.0
	1	33	2.54
	2	32	24.6
	3	11	8.5
	4 and above	2	1.5
The Ages of	18-27	29	22.3
	28-37	40	30.8
	38-47	38	29.2
	48 and above	23	17.7
Education Level	Primary	13	10.0
	Secondary/High School	25	19.2
	Associate	21	16.2
	License	61	46.9
	MSc/PhD	10	7.7
Knowledge of the Cooperative	Yes	50	38.5
	No	21	16.2
	Partially	59	45.4

Table 2. The participants ' socio-economic status in relation to distributions

Socio-economic variables	For the groups in the	Frequency (F)	Percent (%)
In the Work Sector	I don't work for	20	15.4
	I work in public	25	19.2
	I work in the private sector	52	40.0
	Self-employment	18	13.8
	I am a student	9	6.9
	I'm retired	6	4.6
Monthly Income (June 2022)	3000 to 5000 TL	52	40.0
	5001-8000 TL	34	26.2
	above 8001 TL	44	33.8

Table 3. Digital consumers prefer branded products in the marketplace cooperative, relating to the test results, showing differences according to gender and marital status of the reasons

	Digital-to-Cooperative Importance Level of reasons to prefer branded products	
	Average $\overline{X\ and}$	**Standard Deviation**
Gender		
Female (n=74)	4.09	0.63
Male (n=56)	3.93	0.61
p- value		0.133
Marital Status		
Married (N=80)	4.04	0.60
Single (N=50)	3.99	0.67
p- value		0.614

*p<0.05

Table 4. Cooperative Consumers prefer branded products of reason to the age, level of education, income Anova test results showed differences according to their status and cooperatives to know what you knew

	Digital-to-Cooperative Importance Level of reasons to prefer branded products	
	Average $\overline{X\ and}$	**Standard Deviation**
Age		
aged 18-27 years (n=29)	3.98	0.61
aged 28-37 years (n=40)	3.98	0.64
aged 38-47 years (n=38)	4.09	0.61
48 years and older (N=23)	4.03	0.66
p- value		0.870
Education Level		
Primary (N=13)	4.06	0.58
Secondary Education-High School (N=25)	4.20	0.65
undergraduate (N=21)	4.09	0.60
undergraduate (n=61)	3.98	0.56 to
graduate-PhD (N=10),	3.66	- 0.93
, *p*- value		0.202
Monthly Income (June 2022)		
of 3000 to 5000 TL (N=52)	4.10	0.54
5001-8000 TL (n=34)	4.00	0.56
8001 TL and above (N=44)	3.95	0.75
p- value		0.512
Know My Status Cooperatives		
Yes (N=50)	4.05	0.58
No (N=21)	3.80	0.74
Partially (n=59)	4.07	0.61
p- value		0.217
* *p<0.05*		

4. Conclusion

A total of 130 living in the Central District of Edirne province conducted a survey with consumers. In the study, in Turkey, the two most widely used e-commerce platform, which is its own menu, and consumers of their products

Trendyol cooperative focus you on the choice. Giving individuals starting a nuclear family cooperative awareness is very important. Consumers ' demographic, social and economic characteristics is seen as one of the most important factors in the importance of purchasing behavior. The demographic characteristics are investigated for the participants in this study first surveyed the consumers ' Cooperatives of the status of knowledge are examined. In this case, the respondents 45.4% of the cooperatives partly knew, 38.5% is knows the cooperatives and 16.2% knew it was determined that the cooperatives. The great majority know and you know partly it is observed that the view that cooperatives. Giving individuals starting a nuclear family cooperative awareness is very important. Analyzed demographic data from participants, 56.9% women, 43.1% were male, %61.5% married, 38.5% percent are single, the numbers of participants are examined, 40% of the child, the absence of 25.4% he is a child of %and 24.6 percent have two children, the participants in the group above 30 years of age with 77.7 %constitute the largest part of. In the group of participants under the age of 30% and 22.3% constitutes the portion. When we examine the state of Education, 70.8% higher than most high school (university) that have the level of Education, 29.2% part of has been found to have an education level below high school. The monthly household income of the consumers surveyed the level of 40% is concentrated between £ 4000-12999 (June 2022). When considering the poverty line and the poverty line between hunger and starvation were found to have a monthly income consumers. Consumers ' demographic, social and economic characteristics is seen as one of the most important factors in the importance of purchasing behavior. In general, consumers in digital platforms is aware of the fact that is affordable and of higher quality branded products cooperative. More product choice cooperative brands, advertising and promotional activities can be supported by. The cooperative research units of demand for the product that appears to be so cooperative with more attention given to the promotion of branded products to be producing the advertisements may be recommended. Also, cooperative commercials for increasing awareness in the community about the manufacturing process of products can be made.

Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Özdemir, G., Koca Y.; Design: Özdemir, G., Koca Y.; Data Collection or Processing: Özdemir, G., Koca Y.; X.; Statistical Analyses: Özdemir, G., Koca Y.; Literature Search: Özdemir, G., Koca Y.; Writing, Review and Editing: Özdemir, G., Koca Y.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Relationship of SNPs in Octopamine and Tyramine Receptor Genes with Hygienic Behavior in Honey Bees and Their Effects on Breeding Process*

Bal Arılarında Oktopamin ve Tyramine Reseptör Genlerindeki SNP'lerin Hijyenik Davranışla İlişkisi ve Islah Sürecine Etkisi

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Abstract

Hygienic behavior in honey bees is a critical for maintaining colony health, preventing the spread of diseases, and providing resistance to harmful parasites. This behavior is defined as the worker bees detecting diseased, dead or parasitized brood cells and removing and cleaning them from the honeycomb cells. This feature, which is the defense mechanism of the colony, has developed on a genetic basis in natural selection and controlled breeding processes. Therefore, understanding the genetic mechanisms of hygienic behavior has become an important research subject in honey bee breeding studies. Recent studies have shown that neurotransmitter systems and receptor genes in honeybees affect various social and cognitive processes, including hygienic behavior. It is known that biogenic amines, especially octopamine and tyramine, regulate the learning, memory, olfactory perception, decision-making mechanisms and social behaviors of bees. Octopamine receptor and tyramine receptor can have a direct effect on stress response, flight activity, foraging behavior and hygienic behavior by acting as stimulants in the nervous system. In this study, in order to understand the genetic basis of hygienic behavior in Efe ecotype honey bees (*Apis mellifera anatoliaca*), colonies showing hygienic and non-hygienic behavior were determined according to the pin-killed test. Then, single nucleotide polymorphisms (SNPs) were detected in the AmOA1 and AmTYR1 gene regions of worker bees belonging to these colonies. As a result of the sequence analysis, 10 polymorphisms were determined in the AmOA1 receptor gene and 11 polymorphisms were determined in the AmTYR1 receptor gene. However, no significant difference was observed in the distribution of these SNPs between colonies showing hygienic and non-hygienic behavior. These results indicate that there is no direct relationship between hygienic behavior in Efe Bees and SNPs in AmOA1 and AmTYR1 genes. Therefore, no differences were detected between colonies in terms of SNPs. The polymorphisms have not been reported before in Efe Bee and this contributes to the originality of the study. More comprehensive studies to be conducted in the future will increase the knowledge in this field and contribute to the development of new strategies for selecting colonies in terms of hygienic behavior in the beekeeping industry.

Keywords: *Apis mellifera*, Biogenic amines, Colony resistance, Learning and memory, Neurotransmitters

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*This study was summarized from the Neslihan Özsoy's PhD thesis.

Öz

Bal arılarında hijyenik davranış, koloni sağlığının sürdürülmesi, hastalıkların yayılmasının önlenmesi ve zararlı parazitlere karşı direnç sağlanması açısından kritik bir öneme sahiptir. Bu davranış, işçi arıların hastalıklı, ölü veya parazitlenmiş yavru hücrelerini tespit ederek petek gözlerinden çıkarması ve temizlemesi olarak tanımlanmaktadır. Zararlılara karşı kolonin savunma mekanizmasını oluşturan bu özellik, doğal seçilim ve kontrollü ıslah süreçlerinde genetik bir temele dayanarak gelişmiştir. Bu nedenle, hijyenik davranışın genetik mekanizmalarının anlaşılması, bal arısı ıslah çalışmalarında önemli bir araştırma konusu haline gelmiştir. Son yıllarda yapılan çalışmalar, bal arılarındaki nörotransmitter sistemlerinin ve reseptör genlerinin, hijyenik davranış da dahil olmak üzere çeşitli sosyal ve bilişsel süreçleri etkilediğini göstermektedir. Özellikle oktopamin ve tyramin gibi biyojenik aminlerin, arıların öğrenme, hafıza, koku algısı, karar verme mekanizmaları ve sosyal davranışlarını düzenlediği bilinmektedir. Oktopamin reseptörü ve tyramine reseptörü, sinir sisteminde uyarıcı işlev görerek stres yanıtı, uçuş aktivitesi, besin arama davranışı ve hijyenik davranış üzerinde doğrudan etkiye sahip olabilmektedir. Bu çalışmada, Efe ekotipi bal arılarında (*Apis mellifera anatoliaca*) hijyenik davranışın genetik temellerini anlamak amacıyla pin-killed testi uygulanarak hijyenik davranış gösteren ve hijyenik davranış göstermeyen koloniler belirlenmiştir. Ardından, bu kolonilere ait işçi arıların AmOA1 ve AmTYR1 gen bölgelerinde tek nükleotid polimorfizmleri (SNP) tespit edilmeye çalışılmıştır. Dizi analizi sonucunda, AmOA1 reseptör geninde toplam 10 polimorfizm ve AmTYR1 reseptör geninde 11 polimorfizm belirlenmiştir. Ancak, yüksek ve düşük hijyenik davranış gösteren koloniler arasında bu SNP'lerin dağılımında belirgin bir fark gözlenmemiştir. Bu sonuçlar, Efe Arısı'nda hijyenik davranış ile AmOA1 ve AmTYR1 genlerindeki SNP'ler arasında doğrudan bir ilişki olmadığına işaret etmektedir. Daha önce Efe Arısı'nda bu genlerde herhangi bir polimorfizm rapor edilmemiş olması, bu çalışmanın özgün bir katkı sunduğunu göstermektedir. Gelecekte gerçekleştirilecek daha kapsamlı genomik çalışmalar, bu alandaki bilgi birikimini artırarak arıcılık sektöründe hijyenik davranışı yönünden kolonilerin seçilmesi için yeni stratejiler geliştirilmesine katkı sağlayacaktır.

Anahtar Kelimeler: *Apis mellifera*, Biyojenik aminler, Koloni direnci, Öğrenme ve hafıza, Nörotransmitterler

1. Introduction

Insect sensory organs convert mechanical, chemical and light energy coming from the environment into electrical energy of nerve impulses in sensory neurons, and from there the information is transmitted to the brain or ventral nerve cord and causes behavioral responses (Farooqui, 2007). Therefore, a stimulus must be present in the colony for hygienic behavior to occur and that worker bees that are genetically predisposed to hygienic behavior can perform this behavior in the presence of the stimulus (Arathi et al., 2006). For this purpose, the neural processes that occur in worker bees will perceive and respond to stimuli from the environment (Morfin et al., 2019). Therefore, a stimulus must be present in the colony for hygienic behavior to occur and worker bees that are genetically predisposed to hygienic behavior can perform this behavior in the presence of a stimulus (Arathi et al., 2006). For this purpose, the neural processes that occur in worker bees will perceive and respond to stimuli from the environment (Morfin et al., 2019). In this regard, the antennas of honey bees play a very important role in hygienic behavior (McAfee et al., 2017). The olfactory system in honeybees consists of antennae, antennal lobes, and mushroom bodies (MBs), and that ~60,000 olfactory sensory neurons (OSNs) are located within cuticle-covered sensilla along the antennae. Honey bees detect odors and tastes using their antennas and the olfactory receptors located in the OSNs on their antennas (Spivak and Danka, 2021) and worker bees showing hygienic behavior also identify diseased or dead larvae and pupae using olfactory cues (Masterman et al., 2000; Gramacho and Spivak, 2003; Spivak et al., 2003; Arathi et al., 2006; Goode et al., 2006; Bienefeld et al., 2015; Rasolofoarivao et al., 2015; Scannapieco et al., 2017; McAfee et al., 2018; Morfin et al., 2019; Wagoner et al., 2020; Lee et al., 2020; Spivak and Danka, 2021). Hygienic behavior has been defined as the ability of worker bees to detect diseased and dead brood, open these brood and remove them from the cells (Rothenbuhler, 1964; Arechavaleta-Velasco et al., 2011). Worker bees showing hygienic behavior remove diseased brood from the colony before the pathogen reaches the infectious stage (Arathi et al., 2006; Swansan et al., 2009). Bacterial, viral, fungal and parasitic factors are the most important causes of colony losses (Bozdeveci et al., 2024), and colonies with hygienic behavior are resistant to many brood and bee diseases such as American foulbrood (Spivak and Reuter, 2001; Gramacho and Spivak, 2003; Arathi et al., 2006; Lazarov et al., 2020; Lee et al., 2020), chalk brood (Cause: *Ascosphaera apis*) (Gramacho and Spivak, 2003; Arathi et al., 2006; Lazarov et al., 2020; Invernizzi et al., 2011), Varroa (Spivak, 1996; Gramacho and Spivak, 2003; Arathi et al., 2006; Pinto et al., 2012; Ji et al., 2014; Lazarov et al., 2020; Wielewski et al., 2012).

Honey bee behaviors are either under the control or modulation of biogenic amines (Thamm et al., 2017). Biogenic amine receptors are densely expressed in different parts of the bee brain, especially in mushroom bodies (Peng et al., 2021). Octopamine and Tyramine are biogenic monoamines that function as neurohormones, neuromodulators, and neurotransmitters in invertebrates (Ali et al., 2012; Kastner et al., 2014; Braza et al., 2019) and modulate many important physiological processes (Kastner et al., 2014).

Octopamine receptors have been classified as α1-adrenergic-like receptors (Octα1-R, or OA1), α2-adrenergic-like receptors (Octα2R, OA3), β-adrenergic-like receptors (Octβ-R, OA2: Octβ1-R, Octβ2-R, Octβ3-R) (Finetti et al., 2021). It has been reported that octopamine effective in in increasing arousal levels (Sinakevitch et al., 2011), stimuli-increased food consumption behavior (Scheiner et al., 2006), in regulation of forage behavior (Aonuma and Watanabe, 2012), aggression (Sinakevitch et al., 2011), control of locomotion (Sinakevitch et al., 2011; Li et al., 2016), preparing the insect for high-energy actions (Schendzielorz et al., 2015), recognizing nestmates (Barron et al., 2007; Duportets et al., 2010; Sinakevitch et al., 2011; Dimić et al., 2020), walking, mating (Ali et al., 2012), laying eggs (Li et al., 2016; Xu et al., 2020), stinging behavior (Molaei et al., 2005; Farooqui and Farooqui, 2010; Ali et al., 2012), memory formation (Pflüger and Stevenson, 2005; Duportets et al., 2010; Farooqui and Farooqui 2010; Schendzielorz et al., 2015; Blenau and Baumann 2016; Wallberg et al., 2017), tongue (proboscis) extension, juvenile hormone release from corpora allata (Molaei et al., 2005), muscular systems, endocrine tissues (Bischof and Enan, 2004), and learning (Bischof and Enan, 2004; Pflüger and Stevenson, 2005; Scheiner et al., 2006; Schendzielorz et al., 2015; Blenau and Baumann, 2016; Dimić et al., 2020).

Octopamine also plays a role in hygienic behavior (Barron et al., 2007; Sinakevitch et al., 2011). In hygienic honey bees, the brain protocerebral neurons (cluster-3 cells) have significantly higher levels of Octopamine immunoreactivity, which is linked to the ability to detect diseased brood odors (Goode et al., 2006). Hygienic bees

that detect diseased or dead brood open the cells and remove the affected larvae or pupae from the colony under the influence of neuromodulators such as Octopamine (Spivak et al., 2003; Morfin et al., 2019).

Tyramine receptors are classified as TAR1 (or TYR1), TAR2 (or TYR2) and TAR3 (or TYR3) (Finetti et al., 2021). Tyramine has been shown to play a role in learning (Mustard et al., 2005; Guo et al., 2018; Braza et al., 2019; Wang et al., 2020), memory (Guo et al., 2018; Braza et al., 2019; Wang et al., 2020), behavior, energy metabolism (Guo et al., 2018; Braza et al., 2019), sucrose response (Guo et al., 2018; Thamm et al., 2021), reproductive physiology (Lange, 2009; Guo et al., 2018), olfaction (Lange, 2009; Ishida and Ozaki, 2011; Gainetdinov et al., 2018), muscle contraction in insects. (Enan, 2005; Ishida and Ozaki, 2011), insect movement (Lange, 2009; Gainetdinov et. al., 2018; Braza et. al., 2019), pheromone response (Braza et. al., 2019), brain development (Ji et. al., 2016), flight behavior, food search and taste perception (Gainetdinov et. al., 2018). It has been emphasized that Tyramine affects general odor-sensitive ORNs (Olfactory Receptor Neurons) (Zhukovskaya and Polyanovsky, 2017). Tyramine is involved in appetite regulation (Brigaud et al., 2009) and increases behavioral responses to antennal stimulation using taste stimuli (Brigaud et al., 2009; Lange, 2009) and sugar sensitivity (Behrends and Scheiner, 2012), and stimulates ovary development in worker bees (Lange, 2009).

