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Research Article

Occurrence of *Eimeria* species in Naturally Infected Domestic Rabbits (*Oryctolagus cuniculus*) in North of Karbala Province, Iraq

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ABSTRACT

Coccidiosis has an economic impact for poultry and livestock industries. The current study examined the prevalence of *Eimeria* infections in domestic rabbits in musaib city, North of Karbala province. A total of forty-eight faecal samples were taken from several market places located across the city. Individual fresh fecal samples were taken 24 hours prior in containers placed beneath the cages. After being collected, the excrement was moistened, placed in plastic bags, kept, and chilled at 4°C until it was examined. Freshly collected non-sporulated oocysts in each sample were put in Petri dish have 2.5% (W/V) aqueous solution of potassium dichromate. Every faecal sample was collected and then sent to a lab for oocyst detection. The identification of an infection was based on the physical traits. Sporulated oocysts were used to validate the identity of the samples containing *Eimeria* species, and they also provided morphological identification under a microscope. The prevalence of the population with coccidial illnesses was 34 out of 48 which equal for 70.8% . No significant differences were found between male and female at $P \geq 0.05$. Thirty-four rabbit infected with *Eimeria* species were present and identified from oocyst features. *Eimeria stiedae* and *E. magna* were the most prevalent species (25% and 21%), respectively. The results showed that the prevalence and distribution of coccidiosis was high among the rabbit population in musaib city, North of Karbala province. In conclusion, the epidemiological result must be taken into consideration in order to minimize the economic losses caused by coccidiosis.

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INTRODUCTION

Rabbits are a potential livestock resource that can provide high-quality meat that have more protein and less fat and cholesterol than other meats. Numerous *Eimeria* species are the source of the serious diseases known as rabbit coccidiosis, which costs the rabbit industry a great deal of money. Coccidiosis causes economic losses due to its negative impact on weight gain, growth, feeding efficiency, and death in weaning rabbits (Scialfa *et al*., 2021). Only a small number of the eleven coccidian species that infected domestic and wild rabbits were linked to actual illnesses (Athanasiou *et al*., 2023). Eimeriosis is a significant issue in rabbit farming, regardless of the maintenance approach. The disease influence the animals across all age groups, which lead to reduce body weight, impaired feed conversion, increased morbidity, and ultimately mortality (Shkromada and Nedzheria, 2020). Rabbit coccidia infects certain regions of the gut and at varying levels within the mucosa (Pakandl, 2013). Rabbits serve as a substitute for meat, wool, fur, economic, medical and are also often maintained as pets and used in research experiments (Ütük *et al*., 2015; Shkromada and Nedzheria, 2020; Rabie *et al*., 2022). Rabbits often suffer from coccidiosis, which is a significant health issue (Bachene *et al*., 2018). Generally, rabbits are infected by a range of parasites, including ectoparasites and endoparasites. two forms of *Eimeria* spp. could be distinguished the first one is *E. stiedae* which can be deemed the most causative agent of hepatic coccidiosis and the second form is *Eimeria* spp. Which causes the intestinal coccidiosis (Rabie *et al*.,2022). Endoparasitosis in rabbits is a frequent occurrence, particularly in domestic breeding environments. The findings indicated that rabbits bred for reproduction can carry coccidian infections without reveal any symptoms, and they have the ability to release oocysts at any point during their reproductive cycle. The morphological properties of coccidia oocyst were important for identifying the *Eimeria* species (Scialfa *et al*., 2021). *Eimeria stiedae* infects the bile duct, resulting in hepatic coccidiosis in domestic and wild rabbits. Hepatic coccidiosis, which is caused by the parasite *E. stiedae*, leads to a significant infection, widespread outbreaks, and fatalities in juvenile rabbits (Ütük *et al*.,2015). The identification of *Eimeria* species has traditionally relied on the examination of the morphological characteristics of sporulated oocysts (Li *et al*., 2016). In the current study, to assess the infection of *Eimeria* oocysts in fecal samples of domestic rabbits were analyzed based on unsporulated oocyst morphology traits and sporulated method and considered the first study in north of Karbala province, Iraq.

MATERIAL AND METHODS

Location

The study was conducted among the rabbit populations in north of Karbala province, Iraq, which is located between the northern latitudes of 32.616667° and eastern longitudes of 44.033332°E.

Fecal samples

Fecal samples were collected randomly from different locations in the studied area and examined for the presence of oocysts. In these local markets, faecal samples were collected from 48 healthy rabbits. On the other hand While no consider the age factor was ignored due to the different sources of rabbits. Individual fresh fecal samples were taken 24 hours prior in containers placed beneath the cages. After being collected, the excrement was moistened, placed in plastic bags, kept, and chilled at 4°C until it was examined. By collecting, plastic tubes were used to collect samples. Then transferred directly to the laboratory (Department of Parasitology , College of Veterinary Medicine, University of Kerbala, Karbala, Iraq) to analysis. A bout 100 g of fresh faecal pellets were collected from each animal alone, which considered as one sample. Each faecal sample was checked for infection then the type of infection was estimated and calculated as single, dual and triple infection.

Parasitological analysis

The prevalence and intensity of coccidial infection were detected by the coprological methods. The disease was diagnosed by fecal examination, oocyst sporulation. The species were determined based on oocyst morphology to identify the species composition (Karaer, 2001). Freshly collected non-sporulated oocysts in each sample were put in Petri dish have 2.5% (W/V) aqueous solution of potassium dichromate (K2Cr2O7at 24-26°C) with a good aeration (Ütük *et al*.,2015). When the sporozoites inside the sporocysts were completely developed, the sporulation time was calculated (Murshed *et al*., 2023).

Statistical analysis

The statistical package SPSS was used for data analyses, and a value of $P < 0.05$ was considered a significant difference in comparison. No significant by many factors genders, health status, parasitic species distribution and type of infections.

RESULTS

The result showed that out of the 48 examined rabbits, 34 were positively infected with *Eimeria* spp. In the examined rabbits, the total prevalence of *Eimeria* spp. was 70.8% (34/48), and co-infection with more than species of the genus *Eimeria* could be observed in all positive rabbits. Concerning the genders, the prevalence of *Eimeria* spp. was 76.7% (23/30) in male rabbits while it was 61.1% (11/18) in female rabbits. Significant differences were not observed *(P* ≥0.05*)*(Table 1).

Table 1. *Prevalence infection of health status and genders*.

			Gender type		Total
			Male	Female	
Health status	Non-infected	N	7	7	14
		%	23.3%	38.9%	29.2%
	Infected	N	23	11	34
		%	76.7%	61.1%	70.8%
Total			30	18	48
X^2		1.318	*P* value	0.251	No sig.

The morphological characteristic of the recovered from the seven different *Eimeria* species were distributed at different percentages. High of *E. stiedae* were (25%), *E. magna* were (21%), *E. perforans* were (15%), *E. coecicola* and *E. exigua* were (11%), *E. piriformis* were (9%), while less prevalence in *E. media* was (8%) (Table 2). No significant difference of *Eimeria* prevalence was confirmed between males and females. Seven species of *Eimeria* spp. Among ifected rabbits in Karbala were identified by coprological parasitological analysis as *E. stiedae*, *E. perforance*, *E. media*, *E. coecicola*, *E. exigua*, *E. magna* and *E. piriformis*.

Table 2. *Prevalence of the percentage of Eimeria species in male and female.*

	Type of *Eimeria* species						
Genders	***E.stiedae***	***E.perforance***	***E.media***	***E.coecicola***	***E.exigua***	***E.magna***	***E.piriformis***
Male	10	6	2	5	5	6	2
%	28	17	6	14	14	17	6
Female	3	2	2	1	1	5	3
%	18	12	12	6	6	29	18
Total	13	8	4	6	6	11	5
%	25	15	8	11	11	21	9

The total relation type of infection was 55.9%(19/34) in single infection, 32.3%(11/34) in dual infection and 11.7% (4/34) in triple infection. The total infection was (67.7% and 32.3%) in male and female, respectively. However in single, dual and triple infection were 60.9% (14/23), 21.7% (5/23) and 17.4%(4/23) in male, respectively. In female's have single, dual and triple infection were 45.4% (5/11), 54.5% (6/11) and 0% (0/11) respectively. (Table 3).

Table 3. *Relation of type infection with genders.*

Gender	Type of infection							
	Single	**%**	**Dual**	**%**	**Triple**	**%**	**Total**	**%**
Male	14	60.9	5	21.7	4	17.4	23	67.7
Female	5	45.4	6	54.5	0	0	11	32.3
Total of infected animals	19	55.9	11	32.3	4	11.7	34	

The oocysts of 7 *Eimeria* species collected from the domestic rabbits in the present study are illustrated in Figs. 1–2.

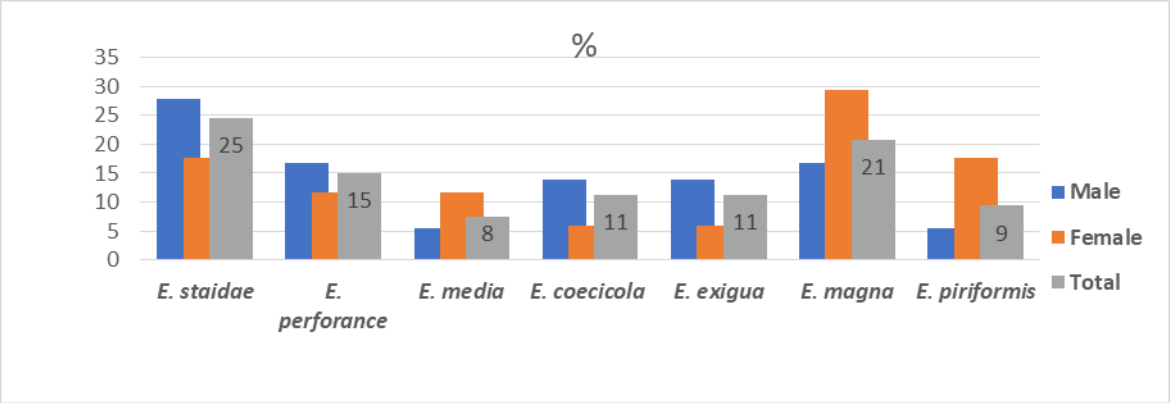

Figure 1. *Distribution of the percentage of Eimeria species.*

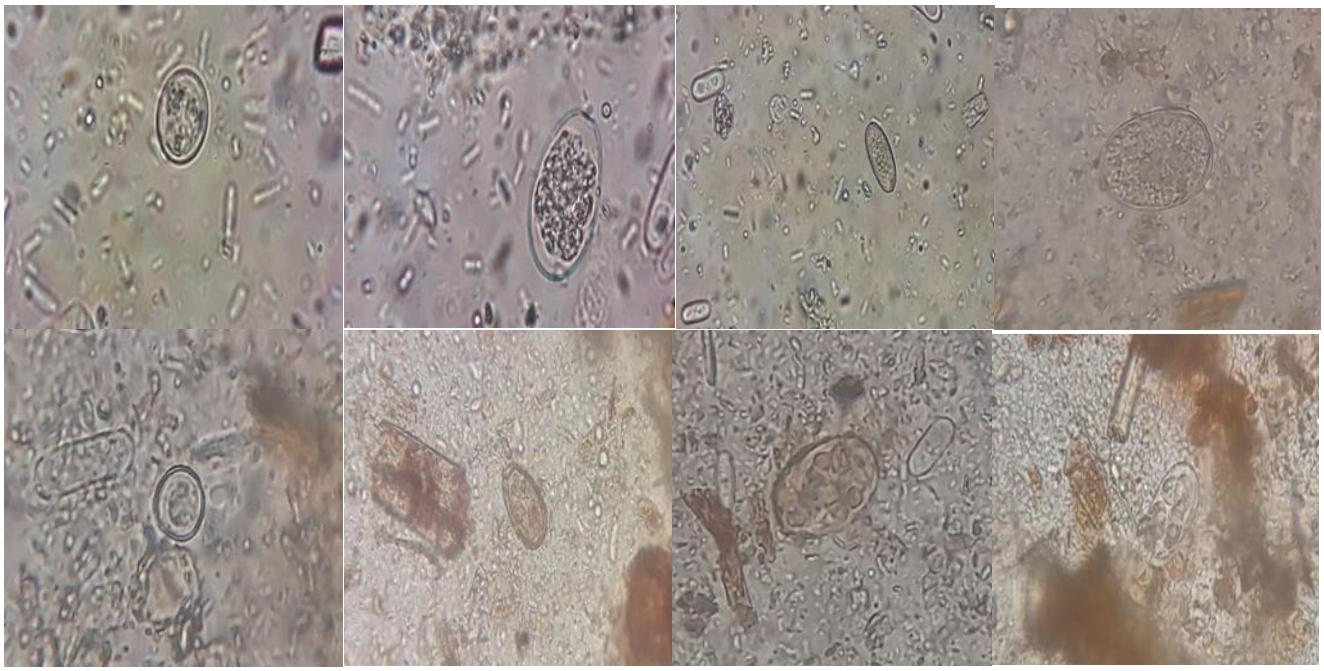

Figure 2: *From left the above photo unsporulated and the under photo sporulated. The name from left, E. exigua, E. magna, E. coecicola, E. perforans*

DISCUSSION

Eimeria spp. is one of the most protozoal parasites that has an important economi issue in the rabbit industries and production, which cause a disease called coccidiosis (Basiaga *et al.*,2020). Rabbit coccidiosis is a common important disease caused by different intestinal and non-intestinal *Eimeria* species (Yuan *et al.*, 2022). In the current study, carpological examination was used for the detection of the presence of *Eimeria* spp. Preparation of slides and sporulation of oocyst are the main steps of the test and basically the diagnosis is depend on the morphological features (Yin *et al.*,2016; Hamid *et al.*,2019; Temim *et al.*, 2019; Al-Sadi and Al-Khafaji, 2000; Pilarczyk *et al.*,2020; Gökpinar *et al.*,2023) they were used sporulation and identification according to morphological characteristic in 2.5% potassium dichromate.

Importantly the results of this study showed that the prevalence of *Eimeria* spp., infection in domestic rabbits in musaib area, North of Karbala province was70.8% (34/48) of the total tested samples. Thus, the high rates could be due to live with infected animal at the same cage, or less using of treatment drugs, stress factors and contaminated food. Our findings agree with the pervious published evidence include Yin *et al.*, (2016) who recorded high prevalence of coccidial infection in rabbits (10-90%) in Sichuan Province, southwest China. Additional study from Indonesia has found that the prevalence rate was 70.3% (527/750) from fecal samples (Hamid *et al.*,2019). The obtained result was in line with (Elhendy *et al.*,2018), was 84% (42/50) in Assiut,

Egypt. While other studies were showed high prevalences as (Basiaga *et al.*,2020), was 100% in Poland and Ukraine, (Nicollas *et al.*,2022), in the Philippines,100%. In contrast, lower prevalence rates of infections were reported with different seasons of the year ranged from 42–15% in autumn-winter period, and 19–6% in spring-summer (Shkromada and Nedzheria,2020). (Temim *et al.*, 2019 was 47.6% in North of Algeria), (Rabie *et al.*,2022 was 50% in Egypt) and (Gökpinar *et al.*,2023, was 37.3% in Ankara and Kırıkkale provinces, Turkey). moreover, most of the previous reports in Iraq were showed various prevalence rates such as (Al-Sadi and Al-Khafaji, 2000, was17% in Nenevah,). (Sulaiman,2005, was 57.14%, in Mosul). (Al-Moula,2005 was 76. 6% in Mosul), (Khider *et al.*, 2015, was 72.5%, in Baghdad) ,(Faraj, 2017, was 19% in Baghdad), and (Marhoon *et al.*,2018, was 61.82% in Al-Diwaniyah).

This difference in prevalence was showed to be associated with the variation in environmental factors geographical area such as the temperature, sporulation of oocysts, increase humidity, the use of chemoprophylaxis, ground breeding systems, kinds of feeding and number of samples were examined (Rabie *et al.*,2022). Thus, the practicality of detecting *Eimeria* infection in small rabbit farms is in the assessment of unsporulated oocyst shape, which aids in the control and prevention of rabbit *Eimeria* infections (Li *et al.*,2016).

From our finding , the prevalence of *Eimeria* spp. was 76.7% (23/30) in male rabbits while it was 61.1% (11/18) in female rabbits. *P* value non-significant (Table 1). these results were consistant with Khider *et al.* (2015) and Heker *et al.* (2017) who found no significant effects on the prevalence of *Eimeria* between male and female and *Eimeria* species. Also in accordance with the present results Pilarczyk et al., (2020) showed no significant variation between male and female in the extensity of *Eimeria* infection. Similarly, the earlier reports of Al-Moula,(2005) who showed that the prevalence rate of infection in Mosul was 23/30 (76.6%) in domestic rabbits and mixed infection was more frequent with no significant variation between genders **.** Other reports were confirmed hepatic coccidiosis infection in ten hindered from rabbits (*Oryctolagus cuniculus*) from Baghdad city. The total infection rate was 19%, with no significant difference at the level of (*P*>0.01) (Faraj, 2017)**.** The difference species distribution with clinical or without clinical signs may be increase probability of infection in animals. The findings indicate that local rabbits are asymptomatic and carriers of coccidian parasites and can shed oocysts all the time throughout the reproductive cycle (Scialfa *et al.*,2021). The oocyst stage of *Eimeria* spp. found ubiquitously in the environment and increases the risk of disease dissemination (Hamid *et al.*,2019).