Genetic studies have determined that 73 genes are related to hygienic behavior and these genes are generally related to neuronal development and sensory perception in insects (Harpur et al., 2019). Octopamine receptor, smell-impaired, odorant binding protein (OBP) 3 and OBP 4 genes are expressed differently between colonies that show hygienic and non-hygienic behavior and may be effective in the perception of diseased odors by worker bees that show hygienic behavior (Scannapieco et al., 2017). It has been determined that 4 SNPs (Adenosine receptor and Cyclin-dependent kinase 5 activator, Octopamine receptor β-2R and OBP 1) are responsible for the detection and opening of Varroa-infected brood cells by honey bees (Spötter et al., 2016).

The goal of the present study was to determine the SNPs of "Octopamine Receptor" and planned to investigate the possibilities of these receptor on use in hygienic behavior breeding in breeder Efe Bee colonies in Aegean Agricultural Research Institute (AARI).

2. Materials and Methods

2.1. Honey bee colonies

The decision regarding the registration of the Efe Bee, which was registered as a result of the breeding studies carried out by the AARI-Beekeeping Research Center between 2008-2018, was published in the Official Gazette dated 16 May 2019 and numbered 30776 in Türkiye. Among 102 breeder Efe Bee colonies, bees were collected from the 5 colonies with the hygienic behavior and the 5 colonies with the non-hygienic behavior and analyzed. Analyses were performed on a total of 60 bee samples.

2.2. Rearing of queen bees

Queen bees were produced from the breeding hives located in AARI apiary in İzmir by the larvae transfer (doolittle) method reported by Laidlaw (1979). The main breeding colonies of Efe Bee are located in Bozcaada and the region is the protection zone of Efe Bee and no other bees are allowed from outside. In order to create breeding queens, the produced queens were taken from the nucleus hives and taken to the AARI apiary in Bozcaada to be mated. After the matings were completed, the nucleus hives were brought to AARI (İzmir) and the fertile breeder queens were transferred to production hives consisting of Langstroth type hives.

2.3. Hygienic behavior tests

Hygienic behavior tests were performed 2 months after the queens were transferred to the Langstroth type hives (between August 10 and September 22). Tests were performed adapted to the pin-killed method reported by Büchler et al., (2013). Accordingly, a pupal area was determined in one frame in each hive and 100 brood (containing pupa) cells in this determined area were punctured with a needle and the cleaning status of these cells at 24 hours was treatment and the average was calculated. Tests were performed 3 times with a 21-day interval and 5 colonies with the hygienic behavior (≥95%; Guzman et al., 2002) and 5 colonies with the non-hygienic behavior were determined. The percentage of hygienic behavior was calculated according to the method reported by Palacio et al., (2000).

Kim et al., (2019) reported that hygienic behavior is generally performed by adult worker bees that are 15-17 days

old. In this regard, as Boutin et al., (2015) stated, worker honey bee samples were taken the day following the hygienic test and only the bees in the brood frame where the hygienic test was performed were sampled. The samples were collected in tubes and placed in a liquid nitrogen tank in the field where the colonies were located until they were stored at -80 °C and immediately taken to the -80 °C freezer in the AARI - Apiculture Research Center after the study in the field was completed.

2.4. Genetic analysis

RNA isolation, cDNA synthesis and PCR analyses were performed at Afyon Kocatepe University - Faculty of Veterinary Medicine, and SNP analyses were performed in a private laboratory in Eskişehir. Worker bee heads were used for RNA isolation. RNA isolation was performed using a commercial kit (TRIzol™ Reagent, Thermo Fisher Scientific, 15596026) according to the protocol recommended by the company. The isolated total RNAs were measured in terms of quality and quantity using both a Nanodrop spectrophotometer (Thermo Fisher Scientific) and a Qubit 2.0 Fluorometer (Invitrogen) using the Qubit RNA Analysis Kit. Those with an RNA DNA^{-1} ratio of 1.8 and above were used in the study.

The primers for the Octopamine receptor gene (AmOA1) and Tyramine receptor gene (AmTYR1) used in the study were designed using the reference mRNA sequence (NM_001011565.1 and NM_001011594.1) obtained from NCBI and the FastPCR Professional 6.1.2 package program (Kalendar et al., 2009). The formation of dimer and hairpin between the primers was checked with the same program and primers that did not form dimer/hairpin were selected. The primers used in the study and the length of the amplified regions are given in the table below (*Table 1*).

Table 1. Forward and reverse primers of octopamine receptor gene and tyramine receptor gene

Gene	Forward primer (5'→3')		Reverse primer (5'→3')		Product size	Tm
Octopamine receptor gene (AmOA1)	F1	taattggacaggacgagggga	R1	ctatccaggctgatggcgcac	1536	60
	F2	tttgtgcgccatcagcctgga	R2	cgcactcgattctcgtcgtgc	1428	60
Tyramine receptor gene (AmTYR1)	F3	gctcgaacagagaagactgga	R3	gccgagtagtgtcccgatgac	1367	59
	F4	gggaaacaagatttgccgccga	R4	tgacggacactctgcccggaa	1452	61
	F5	ttgatgtcggctgcttgcttcc	R5	ctctccttccctcaaacgcga	1379	60

Gradient PCR was applied to determine the annealing temperatures of the primers. For this purpose, a PCR mixture was prepared consisting of 1xPCR buffer, 2mM MgCl2, 0.2 mM dNTPs, 0.3 pmol forward primer, 0.3 pmol reverse primer, 1 U Platinium Taq polymerase (ThermoFisher, 10966034) and 20 ng μL^{-1} cDNA. 10 PCR product tubes representing 10 colonies obtained as a result of PCR were taken to the agarose gel electrophoresis stage. After the running process was completed, the gel was visualized with the VisionCapt (Bio-Vision, Vilber Lourmat) gel imaging system.

DNA sequence analysis was performed to determine the base sequence and SNPs of the PCR products. After DNA sequence analysis, the results were rearranged according to the reference sequence using the Sequencher 5.6.1 package program. Then, all samples were aligned using the BioEdit program (Hall, 1999) and polymorphic SNPs and inserted and deleted regions were determined.

3. Results and Discussion

3.1. Hygienic behavior tests

A total of 3 hygienic behavior tests were performed on 102 breeder Efe Bee colonies every 21 days. According to the test results, a total of 5 hygienic behavior colonies and 5 non-hygienic behavior colonies were determined (*Table 2*).

3.2. Genetic analysis

The bands of the primers octopamine F2-R2 (1428bp) and tyramine F3-R3 (1367bp) were detected, but the bands of the primers octopamine F1-R1 (1536bp), tyramine F4-R4 (1452bp) and tyramine F5-R5 (1379bp) were not detected. The gel images obtained as a result of PCR are shown below (*Figure 1* and *2*). In octopamine F2-R2

and tyramine F3-R3 the bands which the image was detected were evaluated as positive, and the bands which the image was not detected were evaluated as negative. Accordingly, all images (10 images) were obtained as positive in F2-R2 (*Figure 1*) and 9 images were obtained as positive in tyramine F3-R3 (*Figure 2*).

Table 2. Selected hives based on hygienic behavior measurement results

Hive number	Percentage of hygienic behavior	Number of bees taken for genetic analysis	Hive number	Percentage of hygienic behavior	Number of bees taken for genetic analysis
Hygienic behavior			**Non-hygienic behavior**		
101-1-Y	100%	6	123-2-D	73%	6
128-2-Y	100%	6	232-3-D	69%	6
218-2-Y	100%	6	160-2-D	68%	6
172-2-Y	99%	6	185-1-D	67%	6
156-2-Y	98%	6	245-1-D	63%	6
Total		**30**	**Total**		**30**

Figure 1. PCR image of octopamine F2-R2

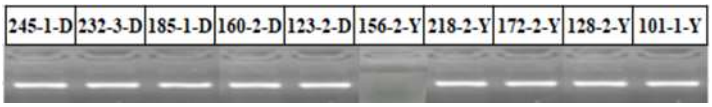


Figure 2. PCR image of tyramine F3-R3

Figure 3 shows the graphic sequence of the AmOA1 (F2-R2 primer) gene. The grey area in the figure is the 5'UTR region. The yellow part is the region where the exons are located, and the brown bases represent the 3'UTR region. Those written in red indicate that there is a mutation or polymorphism. When the figure is examined, it is seen that there are 10 polymorphisms and in 1 sample showing hygienic behavior, a 40-base region was added at base 2291.

The first polymorphism occurred at base 1725 of exon 4 and adenine converted to guanine. This resulted in an amino acid change, caused the conversion of threonine to alanine. Guanine converted to adenine in exon 6, at base 1961 and cytosine converted to thymine in exon 6, at base 2126 and guanine converted to adenine in exon 6, at base 2153 and guanine converted to adenine in exon 7, at base 2351 and thymine converted to cytosine in exon 8, at base 2552 and guanine converted to adenine in exon 8, at base 2606 and cytosine converted to thymine in exon 9, at base 2734. These created a silent SNP. Adenine converted to guanine at base 2843, but this occurred in the 3'UTR region. A 40-base section (CCCAGAAGACCCTAGCAGGAGGAACAGCTGCGAGAGTCCA) was added at base 2291 in exon 7 in one sample showing hygienic behavior. Since the addition of this section can cause a change in the protein sequence, it is thought that it can cause phenotypic changes (*Figure 4* and *5*).

Figure 6 shows the graphic sequence of the AmTYR1 (F3-R3) gene. In the tyramine receptor, 1 exon could be sequenced and all SNPs are located in exon 1. The grey area in the figure is the 5'UTR region. The yellow part is the region where the exons are located, and the brown bases represent the 3'UTR region. Those written in red indicate that there is a mutation or polymorphism. When the figure is examined, it is seen that there are 11 polymorphisms. There is a 3-base deletion starting from base 103 in the 5'UTR region.

The first polymorphism occurred at base103 with a thymine-guanine-adenine deletion, but this deletion is located in the 5'UTR region. At the 158 base, the cytosine is converted to guanine. This resulted in an amino acid change, caused the conversion of aspartic acid to glutamic acid. At the 207 base, the guanine base is converted to adenine. This resulted in an amino acid change, caused the conversion of Valine to Isoleucine. Cytosine converted

to guanine at base 218, guanine converted to cytosine at base 248, cytosine converted to thymine at base 467, cytosine converted to thymine at base 956, guanine converted to adenine at base 1133, cytosine converted to thymine at base 1187, cytosine converted to thymine at base 1063, adenine converted to guanine at base 1133, cytosine converted to thymine at base 1187, guanine converted to adenine at base1211 and guanine converted to adenine at base 1277. These created a silent SNP (*Figure 7*).

GAAATAATTGGACAGGACGAGGGGAGGGGCGGTAATAGAAATTCAATCCCGGAACTCGAAAATTTCTATCT
ATCCTCGACGGATAATAATTTCGAGGAATTTATCAACACGCTCTTCGAAGCGTGAAAACGGGAGGGATTCTT
GTATTCCTTTCGGCAGGAAATGAAGAAACTTTTCTTCTGGAAAACCGGTTATCGAATACTGATATTTCCAGG
TGTATCTATCCCCAGTGCTTTCTATTCTCGAAACAAAGAAAAAGGGGTTCTCGGATCGAGAATATTTCTCCA
TTTCGTATGGAGAACGTTCTTGGACACGTGATATATCCTGAATCAAGTGGACGAGTCAAATTTGTGTTTAAG
ACAGTGTGAAATATTGTTTAAATTTTAAGGACGATGCGAGGAAGAGGACGGTGAAAATAATTTTTTGGTGA
TGATAAATAAAGGAAGGTTGAGATAATTATAGACCGATTTCGAATTGAATGAGGAGTGAACGAGACAATAA
GGAAAATCAGACGACGAAAGTGAAAAAGAAAAGGAAAGGATGGCGTTTGTCGAGGATGAATGGTAAATCT
CGAAGGTGCTAATAGTTTTAATTGTTCTTTTCTGGAACGTTTTGGAGGAGGATTGAACGAGGTGCATGATTC
GAAGCTAATTTTATCATTCATCATTTAAAAATTTCCTCTGAACATCGATCAGTTGTTTTATAATTCTCTTAAT
CTCCGATTATAAGCTGAATCCAAAAAGAAAAAATCAAGAAGAACCTAACCTCTAAATCTAACCTCAAAAAA
CTTGCATGAAACAATCGAGCAAAAATAATTGATCAAACACGTGTAAAAATAAGGAAGCTGCGAAACGAAC
CTAACCTCAAAATAAAAAGAACAGTATCTTCCTCCAAAGACCAAACAAAACGAATAGAACCTAACCTCAAA
AACCTAATTAAAAATTCCTGAACGAACAAAGATATACAAAGAAGAGAGAAAAGAATCGATCAACGATGAT
CTCAGGATTTGCAAAGGATCGATGATCGAATCGTTGCCGTGATGGAGGCGATCCATGCGATCCGTATTCGTC
GCTTTTCTTCCAGTGAAATCGTTTCGCGAGAGTCGTTGTTCGGTGCGTTGTTCGGCAGCAAGCGGTCTGAGA
TGGTTCGAGATTTGGCGCGACAGCTTGCCAACTAAAATGCGAGAGCTGAACGCGACCGCATGTGCTGCCCT
TTACGAGCGCGTCGAGTGGTCCGGACCGTGGATCCTGGTTACCCTGATCGTGCTCGCGATAGTGAACGTGAT
GGTGGTGCTGGGCAACGTGCTCGTGATACTCGCTGTCTATCACACGAGCAAGCTGCGAAACGTGACGAATA
TGTTCATCGTTAGCCTCGCGGTGGCGGATCTGATGGTCGGCCTGGCTGTCCTTCCGTTTAGCGCTACGTGGG
AGGTTTTCAAGGTGTGGATATTCGGTGATCTATGGTGCTCCATCTGGCTGGCGGTCGACGTATGGATGTGCA
CCGCGTCGATATTGAATTTGTGCGCCATCAGCCTGGATAGATACTTAGCTGTGACCAGGCCAGTCAGTTATC
CTCAGATCATGTCGCCGAGGAGAGCAAGGCTGCTGGTTGCAACCGTGTGGATCTTGAGCTTCGTCATCTGCT
TCCCACCCCTGGTCGGCTGGAAAGACAAACGGTCTCATCCCGCGTACAACATGACGTTTGCTCAAAACGGA
CCGTTCAAC**[c.1725A>G]**CCACCACCATCTTCGTCCCCGTGAAACCGTGTCCTTGGATCTGCGAGCTGACCAA
CGATGCCGGCTACGTCGTTTATAGCGCTCTTGGTTCTTTCTATATACCGATGTTGGTCATGCTGTTTTTCTACT
GGAGGATCTATAACGCGGCCGTCTCCACCACAAAGGCTATTAATCAAGGCTTCCGCACGACAAAGAGTTCG
AAAATGTTTGGCTCTAGATTCGACGAAGAGAGGTT**[c.1961G>A]**ACCTTGAGGATCCATCGTGGCCGAGGAA
GCGTGCACAATGGGAGCAACAACGGAAGTCCGAGGAGCCCCGAGTCGAACAGTCGGTGCTCGGTGAAAAG
GGAGAAGATAAAAATCTCGGTGTCGTATCCGAGCACGGAGACGTTGAATACAAAGTGTAACACCCT**[c.2126**
C>T]GAAAGAACGCCATCCAAGTGTTCTCA**[c.2153G>A]**ACCTCTGTGCATTACAGCAATGGGCAGACGCACA
GCCAATTGTGTCCAACCCCCAGAAGCACTCATTTAAAGGTGAGCGGCATCAACAGGGTTGGAAGCACCAGA
AGACCTAGCAGGAGGAACAGCTGCGAGAGTCA**[c.2291Ins>40bp]**ATGATGGGTGATGAGATGTCGTTGCGGG
AGCTCACTCAAGTCACCGAGGAGAAGCCAAG**[c.2351G>A]**GTGATGAAGATGGGGAAGAGAAATATTAAAG
CTCAGGTGAAGAGATTTCGAATGGAGACGAAGGCGGCGAAGACACTGGGCATCATCGTCGGCGGGTTCATC
CTCTGCTGGCTTCCTTTCTTCACAATGTACTTGGTGCGCGCCTTTTGCCGCAACTGCATCCACCCCACTGTGT
TTAGCGTACTGTTTTGGCTAGGCTA**[c.2552T>C]**TGCAACTCCGCAATAAATCCGTGTATCTACGCGCTGTTTA
GCAAGGACTTCCG**[c.2606G>A]**TTCGCGTTCAAAAGTATCATCTGCAAGTGCTTCTGCAAACGGCGGACGAA
CACTTTGAGACGCGGCAGCGATGGAAGTCAATTAGCGATGAGAAACGATCGGAGCCCAAGCTACTCGATGC
AAGTTC**[c.2734C>T]**CCAACAGGGGGCGTCCATCGACGACTCGGACCCGGACCCAAGCTCAGAACCGACTGT
GCATTCGCAGAGCGAGTCGAGATGACTGTAGCGTGCCAGGTGTGGCGCTCA**[c.2843A>G]**CGCGTCACCTTC
GATCCTAGAACCTCGAAAGTGAGGATCCAATCTTTCTAAGGATTTCACGTTTCGTGCCGCGAAATCGAGCAC
GACGAGAATCGAGTGCGAAAGGATGGACGTGGAATTCGCGACAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAACTCGAGGGG

Figure 3. Graphic sequence of the AmOA1 (F2-R2 primer) gene

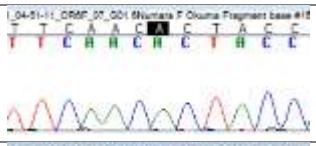
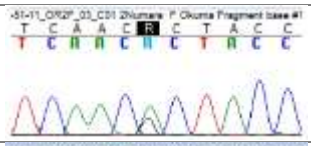
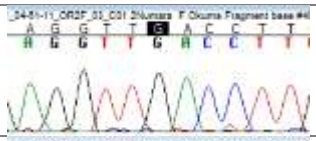
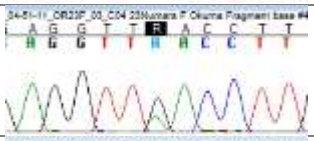
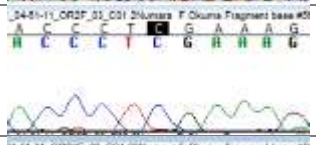
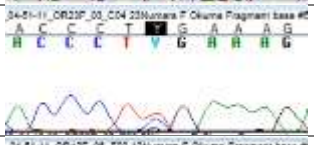
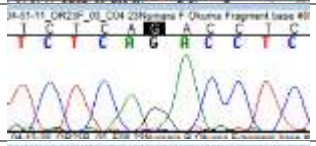
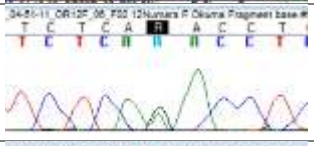
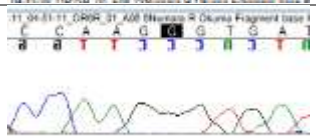
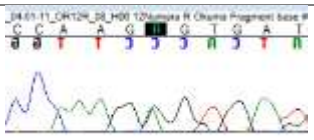
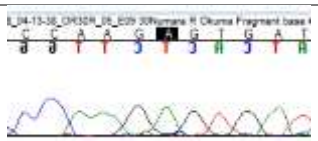
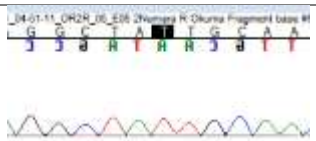
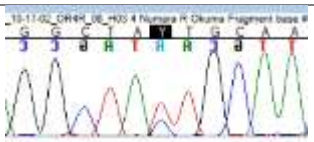
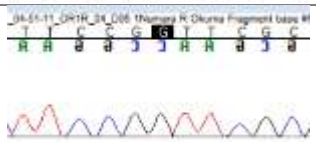
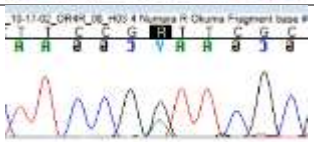
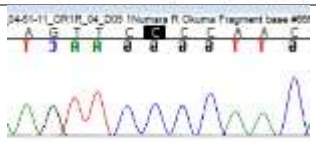
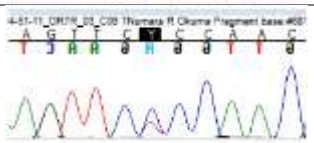
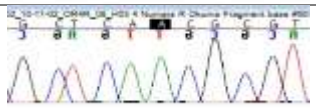
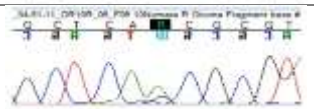
SNP	Chromatogram	Chromatogram	Chromatogram	Amino Acid
c.1725 A>G				Treonin > Alanin
c.1961 G>A				Silent
c.2126 C>T				Silent
c.2153 G>A				Silent
c. 2351 G>A				Silent
c.2552 T>C				Silent
c.2606 G>A				Silent
c.2734 C>T				Silent
c.2843 A>G				3'UTR

Figure 4. Chromatogram image of SNPs in the AmOA1 (F2-R2 primer) gene

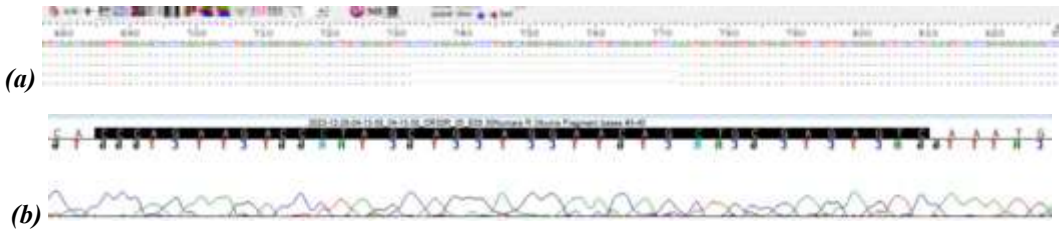


Figure 5. Added bases in one sample but not in the other (a) and chromatogram image (b) (c.2291 Ins >40bp)

CAAAAATGTGACGCTCGGCGTGCGCTCGACGGGCCGGGGCTCGAACAGAGAAGACTGGACGACTATTGGGAGCGTGACG
TTGGATTGACGAGAGCGGGCTCG|c.103-105TGA>del| ACAACATGAACTCGAGCGGGGAA TCAG GC GGGA CGATGAC
CGAGGACTA CGA|c.158C>G|ATGACAGGCTGCGGCCCGCCGGAAGAGGAA ACGGGC TCGAAC
TTGCCG|c.207G>A|TTTGGGAAGC|c.218C>G|GCGGCCGCCTCATTGACGCTTGGCTTC
CT|c.248G>C|GTTCTCGCGACGGTGTTGGGGAACGCGCTCGTGATCCTGAGCGTGTTCACGTACAGGCCCCTTCGTATCGTT
CAGAACTTCTTTATCGTGTCGCTAGCTGTCGCCGATCTCGCGGTCGCGATCCTCGTGATGCCGTTCAACGTCGCCTACCTCC
TCCTCGGCAAGTGGATCTTCGGCATACACCTGTGCAAATTGTGGCTAACCTGCGACGTGCTCTG|c.467C>T|TGCACGGCCA
GCATACTGAATCTGTGCGCCATCGCCCTCGACCGTTACTGGGCGATCACCGATCCCATCAATTACGCCCAGAAACGTACCC
TGAAGAGAGTACTGGCCACGATAGCCGGGGTGTGGATCCTGTCGGGGGCGATCAGCTCGCCCCCCCTGGCCGGTTGGAAC
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GGCCAGGCAGAGCAGGATAAACGCTGTCCAGTCGACGAGGCATCGCGAGGCGGACGACGCCGAGGAGTCGGTCAGCTCG
GAGACGAATCATAACGAGAGGTCGACCCCTCGGTCGCACGCCAAGCCGTCGTTGATCGACGACGAGCCGACCGAGGT|c.95
6C>T|ACGATAGGGGGTGGCGGTACCACGTCCTCGAGGCGGACGACGGGGAGCAGGGCAGCCGCGACCACGACAACGGTT
TACCAATTCATCGAGGAGAGGCAGAGGATCT|c.1063C>T|GTTGTCGAAGGAGAGACGGGCCGCGAGGACATTGGGCGTGA
TAATGGGCGTGTTCGTCGTATGCTGGTT|c.1133A>G|CCATTCTTTCTGATGTACGTGATCGTCCCGTTCTGCCCCGATTGTT
GCCCCTC|c.1187C>T|GATCGTATGGTCTACTTCATCAC|c.1211G>A|TGGCTCGGTTACGTGAACAGCGCCCTCAACCCGCTC
ATCTACACCATCTTCAACCTCGACTACAG|c.1277G>A|AGGGCATTCAGACGGTTGTTGCGCATTCGTTGAACACTTGTTGTT
GGCAACGCTTGTTTATTGCATCTATCGCGAAATTGTGGGAAACAAGATTTGCCGCCGAAATCGTCATCGGGACACTACTCG
GCCCCGCTTGGGATTGGTCGGCGAGGAAGGAAAGAGGATTGGAGTTCGGCTGAGTTTTTCGAGGAAGCGGCACCGAGCTT
GGCACGATTCAAATTCTTTCGAAGGAGGAAACGAGAGGGAAAAAATATGAAGAGTTTATTTTCGCGGAACGAAGAAGAA
GCGTCTAAAATATGGCGGTGGATTATTCGTAGAAACAAAGAGAGAGTTCGATGGAAGATTAAGCGATCAAAGGTCGAATA
CACGATAGTCTAATTTAGCGACGACGATGTTCACTCCCGGAAGAGTCGTTCCATTAAACTTGTTCCATTAATCCTGCTAGG
GAAGCGAGGGAGCGCGGATAAGGAATTTTAAGGAAATGAAGTCGCCGCCCCTGCTCGATTGTCCTATACCTCATTTCATCC
GTCGTTACGCGTTGAGTTCAGCTGAACGATAAATTCACCGCTATCTTCGATCGGTCATGAATAATGGAAATCGGTGGATTC
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TTTATTTTAAGATTCTATAAAAAATGCACAAGATATCGACCGATTTGAAAAATTTCAAATCGACGGACAAGACGATTTTCT
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TAGACCGTGAGACATCGCGTGATACGATGATAATATCCCTAAATGTGCGATTAGACGTTAAACCTAATCCCTAATTTACAC
GAACAATCGCAAATCGTGAATATCGAATAACAAAAGGGAAATCCAAAGAGTGCGAGGTGAAGGCGTAAGAAAAGGGCG
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AATGAAAAGAGAGAAAAATCGTCTGCACGTATCTCTGTATAAAAAAAATTACGTTTAAGTCGCCTCCAATCTTCTTCCCAT
TGACATTTAAAGCGCACACGAATCGTGTACAGGGCGCGTTCACGCGCGAGCCGAATACAAAAACCTTGGCTCCTCGTGCA
TCGGCTCGTTCGTCGATGCGTCGCGATCGCGTTTGAGGGAAGGAGAGGAAAAATCGTTCTCTCTAATGGAAAAAAAAAAA
AGAAAAAAAAAGAGAAAAAAGAAAAAAACGTATAAAAAAAAAAAAAAAA

Figure 6. Graphic sequence of the AmTYR1 (F3-R3 primer) gene

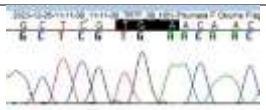
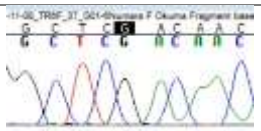
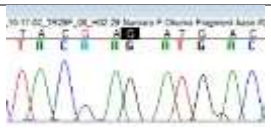
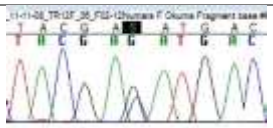
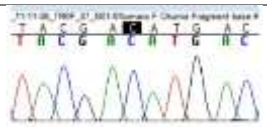
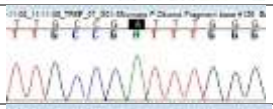
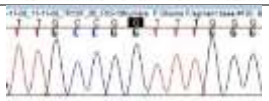
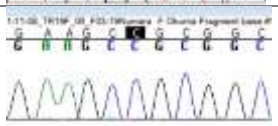
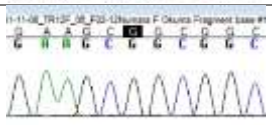
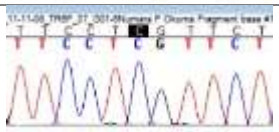
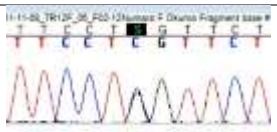
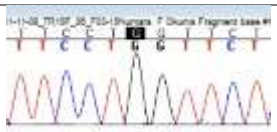
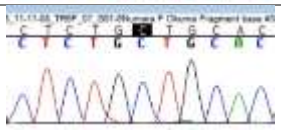
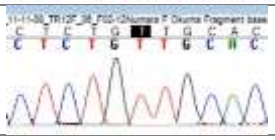
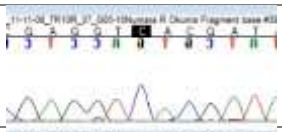
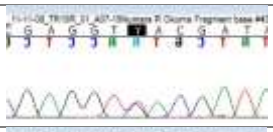
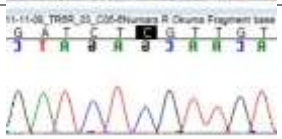
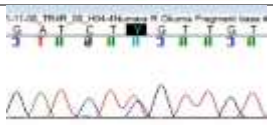
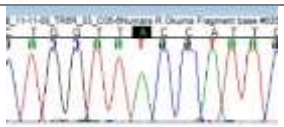
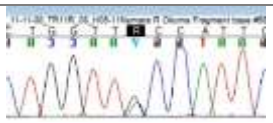
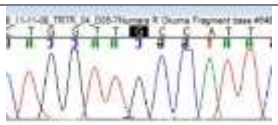
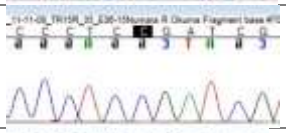
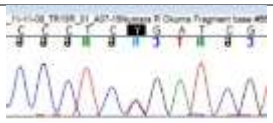
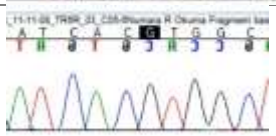
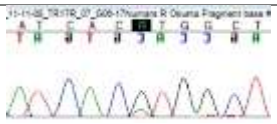
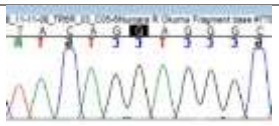
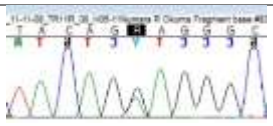
SNP	Chromatogram	Chromatogram	Chromatogram	Amino Acid
c.103-105 TGA>del				5'UTR
c.158 C>G				Aspartic acid > Glutamic acid
c.207 G>A				Valine > Isoleucine
c.218 C>G				Silent
c.248 G>C				Silent
c.467 C>T				Silent
c.956 C>T				Silent
c.1063 C>T				Serine > Leucine
c.1133 A>G				Silent
c.1187 C>T				Silent
c.1211 G>A				Silent
c.1277 G>A				Silent

Figure 7. Chromatogram image of SNPs in the AmTYR1 (F3-R3 primer) gene

4. Conclusions

In this study, hygienic tests were carried out a total of 3 times at 21-day intervals according to the pin-killed method on 102 breeder Efe Bee colonies created from breeder queen bees produced in AARI. As stated by Guzman et al., (2002), colonies showing more than 95% hygienic behavior were determined as hygienic behavior colonies, and colonies showing less than 95% hygienic behavior were determined as non-hygienic behavior colonies. The pin-killed

method has also been used in many scientific studies on hygienic behavior (Palacio et al., 2000; Nicodemo et al., 2013; Oskay et al., 2014; Kekeçoğlu et al., 2015). In this study, the pin-killed method was used to determine colonies that showed hygienic and non-hygienic behavior, and in all pin-killed measurements, bee samples were collected by putting them in tubes and placed in liquid nitrogen, then stored in a -80°C. As Goode et al., (2006) stated, since 15-20 day old worker bees exhibit hygienic behavior, worker bees in the brood area were collected for analysis in this study.

According to all measurement results, it was decided to use 5 hygienic behavior colonies and 5 non-hygienic behavior colonies in SNP analyses.

Studies show that the honey bee octopamine receptor plays a role in processing sensory inputs, modulating behavior and learning, and hormone biosynthesis, and also plays a role in hygienic behavior by contributing to cellular signaling processes. Despite this, there are limited studies on the determination of SNPs in the Octopamine receptor in honey bees. Therefore, the focus was on Octopamine receptors in hygienic behavior and SNPs in the AmOA1 receptor gene were investigated.

Since Farooqui (2007) stated that information about environmental stimuli is transmitted to the insect brain and causes certain behavioral responses, and hygienic behavior occurs with these responses, and Peng et al., (2021) also stated that biogenic amine receptors are expressed in different parts of the bee brain, worker bee heads were used for RNA analysis. SNPs in the Octopamine receptor gene were tried to be determined in the samples sent for sequence analysis.