Many of studies have been recorded about distribution of *Eimeria* species with different prevalences. In the current study, seven *Eimeria* species were identified include *E. stiedae* were (25%) the highest prevalence among the spp., followed by *E. magna* were (21%), *E. perforans* were (15%), *E. coecicola* and *E. exigua* were (11%), *E. piriformis* were (9%), and the lower prevalence was seen with *E. media* was (8%). Which is consistent with (Yin *et al.*,2016) who reported co- infection in Sichuan Province, southwest China 9 species of *Eimeria* were confirmed from positive samples. *Eimeria perforans* was the most prevalent species (42.73 %), *Eimiera media*(35.45%), *E. irresidua* (34.55%), *E. magna*(31.82%), *E. intestinalis*(23.64%), *E. coecicola* (8%), *E. piriformis* and *E. flavescens* (6.36%). Other study was agreed with this study in Banyumas Regency, Indonesia. The prevalence 90.11% from 475 rabbits and were *E. exigua, E. perforans, E. flavescens, E. intestinalis, E. stiedae, E. vejdovskyi and E. caecicola*. They were showed that gender did not have a significant relationship (P> 0.05) (Indrasanti *et al.*,2020). While in Poland seven species were reported from 91 rabbits: *E. magna*, *E. media*, *E. perforans*, *E. stiedae*, *E. coecicola*, *E. exigua*, and *E. irresidua*. From this infection demonstrated a significantly higher infection was *E. magna* (Pilarczyk *et al.*,2020).

Ten species of *Eimeria* spp. were confirmed in Yogyakarta, Indonesia. *Eimeria flavescens* was 80%, *E. coeciola* was 78%, *E. perforans* was 61%, *E. exigua* was 37%, *E. media* was 33%, *E. stiedae* was 31%, *E. irresidua* was 12%, *E. magna* was 11%, *E. intestinalis* was 10%, and *E. piriformis* was 10% (Hamid *et al.*,2019). Co-infection with more than species of the genus *Eimeria* could be observed in all positive rabbits. In rabbits concurrent infections are common and generally, and can infect more than one species of *Eimeria* targeting both the liver and intestine (Murshed *et al.*, 2023). Many factors could influence the prevalence of coccidial infections which include protozoan species, size of samples, strain of animal, test type of diagnosis, geographical regions and mixing of infected with non-infected at the same cage. (Gökpinar *et al.*,2022) was found the prevalence of infection from the cages with two or more rabbits (88.1%), higher than the prevalence from the cages with a single rabbit (12.1%).

The total infection was 55.9%(19/34) in single infection, 32.3%(11/34) in dual infection and 11.7% (4/34) in triple infection. The total infection was (67.7% and 32.3%) in male and female respectively. While single infection more prevalent from the dual and triple. (Table 4). Single infection means that animals are infected at least with one species. the current findings agree with the results of the previous published reports in Iraq and other countries, significant differences were reported between single and mixed infection, with infection in (two-seven) *Eimeria* species was detected infection in Sichuan Province, southwest China (Yin *et al.*,2016).

It has been reported that out of of 750 samples with 2-6 species from examined samples. *E. flavescens* and *E. coeciola* were the major infection among *Eimeria* spp. ($p \leq 0.0001$). *Eimeria* spp. is identified in high infection with commonly mixed infections. Triple infection is more than one and dual infections (Hamid *et al.*,2019).Ten species are identified from 102 feces samples using Fuelleborn's flotation technique, and arrange prevalence of infection from the maximum to lower *E. perforans*, and *E. media*, *E. magna*, *E. exigua*, *E. coecicola*, *E. intestinalis*, *E. piriformis*, *E. flavescens*, *E. stiedae* ve *E. irresidua* (Gökpinar *et al.*,2023). Other study was confirmed ten species in Assiut, Egypt by parasitological examination. Overall prevalence were *E. perforans* (66.7%), *E. exigua* (26.2%), *E. media* (26.2%), *E. magna* (21.4%), *E. intestinalis* (19%), *E. coecicola* (19%), *E. irresidua* (19%), *E. piriformis* (14.3%), *E. flavescens* (7.1%) and *E. stiedae* (7.1%). (Elhendy *et al.*,2018). In the same examined samples more than one species of *Eimeria* oocyst was detected. *E. magna*; *E. flavescens*; *E. exigua*; *E. stiedae* and *E. coecicola*, Single-infection 13/90 (14.4%), dual-infection 39/90 (43.3%) and triple-infection 38/90 (42.2%) from Riyadh City, Al Kharj and ADilam in Saudi Arabia (Murshed *et al.*, 2023).

While Khider *et al.*, (2015) was recorded (72.5%, 58/80) with highly infection *E. perforans* was (31.25%), *E. piriformis* 27.5%, *E. irresidua* 11.25%, *E. media* 17.5%, *E. flavescens* 28.75%, *E. coecicola* 13.75%, *E. exigua* 18.75%, *E. intestinalis* 23.75%, *E. magna* 28.75% and *E. stiedae* 17.5%. The study conducted by Elhendy *et al.* (2018) revealed that 23.8% of the infected rabbits had a single infection of *Eimeria* spp., whereas 76.2% of the rabbits had mixed infections including two, three, or four *Eimeria* spp. The prevalence of mixed infection was equally distributed among males and females, with no statistically significant differences seen (Khider *et al.*, 2015). The prevalence of *Eimeria* infections in domestic rabbits, was 47.6% (197/414) from 414 faecal samples were collected from 50 farms in six regions in Medea province, North of Algeria. Eleven rabbit *Eimeria*'s species were present and identified from oocyst positive samples. *Eimeria magna* and *E. media* were the most prevalent species (47.6% and 47.3%) (Temim *et al.*, 2019). In Iraq, many reports were summarized, using standard diagnostic laboratory test of naturally occurring infection of (300) rabbits reared in Nenevah Province, Iraq, were investigated (17%). Coccidial infection were included *E. stiedae, E. magna, E. perforans, E. media, E. intestinalis* and *E. irresidua* (Al-Sadi and Al-Khafaji, 2000). In the same region was reported in Mosul, eleven species were: *E. exigua* 38.57% , *E. perforans* 32.85%, *E. nagpurensis* 25.71%, *E. elongata* 17.14%, *E.stiedae* 15.71%, *E. media* 14.28%, *E. coecicola* 14.28%, *E. irresidua* 10%, *E. matsubayashii* 8.57%, *E. magna* 5.71% and *E. intestinalis* 5.71%, with total infection 57.14%. Triple infection and more was most common in rabbits was 67.5% (Sulaiman,2005). The important role of rabbits in the dissemination of protozoan and transferring the disease to both humans and animals. The higher prevalence also observed among the wild rabbits *O. cuniculus* in Al-Diwaniyah province/Iraq, 41/55 (74.55%) were infected with eight different types of external and internal parasites (Marhoon *et al.*,2018).

CONCLUSION

In conclusion, the current study revealed seven species were infected of local rabbit and this consider the first report of intestinal coccidiosis in Karbala province, Iraq. The prevalence of rabbit coccidial infection is high. Knowledge and evaluate of current prevalence of coccidiosis will benefit to plan of control programs to minimize the economic losses.

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CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

AUTHOR CONTRIBUTION

All authors contributed equally.

ETHICAL APPROVAL

During the writing process of the study titled "Occurrence of *Eimeria* species in Naturally Infected Domestic Rabbits (*Oryctolagus cuniculus*) in North of Karbala Province, Iraq ", scientific rules, ethical and citation rules were followed; No falsification has been made on the collected data and this study has not been sent to any other academic media for evaluation. Ethics required are approved by the Ethical Committee of college of veterinary medicine/ university of Kerbala under acceptance number- UOK.VET. MI.2023.065.

REFERENCES

Al-Moula, D.H.I. (2005).Study of some endo and ecto parasites in domestic rabbits in Mosul/Iraq. *Iraqi J Vet Sci* 19(2), 143-153.10.33899/IJVS.2005.46707

Al-Sadi, H. I., & Al-Khafaji, N. J. (2000). Clinical and pathological studies on naturally occurring diseases of rabbits. *Iraqi J Vet Sci*, 13,309-316.

Athanasiou L.V., Tsokana C.N., Doukas D., Kantere M.C., Katsoulos P.D., Papakonstantinou G.I., Katsogiannou E.G., Dedousi A. 2023. Hepatic Coccidiosis in Wild Rabbits in Greece: Parasite Detection on Liver Imprints and the Associated Biochemical Profile. *Vet. Sci*.,10:248. https://doi.org/10.3390/vetsci10040248

Athanasiou, L. V., Tsokana, C. N., Doukas, D., Kantere, M. C., Katsoulos, P. D., Papakonstantinou, G. I., & Dedousi, A. (2023). Hepatic Coccidiosis in Wild Rabbits in Greece: Parasite Detection on Liver Imprints and the Associated Biochemical Profile. *Vet. Sci.*,10(4), 248.

Bachene, M. S., Temim, S., Ainbaziz, H., Bachene, A., & Suo, X. (2018). A vaccination trial with a precocious line of Eimeria magna in Algerian local rabbits *Oryctolagus cuniculus*. *Vet Parasitol*, *261*, 73-76. https://doi.org/10.1016/j.vetpar.2018.08.013Get rights and content

Basiaga, M., Levytska, V., Kowal, J., & Nosal, P. (2020). Coccidiosis–a problem in backyard rabbitries. *Annals parasitol*, *66*(1). https://pubmed.ncbi.nlm.nih.gov/32199000/

Elhendy, A., Kuraa, H., & Nageıb, B. (2018). Pathological and parasitological studies on some Eimeria species in rabbits using light and electron microscope. *Assiut Vet. Med. J*, *64*(157), 81-93. https://doi.org/10.21608/AVMJ.2018.168915

Faraj, A. A. (2017). Molecular diagnosis of naturally infection with Eimeria stiedae in domestic rabbits in Baghdad city-Iraq. *Young*, *50*(15), 30. https://www.entomoljournal.com/archives/?year=2017&vol=5&issue=3&ArticleId=1974

Gökpınar, S., Akdeniz, S., & Akkuş, G. N. (2022). Evcil Tavşanlarda Sindirim Sistemi Parazitlerinin Yaygınlığının Araştırılması. *Van Vet. J*, *33*(2), 52-55. https://doi.org/10.36483/vanvetj.1100361

Gökpınar, S., Akdeniz, S., & Akkuş, G. N. (2023). Ankara ve Kırıkkale yöresinde yetiştiriciliği yapılan tavşanlarda Eimeria türlerinin yaygınlığı ve morfolojik teşhisi. *Etlik Vet. Mikro. Derg*, *34*(1), 89-94. https://doi.org/10.35864/evmd.1128877

Hamid, P. H., Prastowo, S., & Kristianingrum, Y. P. (2019). Intestinal and hepatic coccidiosis among rabbits in Yogyakarta, Indonesia. Vet World, 12 (8): 1256–1260. 10.14202/vetworld.2019.1256-1260

Heker, M. M., Nakamura, A. A., Santana, B. N., & Meireles, M. V. (2017). Etiological aspects of Eimeria spp. infection in Brazilian rabbit (Oryctolagus cuniculus) farms. *Vet Parasitol: Regional Studies and Reports*, *8*, 78-81. https://doi.org/10.1016/j.vprsr.2017.02.004 https://www.cabidigitallibrary.org/doi/full/10.5555/20003002296

Indrasanti, D., Indradji, M., Sufiriyanto, S., Samsi, M., Yuwono, E., Nurkhasanah, N., ... & Fauziah, A. U. (2020, July). Prevalensı dan ıdentıfıkası *Eimeria* sp. pada kelıncı dı kabupaten banyumas. In *prosıdıng semınar nasıonal teknologı agrıbısnıs peternakan (STAP)* (Vol. 7, pp. 485-492). https://jnp.fapet.unsoed.ac.id/index.php/psv/article/view/468

Karaer, Z.(2001). Evcil tavşanlarda koksidiozis. In, Dinçer Ş (Ed): Koksidiozis. Türkiye Parazitoloji Derneği, Yaynn No: 17, İzmir.

Khider, A. T., Al-Rubaie, H. M., & Khalil, F. J. (2015). Prevalence of coccidiosis in local breed rabbits (Oryctolagus cuniculus) in Baghdad province. *Al-Qadisiyah J. Vet. Med. Sci*, *14*(1). https://iraqjournals.com/article_162338_0.html

Li, H., Shen, M., Hou, Z., & Yin, X. (2016). Morphology and molecular identification of the Eimeria spp. in domestic rabbits. *Pakistan J. Zoo*, *48*(1). https://www.zsp.com.pk/pdf48/289-291%20(38)%20PJZ-2198-15%2018-9-15.pdf

Marhoon, I. A., Mattar, K. T., & Mohammad, F. I. (2018). Parasitic infection in wild rabbits Oryctolagus cuniculus. *Eurasian J. Analyt. Chem*, *13*(5), 55. https://doi.org/10.29333/ejac/95252

Murshed, M., Mares, M., Aljawdah, H., & Al-Quraishy, S. (2023). A comparison in terms of prevalence, morphological and histopathological changes between Eimeria spp. that infect local rabbits (Oryctolagus cuniculus) in some regions of Saudi Arabia. *Indian J. Anim. Res*, *57*(12), 1662-1669. https://doi.org/10.18805/IJAR.BF-1682

Nicollas, H., Domingo, C., Ferrer, A., & Waminal, S. (2022). Identification of internal parasites of meat-type rabbits (Oryctolagus cuniculus L.) through fecalysis in a State College Bulacan, Philippines. *Agri. CRI. J*, *2*(2), 26-34. https://cbsua.edu.ph/journal_articles2_0/identification-of-internal-parasites-of-meat-type-rabbits-oryctolagus-cuniculus-l-through-fecalysis-in-a-state-college-in-bulacan-philippines/

Pakandl, M. (2013). Coccidia of rabbit: a review. *Folia Parasitolo*, *56*(3), 153-166. https://doi.org/10.14411/fp.2009.019

Pilarczyk, B., Tomza-Marciniak, A., Pilarczyk, R., Januś, E., Stanek, P., Seremak, B., & Sablik, P. (2020). The effect of the sex, age, and breed of farmed rabbits and the choice of management system on the extensity and intensity of Eimeria infection. *Vet. World*, *13*(8), 1654. https://doi.org/10.14202/vetworld.2020.1654-1660

Rabie, S. A., Abuelwafa, W. A., & Hussein, N. M. (2022). Occurrence of Eimeria species (Apicomplexa: Eimeriidae) in domestic rabbits (Oryctolagus cuniculus) in Qena Governorate, Upper Egypt. *J. Parasit. Dis*, *46*(3), 811-832. https://doi.org/10.1007/s12639-022-01494-2

Scialfa, E. A., Allende, L., Fariña, F., Quintana, S., Rivero, M. A., Rodriguez, M., & Pane, S. (2021). Eimeria oocyst excretion in naturally infected rabbit in a farm for meat production. Neotrop. Helminth, 15(2),199-209. https://doi.org/10.24039/rnh20211521276

Shkromada, O., & Nedzheria, T. (2020). Intensity of invasion in emeriosis of rabbits in different methods of keeping. *EUREKA: Health Sci*, (5), 107-114. https://doi.org/10.21303/2504-5679.2020.001419

Sulaiman, E. G. (2005).Diagnostic study of some intestinal protozoa in domestic rabbits in Mosul area. *Iraqi J Vet Sci*, *19*(2), 123-133.10.33899/IJVS.2005.46703

Temim, S., Ainbaziz, H., Bachene, A., & Bachene, M. S. (2019). Prevalence of Rabbit Coccidia in Medea Province, Algeria. *World Vet. J*, *9*(2), 123-128. https://doi.org/10.36380/scil.2019.wvj16

Ütük, A. E., Pişkin, F. Ç., Balkaya, İ., & Karakurum, M. Ç. (2015). Molecular detection of Eimeria stiedae in an Angora rabbit. *Etlik Vet. Mikro. Derg*, *26*(2), 41-44. https://doi.org/10.35864/evmd.513378

Yin, G., Goraya, M. U., Huang, J., Suo, X., Huang, Z., & Liu, X. (2016). Survey of coccidial infection of rabbits in Sichuan Province, Southwest China. *SpringerPlus*, *5*, 1-4. https://doi.org/10.1186/s40064-016-2586-6

Yuan, X., Liu, J., Hu, X., Yang, S., Zhong, S., Yang, T., ... & Li, Y. (2022). Alterations in the jejunal microbiota and fecal metabolite profiles of rabbits infected with Eimeria intestinalis. *Parasites & Vectors*, *15*(1), 231. https://doi.org/10.1186/s13071-022-05340-5

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Research Article

Determination of 8-OHdG and 4-HNE Expressions in Sheep with Hepatic Lipidosis by Immunohistochemical Method

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ABSTRACT

Lipidosis is generally defined as the accumulation of triglycerides in limited droplets within the cytoplasm of parenchymal cells. Lipidosis occurs due to toxic, chemical, infectious, and metabolic causes. This study aimed to reveal the local 8-hydroxy-2'-deoxyguanosine (8-OHdG) and 4-hydroxynonenal (4-HNE) expressions immunohistochemically according to the severity of the disease in sheep with hepatic lipidosis. The study material consisted of a total of 30 male sheep livers, including 6 healthy and 24 with hepatic lipidosis. After the liver samples were fixed in 10% formaldehyde solution, they underwent routine tissue processing to obtain paraffin blocks. Sections taken from the paraffin blocks were then subjected to Hematoxylin-Eosin (H-E) and immunohistochemical staining. Microscopically, control group liver samples showed normal histology. In livers with hepatic lipidosis, sharp-edged vacuoles of various sizes were detected in hepatocytes, and cell nuclei were pushed to the periphery. Additionally, focal hemorrhage and congestion, inflammatory cell infiltration in the portal area, bile duct proliferation, and connective tissue cells were observed. Microscopically, hepatic lipidosis cases were divided into two groups as moderate and severe based on the distribution of vacuoles in the section. In the immunohistochemical examination, 8-OHdG and 4-HNE expressions significantly increased in hepatic lipidosis cases compared to the control group ($p<0.001$). More intense immunoreactivity was detected especially in cases where disease severity increased ($p<0.001$). These results indicate that 8-OHdG and 4-HNE proteins play an important role in the pathogenesis of hepatic lipidosis and may be effective in increasing the severity of the disease.