We tried to compare our groups with hygienic behavior and non-hygienic behavior in order to determine the importance in hygienic behavior breeding. As a result of the sequence analysis, 10 polymorphisms were determined in the AmOA1 (F2-R2 primer) gene in all of the breeder Efe Bees showing hygienic and non-hygienic behavior. An additional gene region was detected in only one sample. In the AmTYR1 (F3-R3 primer) gene, 1 exon could be sequenced and 11 polymorphisms were determined.

Göze and Özdil (2023) reported the need to describe the behavioral characteristics of honey bee races in detail. All the polymorphisms identified and how some of the polymorphisms cause changes in amino acids have not been reported before in Efe Bee. It is thought that the identified SNPs can be evaluated as a breeding criterion, but it is beneficial to study with more samples in future studies to determine the relationship of polymorphisms with hygienic behavior.

No specific article was found that directly relates of the AmOA1 and AmTYR1 receptor genes to hygienic behavior in honey bees.

Classical breeding methods have been used in beekeeping for many years and therefore there is a wide knowledge and experience on this subject. These methods are based on natural selection and the natural behavior of bees, which can help protect genetic diversity. Classical methods are generally less costly, do not require special laboratory equipment, are usually long-term, and require observation and selection over several generations. Selecting targeted features may be less precise and there is a risk of spreading undesirable features. Classical methods may be less effective when genetic information is limited. Molecular breeding methods allow for rapid and precise identification and modification of genetic traits. Genetic modifications enable the effective development of specific traits, such as resistance to certain diseases or pests. Advanced molecular methods enable more conscious and targeted breeding studies using genomic information. Molecular methods are advantageous when specific genetic traits need to be obtained quickly and precisely.

Octopamine receptors and tyramine receptors are proteins that mediate the effects of this neurotransmitter in cells. Octopamine receptor genes and tyramine receptor genes play a key role in regulating the nervous system functions and behaviors of honey bees. Research on these genes can help us better understand bee biology and develop more effective methods to protect the health of bees. Manipulating the functioning of octopamine receptors and the function of octopamine receptor genes may increase the resistance of bees to certain diseases or stress factors. This may allow for the development of new strategies in beekeeping practices.

Octopamine and tyramine are one of the bee's neurotransmitters, and this molecule functions similarly to adrenaline and noradrenaline in invertebrates. Several different octopamine receptor genes and tyramine receptor genes have been identified in honeybees. These genes are expressed in different tissues and cell types and regulate a variety of behaviors

and physiological responses in bees. The functioning and regulation of octopamine receptor genes is also critical to understanding bee responses to environmental stimuli. Breeding studies conducted using molecular methods towards hygienic behavior in honey bees both increase the health and productivity of bee colonies and provide environmental and economic benefits. Such breeding studies play an important role in increasing the sustainability and success of beekeeping. Beekeepers can protect the health of their colonies and reduce chemical use by choosing colonies that exhibit hygienic behavior. This has positive consequences for both bee populations and ecosystem health.

The results obtained from this study have made significant contributions in terms of guiding breeding studies. More comprehensive studies to be conducted in the future will increase the knowledge base on this subject and it will contribute to the development of application issues.

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Ethical Statement

Since this study was conducted on an invertebrate species, *Apis mellifera*, approval from ethics committees was not required.

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Özsoy, N., Yücel, B., Erdoğan, M.; Design: Özsoy, N., Yücel, B., Erdoğan, M.; Data Collection or Processing: Özsoy, N., Yücel, B., Erdoğan, M.; Literature Search: Özsoy, N.; Writing, Review and Editing: Özsoy, N., Yücel, B., Erdoğan, M.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Ekim Dönemlerinin Bazı Oleik ve Linoleik Tip Aspir Çeşitlerinin (*Carthamus tinctorius* L.) Tohum Verimi ve Kalite Özelliklerine Etkisi*

Effect of Sowing Periods on Seed Yield and Quality Traits of Some Oleic and Linoleic Type Safflower Cultivars (*Carthamus tinctorius* L.)

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Öz

Tekirdağ Namık Kemal Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü araştırma ve uygulama arazisinde 2019-2020 ve 2020-2021 yetiştirme sezonunda yürütülen bu araştırmada kışlık ve yazlık olarak ekilen bazı oleik ve linoleik aspir çeşitlerinin tohum verimi ve kalite öğelerine etkilerinin belirlenmesi amaçlanmıştır. Bu amaçla araştırmada 9 adet aspir çeşidi (Dinçer, Balcı, Linas, Olas, Göktürk, Olein, Asol, Hasankendi ve Koç 42) materyal olarak kullanılmış, denemeler kışlık ve yazlık olarak, 'Tesadüf Blokları Deneme Deseni'ne göre 3 tekrarlamalı olarak yürütülmüştür. Tarımsal ve teknolojik özelliklerin belirlenmesi amacıyla araştırmada, bitki boyu (cm), dal sayısı (adet) tabla sayısı (adet), tabladaki tohum sayısı (adet), tabla çapı (cm), 1000 tane ağırlığı (g), olgunlaşma süresi (gün), tohum verimi (kg da^{-1}), yağ oranı (%), yağ verimi (kg da^{-1}), linoleik ve oleik yağ asitleri (%) gibi karakterler incelenmiştir. Yapılan varyans analizi sonucuna göre dönem ve çeşitlerin etkisi incelenen tüm karakterler bakımından istatistiki olarak önemli bulunmuştur. Araştırma sonuçlarına göre kışlık olarak ekilen aspir çeşitlerinin tohum verimi ve yağ oranı değerleri sırasıyla 147.78 kg da^{-1} ve %32.76 olarak saptanırken yazlık ekimlerde bu değerler 79.88 kg da^{-1} ve %34.90 olarak gerçekleşmiştir. Oleik yağ asidi oranı ise ekimlerin kışlık ve yazlık olarak yapılmasına göre farklılık göstermekle birlikte kışlık ekimlerde %28.32 olarak gerçekleşirken yazlık ekimlerde ise bu oran %31.45 olarak gerçekleşmiştir. Araştırmanın sonucu bir bütün olarak irdelendiğinde, Tekirdağ ekolojik koşullarında aspir bitkisinin kışlık ve yazlık olarak yetiştirilebileceği, kışlık ekimlerden daha yüksek tohum ve yağ verimi elde edilebileceği ve diğer çeşitlere nazaran linoleik tiplerden Balcı ve Linas çeşitleri ile oleik tiplerden Olas ve Asol çeşitlerinin daha uygun olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Aspir, Tohum verimi, Yağ oranı, Ekim dönemi, Yağ asitleri kompozisyonu

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Abstract

The aim of this study was to determine the effects of winter and spring sowing on seed yield and quality traits of some oleic and linoleic safflower cultivars in the 2019-2020 and 2020-2021 growing seasons in the research and application field of Tekirdağ Namık Kemal University, Faculty of Agriculture, Department of Field Crops. For this purpose, 9 cultivars (Dinçer, Balcı, Linas, Olas, Göktürk, Olein, Asol, Hasankendi and Koç 42) were used as material in the research, and the experiments were carried out winter and spring, according to the Randomized Complete Block Design with 3 replications. In study to determine the agricultural and technological traits, plant height (cm), branch number (pcs), head number (pcs), seed number per head (pcs), head diameter (cm), 1000 seed weight (g), days to maturity (day), seed yield (kg da^{-1}), oil content (%), oil yield (kg da^{-1}), linoleic and oleic fatty acids (%) were investigated. According to the results of the analysis of variance, the effects of sowing period and cultivars were found to be statistically significant for all characters examined. According to the research results, seed yield and oil content values of safflower varieties sowing in winter were determined as 147.78 kg da^{-1} and 32.76%, respectively, while these values in spring sowing were 79.88 kg da^{-1} and 34.90%. The oleic acid content varied according to winter and spring sowing, and was 28.32% in winter sowing, while this ratio was 31.45% in spring sowing. When the results of the research were examined as a whole, it was concluded that safflower can be grown in winter and spring in Tekirdağ ecological conditions, higher seed and oil yield can be obtained from winter sowing and linoleic type Balci and Linas and oleic type Olas and Asol cultivars are more suitable is more suitable than other cultivars.

Keywords: Safflower, Seed yield, Oil content, Sowing period, Fatty acid composition

1. Giriş

Aspir (*Carthamus tinctorius* L.), *Asteraceae* familyasından, 2n=24 kromozomlu, Güney Asya orijinli, günümüzden yaklaşık 3000 yıl önce kültüre alınmaya başlanmış eski kültür bitkilerinden birisidir. Aspir tohumlarında %25-45 arasında yağ bulunmakta olup, bu yağın yaklaşık %90'ı doymamış yağ asitleri (oleik ve linoleik asit) içermektedir (Johnson ve ark., 1999; Weiss, 2000). Ayrıca kuraklığa dayanıklı olması, sulamaya ihtiyaç duymaması, kışlık ve yazlık olarak yetiştirilebilmesi bitkiyi diğer yağ bitkilerine göre avantajlı duruma getirmektedir.

Aspir yetiştiriciliğinde sanayi açısından öncelik yüksek yağ verimi iken çiftçi açısından yüksek tohum verimi ve dolayısıyla sağladığı kazançtır. Yapılan bazı araştırmalarda aspir ekiminin kışlık ve yazlık olarak yapılmasına göre ve özellikle yazlık ekimlerde ekim zamanın gecikmesiyle tohum veriminin ve buna bağlı olarak yağ veriminin önemli ölçüde etkilendiği birçok araştırıcı tarafından bildirilmiştir (Keleş ve Öztürk, 2012; Kumar Barla ve ark., 2020; El Bey ve ark., 2021; Culpan, 2023a).

Bütün kültür bitkilerinde olduğu gibi birim alandan alınan tohum verimi, çeşitlerin genetik potansiyeline, adaptasyon yeteneğine, ekolojik koşullara ve agronomik uygulamalara doğrudan bağlıdır. Aspirde ekim zamanı iyi ayarlanmadığı takdirde çimlenme ve çıkışlarda sorun yaşanmakta ve dolayısıyla dekardaki optimum bitki sıklığına ulaşılamamaktadır. Aspirde kışlık ekim ya da kışları ekimin mümkün olmadığı bölgelerde ilkbaharda (şubat sonu-mart başı) yapılan erken ekim tohum verimini önemli ölçüde etkilemekte ve artırmaktadır. Aspir ve kolza diğer yağ bitkilerine nazaran soğuklara ve kışa daha toleranslıdır. Bu sebeple aspir erken ilkbaharda, kışları çok soğuk olmayan ılıman bölgelerde ise sonbaharda ekilmelidir. Özellikle bölgeye iyi adapte olabilen aspir çeşitlerinin belirlenmesi ve belirlenen bu çeşitler ile uygun zamanda ekim yapılması durumunda tohum ve yağ verimi istenilen düzeye gelebilecektir.

Ülkemizde tescilli 15 adet (Yenice 5-38, Dinçer 5-18-1, Remzibey-05, Balcı, Linas, Olas, Göktürk, Asol, Hasankendi, Askon 42, Yektay, Servetağa Olein, Koç 42 ve Safir) aspir çeşidi bulunmaktadır (Anonim, 2025). Bu çeşitler biyolojik yazlık çeşitler olup kışları ılıman ve sıcak geçen geçit bölgelerde kışlık olarak başarıyla yetiştirilebilmektedir. Yapılan birçok çalışma aspirde kışlık ekimlerin yazlık ekimlere göre özellikle tohum verimi bakımından avantajlı olduğunu ortaya koymuştur. Aspirin tohum verimi ve verim unsurları ayçiçeği ile karşılaştırıldığında kışlık ekilen aspirlerin ayçiçeğine göre daha müspet sonuçlar verdiği fakat yazlık ekilen aspirlerin yağ oranı hariç diğer özellikler bakımından zayıf kaldığını göstermiştir. Bu araştırmada, Tekirdağ ekolojik koşullarında kışlık ve yazlık ekimlerin bazı oleik ve linoleik aspir çeşitlerinin tohum verimi ve kalite öğelerine etkilerinin belirlenmesi amaçlanmıştır.

2. Materyal ve Metot

2.1. Araştırma yerinin iklim ve toprak özellikleri

Çalışma, Tekirdağ Namık Kemal Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü araştırma ve uygulama arazisinde kışlık ve yazlık ekim yapılarak, 2019-2020 ve 2020-2021 yetiştirme sezonunda yürütülmüştür. Uygulama arazisinin toprak yapısı killi olup (C), pH'sı hafif alkali (7.10) ve organik madde bakımından da fakirdir (%1.25). Kireç problemi olmayan uygulama alanı topraklarının (%2.40), fosfor seviyesi düşük (7.73 ppm), potasyum yönünden zengindir (282.5 ppm).

Çalışmanın yürütüldüğü 2019-2020 ve 2020-2021 yetiştirme sezonunda ortalama sıcaklıklar kışlık ekimlerde benzer düzeyde seyrederken yazlık ekimlerde yıllar arasındaki ekim zamanlarındaki farklılıktan kaynaklı olarak yaklaşık 4.5 °C'lik bir fark meydana gelmiştir. Toplam yağış miktarı ilk yıl kışlık ekimlerde daha düşük iken yazlık ekimlerde ise ilk yıl düşen toplam yağış miktarı daha fazladır (*Tablo 1*).

Aspir, iklim ve toprak istekleri bakımından fazla seçici olmayan ve kuraklığa dayanıklılığıyla ön plana çıkan değerli bir yağ bitkisidir. Bu nedenle, deneme yerinin iklim ve toprak özellikleri incelendiğinde mevcut koşullar aspir tarımı için yeterli ve uygundur.

Tablo 1. Deneme alanının iklim verileri ve uzun yıllar ortalamaları*

*Table 1. The climatic conditions of the experimental area and long-term averages**

Aylar	Ortalama Sıcaklık (°C)			Toplam Yağış (mm)			Oransal Nem (%)		
	2019-2020	2020-2021	Uzun Yıllar (Ort.) **	2019-2020	2020-2021	Uzun Yıllar (Ort.) **	2019-2020	2020-2021	Uzun Yıllar (Ort.) **
Kasım	15.5	11.6	11.5	17.4	1.1	60.9	75.7	72.5	82.9
Aralık	9.5	10.1	7.2	22.3	35.9	78.4	75.2	78.7	83.0
Ocak	5.8	7.8	5.2	32.4	123.5	58.6	71.5	76.4	83.3
Şubat	7.9	7.3	5.8	55.1	48.8	61.1	75.3	73.6	81.3
Mart	9.6	7.0	8.1	26.1	45.2	52.2	74.6	72.7	80.4
Nisan	10.7	10.7	12.0	43.6	49.0	41.4	70.9	73.2	78.2
Mayıs	16.6	17.5	17.1	93.4	57.6	38.4	73.0	70.1	76.7
Haziran	21.3	20.8	21.7	67.3	53.3	39.4	71.3	73.6	73.8
Temmuz	24.6	25.8	24.4	0.0	3.4	27.4	65.6	66.0	70.1
Ağustos	25.0	25.7	24.8	6.2	23.4	16.4	66.4	69.5	70.7
Ort./Top.* **	**14.65**	**14.43**	**13.78**	**363.80**	**441.20**	**474.20**	**71.95**	**72.63**	**78.04**
	17.97	**22.45**		**236.60**	**137.70**		**70.30**	**69.80**	

*Tekirdağ Meteoroloji İstasyonu, **1990-2021, ***Koyu sütunlar ilgili yılın yazlık ekim-hasat aylarını ifade eder.

2.2. Materyal

Çalışmada Eskişehir Geçit Kuşağı Tarımsal Araştırma Enstitüsü tarafından geliştirilmiş olan Dinçer ve Balcı çeşitleri, Trakya Tarımsal Araştırma Enstitüsü tarafından geliştirilmiş olan Linas, Olas ve Asol çeşitleri, Bahri Dağdaş Tarımsal Araştırma Enstitüsü tarafından geliştirilen Koç 42 ve Göktürk çeşitleri, Isparta Uygulamalı Bilimler Üniversitesi tarafından geliştirilen Olein çeşidi ile Tarla Bitkileri Merkez Araştırma Enstitüsü tarafından geliştirilen Hasankendi çeşitleri materyal olarak kullanılmıştır. Çeşitlere ait bazı özellikler *Tablo 2*'de verilmiştir.