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INTRODUCTION

Lipidosis is generally defined as the accumulation of triglycerides in limited droplets within the cytoplasm of parenchymal cells. Lipidosis occurs due to toxic, chemical, infectious, and metabolic causes (Erer et al., 2009; Jubb et al., 2012). Additionally, hypoxia, feeding with diets deficient in choline, ketosis, and abnormal pancreatic secretions constitute other causes. The two main factors known in the pathogenesis of lipidosis are the transport of lipids to the affected cell in amounts greater than it can metabolize and issues related to the synthesis of proteins and lipoproteins necessary for lipid transport. Lipidosis can frequently be observed primarily in the liver, as well as in the kidney and heart (Boden, 1997; Anderson and Borlak, 2008; Erer et al., 2009; Jubb et al., 2012).

Macroscopically, hepatic lipidosis presents with liver enlargement, blunting of edges, and a bulging cut surface, varying according to the severity of fatty change. The liver appears pale and yellowish in color. Microscopically, sharp-edged vacuoles of various sizes are observed in hepatocytes, and the cell nucleus is pushed to the periphery (Johnson et al., 1999; Erer et al., 2009; Jubb et al., 2012; Yeh and Brunt, 2014). Small droplet fatty change is seen in acute metabolic diseases, while large droplet fatty change is observed in toxic and some viral diseases. Hepatic steatosis can be diffuse or local based on its distribution. Centrilobular, peripheral, intermediate, and panlobular fatty changes are forms of diffuse fatty change (Jubb et al., 2012; Yeh and Brunt, 2014).

Hepatic lipidosis is defined as one of the significant metabolic disorders in animals that develops as a result of the abnormal presence of glucogenic and lipogenic products in the liver. It has been better described in large ruminants (Goff and Horst, 1997; Johnson et al., 1999; Al-Habsi et al., 2007). In large ruminants, it is associated with decreased feed intake, lactation, environmental cold, fetal growth, and negative energy balance caused by disease. Pregnancy toxemia, vitamin E deficiency, cobalt deficiency, toxication, and negative energy balance constitute important findings of hepatic steatosis in sheep (Ulvund, 1990, Johnson et al., 1999; Menzies et al., 2004; Al-Habsi et al., 2007). Furthermore, cobalt deficiency in sheep has been described to cause fatty hepatic degeneration, known as ovine white liver disease. It has been reported that hepatic lipidosis in sheep not only causes liver failure but also results in death in advanced stages (Johnson et al., 1999; Ulvund, 1990).

This study aims to demonstrate the 8-hydroxy-2'-deoxyguanosine (8-OHdG) and 4-hydroxynonenal (4-HNE) protein expressions according to the severity of hepatic lipidosis in sheep with hepatic lipidosis using the local immunohistochemical method.

MATERIAL AND METHODS

Animal material

The material for the study consisted of 24 sheep liver (Merino, Male, 6-24 months) samples that were positive for hepatic lipidosis, collected from different farms in Sivas and Yozgat provinces. Additionally, 6 healthy sheep (Merino, Male, 12-18 months) liver tissues were obtained from a nearby slaughterhouse.

Histopathological and Immunohistochemical evaluation

Liver samples were fixed in 10% neutral formaldehyde solution for 24-48 hours. Subsequently, paraffin blocks were obtained through routine processing, passing through alcohol and xylol series. Sections were taken from paraffin blocks onto slides, stained with Hematoxylin-Eosin (H-E), and examined under light microscopy (Akcakavak et al., 2024). Histopathological evaluation was performed semi-quantitatively by a blinded pathologist based on the presence of vacuoles in hepatocytes. Accordingly, vacuoles less than 50% were evaluated as mild (1), between 51% and 75% as moderate (2), and more than 75% as severe (3) (Johnson et al., 2004).

Immunohistochemical staining was performed using a commercial kit according to previously reported studies (Akcakavak et al., 2023; Kazak et al., 2024). 8-OHdG (Santa Cruz Biotechnology, sc-393871, 1/200 dilution, 1 hour incubation) and 4-HNE (Abcam, ab46545, 1/200 dilution, 1 hour incubation) antibodies were used as primary antibodies. 3,3 diaminobenzidine (DAB) was used as a chromogen, and after counterstaining with Mayer's hematoxylin, it was examined under a light microscope. Immunohistochemical

scoring was performed semi-quantitatively (0; none, 1; mild staining, 2; moderate staining, 3; severe staining, 4; very severe staining) (Kazak et al., 2024).

Statistical Analysis

Immunohistochemical findings obtained in the study were evaluated using One-way ANOVA and Duncan's test (SPSS, Inc., Chicago, USA 25.0) as post-hoc tests. The significance level was set at $p<0.05$.

RESULTS

Macroscopic Findings

Control group livers were found to have normal appearance and contour. In livers with hepatic lipidosis, enlargement in size, fragility, blunting of edges, and paleness in color were detected. Cut surfaces had a swollen appearance, and paleness was prominent throughout the parenchyma. Petechial hemorrhages were detected on the liver serosa in 2 cases (Figure 1). Additionally, parasite cysts were observed in 3 different cases in the liver, and parasite migration paths were seen in the liver parenchyma in 2 different cases.

Figure 1. *Macroscopic appearance of pale livers from different sheep.*

Microscopic Findings

Control group liver tissues showed normal histology. In liver samples with hepatic lipidosis, sharp-edged, variously sized vacuoles were detected in hepatocytes, and cell nuclei were pushed to the periphery. Hepatocyte nuclei occasionally showed necrotic changes. Additionally, focal hemorrhage and congestion, inflammatory cell infiltration in the portal area, bile duct proliferation, and connective tissue cells were detected (Figure 2). Moreover, fibrosis foci were found in 6 severe (score 3) cases. In the histopathological evaluation, 7 cases were found to be moderate (score 2) and 17 cases were severe (score 3).

The immunohistochemical statistical scores between the groups are given in Table 1. Immunohistochemically, no 8-OHdG immunopositivity was observed in control group livers. However, 4-HNE immunoreactivity was very mild and/or absent. In livers with hepatic lipidosis, 8-OHdG and 4-HNE expressions were found to be significantly increased (Figure 3). Immunoreactivity in related primers (8-OHdG and 4-HNE) showed cytoplasmic localization. Especially in severe cases (score 3), 8-OHdG and 4-HNE immunoreactivity was more intense and widespread compared to moderate cases (score 2) ($p<0.001$).

Table 1. *Immunohistochemical statistical scores of healthy and hepatic lipidosis livers (Mean+SE).*

Primers	Control (n;6)	Moderate (score 2) (n;7)	Severe (score 3) (n;17)
8-OHdG	0.00 ± 0.00^{c}	1.28 ± 0.19^{b}	2.33 ± 0.28^{a}
4-HNE	0.33 ± 0.21^{c}	1.57 ± 0.20^{b}	2.55 ± 0.17^{a}

$^{a-c}$ Letters in the same row indicate statistical significance ($p<0.001$). (8-OHdG; 8-hydroxy-2'-deoxyguanosine, 4-HNE; 4-hydroxynonenal)

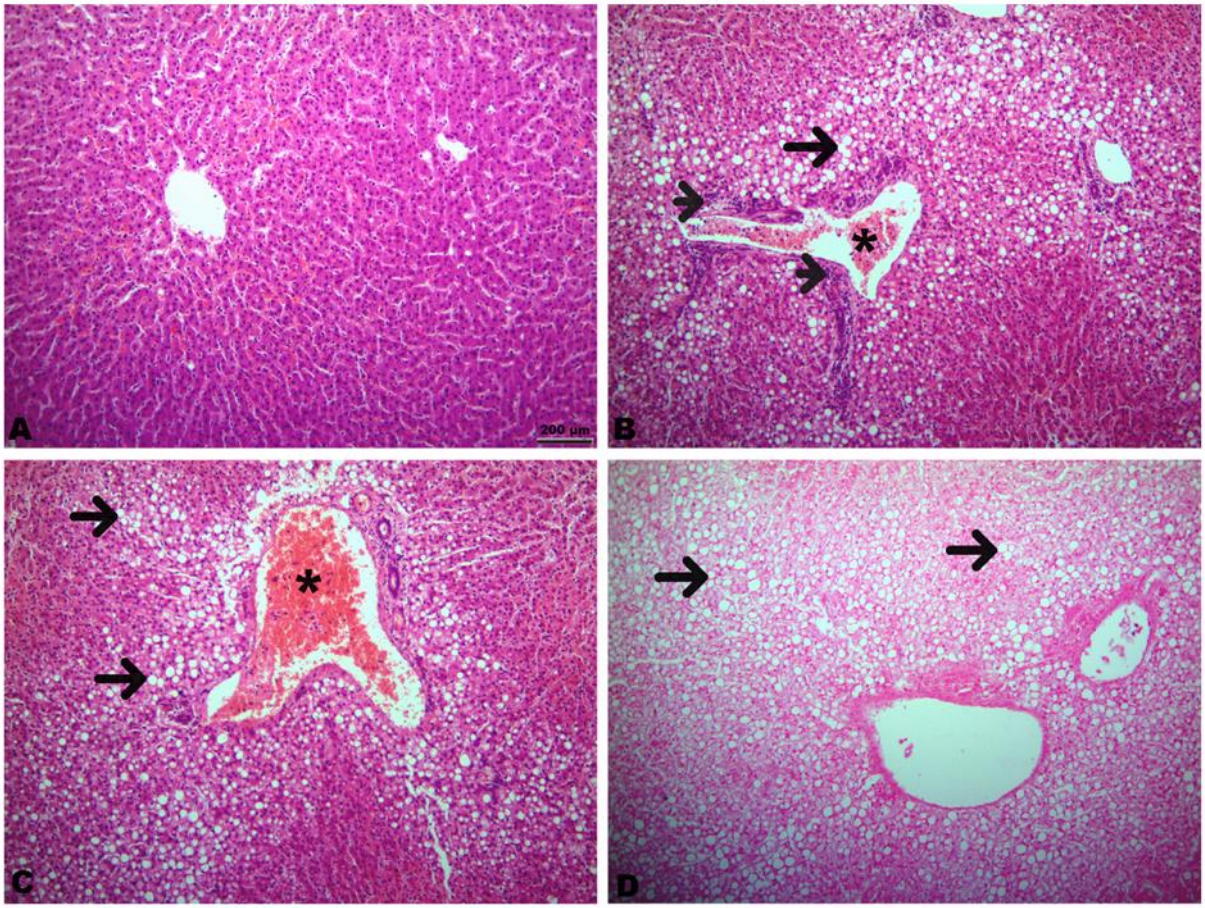

Figure 2. *Microscopic appearance of healthy and hepatic lipidosis livers, Hematoxylin-Eosin (H-E), x100.* ***A.*** *Normal histological appearance of control group liver.* ***B-C.*** *Appearance of liver samples with moderate diffuse (score 2) vacuoles.* ***D.*** *Appearance of liver samples with severe diffuse (score 3) vacuoles. (vacuole appearance (arrows), inflammatory cell infiltration (arrowheads), congestion (asteriks)*

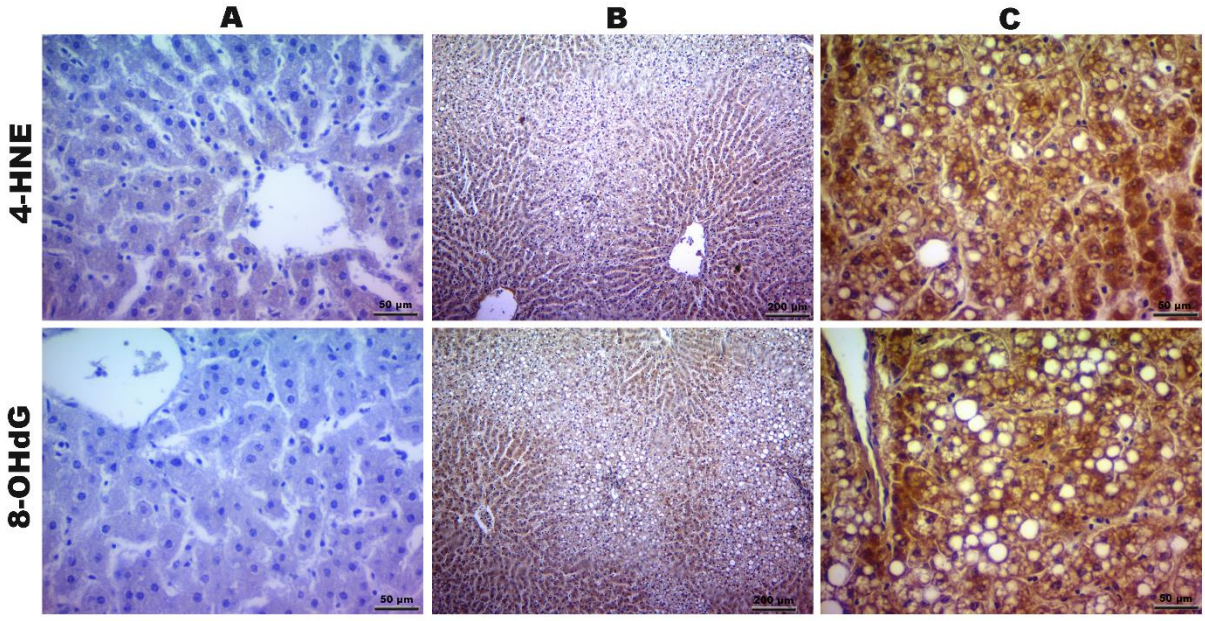

Figure 3. *Microscopic appearance of healthy and hepatic lipidosis livers, immunohistochemical staining (DAB). (A; Control group, B; Liver with moderate diffuse (score 2) vacuoles, C; Liver with severe diffuse (score 3) vacuoles, 4-HNE; 4-Hydroxynonenal, 8-OHdG; 8-hydroxy-2'-deoxyguanosine).*

DISCUSSION

The liver is known as the body's largest metabolic center. It has important functions such as storage and control of carbohydrate metabolism, synthesis of plasma proteins, detoxification of various drugs and toxins, urea production, and fat metabolism. As the liver is the main organ of fat metabolism, hepatic lipidosis condition is frequently encountered. It is also constantly exposed to toxic, chemical, and infectious effects (Thapa and Walia, 2007; Erer et al., 2009). Studies in cattle report that liver fatty cases are encountered at rates of 4-13% (Oruc, 2009; Altun and Saglam, 2014). However, it is stated that the incidence of liver fatty in sheep is lower and is associated with an extensive feeding style. Gözün and Kıran (1999), reported that they detected fatty cases at a rate of 0.38% in 1561 sheep livers with lesions. In addition to the limited number of studies on ovine hepatic lipidosis cases in the literature review, research is more focused on pregnancy toxemia (Iqbal et al., 2022; Ji et al., 2023). In the current study, 8-OHdG and 4-HNE protein expressions were determined immunohistochemically according to the severity and prevalence of steatosis in male sheep with hepatic lipidosis.

In cases of hepatic lipidosis in small ruminants, macroscopically, enlargement, brittle structure and pale color of the liver are reported. Histopathologically, sharp-edged fat vacuoles in hepatocytes, inflammatory cell infiltration in the portal area, bile duct proliferation, and fibrosis are reported (Ulvund, 1990, El-Khodery et al., 1994; Johnson et al., 1999; Al-Habsi et al., 2007). The macroscopic and microscopic findings observed in the present study, especially in severe cases (score 3), exhibited similar findings to the literature. In addition, the detection of occasional fibrosis foci in 6 severe (score 3) cases indicates an advanced state of the disease. Moreover, macroscopic findings related to parasite infestation were found in 5 cases.

8-OHdG is defined as a marker of oxidative DNA damage caused by reactive oxygen species. 8-OHdG is produced from guanine in DNA bases through oxidative stress. 8-OHdG is an important marker that plays a role in the pathogenesis of inflammatory, diabetic, and autoimmune diseases and malignancies (Miyamoto et al., 2011; Varghese et al., 2020). Miyamoto et al. (2011) reported in their study investigating the relationship between metabolic risk factors and oxidative stress in humans that hypertriglyceridemia may be associated with hyperoxidative stress evaluated by 8-OHdG. It is also stated that hypertriglyceridemia can stimulate ROS production and impair the antioxidant defense system (Hiramatsu et al., 1991; Araujo et al., 1995). Additionally, different human studies report that oxidative stress markers such as 8-OHdG and 4-HNE are found in high concentrations in non-alcoholic fatty liver disease (NAFLD). Furthermore, NAFLD is characterized by increased microsomal fatty acid oxidation, which is associated with greater ROS production (Seki et al., 2002; Sumida et al., 2021). Dinçel et al. (2018) reported in their study on streptozotocin-induced type-1 diabetic rats that 8-OHdG expressions significantly increased in the diabetic group compared to the control group, and oxidative DNA damage plays important roles in diabetes-related liver degenerations. In the present study, 8-OHdG expressions were evaluated in hepatic lipidosis in sheep, and it was found that 8-OHdG immunoreactivity increased as the severity of the disease in the liver increased. Previous studies have reported that oxidative stress is upregulated in hepatic lipidosis cases (Yoshino et al., 1992 ; Webb and Twedt, 2008; Elshafey et al., 2023). This suggests that oxidative stress-induced oxidative DNA damage may play an important role in the disease process in hepatic lipidosis in sheep.

In conditions of increased metabolic disorder and inflammation, ROS production may exceed the cell's antioxidant capacity. The resulting free radicals can react with various amino acids and lipids (Herndon et al., 2014). Another oxidative reaction caused by excessive ROS levels is lipid peroxidation. 4-HNE is known as the cytotoxic end product of lipid peroxidation (Yang et al., 2003; Ayala et al., 2014). Lipid peroxidation is thought to play a role in the progression of many diseases, particularly those characterized by lipid accumulation such as NAFLD. In a study conducted by Fu et al. (2022), it was reported that an n-6 PUFA diet had a negative effect on alcohol-induced liver damage and steatosis, and they suggested that this might be related to the upregulation of 4-HNE. In the present study, the highest 4-HNE immunoreactivity was found in severe (group 3) cases, and this indicates that lipid peroxidation may play important roles in the progression of the disease in the pathogenesis of hepatic lipidosis in sheep.

CONCLUSION

In conclusion, in the current study, local expressions of 8-OHdG and 4-HNE were evaluated immunohistochemically in sheep with hepatic lipidosis. The present results show that 8-OHdG and 4-HNE

proteins play an important role in the pathogenesis of the disease and may play an active role in increasing the severity of the disease.

AUTHOR CONTRIBUTION

All authors contributed equally.

ETHICAL STATEMENT

Scientific rules, ethics and citation rules were followed during the writing process of the study titled "**Determination of 8-OHdG and 4-HNE expressions in sheep with hepatic lipidosis by immunohistochemical method**"; There was no tampering with the data collected and this study was not sent to any other academic publication environment for evaluation. The necessary ethics committee permissions were obtained by Sivas Cumhuriyet University Animal Experiments Ethics Committee's Decision dated 16.08.2024 and numbered 2024/55.

CONFLICT OF INTEREST

The authors certify that they have no conflict of interest.

REFERENCES

Akcakavak, G., Kazak, F., Karatas, O., Alakus, H., Alakus, I., Kirgiz, O., Celik, Z., Deveci MZY., Ozdemir, O., & Tuzcu, M. (2024). Eucalyptol regulates Nrf2 and NF-kB signaling and alleviates gentamicin-induced kidney injury in rats by downregulating oxidative stress, oxidative DNA damage, inflammation, and apoptosis. *Toxicol. Mech. Methods, 34*(4), 413-422.

Akcakavak, G., Kazak, F., & Deveci, MZY (2023). Eucalyptol Protects against Cisplatin-Induced Liver Injury in Rats. *Biol. Bull. 50*(5), 987-994.

Al-Habsi, K., Johnson, EH., Kadim, IT., Srikandakumar, A., Annamalai, K., Al-Busaidy, R., & Mahgoub, O. (2007). Effects of low concentrations of dietary cobalt on liveweight gains, haematology, serum vitamin B12 and biochemistry of Omani goats. *Vet. J. 173*(1), 131-137.

Altun, S., & Sağlam, Y. (2014). Erzurum ilinde kesimi yapılan sığırlarda karaciğer lezyonları üzerinde patolojik incelemeler. *Atatürk Üni. Vet. Bilim. Derg*. *9*(1), 7-15.

Anderson, N., & Borlak, J. (2008). Molecular mechanisms and therapeutic targets in steatosis and steatohepatitis. *Pharm. Rev*. *60*(3), 311-357.

Araujo, FB., Barosa, DS., Hsin, CY., Maranhão, RC., & Abdalla, DS. (1995). Evaluation of oxidative stress in patients with hyperlipidemia. *Atherosclerosis, 117*(1), 61-71.

Ayala, A., Muñoz, MF., & Argüelles, S. (2014). Lipid peroxidation: production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. Oxid. Med. Cell Longev. 2014(1), 360438.

Boden, G. (1997). Role of fatty acids in the pathogenesis of insulin resistance and NIDDM. *Diabetes*, *46*(1), 3-10.

Dinçel, GÇ., Yıldırım, S., & Kul, O. (2018). Role of nitric oxide and oxidative stress in pathophysiology of liver injury in streptozotocin-induced type 1 diabetic rats. Ankara Univ. Vet. Fak. Derg. *65*, 39-50.

El-Khodery, S., Hussein, H., Metwally, N., Nassif, M., El-Boshy, M., & Galbat, S. (1994). Ultrasonographic and histopathological evaluation of hepatic lipidosis in sheep with cobalt deficiency. OJVR, *12*, 23-32.

Elshafey, BG., Elfadadny, A., Metwally, S., Saleh, AG., Ragab, RF., Hamada, R., Mandour, AS., Hendawy, A. O., Alkazmi, L., & Ogaly, H. A. (2023). Association between biochemical parameters and ultrasonographic measurement for the assessment of hepatic lipidosis in dairy cows. *Italian J. Anim. Sci. 22*(1), 136-147.

Erer, H., Kıran, M., & Ciftci, M. (2009). Veterinary Genel Patoloji. In: Bahcivanlar Press, Konya, Türkiye, pp. 236.

Fu, A., Li, J., Ding, Q., Guo, R., Pi, A., Yang, W., Chen, Y., Dou, X., Song, Z., & Li, S. (2022). Upregulation of 4-hydroxynonenal contributes to the negative effect of n-6 polyunsaturated fatty acid on alcohol-induced liver injury and hepatic steatosis. *J Agric Food Chem*. *70*(21), 6418-6428.

Goff, J., & Horst, R. (1997). Physiological changes at parturition and their relationship to metabolic disorders. *J dairy sci*. *80*(7), 1260-1268.

Gözün, H., & Kıran, M. (1999). Konya mezbahalarında kesime alınan koyunların karaciğerinde patolojik incelemeler. *Veterinarium, 10*, 1-19.

Herndon, A., Breshears, M., & McFarlane, D. (2014). Oxidative modification, inflammation and amyloid in the normal and diabetic cat pancreas. *J. Comp. Pathol. 151*(4), 352-362.

Hiramatsu, K., Saigusa, Y., & Nakazawa, H. (1991). Low superoxide scavenging activity associated with enhanced superoxide generation by monocytes from male hypertriglyceridemia with and without diabetes. *Atherosclerosis, 90*(1), 39-47.

Iqbal, R., Beigh, S., Mir, A., Shaheen, M., Hussain, S., Nisar, M., & Dar, A. (2022). Evaluation of metabolic and oxidative profile in ovine pregnancy toxemia and to determine their association with diagnosis and prognosis of disease. *Trop. Anim. Health Product. 54*(6), 338.

Ji, X., Liu, N., Wang, Y., Ding, K., Huang, S., & Zhang, C. (2023). Pregnancy Toxemia in ewes: a review of Molecular Metabolic mechanisms and Management Strategies. *Metabolites*, *13*(2), 149.

Johnson, E., Muirhead, D., Annamalai, K., King, G., Al-Busaidy, R., & Shahul Hameed, M. (1999). Hepatic lipidosis associated with cobalt deficiency in Omani goats. *Vet. Res. Commun. 23*, 215-221.

Johnson, E. H., Al-Habsi, K., Kaplan, E., Srikandakumar, A., Kadim, I. T., Annamalai, K., Al-Busaidy, R., & Mahgoub, O. (2004). Caprine hepatic lipidosis induced through the intake of low levels of dietary cobalt. *Vet. J. 168*(2), 174-179.

Jubb, KVF., Kennedy, PC., & Palmer, N. (2012). *Pathology of domestic animals*. Academic press. p. 701.

Kazak, F., Akcakavak, G., Alakus, I., Alakus, H., Kirgiz, O., Karatas, O., Deveci, MZY., & Coskun, P. (2024). Proanthocyanidin alleviates testicular torsion/detorsion-induced ischemia/reperfusion injury in rats. *Tissue and Cell*, *89*, 102459.

Menzies, P., Langs, L., Boermans, H., Martin, J., & McNally, J. (2004). Myopathy and hepatic lipidosis in weaned lambs due to vitamin E deficiency. *Canadian Vet. J. 45*(3), 244.

Miyamoto, M., Kotani, K., Ishibashi, S., & Taniguchi, N. (2011). The relationship between urinary 8-hydroxydeoxyguanosine and metabolic risk factors in asymptomatic subjects. *Med. Princ. and Pract. 20*(2), 187-190.

Oruc, E. (2009). Mezbahada kesilen sığırlarda karaciğer lezyonları üzerine histopatolojik bir çalışma. *Atatürk Üniv. Vet. Bilim. Derg. 4*(2), 97-104.

Seki, S., Kitada, T., Yamada, T., Sakaguchi, H., Nakatani, K., & Wakasa, K. (2002). In situ detection of lipid peroxidation and oxidative DNA damage in non-alcoholic fatty liver diseases. *J. Hepatol*. *37*(1), 56-62.

Sumida, Y., Yoneda, M., Seko, Y., Takahashi, H., Hara, N., Fujii, H., Itoh, Y., Yoneda, M., Nakajima, A., & Okanoue, T. (2021). Role of vitamin E in the treatment of non-alcoholic steatohepatitis. *Free Radic. Biol. Med*. *177*, 391-403.

Thapa, B., & Walia, A. (2007). Liver function tests and their interpretation. *Indian J. Pediatr*. *74*, 663-671.

Ulvund, M. J. (1990). Ovine white-liver disease (OWLD). Changes in blood chemistry. *Acta Vet. Scand. 31*(3), 277.

Varghese, J., Bhat, V., Chianeh, Y. R., Kamath, V., Al-Haj Husain, N., & Özcan, M. (2020). Salivary 8-hydroxyguanosine levels in smokers and non-smokers with chronic periodontitis. *Odontology*, *108*, 569-577.

Webb, C., & Twedt, D. (2008). Oxidative stress and liver disease. *Veterinary Clinics of North America: Small Anim. Pract*. *38*(1), 125-135.

Yang, Y., Sharma, R, Sharma, A., Awasthi, S., & Awasthi, Y. (2003). Lipid peroxidation and cell cycle signaling: 4-hydroxynonenal, a key molecule in stress mediated signaling. *Acta Biochim. Pol. 50*(2), 319-336.

Yeh, M. M., & Brunt, E. M. (2014). Pathological features of fatty liver disease. *Gastroenterology*, *147*(4), 754-764.

Yoshino, K., Katoh, N., Takahashi, K., & Yuasa, A. (1992). Purification of a protein from serum of cattle with hepatic lipidosis, and identification of the protein as haptoglobin. *Am. J. Vet. Res. 53*(6), 951-956.

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Research Article

The Effect of Distance to Boron on Serum Boron Concentration and Some Biochemical and Hematological Parameters in Sheep

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ABSTRACT

Boron is an essential element in relation to underground resources, with Turkey possessing 73.5 per cent of the global boron reserves. Its prevalence in the field of industry has made it the subject of research in the field of health in recent years. There is a very thin boundary between deficiency and toxicity. Its mechanisms in living organisms are not fully understood, therefore, sufficient and complete and consistent data on human and ecosystem health and its place and dose in these areas have not been reached, and data are needed to maintain and increase its importance and necessity in these areas. The amount and duration of boron exposure may increase in boron fields. This is because boron can be found in air, soil and water. This study investigates the changes in boron levels in living organisms as a function of the distance of boron exposure. Statistically significant differences in serum boron, urea, creatinine and BUN levels were observed between different locations. In parallel, statistically significant differences were also observed between some haemogram parameters. The data obtained are valuable with regard to the possible interaction between boron exposure distance and serum boron levels.

Keywords: *Boron, Sheep, Serum*

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INTRODUCTION

Boron (B), a chemical element that has been known to the scientific community for centuries, was first discovered in the year 1808. It is positioned in Group 13 of the periodic table and is represented by the chemical symbol B. Boron is classified as a semi-metal and has an atomic number of 5. It can exist in either a crystalline or amorphous state and is known to exhibit different colours. Boron possesses a distinctive set of chemical properties, leading to its characterisation as one of the most intriguing and complex elements after carbon (Balonos et al., 2004; Kuru and Yarat, 2017). Despite its relative scarcity when compared with hydrogen, carbon, nitrogen or oxygen, boron is ubiquitous in the environment, naturally occurring in rocks, soil and water. Concentrations of boron have been reported in soil ranging from 5-150 mg/kg, in seawater from 0.5-9.6 mg/kg, and in air from 0.5-800 ng/m3. It is the 51st most abundant element in the Earth's crust, with an average concentration of 8 mg/kg (approximately 0.0008%).The combination of its metal and nonmetal properties, in conjunction with its high affinity for oxygen, enables it to form diverse compounds.Boron compounds, of which there are more than 250 types, find primary application in industrial domains such as glass production and fiberglass. Furthermore, some of these compounds have found application in the cleaning sector, for example as antiseptics and in soap. In addition to these uses, they have been employed as herbicides and fertilisers in agriculture, and in recent years they have often been the subject of medical research (Uluisik et al., 2018; Ince et al., 2019).

Its pharmacokinetics have been investigated in both humans and animals. Boron, known to be frequently exposed orally, is absorbed from the gastrointestinal tract. It diffuses rapidly into the body by passive diffusion and has a half-life of approximately 24 hours. Excretion is largely through the kidneys by glomerular filtration. It has been reported to accumulate in certain organs such as the brain, bone, testes and liver until excreted (Oğlakcı-İlhan et al., 2023; Onder et al., 2023). The biochemical mechanism for boron, which is found in low amounts in human and animal tissues, is still unknown. However, it has been reported to play an active role in metabolic and physiological functions, tissue regeneration, anti-inflammatory and antioxidant. In addition, it acts as a co-factor for enzymes in bone mineralization and wound healing (Kuçukkurt et al., 2023; Abdelnour et al., 2018). Furthermore, boron neutron capture therapy (BNCT), which was initially employed in human patients to treat head and neck cancer, is currently being evaluated in animal models of cancer. This is a notable development given the increasing prevalence of cancer, which can be attributed in part to the advancements witnessed in the field of veterinary science (Pizzorno, 2015; Kusaka et al., 2022).

Boron is a trace element that is present in the diet of many organisms. The recommended daily intake of boron for humans is approximately 0.5-1 mg. However, as with all elements, boron can have adverse effects on living organisms. The nature of these effects can vary depending on the concentration, duration and variety of exposure. It is therefore important to understand the risk/benefit balance associated with boron use and exposure, and to assess the potential health effects of boron intake from diet and drinking water. This has reportedly become a critical component of risk assessment in recent years. Toxicity has been reported to occur at elevated boron levels. For this reason, the World Health Organization (WHO) published in 2011 that drinking water should contain 2.4 ppm boron. The amount of boron that should be taken daily because of nutrition has been reported as 2 mg (Ince et al., 2016; Wang et al., 2018; Nielsen and Eckhert, 2020). Moreover, boric acid is categorised by the European Union as a "Category 1B" compound. This designation signifies that the substance belongs to a group of compounds that have the potential to compromise fertility (Kan and Kucukkurt, 2023; Bolt et al., 2020). Excess boron has been shown to be hazardous when administered in excess. The possible adverse effects include nausea, vomiting, diarrhoea and abdominal pain. Furthermore, symptoms such as seizures, irritability, and oedema have been documented. It is noteworthy that the lethality of a single dose is very low, since the excess is excreted in the urine (Devirian and Volpe, 2003). The known side effects of boron are few and far between. Nevertheless, the findings of recent research have served to underscore the significance of this issue.

Urea is a product of protein metabolism and is considered to be one of the quality indicators of the filtration process of the kidney, with BUN (blood urea nitrogen) being another such indicator. Creatine, a by-product of muscle metabolism, has been shown to be related to muscle mass and kidney function in living organisms. Hematologic parameters are of great importance in the detection of disease and metabolic disorders, and they

are also used to monitor the side effects of drugs and drug-like substances. Routinely measured parameters are also useful in explaining changes in mechanisms involved in physiological events.

In the light of all the information given in the literature, in this study, it was thought that blood boron levels, some biochemical and hematological parameters would differ in sheep raised in regions where boron exposure is thought to be at different levels. For this hypothesis, 2 different regions were determined as close and far from the boron mine site. It was aimed to measure blood boron levels, hematological parameters, urea, creatine, BUN by taking blood from sheep living in these regions.