Tablo 2. Denemede kullanılan çeşitler ve bazı özellikleri

Table 2. Cultivars used in the experiment and some of their characteristics

No	Çeşit Adı	Özellikler	Tohum Verimi (kg da^{-1})	Yağ Oranı (%)	Tescil Tarihi
1	Dinçer	Dikensiz, Linoleik	150-250	28-32	1983
2	Balcı	Dikenli, Linoleik	120-240	38-41	2011
3	Linas	Dikenli, Linoleik	250-350	37-38	2013
4	Olas	Dikenli, Oleik	250-350	39-40	2015
5	Göktürk	Dikenli, Linoleik	150-250	30-33	2016
6	Olein	Dikenli, Oleik	200-250	30-33	2016
7	Asol	Dikenli, Oleik	250-350	40-41	2018
8	Hasankendi	Dikenli, Linoleik	150-250	36-38	2018
9	Koç 42	Dikenli, Linoleik	200-250	37-39	2019

2.3. Yöntem

Denemeler kışlık ve yazlık olarak, 'Tesadüf Blokları Deneme Deseni'ne göre 3 tekrarlamalı olarak yürütülmüştür. Denemelerde her çeşit 5 m uzunluğundaki parsellere sıra arası 20 cm (Arslan ve Culpan, 2020), ekim derinliği 3-4 cm olacak şekilde 6 sıra halinde elle ekilmiştir. Toprak analizi sonucuna göre dekara 12 kg saf azot ve 6 kg saf fosfor verilmiştir. Azotun yarısı ekimle beraber diğer yarısı bitkiler sapa kalktığında, fosforun ise tamamı ekimle birlikte verilmiştir (Arslan ve Culpan, 2018). Bitki boyu 10-15 cm'ye ulaştığında ilk çapa yapılmıştır. Yabancı ot yoğunluğuna bağlı olarak, denemelerde farklı dönemlerde iki kez çapa yapılmış ve sulama yapılmamıştır. Denemelerin ekim ve hasat tarihleri *Tablo 3*'te verilmiş olup hasatlar her iki yılda da elle yapılmıştır.

Olgunlaşma ile birlikte hasat öncesi her parselden tesadüfen seçilen 10 bitkide bazı gözlem ve ölçümler gerçekleştirilmiştir. Bu bağlamda, bitki boyu (cm), dal sayısı (adet) tabla sayısı (adet), tabladaki tohum sayısı

(adet), tabla çapı (cm), 1000 tane ağırlığı (g), olgunlaşma süresi (gün), tohum verimi (kg da^{-1}), yağ oranı (%), yağ verimi (kg da^{-1}), linoleik ve oleik yağ asitleri (%) gibi karakterler incelenmiştir (Culpan, 2021).

Tablo 3. Denemelerin ekim ve hasat tarihleri*

Table 3. Sowing and harvesting dates of the experiments

Yıl	Dönem	Ekim	Hasat
2019-2020	Kışlık	08/11/2019	11/08/2020
	Yazlık	18/03/2020	11/08/2020
2020-2021	Kışlık	02/11/2020	27/08/2021
	Yazlık	01/05/2021	27/08/2021

*: İkinci yıl yazlık ekimleri, covid-19 önlemleri nedeniyle arazinin ekime hazırlanamamasından dolayı ilk yıla göre gecikmiştir.

Araştırmada yağ içeriği, Nükleer Manyetik Rezonans (NMR) cihazında yüzde (%) okuma yapılarak belirlenmiştir. Her parselden alınan 50 g numune, fırında 105 ºC de 8 saat kurutulduktan sonra, %0 nem oranında analiz edilerek belirlenmiştir. Yağ asitleri kompozisyonu ise alev iyonlaşma detektörüne (FID-Flame Ionization Dedector) sahip gaz kromotografisi (Agilent 7820A) cihazında belirlenmiştir. Yağların metillendirilmesi için soğuk pres tekniği ile elde edilmiş 1 mg ham yağ üzerine 0.5 ml metanollü potasyum hidroksit ilave edilerek çalkalanmıştır. Daha sonra bu karışımın üzerine 10 ml n-heptan eklenerek çözelti tekrar çalkalanmış ve gliserolün ayrılmasıyla çözelti bulanıklaşmıştır. 1 saat bekledikten sonra gliserolün çökelmesiyle beraber oluşan faz ayrımında üst faz metil esterleri alınarak Gaz Kromatografi (GC) cihazına direk olarak verilmiş ve analiz yapılmıştır. Yağ asitlerine ilişkin kromatogramlar elde edilerek palmitik ($C_{16:0}$), stearik ($C_{18:0}$), oleik ($C_{18:1}$) ve linoleik ($C_{18:2}$) yağ asitlerinin % oranları tespit edilmiştir. Elde edilen kromotogramlardaki pikler ticari standart yağ asidi metil ester karışımına (Sigma, Supelco® 37 Component FAME Mix) göre isimlendirilmiştir. GC cihazının çalışma koşulları *Tablo 4*'te verilmiştir.

Tablo 4. GC cihazının çalışma koşulları

Table 4. Operating conditions of the GC device

Cihaz	Agilent 7820A GC
Dedektör Tipi	FID - Alev İyonizasyon Dedektörü
Kullanılan Kolon	J&A 112-88A7 (100 m × 0.25 mm, 0.2 µm)
Enjektör Sıcaklığı	250 ºC
Dedektör Sıcaklığı	280 ºC
Enjektör Kapasitesi	1 µm
Gaz Hızları	Hidrojen (40 mL/dk) Hava (450 mL/dk) Helyum (30 mL/dk)
Fırın Sıcaklığı	120 ºC'de 1 dk bekledikten sonra 175 ºC'ye 10 ºC/dk artışla ulaşıyor. 175 ºC'de 10 dk bekliyor. 5 ºC/dk artışla 210 ºC'ye ulaşıyor. Bu sıcaklıkta 5 dk bekliyor. 5 ºC/dk artışla 230 ºC'e ulaşıyor. Bu sıcaklıkta da 5 dk bekliyor.

2.4. Verilerin Değerlendirilmesi

Araştırma sonucundan elde edilen verilerin varyans analizi tesadüf blokları deneme desenine göre yapılmıştır. Ortalamalar arasındaki farklılıkların istatistiki olarak önem düzeyleri belirlenerek EKÖF (En küçük önemli fark) değerleri TARİST istatistiki analiz programı yardımıyla ortaya konulmuştur.

3. Araştırma Sonuçları ve Tartışma

Araştırmadan elde edilen verilerin varyans analizi sonucuna göre, ekim dönemlerinin etkisi tabladaki tohum sayısı ve yağ oranı hariç ($p \leq 0.05$) istatistiki olarak $p \leq 0.01$ düzeyinde önemli bulunurken, çeşitlerin etkisi incelenen tüm karakterler bakımından istatistiki olarak $p \leq 0.01$ düzeyinde önemli bulunmuştur (*Tablo 5*). Ayrıca Dönem x Çeşit interaksiyonunun etkisi tabla sayısı ve tabla çapı hariç istatistiki olarak önemli bulunmuştur.

Tablo 5. 2019-2020 ve 2020-2021 yılı verim ve kalite özelliklerine ilişkin birleştirilmiş varyans analizi

Table 5. The results of combined variance analysis of yield and quality traits of 2019-2020 and 2020-2021

VK	sd	BB	DS	TS	TTS	TÇ	BTA	OS	TV	YO	YV	LA	OA
Yıl (Y)	1	öd	*	*	öd	öd	*	**	**	öd	*	*	**
Tekerrür	4	öd	*	*	öd	öd	öd	*	öd	öd	öd	öd	öd
Dönem (D)	1	**	**	**	*	**	**	**	**	*	**	**	**
Y × D	1	*	**	**	öd	öd	*	**	**	öd	**	öd	*
Hata$_1$	4												
Çeşit (Ç)	8	**	**	**	**	**	**	**	**	**	**	**	**
Y × Ç	8	öd	öd	öd	öd	öd	öd	öd	öd	öd	*	öd	**
D × Ç	8	**	*	öd	**	öd	**	**	**	*	**	**	**
Y × D × Ç	8	*	öd	öd	öd	öd	öd	öd	öd	öd	öd	öd	**
Hata	64												
Genel	107	--	--	--	--	--	--	--	--	--	--	--	--
CV (%)		**16.52**	**13.57**	**18.03**	**27.51**	**8.08**	**4.54**	**0.58**	**6.74**	**4.05**	**7.05**	**1.25**	**1.77**

**: $p \leq 0.01$ düzeyinde önemli, *: $p \leq 0.05$ düzeyinde önemli, öd: önemsiz, VK: Varyasyon kaynağı, CV: Varyasyon katsayısı, sd: Serbestlik derecesi, BB: Bitki boyu, DS: Dal sayısı, TS: Tabla sayısı, TTS: Tabladaki tohum sayısı, TÇ: Tabla çapı, BTA: Bin tane ağırlığı, OS: Olgunlaşma süresi, TV: Tohum verimi, YO: Yağ oranı, YV: Yağ verimi, LA: Linoleik asit oranı, OA: Oleik asit oranı.

Bitki boyu: Dönem ortalamaları incelendiğinde kışlık ekimlerde bitki boyu 121.80 cm, yazlık ekimlerde ise 78.48 cm olarak belirlenmiştir. Çeşit ortalamalarında ise en düşük bitki boyu Koç 42 (82.78 cm) ve Asol (95.05 cm) çeşitlerinde saptanmıştır (*Tablo 6*). Aspirde ideal bitki boyunun 60-80 cm arasında olduğu, bitki boyunun ekim zamanı ile ekimlerin kışlık ve yazlık olarak yapılmasına göre bitki boyunun değiştiği bildirilmiştir (Weiss, 2000; Paşa, 2008; İnan, 2014; Arslan ve Culpan, 2018). Ayrıca yapılan birçok çalışmada aspirde bitki boyunun ekolojik koşullar, genotip, ekim mesafeleri, azotlu gübreleme ve kullanılan tohumluk miktarına göre önemli değişiklik gösterdiği bildirilmiştir (Katar ve ark., 2015; Köse ve Bilir, 2017; Gürsoy ve ark., 2018). Yapılan bazı çalışmalarda kışlık olarak ekilen aspirde bitki boyunu Paşa (2008) 132.16-207.50 cm, Yılman (2017) 112.93-120.68 cm belirlerken, yazlık olarak ekilen aspirde bitki boyunu Aykaç (2017) 74.0-75.8 cm, Culpan (2021) 53.63-77.50 cm olarak belirlemişlerdir. Ayrıca Culpan ve Arslan (2022) yazlık olarak yetiştirilen oleik ve yarı oleik bazı aspir genotiplerinde bitki boyu değerlerinin 72.35-81.40 cm arasında değiştiğini bildirmişlerdir. Elde edilen sonuçlar literatürde belirtilen araştırıcıların sonuçları ile benzerlik göstermektedir.

Dal sayısı: Dönem ortalamalarında kışlık ekimlerde dal sayısı 6.11 adet olarak belirlenirken yazlık ekimlerde bu değer 4.83 adet olarak belirlenmiştir. Dönem x Çeşit interaksiyonunda ise en yüksek dal sayısı 7.38 adet ile kışlık olarak yetiştirilen Balcı çeşidinden elde edilmiştir (*Tablo 6*). Aspirde optimum dal sayısının 6 ila 8 adet arasında olduğu bildirilmekle birlikte (Weiss, 2000) bu karakter iklim şartlarından (Pearl ve ark., 2014), kışlık ve yazlık ekimlerden (Öz, 2016), ekim mesafelerinden (Gürsoy ve ark., 2018) ve genotipe bağlı olarak (Culpan, 2021) oldukça farklılık göstermektedir. Yapılan bazı çalışmalarda kışlık ekilen aspirlerden yazlık ekilenlere göre daha fazla dal sayısı elde edildiği (Paşa, 2008; İnan, 2014) ve özellikle yazlık ekimlerde ekimlerin gecikmesiyle dal sayısının önemli derecede azaldığı bildirilmiştir (Oruç ve Yılmaz, 2019; Aslantaş ve Akınerdem, 2020; Ghareeb, 2024).

Tabla sayısı: Dönem ortalamaları incelendiğinde kışlık ekimlerde tabla sayısı 10.81 adet, yazlık ekimlerde ise 7.56 adet olarak saptanmıştır. Çeşit ortalamalarında ise en düşük tabla sayısı Olein (7.19 adet) ve Asol (8.46 adet) çeşitlerinden elde edilmiştir (*Tablo 6*). Aspirde tabla sayısı, tohum verimini doğrudan etkileyen önemli kriterler olup (Weiss, 2000; Tunçtürk ve ark., 2005; Koç, 2021) çeşit, ekim mesafeleri, ekim zamanı ve iklim gibi çevre koşullarından önemli ölçüde etkilenmektedir (Arslan ve ark., 2003; Köse ve Bilir, 2017; Arslan ve Güler, 2022). Yapılan çalışmalarda aspirde bitki başına tabla sayısını Köse ve ark. (2018), 9.4-13.0 adet, Atan ve ark. (2019) 11.53-16.20 adet, Arslan ve Culpan (2020) ise bu değerin 8.05-14.50 adet olduğunu bildirmişlerdir. Ayrıca benzer çalışmalarda dal sayısını yazlık ve kışlık olarak sırasıyla Coşge ve Kaya (2008) 8.58 ve 15.57 adet olarak belirlerken Aykaç (2017) 10.3 ve 18.1 adet olarak belirlemiştir. Araştırmanın her iki yılında da en yüksek tabla sayısı kışlık ekimlerden elde edilmiş olup benzer çalışmalar da (Kızıl, 2002; Öz, 2016; Sezek, 2018; Oruç ve Yılmaz, 2019) kışlık ekimlerde tabla sayısının yüksek olduğunu ortaya koymuş ve yapılan çalışma ile paralellik göstermiştir.

Tablo 6. Ekim dönemlerine göre incelenen bazı verim özelliklerine ait ortalama değerler

Tablo 6. Mean values of some yield traits analyzed according to sowing periods

Faktör		Bitki Boyu (cm)	Dal Sayısı (adet)	Tabla Sayısı (adet)	Tabladaki Tohum Sayısı (adet)	Tabla Çapı (cm)	Bin Tane Ağırlığı (g)
Yıl (Y)							
2019-2020		103.59	5.34 **b**	8.96 **b**	20.65	2.21	32.06 **b**
2020-2021		96.70	5.60 **a**	9.41 **a**	24.82	2.19	34.25 **a**
EKÖF (p≤0.05)		--	*0.23*	*0.33*	--	--	*1.40*
Dönem (D)							
Kışlık		121.80 **a**	6.11 **a**	10.81 **a**	26.43 **a**	2.35 **a**	34.59 **a**
Yazlık		78.48 **b**	4.83 **b**	7.56 **b**	19.05 **b**	2.06 **b**	31.72 **b**
EKÖF (p≤0.05)		*14.00*	*0.23*	*0.33*	*4.59*	*0.12*	*1.40*
Çeşit (Ç)							
Dinçer		108.44 **ab**	5.35 **b**	9.43 **a-d**	21.40 **bcd**	2.17 **bc**	34.18 **bc**
Balcı		102.85 **ab**	6.15 **a**	10.22 **ab**	26.73 **a**	2.22 **ab**	33.72 **bc**
Linas		109.87 **a**	5.99 **a**	9.17 **bcd**	23.45 **abc**	2.23 **ab**	36.33 **a**
Olas		101.81 **ab**	5.76 **ab**	9.87 **abc**	23.78 **abc**	2.17 **bc**	30.72 **d**
Göktürk		100.51 **ab**	5.37 **b**	8.98 **bcd**	20.80 **bcd**	2.16 **bc**	30.98 **d**
Koç 42		82.78 **c**	5.66 **ab**	8.68 **cd**	16.55 **d**	2.03 **c**	30.18 **d**
Asol		95.05 **bc**	5.24 **b**	8.46 **de**	27.34 **a**	2.35 **a**	34.18 **bc**
Hasankendi		102.72 **ab**	5.72 **ab**	10.70 **a**	25.72 **ab**	2.34 **a**	34.94 **b**
Olein		97.23 **ab**	3.97 **c**	7.19 **e**	18.88 **cd**	2.18 **b**	33.17 **c**
EKÖF (p≤0.05)		*13.49*	*0.60*	*1.35*	*6.50*	*0.14*	*1.22*
Y × D							
2019-2020	Kışlık	117.15 **a**	5.61 **b**	9.92 **b**	24.37	2.30	32.40 **b**
	Yazlık	90.02 **b**	5.07 **c**	7.99 **c**	16.94	2.12	31.73 **b**
2020-2021	Kışlık	126.44 **a**	6.61 **a**	11.69 **a**	28.48	2.40	36.78 **a**
	Yazlık	66.95 **c**	4.59 **d**	7.14 **d**	21.15	1.99	31.72 **b**
EKÖF (p≤0.05)		*19.81*	*0.32*	*0.47*	--	--	*0.43*
D × Ç							
	Dinçer	124.43 **a**	6.52 **b**	11.72	23.83 **c**	2.29	34.92 **bcd**
	Balcı	118.30 **a**	7.38 **a**	12.00	31.93 **ab**	2.38	35.37 **bc**
	Linas	136.60 **a**	6.40 **bcd**	10.83	26.00 **bc**	2.37	38.63 **a**
	Olas	126.95 **a**	6.15 **b-e**	12.08	23.88 **c**	2.23	33.62 **def**
Kışlık	Göktürk	122.95 **a**	5.78 **b-f**	9.85	19.80 **cd**	2.21	32.52 **e-h**
	Koç 42	87.55 **bc**	6.40 **bcd**	9.80	19.70 **cd**	2.24	30.98 **hi**
	Asol	120.95 **a**	5.63 **c-g**	9.98	35.73 **a**	2.61	34.32 **cd**
	Hasankendi	133.10 **a**	6.48 **bc**	12.87	32.07 **ab**	2.49	36.50 **b**
	Olein	125.37 **a**	4.25 **hi**	8.13	24.88 **bc**	2.35	34.48 **cd**
	Dinçer	92.45 **b**	4.20 **hi**	7.15	18.97 **cd**	2.05	33.45 **d-g**
	Balcı	87.42 **bc**	4.92 **gh**	8.43	21.52 **c**	2.06	32.08 **fgh**
	Linas	83.15 **bc**	5.58 **d-g**	7.52	20.90 **c**	2.085	34.03 **cde**
	Olas	76.67 **bc**	5.37 **efg**	7.65	23.68 **c**	2.10	27.83 **j**
Yazlık	Göktürk	78.08 **bc**	4.95 **fgh**	8.10	21.80 **c**	2.11	29.45 **ij**
	Koç 42	78.02 **bc**	4.92 **gh**	7.55	13.40 **d**	1.82	29.38 **ij**
	Asol	69.17 **c**	4.85 **gh**	6.93	18.95 **cd**	2.09	34.05 **cde**
	Hasankendi	72.35 **c**	4.97 **fgh**	8.53	19.37 **cd**	2.18	33.38 **d-g**
	Olein	69.10 **c**	3.70 **i**	6.25	12.88 **d**	2.00	31.85 **gh**
EKÖF (p≤0.05)		*19.09*	*0.85*	--	*5.10*	--	*1.73*
Ortalama		**100.14**	**5.46**	**9.18**	**22.73**	**2.20**	**33.15**