MATERIALS AND METHODS

Animals and Sample Collection

Two locations were determined for the hypothesis. The first study location was the Bigadiç district, where a boron mine is located. The second location was the centre of Balıkesir province. Blood was taken from a total of 20 sheep. The sheep were checked for pregnancy and general health status. The neck area was shaved and two tubes were taken from the vena jugularis. One tube was used to obtain whole blood (for haemogram) and the other tube was used to obtain serum (for urea, creatine, BUN and boron concentration).

Biochemical and Hematological Analysis

The collected whole blood samples were kept in cold chain and analyzed within 2 hours and without clotting/disintegration. Blood tubes were carefully placed in the VETMAC VH30 Hemogram Device to obtain information on WBC, LYM#, MID#, GRAN#, LYM%, MID%, GRAN%, NLR, PLR, RBC, HGB, HCT, MCV, MCH, MCHC, RDW-CV, RDW-SD, PLT, MPV, PDW-CV, PDW-SD, PCT, P-LCC, P-LCR parameters.

After the other blood tubes were collected from the animals, they were transported in cold chain and serum was separated by centrifugation at 4000 rpm for 5 minutes (ISOLAB). Serum samples were collected in double-redundant 2 ml ependorfs and stored at -18ºC until analysis. Serum samples for urea, creatine and BUN analysis were delivered to BALLAB without breaking the cold chain. These analyzes were performed as a service procurement and the results were obtained (ERBA, XL 2000).

Boron Analysis

Serum samples for determination of boron concentration were thawed at +4. Then the sample volume was determined and taken into the container and nitric acid and hydrogen peroxide were added according to the method. It was left to heat under a fume hood, taking care not to boil. The samples purified from organic substances were then taken into a balloon jug and the volume was completed to 10 ml by adding ultrapure water. The prepared samples were analyzed in ICP-OES device at Balıkesir University Science and Technology Application and Research Center (Perkin-Elmer OPTIMA7300) (Tokay and Bagdat, 2022a ve 2022b).

Statistical Analysis

In the study, Kolmogorov-Smirnov test was applied for normality assumptions. Independent t-test, one of the parametric tests, was applied to determine whether there was a significant difference between the groups. The data obtained were analysed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). In case of a significant difference between the groups, post-Hoc test was used to determine between which groups there was a significant difference. $p<0.05$ was considered statistically significant.

RESULTS

Blood samples taken from sheep in the Centre group and Bigadiç group selected from the region close to the boron mine site were analyzed. The proximity to the mine site was determined by the high boron levels in the Bigadiç group. The statistically significant difference between the groups is shown *(Figure 1).*

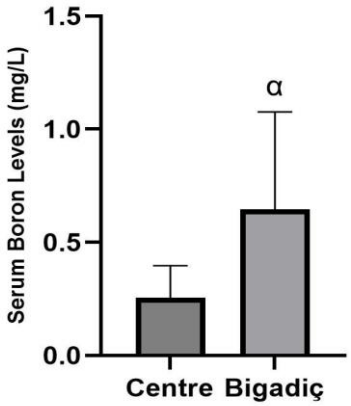

Figure 1. *Serum boron levels (mg/L) of the animals in the Centre and Bigadiç groups.*

Urea, creatine and BUN were measured in the sera obtained from the blood collected from the Bigadiç group and the Centre group. Significant differences in these parameters were determined statistically and are shown below (Figure 2).

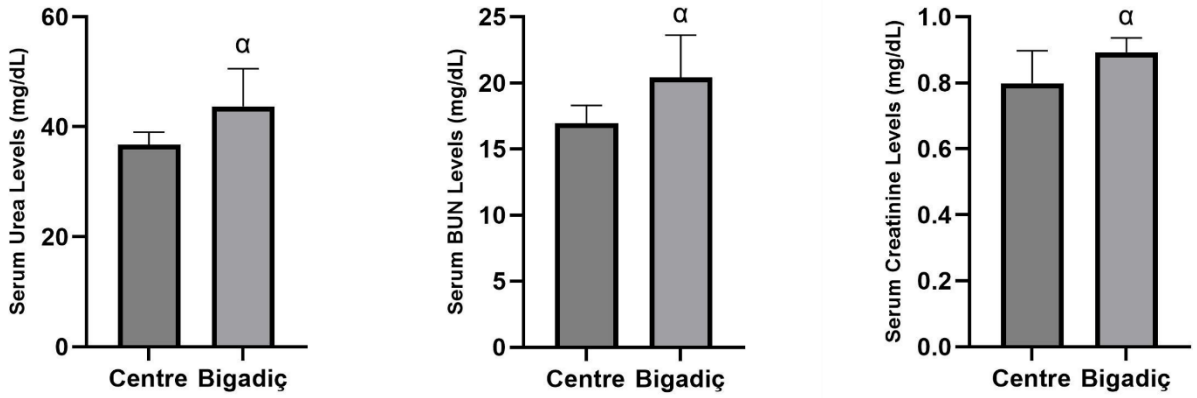

Figure 2. *Serum urea, BUN and creatinine levels (mg/L) of the animals in the Centre and Bigadiç groups.*

Whole blood samples taken from the sheep were analyzed considering the time period. There were no differences between the groups in most of the parameters, but GRAN%, NLR, RDW-CV, PLT and MPV values showed statistically significant differences. All parameters are shown in the table (Table 1).

Table 1. *Blood parameters of the animals in the Centre and Bigadiç groups.*

	Bigadiç		Centre		
	Mean±SD	**Min-Max**	**Mean±SD**	**Min-Max**	**P**
WBC (10^9/L)	32.90±4.64	15.69-58.88	28.96±4.32	9.46-49.32	**0.542**
LYM# (10^9/L)	21.01±2.41	12.00-36.18	17.12±2.53	5.90-30.09	**0.281**
MID# (10^9/L)	6.36±1.23	1.29-12.33	4.41±0.84	1.22-9.22	**0.209**
GRAN# (10^9/L)	6.98±1.17	2.01-14.19	7.43±1.08	2.34-13.26	**0.784**
LYM% (%)	0.64±0.02	0.56-0.78	0.59±0.01	0.54-0.66	**0.076**
MID% (%)	0.14±0.01	0.08-0.21	0.14±0.01	0.11-0.18	**0.970**
GRAN% (%)	0.20±0.01	0.08-0.26	0.26±0.01	0.18-0.31	**0.014***
NLR	0.32±0.03	0.11-0.45	0.44±0.03	0.28-0.58	**0.022***
PLR	28.84±4.21	16.13-52.08	32.93±6.42	14.97-67.80	**0.602**
RBC (10^12/L)	10.72±0.34	9.60-12.85	9.75±0.38	8.17-11.37	**0.079**
HGB (g/L)	104.6±3.58	92-128	97.40±3.81	80-114	**0.185**
HCT	0.36±0.01	0.31-0.43	0.33±0.01	0.28-0.38	**0.141**
MCV (fL)	33.95±0.34	32.50-35.80	34.74±0.38	32.90-36.70	**0.143**
MCH (pg)	9.83±0.12	9.30-10.40	10±0.15	9.50-11	**0.402**
MCHC (g/L)	291±0.96	283-294	287.5±2.36	274-299	**0.187**
RDW-CV (%)	0.20±0.001	0.20-0.21	0.19±0.002	0.18-0.20	**0.002***
RDW-SD (fL)	25.71±0.39	23.40-27.60	25.34±0.27	23.70-26.90	**0.426**
PLT (10^9/L)	568.2±46.87	331-757	436.4±27.58	296-592	**0.026***
MPV (fL)	4.32±0.03	4.10-4.50	4.57±0.10	4.10-5.00	**0.033***
PDW-CV (%)	0.14±0.08	0.11-0.18	0.15±0.01	0.11-0.20	**0.519**
PDW-SD (fL)	9.60±1.96	4.70-26.20	8.21±0.97	4.40-12.40	**0.533**
PCT (%)	2.27±0.23	1.19-3.20	1.98±0.10	1.40-2.40	**0.275**
P-LCC (10^9/L)	171.7±11.92	107-218	147.8±6.20	121-187	**0.092**
P-LCR (%)	0.30±0.08	0.27-0.35	0.34±0.02	0.21-0.41	**0.127**

[1]Analysis results were considered significant for p values less than 0.05.

[2]Standart deviation, Min: Minumum, Max: Maximum, WBC: White blood cell, LYM: Lenfosite, MID: Monosite, GRAN: Granulosite, NLR: Neutrophil lymphocyte ratio, PLR: Platelet-lymphocyte ratio RBC: Red blood cell, HGB: Haemoglobin, HCT: Hematocrit, MCV: Mean corpuscular volume, MCH: Mean corpuscular hemoglobin, MCHC: Mean corpuscular hemoglobin concentration, RDW-CV: Red blood cell distribution width, PLT: Platelet count, MPV: Mean platelet volume, PDW: Platelet distribution width, PCT: Procalcitonin, P-LCR: Platelet large cell ratio, P-LCC: Platelet large cell coefficient

DISCUSSION

Boron is an important element whose metabolism is not yet fully understood, especially in oral exposure. Although there are limited studies on its distribution in tissues, it has been reported that it is almost completely absorbed in the gastrointestinal system and frequently excreted in the urine (Kuru and Yarat, 2017). Its effects in living metabolism include osteoporosis and arthritis treatment, antioxidant and memory effects and serious diseases such as cancer. However, toxicity research on boron compounds is ongoing. Therefore, boron exposure is important for all living things today (Pizzorno, 2015). Alterations in hematologic and biochemical parameters are of paramount importance in the diagnosis, severity determination and treatment follow-up of diseases. Furthermore, metabolic events within the body offer researchers invaluable insights into organ function (Etim et al., 2014). The present study investigates the effects of varying distances to the boron mine site on serum boron levels, along with selected biochemical and haematological parameters.

In a study, leukocytes decreased due to gentamicin application and decreased as the dose of boron application increased. This showed that boron, which is claimed to have antioxidant properties, was not sufficient to protect leukocytes. In the same study, it was observed that any dose of boron application had no effect on leukocyte percentages. It was reported that erythrocyte count and haemoglobin levels were not affected by boron concentrations, but the decrease in haematocrit value with gentamicin was prevented by boron. In addition, erythrocyte volume (MCV), mean erythrocyte haemoglobin (MCH), mean erythrocyte haemoglobin level (MCHC) and platelet count were found within normal limits compared to rats (Durmus et al., 2018). In a study investigating the protective effect of boron on blood parameters in experimental cadmium (Cd) toxicity, 15 mg/kg lithium borate (LTB) was given orally for 5 days. In the study, WBC, % neutrophil increased in Cd and

Cd+LTB groups. Lymphocyte and monocyte levels decreased significantly. It was reported that LTB did not cause any change in RBC, haematocrit and haemoglobin levels (Yildirim et al., 2018). In another study, cyclophosphamide (CP) toxicity was induced and the effects of boron on changes in some blood parameters were investigated. In another study, cyclophosphamide (CP) toxicity was induced and the effects of boron on changes in some blood parameters were investigated. In particular, erythrocyte and hemoglobin counts, which decreased with CP treatment, approached the control group with B treatment. While CP alone suppressed leukocytes by 96%, boron significantly reduced the suppression of the affected bone marrow and decreased the leukocyte count by 50% compared to control. A similar result was obtained in platelet count (Cengiz, 2018). In a study investigating the effect of boron application on haematological parameters in dairy cattle in the periparturient period, there was no change in MCHC levels in the prenatal and calving period, but it caused a decrease in the postpartum period. WBC levels did not change for control and boron groups in the periparturient period. No significant change was reported for RBC, MCV, HCT, HB, PLT, MPV, Lymphocyte, Monocyte values (Kabu et al., 2014). In our study, some results were obtained which were in parallel with most of the studies. Although WBC, LYM, MID, LYM%, RBC, HGB, HCT, MCHC, P-LCC, PCT, PDW-SD values decreased between the groups, this difference was not statistically significant. GRAN%, NLR, RDW-CV, PLT, MPV values showed a significant difference between the groups. The increase in some of these values may be due to infection especially in sheep. Therefore, it is recommended to conduct more comprehensive research on whether the difference is due to boron exposure. Expanding the scope of the study in terms of both the number of animals and the parameters examined will greatly facilitate the evaluation of possible results. In addition, the significant difference in urea, creatinine and BUN results in our study was in parallel with the results of some studies. It is thought that this may be due to the boron intake from the water and feed material consumed and the air inhaled due to the small distance to boron sources. The increase in the amount of boron entering the body also affected the parameters by making changes in excretion.

Some blood parameters and blood boron levels were investigated in rabbits following boron administration at different doses. In the study, no statistically significant difference was found in urea and creatinine levels at any level. However, serum B concentrations increased in parallel with the boron doses administered. This was reported as an indication that the boron taken into the body was absorbed and passed into the blood (Yiğit et al., 2013). Thirteen healthy women were added boron-containing foods (more than 10 mg) to their diet for 1 month. Increased boron concentrations were observed in blood, urine and saliva samples taken before and after the diet. However, decreases in body weight, body fat weight and body mass index were reported. There is a need to investigate the effects of boron-rich diet on animal health with more detailed studies (Kuru et al., 2019). In a study, pregnant rats were given 0-20 mg B/kg/day (boric acid) by gavage from day 6 to day 21 and pups from day 1 to day 28. It was reported that postnatal weight gain was significantly reduced at 20 mg B/kg and plasma boron concentrations in the offspring increased in proportion to the dose. These findings confirmed that growth was affected by boron exposure (Watson et al., 2020). In a study on boron, which is reported to be risky in terms of developmental toxicity, mothers and babies in a settlement with boron in drinking water between 0.38 and 16.1 mg B/l were examined. Boron concentrations in breast milk and serum showed a strong correlation, while urinary boron concentrations in infants showed an inverse relationship with body weight, head circumference and length (Hjelm et al., 2019). In our study results, a statistically significant elevation was determined between serum boron levels. The elevation in the samples taken from Bigadiç may be due to the small distance to the mine site. Boron concentrations are also high in water, air and soil materials in the living areas near the mine site**.**

CONCLUSION

In conclusion, the present literature review and study have determined that the distance of exposure to boron is an important factor in the concentration of boron in the blood. Furthermore, although significant differences were found in hemogram and some biochemical parameters in the present study, it should be determined whether this situation is boron-induced with a more comprehensive study. The toxic effects of boron in environmental contamination or its possible beneficial effects for living organisms are very open areas for study. Further research is required to address the existing lacunae in the extant literature pertaining to boron.

NOTE

*This study was presented as an oral presentation at the "7th International Eurasian Conference on Biological and Chemical Sciences", October 02-04, 2024.

ETHICAL APPROVAL

During the writing process of the study titled 'The Effect of Distance to Boron on Serum Boron Concentration and Some Biochemical and Haematological Parameters in Sheep', scientific, ethical and citation rules were followed; no falsification was made on the collected data and this study was not sent to another academic medium for evaluation. Approval for this study was granted by the Balıkesir University Animal Experiments Local Ethics Committee (Approval no. 2024/4-8). Significant efforts were made to minimise animal suffering, with strict adherence to the '3Rs' rule in accordance with established ethical principles.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

AUTHOR CONTRIBUTION

All authors contributed equally.

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DATA AVAILABILITY

The original data collected during the study are included in the article. Further inquiries can be directed to the corresponding author.

APPROVAL FOR PUBLICATION

All authors declare that they have seen and approved the final version of the submitted manuscript.

REFERENCES

Abdelnour, S. A., El-Hack, M. E. A., Swelum, A. A., Perillo, A., & Losacco, C. (2018). The vital roles of boron in animal health and production: A comprehensive review. Journal of Trace Elements in Medicine and Biology, 50, 296–304. https://doi.org/10.1016/j.jtemb.2018.07.018

Bolaños, L., Lukaszewski, K., Bonilla, I., & Blevins, D. (2004). Why boron? Plant Physiology and Biochemistry, 42(11), 907–912. https://doi.org/10.1016/j.plaphy.2004.11.002

Bolt, H. M., Başaran, N., & Duydu, Y. (2020). Effects of boron compounds on human reproduction. Archives of Toxicology, 94(3), 717–724. https://doi.org/10.1007/s00204-020-02700-x

Cengiz, M. (2018). Boric acid protects against cyclophosphamide-induced oxidative stress and renal damage in rats. Cellular and Molecular Biology, 64(12), 11–14. https://doi.org/10.14715/cmb/2018.64.12.3

Devirian, T. A., & Volpe, S. L. (2003). The Physiological Effects of Dietary Boron. Critical Reviews in Food Science and Nutrition, 43(2), 219–231. https://doi.org/10.1080/10408690390826491

Durmuş, İ., İnce, S., Salim, M. N., Eryavuz, A., & Küçükkurt, İ. (2018). Gentamisin verilen sıçanlara bor uygulamasının hematolojik parametre düzeylerine etkileri. Kocatepe Veterinary Journal, 11(2), 11–12. https://doi.org/10.30607/kvj.394370

Etim, N. N., Enyenihi, G. E., Akpabio, U., Offiong, E. E. (2014). Effects of nutrition on haematology of rabbits: a review. European Scientific Journal, 10(3), 413-24.

Hjelm, C., Harari, F., & Vahter, M. (2019). Pre- and postnatal environmental boron exposure and infant growth: Results from a mother-child cohort in northern Argentina. Environmental Research, 171, 60–68. https://doi.org/10.1016/j.envres.2019.01.012

Ince, S., Filazi, A., & Yurdakök-Dikmen, B. (2016). Boron, Gupta RC (Ed): Reproductive and Developmental Toxicology, 978-0-12-804239-7, 257-94, Academic Press. United States.

Ince, S., Kucukkurt, I., Acaroz, U., Arslan-Acaroz, D., & Varol, N. (2018). Boron ameliorates arsenic-induced DNA damage, proinflammatory cytokine gene expressions, oxidant/antioxidant status, and biochemical parameters in rats. Journal of Biochemical and Molecular Toxicology, 33(2). https://doi.org/10.1002/jbt.22252

Kabu, M., Civelek, T., & Birdane, F. M. (2014). Effects of boron, propylene glycol and methionine administration on some hematological parameters in dairy cattle during periparturient period. Vet Arh, 84(1), 19-29.

Kan, F., & Kucukkurt, I. (2023). The effects of boron on some biochemical parameters: A review. Journal of Trace Elements in Medicine and Biology, 79, 127249. https://doi.org/10.1016/j.jtemb.2023.127249

Kucukkurt, I., Ince, S., Eryavuz, A., Demirel, H. H., Arslan-Acaroz, D., Zemheri-Navruz, F., & Durmus, I. (2022). The effects of boron-supplemented diets on adipogenesis-related gene expressions, anti-inflammatory, and antioxidative response in high-fat fed rats. Journal of Biochemical and Molecular Toxicology, 37(2). https://doi.org/10.1002/jbt.23257

Kuru, R., & Yarat, A. (2017). Boron and a Current Overview of its Effects On Health. Clinical and Experimental Health Sciences, 7(3), 107–114. https://doi.org/10.5152/clinexphealthsci.2017.314

Kuru, R., Yilmaz, S., Balan, G., Tuzuner, B. A., Tasli, P. N., Akyuz, S., Ozturk, F. Y., Altuntas, Y., Yarat, A., & Sahin, F. (2019). Boron-rich diet may regulate blood lipid profile and prevent obesity: A non-drug and self-controlled clinical trial. Journal of Trace Elements in Medicine and Biology, 54, 191–198. https://doi.org/10.1016/j.jtemb.2019.04.021

Kusaka, S., Morizane, Y., Tokumaru, Y., Tamaki, S., Maemunah, I. R., Akiyama, Y., Sato, F., & Murata, I. (2022). Cerebrospinal fluid-based boron delivery system may help increase the uptake boron for boron neutron capture therapy in veterinary medicine: A preliminary study with normal rat brain cells. Research in Veterinary Science, 148, 1–6. https://doi.org/10.1016/j.rvsc.2022.04.008

Nielsen, F. H., & Eckhert, C. D. (2019). Boron. Advances in Nutrition, 11(2), 461–462. https://doi.org/10.1093/advances/nmz110

İlhan, A. O., Can, B., Kar, F., Gündoğdu, A. Ç., Söğüt, İ., & Kanbak, G. (2023). An Investigation into the Protective Effects of Various Doses of Boric Acid on Liver, Kidney, and Brain Tissue Damage Caused by High Levels of Acute Alcohol Consumption. Biological Trace Element Research, 201(11), 5346–5357. https://doi.org/10.1007/s12011-023-03699-9

Onder, G. O., Goktepe, O., Karaman, E., Karakas, E., Mat, O. C., Bolat, D., Okur, E., Tan, F. C., Balcioglu, E., Baran, M., Ermis, M., & Yay, A. (2023). Nonylphenol Exposure-Induced Oocyte Quality Deterioration Could be Reversed by Boric Acid Supplementation in Rats. Biological Trace Element Research, 201(9), 4518–4529. https://doi.org/10.1007/s12011-023-03657-5

Pizzorno, L. (2015). Nothing boring about boron. Integrative Medicine: A Clinician's Journal, 14(4), 35.

Tokay, F., & Bağdat, S. (2022). A novel and simple approach to element fractionation analysis: Single step fractionation of milk. Food Chemistry, 379, 132162. https://doi.org/10.1016/j.foodchem.2022.132162

Tokay, F., & Bağdat, S. (2022a). Schiff base functionalized silica gel for simultaneous separation and preconcentration of Cu(II), Ni(II), and Cd(II) in pharmaceuticals and water samples. TURKISH JOURNAL OF CHEMISTRY, 46(2), 459–474. https://doi.org/10.55730/1300-0527.3320

Uluisik, I., Karakaya, H. C., & Koc, A. (2017). The importance of boron in biological systems. Journal of Trace Elements in Medicine and Biology, 45, 156–162. https://doi.org/10.1016/j.jtemb.2017.10.008

Wang, S., Zhou, Y., & Gao, C. (2018). Novel high boron removal polyamide reverse osmosis membranes. Journal of Membrane Science, 554, 244–252. https://doi.org/10.1016/j.memsci.2018.03.014

Watson, A. T. D., Sutherland, V. L., Cunny, H., Miller-Pinsler, L., Furr, J., Hebert, C., Collins, B., Waidyanatha, S., Smith, L., Vinke, T., Aillon, K., Xie, G., Shockley, K. R., & McIntyre, B. S. (2020). Postnatal effects of gestational and lactational gavage exposure to boric acid in the developing Sprague Dawley rat. Toxicological Sciences, 176(1), 65–73. https://doi.org/10.1093/toxsci/kfaa061

Yiğit, P., Eren, M., Sarıca, Z. S., & Şentürk, M. (2013). Tavşanlarda borik asidin kan kimyasına etkisi. Erciyes. Üniversitesi Veteriner Fakültesi Dergisi, 10(2), 77-85.

Yildirim, S., Celikezen, F. C., Oto, G., Sengul, E., Bulduk, M., Tasdemir, M., & Cinar, D. A. (2017). An investigation of protective effects of litium borate on blood and histopathological parameters in acute Cadmium-Induced rats. Biological Trace Element Research, 182(2), 287–294. https://doi.org/10.1007/s12011-017-1089-9

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Research Article

Investigation of the Prevalence of Hydatid Cysts and Liver Condemnation Losses in Sheep and Goats Slaughtered in Van Province, Türkiye

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ABSTRACT

This study was conducted to determine the financial losses and distribution in internal organs caused by liver condemnation due to hydatid cysts in sheep and goats slaughtered in slaughterhouses in Van province of Türkiye. Hydatid cysts were detected in 247 out of 1200 sheep (20.58%) and 26 out of 150 goats (17.33%), totaling 273 animals (20.22%). According to organ localizations, hydatid cysts were most frequently seen in both the liver and lungs in 96 (39.52%) sheep and 9 (34.62%) goats, totaling 105 (38.46%) animals. It was determined that the prevalence of hydatid cysts in sheep and goats slaughtered in Van province was high. The high incidence of hydatid cyst infections in sheep and goats in Van province poses a risk to human and animal health in the region and causes significant financial losses. Therefore, studies should be carried out to prevent the spread of the disease and financial losses, and taking protective measures is essential.

Keywords: *Financial loss, Hydatid cyst, Van*

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INTRODUCTION

Echinococcus granulosus is a zoonotic helminth that infect various animal species and humans and widespread in Türkiye and the world. Carnivores including dogs are final hosts which while humans and animals are the intermediate hosts. While the adult form of *Echinococcus granulosus* settles in the small intestine of carnivores, the larval form settles in the internal organs of the intermediate hosts including sheep, goats, cattle, pigs as well as humans, and causes hydatid cysts, which leads to significant health problems (Almulhim and John, 2022; Toparlak and Tüzer, 2012). The life cycle of *Echinococcus granulosus* begins with the ingestion of water and food contaminated with the eggs found in the feces of infected carnivores (Toparlak and Tüzer, 2012; Ertabaklar et al., 2019). Hydatid cyst infections caused by *Echinococcus granulosus* show significant differences between developed and developing countries. In developed countries, high levels of public education and regular administration of antiparasitic drugs to dogs have significantly reduced the spread of hydatid cyst infections (Akyol, 2001). Such preventive health measures are effective for public health strategy and contribute to the control of the infection. The prevention of cystic echinococcosis relies on implementing integrated strategies aimed at disrupting the parasite's life cycle. One of the most critical steps is the regular deworming of dogs, the primary definitive hosts, with anthelmintic drugs such as praziquantel to prevent the release of parasite eggs into the environment (WHO, 2020). Additionally, preventing dogs from consuming raw offal especially livers and lungs from infected livestock is essential to stop the acquisition of the parasite (Craig et al., 2017). Ensuring proper hygiene and inspection in slaughterhouses and eliminating illegal home slaughter practices can significantly reduce environmental contamination (ECDC, 2021). From the human health perspective, especially in rural areas, public health education on hand hygiene, washing vegetables and fruits before consumption, and avoiding direct contact with stray dogs can reduce transmission risk (Torgerson & Macpherson, 2011). The implementation of surveillance programs in livestock populations is also crucial for early detection and control in endemic regions (Romig et al., 2020). The World Health Organization and the Food and Agriculture Organization advocate for a "One Health" approach, emphasizing integrated control strategies that consider the interconnectedness of human, animal, and environmental health (WHO, 2020; FAO, 2019). On the other hand, factors such as uncontrolled or illegal animal slaughter, large numbers of stray dogs, and the disposal of infected organs into the environment without destroying them facilitate the spread of hydatid cyst infections in developing countries. Inadequate hygiene conditions, limited access to health services, and lack of sufficient information in the society are also important factors in these countries. (Almulhim and John, 2022; Ertabaklar et al., 2019; Toncheva and Zhelyaskov, 1999).

Cystic echinococcosis is a zoonotic parasitic disease that causes significant public health concerns and economic losses, especially in regions where close contact with livestock is common. According to the World Health Organization (WHO), echinococcosis affects nearly one million people annually and is endemic in areas such as South America, the Middle East, North Africa, Central Asia, and parts of Europe (WHO, 2020). Prevalence rates can exceed 4% in countries like Türkiye, Iran, China, Kenya, and Peru (Torgerson et al., 2015). Economically, the disease results in billions of dollars in losses due to healthcare costs and reductions in livestock productivity. A global analysis by Torgerson et al. (2015) estimated the total annual economic burden of cystic echinococcosis including both human health and livestock production losses at approximately 3 billion USD. These losses include carcass condemnation, decreased milk and wool production, treatment expenses, and labor loss (Budke, Deplazes, & Torgerson, 2006; Torgerson et al., 2015).

This study was conducted to determine the prevalence of hydatid cysts in sheep and goats slaughtered in Van province and the financial losses resulting from liver condemnation.

MATERIAL AND METHODS

This study was conducted on a total of 1350 the internal organs of animals including1200 sheep and 150 goats slaughtered in slaughterhouses under the control of Van Metropolitan Municipality in Van province of Türkiye between February and November 2023, which constituted the study material, by visiting once a week. After slaughter, the internal organs of the animals (liver, lungs, spleen, kidney and heart) were examined in detail by inspection and palpation and evaluated for the presence of hydatid cysts. Financial losses caused by condemnation of livers due to hydatid cysts in particular, were calculated based on the 2023 liver sales price and certain parameters to calculate these losses. On average, liver weight in sheep and goats was assumed 0.5-1.26 kg and its ratio to body weight as1.45%. Accordingly, the average price per kilogram of liver in sheep

and goats was as 1$ = 26 TL (September 2023). (Table 1). Financial loss was calculated according to the formula in table 1. (Sarıözkan and Yalçın, 2009).

Table 1. *Estimating method of production losses due to CE in ruminants.*

Loss	Calculation method
Liver Loss	(Number of slaughtered animals x Cystic echinococcosis rate) x Average liver weight x Price per kg of liver]

RESULTS

Hydatid cysts were detected in 247 of 1200 sheep (20.58%) and 26 of 150 goats (17.33%) slaughtered in slaughterhouses under the control of Van Metropolitan Municipality between February and November 2023, totaling 273 (20.22%) animals (Table 2). When the organ localizations of the cysts were examined; it was determined that the presence of hydatid cysts was mostly seen in the liver and lungs in 96 (39,52%) sheep and 9 (34,62%) goats (Table 2).

Table 2. *Numerical data of sheep and goats infected and uninfected with hydatid cysts*

Type	**Hydatid cyst (+)**		**Hydatid cyst (-)**		**Total**	
	Number	%	Number	%	Number	%
Sheep	247	20,58	953	79,42	1200	88,88
Goat	26	17,33	124	82,67	150	11,12
Total	273	20,22	1077	79,78	1350	100

The detailed distribution of hydatid cysts by organs is shown in Table 3.

Table 3. *Distribution of hydatid cyst according to infected organ locations*

Organs	**Sheep**		**Goat**		**Total**	
	Number	%	Number	%	Number	%
Liver only	79	32,10	7	26,91	86	31,50
Lung only	58	23,42	8	30,77	66	24,18
Lung + liver	96	39,52	9	34,62	105	38,46
Other organs (Heart, Spleen, Kidney)	14	4,95	2	7,70	16	5,86

All 273 livers with hydatid cysts were destroyed. The unit price of an average 1 kg sheep and goat liver in 2023 has been determined as 175 TL/kg, and the total material value of liver loss due to cystic echinococcosis has been determined as 47775 TL (=1837.5$). According to the data obtained from the relevant institutions, a total of 16500 small cattle, including 14500 sheep and 2000 goats, were slaughtered in Van province in 2023. In total, the material loss incurred as a result of the condemnation of livers in sheep and goats slaughtered annually in 2023 has been determined as (16500 x %20.58) x (1 x 175) = 597247,5 TL (=22855.67$).

DISCUSSION

Hydatid cyst is one of the most important parasitic zoonoses in the world, affecting both humans and domestic animals (Toparlak and Tüzer, 1999; Soulsby, 1986; Balkaya and Şimşek, 2010). Hydatid cyst is a zoonotic parasitic disease that is common in Türkiye as well as all over the world. In Türkiye, the adult form of the *Echinococcus granulosus* parasite is found in the small intestine of carnivores, especially dogs, while the larval form is found in animals such as sheep and goats, cattle, horses, donkeys, mules and pigs (Díaz, 2017). The disease mostly settles in tissues and organs such as the lungs, liver, spleen, kidney, heart, bone marrow, eye and brain, forming fluid-filled cysts (Agudelo et al., 2016). Hydatid cysts are frequently seen especially in regions where animal husbandry is done, but they still maintain their importance due to both public health and financial losses they cause (Yazar, 2005). According to TUİK data, 18.4% of the active population in Türkiye is engaged in agriculture and animal husbandry, and *Echinococcus granulosus* is still commonly encountered

today due to the uncontrolled slaughter of animals, especially in rural areas, and the feeding of cystic organs to stray dogs (Demir and Mor, 2011; TUİK, 2011; Hakverdi et al., 2008). Many studies have been conducted in different countries of the world to determine the prevalence of hydatid cysts in farm animals. According to recent studies; hydatid cysts in sheep have been reported at a rate of 65.6% in Romania (Mitrea et al., 2014), 61.9% in Moldova (Chihai et al., 2016), 18.1% in Algeria (Ouchene et al., 2014), 2.9% in Iran (Borji et al., 2012), 10.6% in Ethiopia (Kebede et al., 2009) and 3.5% in China (Guo et al., 2019). In studies conducted in various slaughterhouses in Türkiye; The prevalence of cystic echinococcosis in Afyon is 29.5% (Köse, 2008), 9.8% in Ankara (Öge, 1998), 3.2% in Antakya (Hakverdi et al., 2008), 13.5% in Burdur (Umur, 2003), 34.3-46.4% in Erzurum (Arslan and Umur, 1997; Balkaya and Şimşek, 2001), 31.3% in Kars (Gıcık et al., 2004), 3% in Kayseri (Düzlü et al., 2010), 14.2% in Kırıkkale (Yıldız and Tuncer, 2005), 9.4% in Konya (Dik et al., 1992), 21.1% in Samsun (Celep et al., 1990), and 4.5-35.7% in Sivas (Acıöz et al., 2008) reported that it was 37.8% in Van (Değer et al., 2001). In this study, the cystic echinococcosis rate determined in sheep and goats was determined as 20.22%. The findings obtained in this study are parallel to the previous studies conducted in Afyon, Erzurum, Kars, Samsun, Sivas and Van provinces. We suggest that the reason for these high rates may be pasture-based animal husbandry, the continuous walking of dogs with sheep and cattle in the pastures during the day, their sleeping in barns at night and uncontrolled slaughtering of animals.