Aynı harfle gösterilen ortalamalar arasında fark bulunmamaktadır

Tabladaki tohum sayısı: Dönem ortalamalarında kışlık ekimlerde tabladaki tohum sayısı 26.43 adet olarak belirlenirken yazlık ekimlerde 19.05 adet olarak belirlenmiştir. Dönem x Çeşit interaksiyonunda ise en yüksek tabladaki tohum sayısı kışlık olarak yetiştirilen Asol (35.73 adet), Hasankendi (32.07 adet) ve Balcı (31.93 adet)

çeşitlerinden elde edilmiştir (*Tablo 6*). Aspirde tabladaki tohum sayısı, tabla sayısında olduğu gibi tohum verimini doğrudan etkileyen önemli bir kriterdir. Weiss (2000) aspirde ideal bir tohum verimi için tabladaki tohum sayısının 30-40 adet arasında olması gerektiğini rapor etmiş ve birçok çalışmada tabladaki tohum sayısının geniş bir varyasyon gösterdiği bildirilmiştir (Reddy ve ark., 2004; Çamaş ve Esendal, 2006; Adalı ve Öztürk, 2016; Atan ve ark., 2019). Benzer çalışmalarda tabladaki tohum sayısını yazlık ve kışlık olarak sırasıyla Golzarfar ve ark. (2012) 20.85 ve 29.86 adet olarak belirlerken İnan (2014) 11.00 ve 24.50 adet olarak belirlemiştir. Elde edilen sonuçlar literatür bulgularıyla uyum içerisindedir.

Tabla çapı: Dönem ortalamaları incelendiğinde kışlık ekimlerde tabla çapı 2.35 cm, yazlık ekimlerde ise 2.06 cm olarak ölçülmüştür. Çeşit ortalamalarında ise en yüksek tabla çapı Asol (2.35 cm), Hasankendi (2.34 cm), Linas (2.23 cm) ve Balcı (2.22 cm) çeşitlerinden elde edilmiştir (*Tablo 6*). Yapılan birçok çalışmada aspirde tabla çapı ile tohum verimi arasında olumlu ve önemli korelasyon olduğu bildirilmiştir (Çamaş ve ark., 2005; Arslan, 2007; Ali ve ark., 2020). Aspirde tabla çapı çok değişken bir karakter olup 1.57-4.13 cm arasında değişmektedir (Aydın, 2012; Arslan ve Culpan, 2018; Aslan, 2021). Aspir bitkisinde ekimlerin yazlık ve kışlık olarak yapılmasına göre tabla çapı değişmekle beraber bu değerleri sırasıyla Sezek (2018) 1.90 ve 2.10 cm belirlerken Çakır (2023) 2.12 ve 2.31 cm olarak belirlemiştir.

Bin tane ağırlığı: Dönem ortalamalarında kışlık ekimlerde bin tane ağırlığı 34.59 g olarak gerçekleşirken yazlık ekimlerde ise 31.72 g olarak gerçekleşmiştir. Çeşit ortalamalarında en yüksek bin tane ağırlığı Linas (36.33 g) çeşidinden elde edilirken, en düşük ise Koç 42 (30.18 g), Olas (30.72 g) ve Göktürk (30.98 g) çeşitlerinden elde edilmiştir. (*Tablo 6*). Aspirde tohum verimini ve dolayısıyla yağ verimini belirleyen en önemli kriterlerinden birisi de bin tane ağırlığıdır (Weiss, 2000). Tomar (1995) ve Öztürk (2019) aspirde ekim zamanının gecikmesiyle bin tane ağırlığının diğer özelliklere kıyasla daha fazla etkilendiğini ve azaldığını, bunun başlıca nedeninin ise sıcak ve kuru rüzgarlar ile tane doldurma dönemindeki muhtemel kuraklık olduğunu bildirmiştir. Araştırma sonuçlarımızla benzer olarak (Esendal ve ark., 2008; El Bey ve ark., 2021; Aydın, 2023) kışlık ekime kıyasla yazlık ekimlerin bin tane ağırlığının düştüğü ifade edilirken bazı araştırıcılar (Coşge ve Kaya, 2008; Aslantaş ve Akınerdem, 2020; Sajid ve ark., 2024) ekim zamanın gecikmesiyle bin tane ağırlığının arttığını rapor etmişlerdir. Çalışmalar arasındaki farklılıkların kullanılan çeşit farklılığı ve farklı çevre koşulları olduğu tahmin edilmektedir.

Olgunlaşma süresi: Dönem ortalamaları incelendiğinde kışlık ekimlerde olgunlaşma süresi 265.90 gün, yazlık ekimlerde ise 131.63 gün olarak belirlenmiştir. Dönem x Çeşit interaksiyonunda ise en geç olgunlaşma kışlık olarak ekilen Linas (269.50 gün), Hasankendi (269.00 gün) ve Asol (268.67 gün) çeşitlerinde gözlemlenirken en erken olgunlaşma ise yazlık olarak ekilen Göktürk (130.00 gün) ve Olein (130.67 gün) çeşitlerinden elde edilmiştir (*Tablo 7*). Aspirde olgunlaşma için yaklaşık 110 günlük bir vejetasyon süresine ihtiyaç vardır. Normal koşullarda yazlık aspir çeşitlerinin olgunlaşma süresi 120-150 gün iken, kışlık çeşitlerin olgunlaşma süresi ise yaklaşık 270 gün civarındadır (Paşa, 2008; Coşkun, 2014; Adıyaman, 2019). Yapılan bazı çalışmalarda yazlık aspir ekimlerinde olgunlaşma süresinin 120-143 gün (Sirel, 2011) ve 118-124 (Şeker, 2019) gün arasında, kışlık ekimlerde ise 293.67-296.00 gün (Paşa, 2008) ve Çakır (2023) 256.67-265.33 gün arasında değiştiği bildirilmiştir.

Tohum verimi: Dönem ortalamalarında kışlık ekimlerde tohum verimi 147.48 kg da^{-1} olarak gerçekleşirken yazlık ekimlerde ise 79.88 kg da^{-1} olarak gerçekleşmiştir. Çeşit ortalamalarında en yüksek tohum verimi Balcı (138.48 kg da^{-1}) çeşidinden elde edilirken, en düşük ise Koç 42 (92.02 kg da^{-1}) ve Dinçer (93.00 kg da^{-1}) çeşitlerinde saptanmıştır. Dönem x Çeşit interaksiyonunda ise en yüksek tohum verimi 185.90 kg da^{-1} ile kışlık olarak yetiştirilen Balcı çeşidinden elde edilmiştir (*Tablo 7*). Birçok araştırmacı aspirde sonbahar veya erken kış ekimlerinin, geç kış veya erken ilkbahar ekimlerine kıyasla daha yüksek tohum verimi alındığını vurgulamışlardır (Yau, 2007; Emongor, 2010; Cerrotta ve ark., 2020). Aspir bitkisinde ekimlerin yazlık ve kışlık olarak yapılmasına göre tohum verimi değişmekle birlikte bu değerleri sırasıyla Esendal ve ark. (2008) 139.00 ve 229.3 kg da^{-1}, Coşge ve Kaya (2008) 112.30 ve 200.74 kg da^{-1}, Sezek (2018) 82.90 ve 133.20 kg da^{-1}, Ghareeb (2024) 125.10 ve 154.46 kg da^{-1} olarak belirlemişlerdir. Çalışmamız bulguları ile diğer araştırıcıların bulguları arasındaki farklılığın; kullanılan çeşitler, lokasyon farklılıkları, iklim ve toprak özellikleri ile ekim zamanları arasındaki farklılıklarından kaynaklandığı söylenebilir.

Tablo 7. Ekim dönemlerine göre incelenen tohum verimi ve kalite özelliklerine ait ortalama değerler

Tablo 7. Mean values of seed yield and quality traits analyzed according to sowing periods

Faktör		Olgunlaşma Süresi (gün)	Tohum Verimi (kg da^{-1})	Yağ Oranı (%)	Yağ Verimi (kg da^{-1})	Linoleik Asit Oranı (%)	Oleik Asit Oranı (%)
Yıl (Y)							
2019-2020		203.98 **a**	109.40 **b**	33.41	36.71 **b**	62.00 **a**	29.48 **b**
2020-2021		193.55 **b**	117.96 **a**	34.26	40.03 **a**	61.39 **b**	30.29 **a**
EKÖF (p≤0.05)		*0.25*	*4.63*	--	*2.36*	*0.52*	*0.38*
Dönem (D)							
Kışlık		265.90 **a**	147.48 **a**	32.76 **b**	48.81 **a**	63.01 **a**	28.32 **b**
Yazlık		131.63 **b**	79.88 **b**	34.90 **a**	27.93 **b**	60.38 **b**	31.45 **a**
EKÖF (p≤0.05)		*0.35*	*4.63*	*1.71*	*2.36*	*0.52*	*0.38*
Çeşit (Ç)							
Dinçer		196.17 **c**	93.00 **ef**	27.70 **e**	25.79 **g**	76.32 **bc**	14.64 **f**
Balcı		198.33 **b**	138.48 **a**	35.04 **b**	48.04 **a**	76.68 **b**	14.43 **f**
Linas		200.42 **a**	127.85 **b**	35.78 **ab**	45.68 **b**	74.41 **d**	16.61 **d**
Olas		199.17 **b**	120.43 **c**	36.06 **ab**	43.02 **c**	32.91 **g**	60.15 **b**
Göktürk		198.25 **b**	98.49 **e**	31.39 **d**	30.63 **f**	74.99 **d**	16.53 **d**
Koç 42		198.58 **b**	92.02 **f**	33.76 **c**	30.54 **f**	75.98 **c**	15.75 **e**
Asol		200.17 **a**	124.85 **bc**	36.15 **ab**	44.67 **bc**	34.70 **e**	56.73 **c**
Hasankendi		200.92 **a**	109.36 **d**	36.74 **a**	39.75 **d**	79.92 **a**	11.51 **g**
Olein		196.92 **c**	118.67 **c**	31.88 **d**	37.19 **e**	29.33 **g**	62.59 **a**
EKÖF (p≤0.05)		*0.95*	*6.26*	*1.12*	*2.20*	*0.63*	*0.43*
Y × D							
2019-2020	Kışlık	261.48 **b**	128.82 **b**	32.43	42.31 **b**	63.29	28.23 **c**
	Yazlık	146.48 **c**	89.99 **c**	34.38	31.10 **c**	60.70	30.73 **b**
2020-2021	Kışlık	270.33 **a**	166.14 **a**	33.10	55.30 **a**	62.71	28.41 **c**
	Yazlık	116.78 **d**	69.78 **d**	35.42	24.75 **d**	60.06	32.17 **a**
EKÖF (p≤0.05)		*0.35*	*6.55*	--	*3.33*	--	*0.54*
D × Ç							
	Dinçer	260.50 **e**	116.88 **c**	27.39 **k**	32.25 **gh**	77.03 **cd**	13.52 **i**
	Balcı	265.50 **bc**	185.90 **a**	34.15 **efg**	63.40 **a**	77.77 **c**	13.09 **ij**
	Linas	269.50 **a**	158.25 **b**	35.66 **cde**	56.50 **b**	74.93 **ef**	15.97 **g**
	Olas	265.83 **bc**	160.57 **b**	35.12 **de**	56.36 **b**	33.63 **i**	59.20 **d**
Kışlık	Göktürk	266.50 **b**	117.50 **c**	29.75 **j**	35.07 **fg**	75.49 **e**	15.84 **g**
	Koç 42	264.50 **cd**	120.77 **c**	31.79 **hi**	38.51 **e**	76.64 **d**	14.68 **h**
	Asol	268.67 **a**	153.20 **b**	34.83 **def**	53.18 **c**	37.83 **h**	53.29 **e**
	Hasankendi	269.00 **a**	155.27 **b**	35.88 **cd**	55.65 **bc**	80.69 **a**	10.18 **k**
	Olein	263.17 **d**	159.00 **b**	30.30 **ij**	48.34 **d**	33.04 **ij**	59.07 **d**
	Dinçer	131.83 **f-i**	69.12 **f**	28.01 **k**	19.32 **k**	75.61 **e**	15.78 **g**
	Balcı	131.17 **hij**	91.07 **d**	35.92 **bcd**	32.68 **gh**	75.59 **e**	15.77 **g**
	Linas	131.33 **g-j**	97.45 **d**	35.91 **bcd**	34.86 **fg**	73.88 **g**	17.25 **f**
	Olas	132.50 **fgh**	80.28 **e**	37.01 **abc**	29.68 **h**	32.18 **jk**	61.10 **b**
Yazlık	Göktürk	130.00 **j**	79.48 **e**	33.02 **gh**	26.19 **i**	74.49 **fg**	17.21 **f**
	Koç 42	132.67 **fg**	63.28 **f**	35.72 **cde**	22.57 **j**	75.33 **ef**	16.81 **f**
	Asol	131.67 **f-i**	96.50 **d**	37.48 **ab**	36.16 **ef**	31.58 **k**	60.18 **c**
	Hasankendi	132.83 **f**	63.45 **f**	37.61 **a**	23.85 **ij**	79.15 **b**	12.84 **j**
	Olein	130.67 **ij**	78.33 **e**	33.45 **fg**	26.05 **i**	25.63 **l**	66.12 **a**
EKÖF (p≤0.05)		*1.34*	*8.85*	*1.58*	*3.12*	*0.89*	*0.61*
Ortalama		**198.77**	**113.68**	**33.83**	**38.36**	**61.69**	**29.88**

Aynı harfle gösterilen ortalamalar arasında fark bulunmamaktadır

Yağ oranı: Dönem ortalamaları incelendiğinde kışlık ekimlerde yağ oranı %32.76, yazlık ekimlerde ise %34.90 olarak belirlenmiştir. Çeşit ortalamalarında en yüksek yağ oranı Hasankendi (%36.74), Asol (%36.15), Olas (%36.06) ve Linas (%35.78) çeşitlerinden elde edilirken, en düşük yağ oranı ise Dinçer (%27.70) çeşidinden

elde edilmiştir. Dönem x Çeşit interaksiyonunda ise en yüksek yağ oranı her iki dönemde de (kışlık ve yazlık) Hasankendi çeşidinde belirlenmiştir (sırasıyla %35.88 ve %37.61) (*Tablo 7*). Sıcaklık, aspirde tohum verimi ve yağ oranı üzerinde önemli bir etkiye sahiptir. Özellikle çiçeklenme aşamasındaki yüksek sıcaklıklar aspirin yağ oranını azaltabilirken, tohum dolum aşamasındaki düşük sıcaklıklar ise yağ oranını artırabilmektedir (Abou Chehade ve ark., 2022; Rahnama ve ark., 2024; Sajid ve ark., 2024). Birçok araştırmacı aspirde yazlık ve kışlık ekimlere göre yağ oranının değiştiğini rapor etmiştir. Yapılan bazı çalışmalarda yağ oranı değerlerini yazlık ve kışlık olarak sırasıyla Coşge ve Kaya (2008) %22.14 ve %26.75, Ghareeb (2024) %25.67 ve %29.18 olarak belirlerken, İnan (2014) %31.8 ve %30.9, Aykaç (2017) %23.2 ve %21.2 olarak belirlemişlerdir. Çalışmamız bulguları ile bazı araştırıcıların bulguları paralellik gösterse de bazılarıyla zıtlık göstermiştir. Bu farklılığın temel nedeninin kullanılan çeşitler, yıllar arasındaki iklimsel farklılıklar ve döllenme dönemindeki sıcaklık farklılıkları olduğu söylenebilir.