Although no significant clinical symptoms are observed in animals due to cystic echinococcosis, significant economic losses occur due to decrease in meat and milk yield, increase in infertility rate, and disposal of offal, especially liver and lungs, after slaughter (Balkaya and Şimşek, 2010; Düzlü et al., 2010; Sarıözkan and Yalçın, 2009; Umur, 2003; Köroğlu and Şimşek, 2004). In a study conducted throughout Türkiye, it was estimated that there is an annual economic loss of 32,400,000$ (26,200,000$-39,100,000$) due to carcass, milk yield, birth and offal loss (Sarıözkan and Yalçın, 2009). In studies conducted worldwide, it has been reported that the annual economic loss due to hydatid cyst is 232.3$ million in Iran (Fasihi Harandi et al., 2012), 212.35$ million in India (Singh et al., 2014), 141,605,195$ in the USA (Budke et al., 2006), and $58,114.62 in Ethiopia (Guduro and Desta, 2019). In a study conducted in a slaughterhouse in Southwestern Ethiopia, the annual economic loss was calculated as 12,758.21$ (Mesay et al., 2017). In a study conducted in Erzurum, the economic loss due to liver condemnation due to hydatid cyst has been estimated as 3,320 TL (Balkaya and Şimşek, 2010). In a study covering three slaughterhouses in Kayseri, the economic loss due to hydatid cyst was determined to be 31,372$ (Düzlü et al., 2010). In Kars province, the annual economic loss due to liver condemnation alone was reported as 12,180 TL (Demir and Mor, 2011). In Bursa, the total loss due to hydatid cyst was calculated as 12,321$ (Yibar et al., 2015). In a study covering all of Türkiye, the economic loss due to hydatid cyst was reported as 36.3% for cattle, 60.7% for sheep and 3.0% for goats (Sariözkan and Yalçin, 2009). In a study, it was reported that direct and indirect economic losses in Türkiye could be 98,558$ and 466,891$, respectively. It was also reported that the total monetary loss due to Hydatidosis in Türkiye in 2020 could be an estimated $565,448. (Acıöz and Bozkaya., 2022).

CONCLUSION

In this study, it was calculated that the liver condemnation caused by cystic echinococcosis determined in sheep and goats was 47775 TL (=1837.5$). The financial loss arising as a result of the condemnation of livers in sheep and goats slaughtered annually in Van province in 2023 was determined as (=22855.67$). However, when indirect yield losses due to cystic echinococcosis are calculated, it can be said that this value will be even higher. As a result, it can be argued that the high frequency of cystic echinococcosis in sheep and goats in Van province poses a risk to human and animal health in the region and leads to significant financial losses. It is thought that informing breeders about the transmission routes and protection measures regarding hydatid cyst, one of the important zoonoses, taking the necessary precautions for stray dogs, preventing uncontrolled and illegal slaughtering and ensuring that cystic organs are destroyed under appropriate conditions will be an effective eradication program in reducing the prevalence of the disease.

COMPLIANCE WITH ETHICAL STANDARDS

This research study complies with research and publication ethics. The scientific and legal responsibility of the articles published in MJAVL belongs to the author(s).

CONFLICT OF INTEREST

There is no conflict of interest between the authors in this section.

AUTHOR CONTRIBUTION

V.D: 50%, A.S.K: 50% contributed.

ETHICS APPROVAL

This study does not require ethics committee approval.

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REFERENCES

Acıöz, M., Çeliksöz, A., Özçelik, S., & Değerli, S. (2008). Prevalence of cyst hydatic in slaughtered cattle between April and May 2005 in Sivas. *Turkish Journal of Parasitology*, 32: 205-7.

Aciöz, M., & Bozkaya, F. (2022). The monetary losses associated with hydatidosis in slaughtered ruminants in Türkiye. Helminthologia, 59(3), 246-252.

Agudelo Higuita, N.I., Brunetti, E., & McCloskey, C. (2016). Cystic echinococcosis. *Journal of Microbiology*, 54: 518-23.

Akyol, Ç.V. (2001). Hidatidoz ve halk sağlığı yönünden önemi. *Uludağ Üniversitesi Veteriner Fakültesi Dergisi,* 20: 137-42.

Almulhim AM, & John S. "*Echinococcus granulosus*". https:// europepmc.org/article/nbk/nbk539751#free-full-text/ 10.05.2022

Arslan, M.O., & Umur, Ş. (1997). Prevalence and economic importance of Hydatidosis in slaughtered sheep and cattle in Erzurum' slaughterhouses. *Kafkas Üniversitesi Veteriner Fakültesi Dergisi*, 3: 167-71.

Balkaya, İ., & Şimşek, S. (2010). Prevalence and economic ımportance of hydatidosis and fasciolosis in slaughtered cattle in Erzurum province of Türkiye. *Kafkas Üniversitesi Veteriner Fakültesi Dergisi*, 16: 793-7.

Borji, H., Azizzadeh, M., & Kamelli, M. (2012). A retrospective study of abattoir condemnation due to parasitic infections: Economic importance in Ahwaz, southwestern Iran. *Journal of Parasitology*, 98: 954-957.

Budke, C. M., Deplazes, P., & Torgerson, P. R. (2006). Global socioeconomic impact of cystic echinococcosis. *Emerging Infectious Diseases*, 12(2), 296–303. https://doi.org/10.3201/eid1202.050499

Budke, C.M., Deplazes, P., & Torgerson, P.R. (2006). Global socioeconomic impact of cystic echinococcosis. *Emerging Infectious Diseases,* 12: 296-303.

Celep, A., Açıcı, M., Çetindağ, M., Coşkun, S.Z, & Gürsoy, S. (1990). Helmintological examinations in cattle around Samsun. *Etlik Veteriner Mikrobiyoloji Dergisi*, 6: 117-30.

Chihai, O., Umhang, G., Erhan, D., & et al. (2016). Slaughterhouse survey of cystic echinococcosis in cattle and sheep from the Republic of Moldova. *Journal of Helminthology*, 90: 279-283.

Craig, P. S., Hegglin, D., Lightowlers, M. W., Torgerson, P. R., & Wang, Q. (2017). Echinococcosis: control and prevention. *Advances in Parasitology*, 96, 55–158. https://doi.org/10.1016/bs.apar.2016.08.002

Değer, S., Ayaz, E., Gül, A., Biçek, K., & Eraslan, E. (2001). The distrubution of hydatidosis in sheep, cattle and goat slaughtered the in Van. *Yüzüncü Yıl Üniversitesi Sağlık Bilimleri Dergisi*, 7: 37-40.(İn Turkish).

Demir, P., & Mor, N., (2011). Seasonal distribution and economic ımportance of cystic echinococcosis in cattle slaughtered at Kars municipal abattoir, Türkiye. *Turkish Journal of Parasitology,* 35: 185-188. (İn Turkish).

Díaz, Á. (2017). Immunology of cystic echinococcosis (hydatid disease). *British Medical Bulletin*, 124: 121-33.

Dik, B., Cantoray, R., & Handemir, E. (1992). Prevalence and economic importance of hydatidosis in small and large cattle slaughtered in Konya meat and fish ınstitution combine. (Konya Et ve Balık Kurumu Kombinasında kesilen küçük ve büyükbaş hayvanlarda hidatidozun yayılışı ve ekonomik önemi). *Turkish Journal of Parasitology*. 16: 91-99. (İn Turkish).

Düzlü, Ö., Yıldırım, A., Sarıözkan, S., & İnci, A. (2010). The economic importance of cystic echinococcosis in sheep and cattle slaughtered in three different slaughterhouses in Kayseri region. (Kayseri yöresinde üç farklı mezbahada

kesilen koyun ve sığırlarda kistik echinococcosis'in ekonomik önemi). *Erciyes Üniversitesi Veteriner Fakültesi Dergisi*, 7: 7-11. (İn Turkish).

Ertabaklar, H., Yıldız, İ., Malatyalı, E., & et al., (2019). Retrospective analysis of cystic echinococcosis results in Aydın Adnan Menderes University training and research hospital parasitology laboratory between 2005 and 2017. (Aydın Adnan Menderes Üniversitesi Eğitim ve Araştırma Hastanesi Parazitoloji Laboratuvarı'na 2005-2017 yılları arasında kistik ekinokokkozis şüphesiyle başvuran olguların retrospektif olarak değerlendirilmesi). *Turkish Journal of Parasitology*, 43: 118-122

European Centre for Disease Prevention and Control (ECDC). (2021). *Echinococcosis – Annual Epidemiological Report for 2019*. https://www.ecdc.europa.eu/en/echinococcosis

Fasihi Harandi, M., Budke, C.M., & Rostami, S. (2012). The monetary burden of cystic echinococcosis in Iran. *PLOS Neglected Tropical Diseases*, 6: 1915.

Food and Agriculture Organization of the United Nations (FAO). (2019). *Echinococcosis: Zoonoses fact sheet*. http://www.fao.org/echinococcosis

Gıcık, Y., Arslan, M.Ö., Kara, M., & Köse, M. (2004). The Prevalence of cystic echinococcosis in cattle and sheep slaughtered in the Kars Province. (Kars ilinde kesilen sığır ve koyunlarda kistik ekinokokkozis'in yaygınlığı). *Turkish Journal of Parasitology*, 28: 136-9.

Guduro, G.G., Desta, A.H. (2019). Cyst viability and economic significance of hydatidosis in southern Ethiopia. *Journal of Parasitology Research*, 2038628.

Guo, B., Zhang, Z., Zheng, X., & et al. (2019). Prevalence and molecular characterization of Echinococcus granulosus sensu stricto in northern Xinjiang, China. *The Korean Journal of Parasitology*, 57: 153.

Hakverdi, S., Çulha, G., Canda, M.Ş., Yaldız, M., & Altıntaş, S. (2008). Problem of cystic echinococcoss in Hatay. *Turkish Journal of Parasitology*, 32: 340-2.

Kebede, N., Mitiku, A., & Tilahun, G. (2009). Hydatidosis of slaughtered animals in Bahir Dar abattoir, northwestern Ethiopia. *Tropical Animal Health and Production*, 41: 43-50.

Köroğlu, E., & Şimşek, S. (2004). Hidatidosisin neden olduğu ekonomik kayıplar. In, Altıntaş N, Tınar R, Çoker A (Eds): *Echinococcosis*. s. 333-354, Türkiye Parazitoloji Derneği Yayın No:19, META Basım, Bornova, İzmir.

Köse, M., & Kırcalı Sevimli, F. (2008). Prevalence of cystic echinococcosis in slaughtered cattle in Afyonkarahisar. *Turkish Journal of Parasitology*, 32: 27-30.

Mesay, M., Wodajnew, B., & Jaleta, H. (2017). Hydatidosis: prevalence and assessment of financial loss on bovine slaughtered at Bedele municipal abattoir, southwest Ethiopia. *Report and Opinion*, 9: 60-8.

Mitrea, I. L., Ionita, M., Costin, I., & et al. (2014). Occurrence and genetic characterization of Echinococcus granulosus in naturally infected adult sheep and cattle in Romania. *Veterinary Parasitology*, 206: 159-166.

Ouchene, N., Bitam, I., Zeroual, F., & et al. (2014). Cystic echinococcosis in wild boars (Susscrofa) and slaughtered domestic ruminants in Algeria. *Asian Journal of Animal and Veterinary Advances*, 9: 767-774.

Öge, H., Gıcık, Y., Kalınbacak, F., & Yıldız, K. (1998). The prevalence of so me metacestodes (Hydatid cyst, Cysticercus tenuicollis, Cysticercus boyis) in sheep, go at and cattle in slaughtered Ankara province. (Ankara yöresinde kesilen koyun, keçi ve sığırlarda bazı metasestodların (Hidatid kist, Cysticercus tenuicollis, Cysticercus bovis) yayılışı). *Ankara Üniversitesi Veteriner Fakültesi Dergisi*, 45: 123-30.

Romig, T., Deplazes, P., Jenkins, D., Giraudoux, P., Massolo, A., Craig, P. S., & Kern, P. (2020). Ecology and life cycle patterns of Echinococcus species. *Advances in Parasitology*, 95, 213–314. https://doi.org/10.1016/bs.apar.2016.11.002

Sarıözkan, S., & Yalçın, C. (2009). Estimating the production losses due to cystic echinococcosis in ruminants in Türkiye. *Veterinary Parasitology*, 163: 330-4.

Singh, B.B., Dhand, N.K., Ghatak, S., & Gill, J.P. (2014). Economic losses due to cystic echinococcosis in India: Need for urgent action to control the disease. *Preventive Veterinary Medicine*, 113: 1-12.

Soulsby, E.J.L. (1986). Helminths, arthropods and protozoa of domesticated animals Bailliere Tindall, London. 119-27.

Toncheva, V., & Zhelyaskov, P. (1999). Prevalance of the hydatid echinococcus in Plovdiv distrist. *Bulgarian Journal of Agricultural Science*, 5: 525-8.

Toparlak, M., & Tüzer, E. (1999). *Veteriner Helmintoloji*. İ.Ü. Veteriner Fakültesi Parazitoloji Anabilim Dalı Ders Notu.

Torgerson, P. R., & Macpherson, C. N. L. (2011). The socioeconomic burden of parasitic zoonoses: Global trends. *Veterinary Parasitology*, 182(1), 79–95. https://doi.org/10.1016/j.vetpar.2011.07.017

Torgerson, P. R., Keller, K., Magnotta, M., & Ragland, N. (2015). The global burden of alveolar and cystic echinococcosis. *PLoS Neglected Tropical Diseases*, 9(5), e0003897. https://doi.org/10.1371/journal.pntd.0003897

TUİK. *Bölgesel İstatistikler*. Erişim: www. tuik.gov.tr Erişim Tarihi:01.06.2011.

Umur S. (2003). Prevalence and economic importance of cystic echinococcosis in slaughtered ruminants in Burdur, Türkiye. *Journal of Veterinary Medicine, Series B,* 50: 247-52.

World Health Organization (WHO). (2020). *Echinococcosis*. https://www.who.int/news-room/fact-sheets/detail/echinococcosis.

Yazar, S. (2005). Cystic echinococcosis in Kayseri during the last six years. *Turkish Journal of Parasitology,* 29: 241-243.

Yıldız, K., &Tunçer, Ç. (2005). Prevalence of hydatid cysts in cattle in the province of Kırıkkale. (Kırıkkale'de sığırlarda kist hidatik'in yayılışı). *Turkish Journal of Parasitology,* 29: 247-250.

Yibar, A., Selcuk, O., & Senlik, B. (2015). Major causes of organ/carcass condemnation and financial loss estimation in animals slaughtered at two abattoirs in Bursa Province, Türkiye. *Preventive Veterinary Medicine*, 118: 28-3.

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Research Article

Evaluation of Postoperative Outcomes for Linear and Non-linear Gastrointestinal Foreign Body Obstruction in Cats (Retrospective Study of 52 Cases)

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ABSTRACT

This study aims to determine the localisation of foreign bodies (FBs), surgical sites, the impact of the time elapsed after FB ingestion on prognosis, and survival rates in cats. A total of 52 cats presented to Selcuk University Faculty of Veterinary Medicine with suspected FB ingestion between 2022 and 2024 were evaluated. Among these cats, 63.4% were short-haired domestic cats, 59.6% were female, and 51.9% were under two years old. The most common types of FBs were linear (40.5%) and plastic (40.5%). The most frequent clinical signs were vomiting, anorexia, lethargy, and abdominal distension. Hematological examinations revealed hypokalaemia (61.9%) and electrolyte imbalances. Radiographic and ultrasonographic evaluations showed gastrointestinal obstruction, intestinal dilation, and reduced peristaltic movements. Surgical procedures, including gastrotomy and enterotomy, were performed, with multifocal intervention required in 36.5% of cases. The survival rate was 76.9%, while the mortality rate was 23.1%, mainly due to complications from linear FBs. Postoperative complications such as septic peritonitis and sepsis were observed in 21% of cases, contributing to the mortality rate. The average time to surgery was 67.2 hours in survivors and 96 hours in those who did not survive. In conclusion, early diagnosis and appropriate surgical intervention are crucial, with prognosis depending on the type of FB and the intervention time.

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Kedilerde Linear ve Linear Olmayan Gastrointestinal Yabancı Cisim Tıkanıklıklarının Postoperatif Sonuçlarının Değerlendirilmesi (52 Olgunun Retrospektif Çalışması)

ÖZET

Bu çalışma, kedilerde yabancı cisim (YC) yutma vakalarında, YC'lerin lokalizasyonu, operasyon bölgeleri ve YC yutma sonrası geçen sürenin prognoz üzerindeki etkisi ile sağkalım oranlarının belirlenmesini amaçlamaktadır. 2022-2024 yılları arasında Selçuk Üniversitesi Veteriner Fakültesi'ne YC yutma şüphesiyle getirilen 52 kedi değerlendirilmiştir. Çalışmadaki kedilerin %63,4'ü kısa tüylü ev kedisi, %59,6'sı dişi ve %51,9'u iki yaşın altındaydı. YC türleri olarak en sık; linear YC'ler (%40,5 (n = 21)) ve plastik YC'ler (%40,5, n = 21) tespit edilmiştir. En yaygın klinik belirtiler arasında kusma, anoreksi, halsizlik ve abdominal distansiyon gözlemlenmiştir. Hematolojik incelemelerde hipokalemi (%61,9) ve diğer elektrolit dengesizlikleri dikkat çekmiştir. Radyografik ve ultrasonografik incelemelerde, gastrointestinal obstrüksiyon, bağırsak segmentlerinde genişleme ve peristaltik hareketlerde azalma görülmüştür. Cerrahi müdahaleler arasında gastrotomi ve enterotomi uygulanmış olup, bunların %36,5'inde multifokal girişimde bulunulmuştur. Çalışmada olguların sağkalım oranı %76,9 iken, %23,1 oranında mortalite, özellikle lineer YC kaynaklı komplikasyonlara bağlı olarak görülmüştür. Postoperatif komplikasyonlar arasında septik peritonit ve sepsis, vakaların %21'inde gözlenmiş ve mortalite oranına katkıda bulunmuştur. Sağ kalanlarda cerrahiye kadar geçen ortalama süre 67,2 saat iken, hayatını kaybedenlerde bu süre 96 saat olarak belirlenmiştir. Sonuç olarak, YC yutma vakalarında erken teşhis ve uygun cerrahi müdahalelerin önem taşıdığı, prognozun YC'nin türüne ve müdahale süresine bağlı olduğu sonucuna varılmıştır.