Yağ verimi: Dönem ortalamalarında kışlık ekimlerde yağ verimi 48.81 kg da^{-1}, yazlık ekimlerde ise 27.93 kg da^{-1} olarak gerçekleşmiştir. Çeşit ortalamalarında en yüksek yağ verimi Balcı (48.04 kg da^{-1}) çeşidinden elde edilirken, en düşük yağ verimi ise Koç 42 (30.54 kg da^{-1}) ve Göktürk (30.63 kg da^{-1}) çeşitlerinde saptanmıştır. Dönem x Çeşit interaksiyonunda ise en yüksek yağ verimi 63.40 kg da^{-1} ile kışlık olarak yetiştirilen Balcı çeşidinden elde edilmiştir (*Tablo 7*). Tohum veriminde olduğu gibi aspirde yağ verimi de ekimlerin yazlık ve kışlık olarak yapılmasına göre farklılık göstermektedir. Yapılan birçok çalışmada, yüksek tohum veriminin kışlık ya da erken ilkbahar ekimlerinden elde edildiği, ekimlerin gecikmesiyle tohum veriminin ve dolaysıyla yağ veriminin azaldığı tespit edilmiştir (Kızıl, 2002; Esendal ve ark., 2008; Sezek, 2018; Abou Chehade ve ark., 2022). Elde edilen sonuçlar, ekimlerin yazlık ve kışlık olarak yapılması ve ekim zamanının gecikmesiyle yağ veriminin düştüğünü rapor eden araştırmacıların bulgularıyla uyumludur (Yau, 2007; Gholami Baseri ve ark., 2022; Culpan, 2023b).

Linoleik asit oranı: Dönem ortalamalarında kışlık ekimlerde linoleik asit oranı %63.01 olarak belirlenirken yazlık ekimlerde ise %60.38 olarak belirlenmiştir. Dönem x Çeşit interaksiyonunda en linoleik asit oranı %80.69 ile kışlık olarak yetiştirilen Hasankendi çeşidinden elde edilmiştir (*Tablo 7*). Aspir diğer yağ bitkilerine nazaran yağ asitleri komposizyonu bakımından geniş varyasyon göstermektedir (Bergman ve ark., 1997). Aspir yağının başlıca doymamış yağ asitleri linoleik ve oleik asit olup bitkinin yüksek linoleik (%83.1) ve yüksek oleik (%81.9) olmak üzere iki ayrı tipi bulunmaktadır (Johnson ve ark., 1999). Bu yağ asitleri ekim dönemi (kışlık ve yazlık) ve hasat zamanlarına göre değişmekle beraber düşük sıcaklıklarda linoleik yağ asidi oranı artmaktadır (Bortolheiro ve Silva, 2017; Roche ve ark., 2019; Yilmaz ve ark., 2023). Sonuçlarımız, ekimlerin kışlık ve yazlık olarak yapılmasıyla linoleik yağ asidi oranının değiştiğini rapor eden araştırmacıların bulgularıyla örtüşmektedir.

Oleik asit oranı: Dönem ortalamalarında kışlık ekimlerde oleik asit oranı %28.32 olarak belirlenirken yazlık ekimlerde bu değer %31.45 olarak belirlenmiştir. Dönem x Çeşit interaksiyonunda ise en yüksek oleik asit oranı %66.12 ile yazlık olarak yetiştirilen Olein çeşidinden elde edilmiştir (*Tablo 7*). Aspirde ekim dönemlerinin oleik yağ asidi bileşimi üzerine etkileri oldukça değişken olup çeşide, çevre koşullarına ve kültürel uygulamalara bağlı olarak değişebilir (Abou Chehade ve ark., 2022; Sajid ve ark., 2024). Bazı araştırmacılar kışlık ekimlere kıyasla yazlık ekimlerden daha yüksek oleik asit elde edildiğini rapor etmişlerdir (Kalantar Ahmadi ve Sarhangi, 2025). Geçgel ve ark. (2007) ile Rahnama ve ark. (2024), aspirde sıcaklığın yağ asitleri içeriğini farklı şekillerde etkilediğini ve yüksek sıcaklıklarda oleik asit sentezinin, düşük sıcaklıklarda ise linoleik asit sentezinin arttığını bildirmişlerdir. Ayrıca yüksek sıcaklıkların oleik asidi linoleik aside dönüştüren desaturaz enzimlerini engellediği ve bunun da ekimlerin gecikmesiyle aspirde linoleik asit oranının düşmesine neden olduğu bildirilmiştir (Schulte ve ark., 2013). Literatür bulguları yapılan çalışma sonuçlarını doğrulamaktadır.

4. Sonuç

Ülkemizin birçok bölgesi aspir tarımı için uygun olmasına rağmen, bazı bölgelerin iklim koşulları ekonomik üretim için sınırlayıcı olabilmektedir. Aspir tarımının yaygınlaştırılabilmesi için kışlık ekim ya da kışları ekimin mümkün olmadığı bölgelerde erken ilkbaharda (şubat sonu-mart başı) ekiminin teşvik edilmesi, yağ verimi bakımından ayçiçeği ile rekabet edebilmesini sağlayabilecektir. Tekirdağ ekolojik koşullarında kışlık ve yazlık olarak 9 aspir çeşidi ile yürütülmüş olan bu araştırmanın sonucuna göre özellikle tohum verimi ve buna bağlı olarak yağ verimi bakımından kışlık olarak yapılan yetiştiriciliğin ön plana çıktığı görülmektedir. Kışlık olarak yetiştiricilikte bitkilerin ilkbahar yağışlarından daha fazla yararlanması ve uzun vejetasyon süresi tohum verimi ve verim unsurlarını olumlu yönde

etkilemiştir. Araştırmanın sonucu bir bütün olarak ele alındığında, Tekirdağ ekolojik koşullarında aspir bitkisinin kışlık ve yazlık olarak yetiştirilebileceği, kışlık ekimlerden daha yüksek tohum ve yağ verimi elde edilebileceği ve diğer çeşitlere nazaran linoleik tiplerden Balcı ve Linas çeşitleri ile oleik tiplerden Olas ve Asol çeşitlerinin daha uygun olduğu sonucuna varılmıştır.

Etik Kurul Onayı

Bu çalışma için etik kuruldan izin alınmasına gerek yoktur.

Çıkar Çatışması Beyanı

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

Yazarlık Katkı Beyanı

Planlama: Arslan, B., Çakır, H.; Materyal ve Metot: Arslan, B., Çakır, H., Culpan, E.; Veri toplama ve İşleme: Arslan, B., Çakır, H., Culpan, E.; İstatistiki Analiz: Culpan, E.; Literatür Tarama: Arslan, B., Çakır, H., Culpan, E.; Makale Yazımı, İnceleme ve Düzenleme: Culpan, E.

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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Energy and Economic Balance of Lavender Honey Production in Isparta Province*

Isparta İlinde Lavanta Balı Üretiminin Enerji ve Ekonomik Bilançosu

Engin ÖZCAN[1], Osman GÖKDOĞAN[2*]

Abstract

This study aims to determine the energy use efficiency and economic efficiency in lavender honey production. Within the scope of the study, total energy input, total energy output, energy use efficiency, specific energy, energy efficiency, net energy, direct energy inputs, indirect energy inputs, renewable energy inputs, non-renewable energy inputs and economic analysis computations were made with respect to lavender honey production. With the subsequent economic analysis, the profit and cost conditions were revealed by determining the economic efficiency of the lavender honey production enterprise. In addition, recommendations are given to increase the efficiency and profitability of energy usage in lavender honey production. This study was conducted at the lavender honey producing trials during the 2022 production seasons in Isparta province of in Türkiye. According to energy use efficiency computations in lavender honey production, a total of 525.50 kg of honey was produced. As a result of the process, total energy input was computed as 12.506.29 MJ, total energy output as 6727.26 MJ, energy use efficiency as 0.54, specific energy as 23.80 MJ kg^{-1}, energy productivity as 0.04 kg MJ^{-1} and net energy value as -5779.03 MJ kg^{-1}. Energy inputs in lavender honey production consist of direct energy with 3118.23 MJ (24.93%), indirect energy with 9388.06 MJ (75.07%), renewable energy with 1099.10 MJ (8.79%) and non-renewable energy with 11.407.19 MJ (91.21%). The total cost incurred in the production of lavender honey was 30.628.77 TL, the amount of honey produced was 525.50 kg and the production cost of 1 kg of lavender honey was 58.28 TL. Profitability indicators of the lavender honey business on a business basis were examined. According to these indicators, gross production value was computed as 131.825 TL, variable costs as 10.839.25 TL, fixed costs as 19.789.52 TL, production costs as 30.628.77 TL, gross profit as 120.985.75 TL, net profit as 101.196.23 TL and relative profit as 4.30. It is important as it will contribute to the literature as it is the first comprehensive study in its field on the energy and economic balance of lavender honey.

Keywords: Energy usage, Economic efficiency, Lavender honey, Relative profit, Specific energy

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Öz

Bu çalışmada lavanta balı üretiminde enerji kullanımının ve ekonomik etkinliğinin belirlenmesi amaçlanmıştır. Lavanta balı üretiminde toplam enerji girdisi & çıktısı, enerji kullanımı, özgül enerji, enerji verimliliği, net enerjisi, doğrudan enerji girdileri, dolaylı enerji girdileri, yenilenebilir enerji girdileri, yenilenemez enerji girdileri ve ekonomik analiz hesaplamaları yapılmıştır. Ekonomik analizin yapılması ile birlikte lavanta balı üretimi yapılan işletmede ekonomik etkinliğinin belirlenmesi ile kar maliyet durumu ortaya konulmuştur. Bu çalışmada lavanta balı üretiminde enerji kullanım etkinliğini ve karlılığını artırmak için yapılması gereken öneriler verilmiştir. Bu çalışma, Türkiye'nin Isparta ilinde 2022 üretim sezonunda lavanta balı üretim denemeleri yürütülmüştür. Lavanta balı üretiminde enerji kullanım etkinliği hesaplamalarına göre toplam 525.50 kg bal üretilmiş olup toplam enerji girdisi 12.506.29 MJ, toplam enerji çıktısı 6727.26 MJ, enerji kullanım etkinliği 0.54, spesifik enerji 23.80 MJ kg^{-1}, enerji verimliliği 0.04 kg MJ^{-1} ve net enerji değeri ise -5779.03 MJ kg^{-1} olarak hesaplanmıştır. Lavanta balı üretiminde enerji girdilerinin 3118.23 MJ (%24.93) ile doğrudan enerjiden, 9388.06 MJ (%75.07) ile dolaylı enerjiden, 1099.10 MJ (%8.79) ile yenilenebilir enerjiden ve 11.407.19 MJ (%91.21) ile yenilenemez enerjiden oluşmuştur. Lavanta balı üretiminde toplam masraf 30.628.77 TL, üretilen bal miktarı 525.50 kg olup 1 kg lavanta balının üretim maliyeti ise 58.28 TL olmuştur. Lavanta balı işletmesinin işletme bazında karlılık göstergelerine göre gayrisafi üretim değeri 131.825 TL, değişken masraflar 10.839.25 TL, sabit masraflar 19.789.52 TL, üretim masrafları 30.628.77 TL, brüt kar 120.985.75 TL, net kar 101.196.23 TL ve nispi kar 4.30 olarak hesaplanmıştır. Lavanta balının enerji ve ekonomik dengesi konusunda alanında ilk kapsamlı çalışma olması nedeniyle literatüre katkı sağlayacak olup önem arz etmektedir.

Anahtar Kelimeler: Enerji kullanımı, Ekonomik etkinlik, Lavanta balı, Nispi kar, Spesifik enerji

1. Introduction

Data for 2019 show that there are 90.116,000 hives worldwide and 8.128.000 in Türkiye. World honey production is 1.852.598 tons, and Türkiye's honey production is 114.067 tons. In 2019, the yield per hive in the world was approximately 20.7 kg. For 2019, China ranked first in terms of export volume as in world honey production, and Türkiye ranked second in terms of production volume and ranked 22nd in exports with 5543 tons (FAO, 2021; TÜİK, 2021; TEPGE, 2021). Lavender honey is a type of monoflorabal (single flower honey) obtained by bees collecting nectars mainly from lavender flowers and has a golden yellow color close to amber. It leaves a balanced taste where the scent of flowers is felt intensely on the palate. It has a suitable and pleasant taste for recipes with a medium sweetness level. Similar to other types of honey, lavender honey also contains nutritional components such as carbohydrates, proteins, vitamins, minerals, phenolic substances and enzymes. Thus, in addition to its unique taste on the palate, it helps meet the body's daily nutritional needs. 100 grams of lavender honey contains approximately 304 calories (Anonymous, 2023).

Lavender plants are grown in 5000 acres of land in the Kuyucak village of Keçiborlu district of Isparta province, where the study was conducted. Lavender starts to bloom at the beginning of July, although seasonal conditions such as temperature and rainfall affect it. Harvesting continues from the end of July to the middle of August. 90% of Türkiye's lavender production takes place in Kuyucak village. Lavender flowers, which are offered for sale by producers as fresh or dried after harvest, are processed in factories and turned into products such as cream, soap, oil, cologne and reach consumers. Lavender plants and lavender-containing products are used to calm nerves, treat sleep disorders, relieve rheumatism and muscle pain, and strengthen hair roots. In addition, they have different areas of use such as keeping harmful insects away from homes and clothes, providing a pleasant scent, etc (Anonymous, 2022a).

When examining agricultural production, the energy value of total inputs should be compared with the energy value of the product obtained as output. This is a more accurate approach in evaluating production efficiency. A low energy rate indicates that the inputs are not used on time or sufficiently, along with the lack of effective production techniques. Increasing energy use efficiency is important in terms of environmental impact assessment of energy resources. In addition, in order to use less energy and to cause less damage to the environment, system efficiency should be increased (Öztürk, 2011).

It is significant for producers and economic policy makers to determine the costs and incomes of agriculture products. If producers have cost information, they can make production plans in the long and medium term. Close examination of the living standards of people who earn their living from the agricultural sector should be an indispensable economic and social policy goal for countries. The results obtained from studies on the costs of agricultural products are a source that governments can use to define their pricing policies. The costs of agricultural products are widely used in examining the use of physical production inputs in enterprises, planning the workforce, making financing programs and preparing product balance (Anonymous, 2001; Demircan et al., 2005).

Examples of studies conducted on the subject can be given. For example; energy and economy in honey production (Omidi-Arjenaki et al., 2016; Vaziritabar and Esmaeilzade, 2016; Moraru et al., 2019; Sert, 2017; Aktürk and Aydın, 2019; Aydın et al., 2020; Aydın and Aktürk, 2021; Uysal, 2021; Vahid-Berimanlou and Nadi, 2021), sorghum x sudan grass (Tutar et al., 2025), orange (Ağızan et al., 2025), table grape (Ağızan et al., 2024), wheat (Demirel et al., 2024), walnut (Ayran Çolak et al., 2024), pomegranate (Yalçın Dokumacı et al., 2023), lemon (Özbek et al., 2023), canola (Özpınar, 2023), garlic (Baran et al., 2023), alfalfa (Güngörmez et al., 2023), pistachio (Gökdoğan et al., 2022), avocado (Gökduman et al., 2022), grape (Şimşek et al., 2022), orange (Saltuk et al., 2022), kiwi fruit (Gökdoğan, 2022), lavender (Demir et al., 2022), fig (Oğuz et al., 2022), cotton (Baran et al., 2021), cumin (Yilmaz et al., 2021), olive (Ozpinar, 2020), nectarine (Oğuz et al., 2019a), wolfberry (Oğuz et al., 2019b), egg (Gokdogan and Baran, 2019), maize (Kokten et al., 2019), potato (Gokdogan et al., 2018), biogas (Özpınar, 2018), organic grape (Baran et al., 2017), bitter vetch (Kokten et al., 2017), sesame (Baran and Gökdoğan, 2017), wheat (Gökdoğan and Sevim, 2016), sunflower (Bayhan, 2016), castor oil (Gokdogan et al. 2015), paddy (Hacıoğlu et al., 2024), biogas (Kayisoglu and Goncu, 2020), peach (Demir and Gökdoğan, 2023), watermelon (Demir, 2023), etc.

2. Materials and Methods

Isparta province is located in the western-central part of the Mediterranean Region and is the centre of the "Lakes Region". Its geographical location is between 30° 20' and 31° 33' east longitudes and 37° 18' and 38° 30' north latitudes (Anonymous, 2022b). The average altitude of Isparta province, which has a surface area of 8933 km^2, is 1050 meters (Anonymous, 2022c). Its average altitude is 1010 m and its surface area is 562 km² (Anonymous, 2022d). Tests were carried out in 2022 in the enterprise producing lavender honey in Kuyucak village of Keçiborlu district of Isparta province. As a method, the records kept during the lavender honey production period in the enterprise were analyzed and evaluated in order to determine the usage amounts of inputs per hive and the production costs of the enterprise.

In lavender honey production, there are human labour, tractor, diesel fuel, electricty, medicine, sugar, water inputs (*Table 1*). The total of energy inputs (EI) were determined by multiplying the use of these inputs per hive and the energy equivalents of these uses. The energy output (EO) is lavender honey. The energy balance sheet of lavender honey production was created by combining the inputs and outputs in the table. With the creation of the energy balance sheet, energy use efficiency (EUE), specific energy (SE), energy productivity (EP) and net energy (NE) computations were made in lavender honey production. In order to make EUE, SE, EP and NE computations in lavender honey production, computations were made using the following formulas (1-4) according to Moraru et al. (2019). According to Moraru et al. (2019); "These indicators have been used in previous studies for the same purpose (Demircan et al., 2006; Omidi-Arjenaki et al., 2016)."

$$\text{EUE} = \frac{\text{Energy output } (\frac{\text{MJ}}{\text{hive}})}{\text{Energy input}(\frac{\text{MJ}}{\text{hive}})} \quad \text{(Eq. 1)}$$

$$\text{SE} = \frac{\text{Energy input } (\frac{\text{MJ}}{\text{hive}})}{\text{Product output } (\frac{\text{kg}}{\text{hive}})} \quad \text{(Eq. 2)}$$

$$\text{EP} = \frac{\text{Product output } (\frac{\text{kg}}{\text{hive}})}{\text{Energy input } (\frac{\text{MJ}}{\text{hive}})} \quad \text{(Eq. 3)}$$

$$NE = EO\ (MJ/hive) - EI\ (MJ/hive) \quad \text{(Eq. 4)}$$

Time measurements were made, and effective work efficiency was computed. In this process, three chronometer measurement sets were used (Özcan, 1986; Sonmete, 2006). The full tank method was used to define fuel consumption (Göktürk, 1999; El Saleh, 2000; Sonmete, 2006). EI was categorized as direct (DE), indirect (IDE), renewable (RE) and non-renewable (NRE) energy (Kizilaslan, 2009; Omidi-Arjenaki et al., 2016). IDE includes the energy spent in transportation (by road), while DE includes human labour and fuel used in the honey production process. NRE includes fuel, sugar, electricity and medicine and RE consists of human labour (Omidi-Arjenaki et al., 2016).

Table 1. Energy coefficiencts in honey production

Inputs	Unit	Energy coefficienct (MJ unit^{-1})	References
Human labour	h	1.96	Mani et al. (2007); Karaağaç et al. (2011)
Tractor	h	33.97	Fluck (1992); Ekinci et al. (2020)
Diesel fuel	l	56.31	Singh (2002); Demircan et al. (2006)
Electricity	kWh	3.60	Ozkan et al. (2004)
Medicine	kg	13.64	Omidi-Arjenaki et al. (2016); Aydın and Aktürk (2021)
Sugar	kg	15.40	Omidi-Arjenaki et al. (2016); Aydın and Aktürk (2021)
Water	m^3	0.63	Yaldiz et al. (1993); Ekinci et al. (2020)
Outputs			
Honey	kg	12.72	Omidi-Arjenaki et al. (2016); Aydın and Aktürk (2021)
Pollen	kg	14.30	Lilek et al. (2015)

The economic balance of lavender honey production was made. During this analysis, the production costs per hive in lavender honey production were computed from the honey production preparation stage to transportation. Production costs were computed by computing fixed and variable costs. The profitability status, net profit, relative

profit and cost of one kg of product computations were made according to Açıl and Demirci (1984), Kral et al. (1999), Tanrıvermiş (2000), Anonymous (2001), Demircan et al. (2005), Demircan et al. (2006) and Sert (2017).

Depreciation of fixed cost elements such as equipment and machinery was computed. For this purpose, the depreciation rate was taken as 10% (Ören et al., 2010; Sert, 2017). Then, interest provisions of equipment and machinery and bee capital were computed, and half of the new value of equipment and machinery and bee capital was taken, and real interest rate was applied to the found value (Kral et al., 1999; Sert, 2017). In computating general administrative expenses, 3% of total variable expenses were taken (Sert, 2017). In computing revolving fund interest, computation was made by applying half of the agricultural loan interest rate applied by Ziraat Bank for beekeeping production activity to the total of variable expenses (Sert, 2017). There is no membership fee expense, credit expense, transportation expense, or traveller labour expense in production.

3. Results and Discussion

The hive, which is the main tool and machine used in beekeeping, is the basic input of beekeeping. There are a total of 85 hives in the business (including empty hives). The number of hives included in production in 2022 is 75. The hives are modern and have a plastic base and wooden structure. The hives are windproof, covered with trees and positioned 2 km above the village. The energy balance sheet for lavender honey production is given in *Table 2*. As seen in *Table 2*, for a total of 525.50 kg of honey produced.

The total EI in lavender honey production was computed as 12,506.29 MJ and the EO as 6727.26 MJ. The energy inputs consisted of 7700 MJ (61.57%) sugar energy, 2015.90 MJ (16.12%) diesel fuel energy, 1647.55 MJ (13.17%) tractor energy, 1086.62 MJ (8.69%) human labour energy, 40.51 MJ (0.32%) medicine energy, 12.47 MJ (0.10%) water energy, 3.24 MJ (0.03%) electricity energy, respectively. The total EI in the production of 1 hive of lavender honey was computed as 166.75 MJ hive^{-1} and the EO as 122.10 MJ hive^{-1}. The EI were 102.67 MJ hive^{-1} (61.57%) sugar energy, 26.88 MJ hive^{-1} (16.12%) diesel fuel energy, 21.97 MJ hive^{-1} (13.17%) tractor energy, 14.49 MJ hive^{-1} (8.69%) human labour energy, 0.54 MJ hive^{-1} (0.32%) medicine energy, 0.17 MJ hive^{-1} (0.10%) water energy, 0.04 MJ hive^{-1} (0.03%) electricity energy, respectively.

Table 2. EB in lavender honey production

Inputs	Energy coefficenct (MJ unit^{-1})	Amount (Unit)	MJ	MJ hive^{-1}	MJ kg^{-1}	Rate (%)
Human labour	1.96	554.40	1086.62	14.49	2.07	8.69
Tractor	33.97	48.50	1647.55	21.97	3.14	13.17
Diesel fuel	56.31	35.80	2015.90	26.88	3.84	16.12
Electricity	3.60	0.90	3.24	0.04	0.01	0.03
Medicine	13.64	2.97	40.51	0.54	0.08	0.32
Sugar	15.40	500	7700	102.67	14.65	61.57
Water	0.63	19.80	12.47	0.17	0.02	0.10
Total			12,506.29	166.75	23.80	100
Outputs						
Honey	12.72	525.50	6684.36	121.53		
Pollen	14.30	3	42.90	0.57		
Total	-	-	6727.26	122.10		

The total EI required for the production of 1 kg of lavender honey was computed as 23.80 MJ kg^{-1}. EI consist of 14.65 MJ kg^{-1} (61.57%) sugar energy, 3.84 MJ kg^{-1} (16.12%) diesel fuel energy, 3.14 MJ kg^{-1} (13.17%) tractor energy, 2.07 MJ kg^{-1} (8.69%) human labour energy, 0.08 MJ kg^{-1} (0.32%) medicine energy, 0.02 MJ kg^{-1} (0.10%) water energy and 0.01 MJ kg^{-1} (0.03%) electricity energy. *Table 3* shows the EUE, SE, EP and NE figures in lavender honey production.

EUE computations were made in lavender honey production. According to these computations, a total of 525.50 kg of honey was produced, total EI was computed as 12,506.29 MJ, total EO was computed as 6727.26 MJ. EUE was computed as 0.54, SE as 23.80 MJ kg^{-1}, EP as 0.04 kg MJ^{-1} and net energy value as -5779.03 MJ

kg^{-1}. In other studies in the field of EUE in lavender honey production. Moraru et al. (2019) computed the EUE as 0.47, SE as 27 MJ kg^{-1} and NE value as -417.3 MJ in the EUE study of honey production; Aydın and Aktürk (2021) computed the EUE as 0.91, EP as 0.07 kg MJ^{-1} and SE as 13.90 MJ kg^{-1} in honey production.

Table 3. EUE computations in lavender honey production

Computations	Unit	Values
Product (Honey)	kg	525.50
EI	MJ	12.506.29
EO	MJ	6727.26
EUE	-	0.54
SE	MJ kg^{-1}	23.80
EP	kg MJ^{-1}	0.04
NE	MJ kg^{-1}	-5779.03

There have been other studies on EUE in honey production. Moraru et al. (2019) computed the average fuel consumption per hive as 303.9 MJ, sugar consumption as 246.7 MJ, transportation consumption as 163.3 MJ, human labour consumption as 35.7 MJ, electricity consumption as 4.7 MJ, and medicine consumption as 0.522 MJ; Aydın and Aktürk (2021) computed the average fuel consumption as 117.18 MJ, sugar consumption as 60.50 MJ, transportation consumption as 25.83 MJ, human labour consumption as 15.34 MJ, and medicine consumption as 6.87 MJ per hive. In lavender honey production, EI types are divided into DE, IDE, RE and NRE energies (*Table 4*).

Table 4. EI types in lavender honey production

Energy types	EI (MJ)	Rate (%)
DE	3118.23	24.93
IDE	9388.06	75.07
Total	12.506.29	100
RE	1099.10	8.79
NRE	11.407.19	91.21
Total	12.506.29	100

Energy inputs in lavender honey production consisted of 3118.23 MJ (24.93%) DE, 9388.06 MJ (75.07%) IDE, 1099.10 MJ (8.79%) RE and 11,407.19 MJ (91.21%) NRE and the relevant data are given in *Table 4*. Similar to the results in the EUE study in lavender honey production, Moraru et al. (2019) computed direct energy as 38.1% and renewable energy as 5.1% in their EUE study in honey production. Aydın and Aktürk (2021) computed DE as 36.64% and RE as 6.80% in their study.

When evaluating the costs related to beekeeping activities, they are classified as fixed costs (FC) and variable costs (VC). VC are costs that increase or decrease depending on the production volume. These costs are costs that occur when production is made and change depending on the production amount. On the other hand, FC are costs that do not change depending on the production volume and occur whether or not production is made (İnan, 2016; Sert, 2017). The cost elements of lavender honey production are given in *Table 5*.

According to *Table 5*, the total cost of lavender honey production is 30.628.77 TL. Of this amount, 10.839.25 TL is total variable costs, and 19.789.52 TL is total fixed costs. Total variable costs consist of 5029.20 TL (46.40%) feeding, 3622 TL (33.42%) packaging, 798.34 TL (7.37%) transportation, 500 TL (4.61%) comb, 445.50 TL (4.11%) medicine, 442.89 TL (4.09%) revolving fund interest and 1.33 TL (0.01%) electricity. Total fixed costs consist of family labour with 11.088 TL (56.03%), tool-machine depreciation with 6282.27 TL (31.75%), tool-machine interest with 1570.57 TL (7.94%), bee capital interest with 523.50 TL (2.65%) and general administrative expenses with 325.18 TL (1.64%). Total cost in lavender honey production is 30.628.77 TL, the amount of honey produced is 525.50 kg and the production cost of 1 kg of lavender honey is 58.28 TL. The profitability indicators of the lavender honey enterprise are given in *Table 6*.

Table 5. Production costs in lavender honey production

Costs	Value (TL)	Rate (%)
	A. Variable costs	
Feeding	5029.20	46.40
Transportation (Tractor)	798.34	7.37
Electricity	1.33	0.01
Comb	500	4.61
Medicine	445.50	4.11
Packaging	3622	33.42
Revolving fund interest	442.89	4.09
Total VC	10.839.25	100
	B. Fixed costs	
Family labour	11.088	56.03
General administrative expenses	325.18	1.64
Bee capital interest	523.50	2.65
Tool-machine depreciation	6282.27	31.75
Tool-machine interest	1570.57	7.94
Total FC	19.789.52	100
	Total costs	
Total costs	30.628.77	
Produced honey amount (kg)	525.50	
1 kg honey production cost	58.28	

1 US$ = 16.59 TL in 2022 (average)

Table 6. Profitability indicators of enterprise

Profitability indicators (TL enterprise^{-1})	
Profitability indicators (TL enterprise^{-1})	
Gross production value	131.375
VC	10.839.25
FC	19.789.52
Production costs	30.628.77
Gross profit	120.985.75
Net profit	101.196.23
Relative profit	4.30
Profitability indicators (TL hive^{-1})	
Gross production value	1757.67
VC	144.52
FC	263.86
Production costs	408.38
Gross profit	1613.14
Net profit	1349.28
Relative profit	4.30

*: 1 kg lavender honey sale price: 250 TL

Table 6 shows the profitability indicators of the lavender honey enterprise on a business basis. According to these indicators, the gross production value was computed as 131.375 TL, variable costs as 10.839.25 TL, fixed costs as 19.789.52 TL, production costs as 30.628.77 TL, gross profit as 120.985.75 TL, net profit as 101.196.23 TL and relative profit as 4.30. The profitability indicators of the lavender honey enterprise on a hive basis were examined and the gross production value was computed as 1757.67 TL, VC as 144.52 TL, FC as 263.86 TL, production costs as 408.38 TL, gross profit as 1613.14 TL, net profit as 1349.28 TL and relative profit as 4.30.

4. Conclusions

In this study, EUE, SE, EP and NE values were computed in lavender honey production and economic analysis was performed. A total of 525.50 kg of honey was produced in relation to lavender honey production. EUE computations were made. Total EI was computed as 12.506.29 MJ, total EO as 6727.26 MJ, EUE as 0.54, SE as 23.80 MJ kg^{-1}, EP as 0.04 kg MJ^{-1} and NE value as -5779.03 MJ kg^{-1}. Lavender honey production was not considered an economic activity as of 2022 in terms of EUE (0.54).

The EI in lavender honey production consist of 7700 MJ (61.57%) sugar energy, 2015.90 MJ (16.12%) diesel fuel energy, 1647.55 MJ (13.17%) tractor energy, 1086.62 MJ (8.69%) human labour energy, 40.51 MJ (0.32%) medicine energy, 12.47 MJ (0.10%) water energy and 3.24 MJ (0.03%) electricity energy. The total energy input for 1 hive of lavender honey production is 166.75 MJ $hive^{-1}$, the energy output is 122.10 MJ $hive^{-1}$; the total energy input for 1 kg of lavender honey production is computed as 23.80 MJ kg^{-1}.

The energy inputs in lavender honey production consist of 3118.23MJ (24.93%) DE, 9388.06 MJ (75.07%) IDE, 1099.10 MJ (8.79%) RE and 11.407.19 MJ (91.21%) NRE. The rate of RE inputs in lavender honey production (8.79%) is very low. In order to increase the renewable energy rate, it is recommended to use solar collectors instead of non-renewable energy sources and to use natural products instead of medicines.

In order to increase EUE and income in lavender honey production, the number of hives should also be increased. Queen bees should be selected from quality breeds and queen bees should be changed every two years. If the product pattern obtained from bees is increased, income will naturally increase. In order to overcome the market difficulty, cooperatives should be established, advertisements should be made.

The total cost of lavender honey production is 30.628.77 TL, 10.839.25 TL of which is total variable costs, 19.789.52 TL of which is total fixed costs. Total variable costs consist of 5029.20 TL (46.40%) feeding, 3622 TL (33.42%) packaging, 798.34 TL (7.37%) transportation, 500 TL (4.61%) comb, 445.50 TL (4.11%) medicine, 442.89 TL (4.09%) revolving fund interest and 1.33 TL (0.01%) electricity.

Total cost in lavender honey production was 30.628.77 TL, and the amount of honey produced was 525.50 kg. The production cost of 1 kg of lavender honey was 58.28 TL. According to the profitability indicators of the lavender honey enterprise on a business basis, gross production value was 131.825 TL, variable costs were 10.839.25 TL, fixed costs were 19.789.52 TL, production costs were 30,628.77 TL, gross profit was 120.985.75 TL, net profit was 101.196.23 TL and relative profit was computed as 4.30. According to the profitability indicators of the lavender honey business on a hive basis, the gross production value was computed as 1757.67 TL, variable costs as 144.52 TL, fixed costs as 263.86 TL, production costs as 408.38 TL, gross profit as 1613.14 TL, net profit as 1349.28 TL and relative profit as 4.30. It was concluded that lavender honey is a profitable production according to the relative profit rate.

Ethical Statement

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

Conflicts of Interest

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

Authorship Contribution Statement

Concept: Gökdoğan, O., Özcan, E.; Design: Gökdoğan, O., Özcan, E.; Data Collection or Processing: Özcan, E., Gökdoğan, O.; Literature Search: Özcan, E., Gökdoğan, O.; Writing, Review and Editing: Özcan, E., Gökdoğan, O.

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