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INTRODUCTION

Gastrointestinal (GI) foreign body (FB) ingestion is a common condition in veterinary practice, particularly in cats, and often necessitates prompt medical or surgical intervention. This condition is frequently linked to pica, a compulsive behavioural disorder influenced by factors such as genetic predisposition, early weaning, boredom, lack of social interaction, malnutrition, and anxiety. GI obstruction caused by FB ingestion can be categorised as partial or complete, with clinical manifestations varying depending on whether the FB is linear or non-linear (Parlak et al., 2022).

Linear FBs are associated with higher morbidity and mortality due to their potential to cause severe complications, including peritonitis and sepsis. These complications arise from mechanical trauma, leading to intestinal plication, ischemia, and subsequent necrosis (Parlak et al. 2022). Radiographically, linear FBs typically present as dilated, tortuous intestinal loops with multiple intraluminal gas bubbles. Additionally, the presence of free air on abdominal radiographs suggests peritonitis, warranting immediate surgical intervention (Willis and Farrow, 1991; Papazoglou et al., 2003). While clinical signs of linear FBs are typically acute, some cases may follow a more protracted course. In contrast, non-linear FBs are more likely to cause complete obstruction, resulting in complications such as proximal gas accumulation, bowel distension, and bowel wall edema or necrosis. These cases often present acutely and carry significant risks of morbidity and mortality (Willis and Farrow, 1991; Papazoglou et al., 2003). The clinical manifestations of GI FB ingestion in cats—including vomiting, regurgitation, depression, anorexia, and hypoxia—vary depending on the type, location, severity, and duration of the obstruction. Radiographic findings frequently reveal segmental bowel enlargement, a characteristic indicator of obstruction (Gülaydın and Akgül, 2024).

The management of GI FBs involves medical or surgical intervention based on the nature of the FB, the severity of obstruction, and the risk of perforation. Timely and appropriate treatment is critical to mitigating the pathophysiological consequences and preventing complications (Pratt et al., 2014). While gastrotomy or a single incision enterotomy may suffice for non-linear FBs, the removal of linear FBs often requires multiple enterotomies (Miller et al., 2024).

The aim of this study was to analyse the characteristics of linear and non-linear FBs in feline GI cases and evaluate their relationships with clinical signs, time to intervention, and treatment methods in relation to survival rates.

MATERIAL AND METHODS

This study was conducted with the approval of the Selcuk University Faculty of Veterinary Medicine Experimental Animal Production and Research Center Ethics Committee, dated 30.01.2025 and numbered 2025/13. The study cohort comprised 52 cats presented to the Faculty of Veterinary Medicine at Selcuk University between 2022 and 2024 with symptoms of FB ingestion or severe vomiting and anorexia of unknown origin. These cats were diagnosed with FBs of varying characteristics through clinical, radiografic, and ultrasonographic (USG) imaging. Inclusion criteria required the availability of complete USG and radiographic data, as well as accessible clinical records.

Anamnestic data collected from the patients, including loss of personal belongings, partial protrusion of FBs from the mouth or anus, expulsion of FBs via vomiting, and the presence of a string at the root of the tongue, were systematically documented in patient observation forms. Following a brief initial clinical examination, a comprehensive inspection of the oral cavity, particularly the root of the tongue, was performed to detect any linear FBs. In addition to the physical examination, venous blood samples were collected for venipuncture (v. cephalica) for systemic blood gas analysis (GEM Premier 3000, Werfen, Barcelona, Spain), complete blood count (MS4e, Melet Schloesing, Maria Enzersdorf, Austria), and biochemical analyses (BT 3000, Biotecnica Instruments, Roma, Italy) at the Central Laboratory of the Faculty of Veterinary Medicine, Selcuk University. Fluid replacement therapy was initiated based on the patients' blood parameters.

To determine the location of the FB, assess indicators of peritonitis, and detect obstruction, USG and direct radiography (Siemens X-ray, Rayence Veterinary DR unit) were performed in all cases. In cases where clinical,

radiological, and haematological examinations did not suggest peritonitis and no intestinal perforation was present, contrast radiography with 60% barium sulphate solution (2 mL/kg, orally) was performed. Radiographic imaging was utilised to ascertain the FB's location, degree of obstruction, and its characteristics. Treatment decisions were based on factors including the FB's diameter, location, and composition, as well as the severity of obstruction, food intake, defecation status, clinical presentation, the owner's financial capacity, and the patient's blood parameters.

For surgical sedation, Medetomidine HCl (Domitor®, Zoetis, New Jersey, USA) (0.025 mg/kg, IM) and butorphanol (Butomidor, Interhas, Ankara, Turkey) (0.1 mg/kg, IM) were administered. Anaesthesia was induced with propofol (Propofol-Lipuro 1%®, B. Braun, Melsungen, Germany) (1.5–3 mg/kg, IV) and maintained with isoflurane (2% isoflurane-Adeka Pharmaceuticals, Samsun, Turkey) at a flow rate of 2 L/min with 100% oxygen after endotracheal intubation. Following routine surgical preparation (shaving, asepsis, antisepsis), the patient was placed in the ventro-dorsal position on the operating table.

Except for cases where FBs were located in or around the oesophagus, all cats underwent abdominal exploration extending from the stomach to the rectum, with careful examination of the intestinal segments. Once the location of the FB was identified, it was removed via enterotomy or gastrotomy. In cases where linear FBs had caused chronic penetration into the intestinal mesenchyme or perforation, multiple enterotomies were performed to minimise further trauma to the intestinal mesenchyme. After the removal of all FBs, the incisions were closed using a double continuous suture technique with atraumatic polydioxanone (PDO 4/0) or polyglycolic acid (PGA 4/0) sutures, employing parallel suturing in the antimesenteric region or transverse suturing in stenotic segments (Fig. 1). Following suture placement, the intestinal segments were meticulously examined for any leaks. Prior to the closure of the abdominal wall, the abdominal cavity was irrigated with a body-temperature isotonic (0.9%) solution. Postoperative care included the administration of Metoclopramide HCl (0.2 mg/kg, IM) to prevent vomiting, along with appropriate fluid therapy (Lactated Ringer, isotonic 0.9% NaCl, etc.) to correct dehydration and improve tissue perfusion, based on blood gas results. Antibiotic therapy consisted of metronidazole (Polygyl 0.5%, Polifarma, Istanbul, Turkey) (7.5 mg/kg, q24h, IV) for 3 days and cefazolin sodium (Iespor®, Ulagay Pharmaceutical, Istanbul, Turkey) (30 mg/kg, q24h, IM) for 7 days. Analgesia was provided with meloxicam (Metacam®, Boehringer Ingelheim, Ingelheim, Germany) on day 1 (0.1 mg/kg, q24h, PO), followed by 0.05 mg/kg (q24h, PO) for the next 2 days. If non-steroidal analgesics were insufficient, additional analgesia was administered via subcutaneous injection of butorphanol hydrogen tartrate at a dose of 0.4 mg/kg (Butomidor-Interhas, Ankara, Turkey) (0.1 mg/kg, IM).

As a statistical method in the study, the findings were evaluated by taking the statistical average.

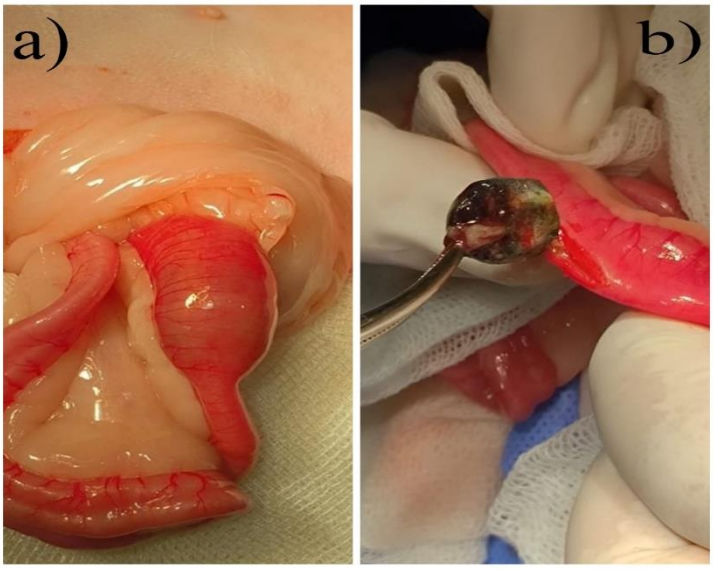

Figure 1. *a) The non-linear plastic FB causing complete obstruction in the intestinal region of case 6, b) the non-linear plastic FB removed from the intestinal region of case 6 via enterotomy.*

RESULTS

Clinical findings

The breed distribution of the cases included in the study was as follows: Domestic Shorthair (63.5%) (n=33), Scottish Fold (13.5%) (n=7), British Shorthair (9.5%) (n=5), Angora (7.5%) (n=4), Siamese (2%) (n=1), Chinchilla (2%) (n=1) and Persian (2%) (n=1). The age distribution of the cases was as shown below: 27% were less than 1 year old (n=14), 25% were 2 years old (n=13), 21% were 1 year old (n=11), 11.5% were 3 years old (n=6), 4% were 4 years old (n=2), 7.5% were 5 years old (n=4), 2% were 6 years old (n=1) and 2% were 10 years old (n=1). When analysing the gender distribution of the cases, 59.6% were female (n=31) and 40.4% were male (n=21). In some cases with linear FBs, they FBs were located in the oral cavity or at the root of the tongue, extended outwards from the anus, or included ingested needles attached to the FB. Cases with linear FBs at the root of the tongue often exhibited chewing movements, and in some cases, transversal cuts were observed on the tongue due to the FBs. In all cases of linear FB, severe vomiting (more than five times per day), anorexia, weakness, pyrexia and abdominal tenderness were observed (Fig. 2) (Table 1).

Clinical examination of other cases of FB revealed clinical symptoms of anorexia, weakness, severe vomiting, dehydration, abdominal distension and increased tenderness. Defecation varied depending on the FB's location in the GI tract and the degree of obstruction, being observed in some cases but absent in others.

Figure 2. *Detection of a linear FB at the root of the tongue in a cat.*

Table 1. *Details of the cases included in the study.*

Cases	Breed	Age (Month)	Sex	Intervention Time (Day)	Surgical Procedure	Foreign Body(FB)	Minor Postoperative Complications	Major Postoperative Complications	Prognosis	Hospitalization Duration (Hours)
1	Persian	6	Male	0	Duodenal enterotomy	Non-Linear FB (Plastic)	Wound infection	-	Moderate	-
2	Scottish Fold	12	Male	6	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	Anorexia, Pyrexia	Septic peritonitis, Sepsis	Expired at 12th Hour	12
3	Mixed breed	24	Female	0	Esophageal FB-Endoscopic intervention	Non-Linear FB (Bone)	-	-	Good	12

4	British	12	Male	0	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	-
5	Mixed breed	24	Male	3	Duodenal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	-
6	Mixed breed	12	Female	2	Jejunal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-
7	Mixed breed	36	Male	8	Duodenal enterotomy	Non-Linear FB (Plastic)	Bloody diarrhoea, Pyrexia, Vomiting Anorexia	Septic Peritonitis, Sepsis	Expired on 14th Day	-
8	British	9	Female	6	Duodenal enterotomy	Non-Linear FB (Plastic)	Anorexia	-	Expired on 2nd Day	48
9	Mixed breed	24	Male	0	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	72
10	Mixed breed	72	Female	3	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	İlues, Wound infection	Septic Peritonitis, Sepsis	Expired on 2nd Day	-
11	Scottish Fold	36	Male	3	Duodenal enterotomy	Non-Linear FB (Cat hair)	Anorexia	-	Expired on 7th Day	72
12	Mixed breed	120	Female	5	EsophagealFB-Endoscopic intervention	Non-Linear FB (Bone)	Anorexia	-	Moderate	72
13	Mixed breed	12	Female	2	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	-
14	Mixed breed	24	Female	0	Gastric endoscopic procedure	Non-Linear FB (Cat hair)	-	-	Good	-
15	Mixed breed	12	Male	3	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-
16	Ankara	4	Female	10	Jejunal enterotomy	Non-Linear FB (Fruit seed)	Anorexia	-	Expired on 6th Day	-
17	Mixed breed	36	Female	2	Jejunal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-
18	Mixed breed	60	Female	2	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	-
19	Mixed breed	60	Female	1	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	Incisional hernia	-	Expired on 1st Day	-
20	Mixed breed	8	Female	2	Jejenum	Non-Linear FB (Plastic)	-	-	Good	-
21	Mixed breed	36	Female	4	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	Vomiting	-	Moderate	-
22	Scottish Fold	12	Female	2	Gastrotomy	Non-Linear FB (Plastic)	-	-	Good	-

23	Scottish Fold	24	Male	2	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	12
24	British	4	Male	4	Duodenal enterotomy	Non-Linear FB (Fruit seed)	-	-	Good	-
25	Siamese	7	Female	1	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	12
26	Mixed breed	60	Male	8	EsophagealFB-Endoscopic intervention	Non-Linear FB (Bone)	-	-	Good	-
27	Mixed breed	24	Female	4	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	Septic Peritonitis, Sepsis	Espired on 2nd Day	-
28	Scottish Fold	24	Male	10	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	İleus	-	Moderate	-
29	Mixed breed	24	Female	0	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Intraoperatif Ex	-
30	Mixed breed	36	Female	2	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	12
31	Mixed breed	9	Male	2	Gastrotomy	Non-Linear FB (Plastic)	-	-	Good	12
32	Mixed breed	6	Male	12	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-
33	Mixed breed	12	Male	5	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Expired on 1st Day	-
34	Ankara	8	Female	2	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	168
35	Mixed breed	24	Male	3	Duodenal enterotomy	Non-Linear FB (Plastic)	Incisional hernia	-	Moderate	--
36	Mixed breed	24	Female	3	Ileum enterotomy	Non-Linear FB (Plastic)	Wound infection	Local peritonitis	Worst	168
37	Mixed breed	6	Female	2	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-
38	Mixed breed	12	Female	0	Duodenal enterotomy	Non-Linear FB (Needle)	-	-	Good	-
39	Chinchilla	8	Male	0	Gastric endoscopic procedure	Non-Linear FB (Plastic)	-	-	Good	-
40	Mixed breed	12	Female	0	Gastrotomy	Non-Linear FB (Needle)	-	-	Good	-
41	British	24	Male	1	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-
42	Mixed breed	12	Female	4	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	Incisional hernia	-	Moderate	-
43	Mixed breed	60	Female	3	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	48
44	Ankara	7	Male	1	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Expired on 1st Day	-

45	Ankara	36	Male	7	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	-
46	Scottis h Fold	11	Female	7	Multifocal enterotomy	Linear FB (String, Thread, Wire, etc.)	-	-	Good	-
47	British	5	Female	4	Jejunal enterotomy	Non-Linear FB (Plastic)	Wound ınfection	-	Moder ate	-
48	Mixed breed	48	Female	1	Jejunal enterotomy	Non-Linear FB (Plastic)	Anorexia	-	Expire d on 4th Day	168
49	Mixed breed	12	Male	1	Gastrotomy	Non-Linear FB (Plastic)	-	-	Good	72
50	Mixed breed	24	Female	3	Duodenal enterotomy	Non-Linear FB (Needle)	-	-	Good	-
51	Scottis h Fold	24	Female	3	Jejunal enterotomy	Linear FB (String, Thread, Wire, etc.)	İleus	-	Moder ate	-
52	Mixed breed	48	Female	2	Duodenal enterotomy	Non-Linear FB (Plastic)	-	-	Good	-

Haematological findings

In the preoperative blood parameters (whole blood, blood gas and serum biochemistry) of patients presenting with FB complaints (Table 2), the following findings were observed: hypokalaemia (61.90%, n=26), hypernatraemia (42.8%, n=18), hypochloraemia (40.47%, n=17), decreased BUN (66.66%, n=14), elevated HCO_3 (26.19%, n=11), decreased HCO_3 (14.28%, n=6), decreased total protein (42.85%, n=9), elevated total protein (19.04%, n=4), metabolic alkalosis (19.04%, n=8), decreased creatinine (33.33%, n=7), hyperlactataemia (16.66%, n=7), increased Hct (15%, n=3), hyponatraemia (7%, n=3), decreased Hct (5%, n=1), and decreased WBC (5%, n=1) (Table 2).

Tablo 2. *Preoperative biochemical, hematologic and blood-gas values for cats with GI FB obstruction.*

Parameters	Mean	Reference Range	Below the reference (n)	Above Reference (n)	Total Cases (n)
White blood cells 10^9/L	12.11	5.5-19.5	1	-	20
Haematocrit %	44.08	31-48	1	3	20
Ph	7.35	7.24-7.40	3	8	42
Potassium (K) mmol/L	3.48	3.7-6.1	26	-	42
Sodium (Na) nmol/L	155	146-156	3	18	42
Chlorine (Cl) nmol/L	113.07	115-130	17	-	42
Lactat nmol/L	3.24	0.9-3.9	-	7	42
Hco3 nmol/L	20.88	17-24	6	11	42
BUN mg/dL	27.32	19-34	14	-	21
Creatinine mg/dL	1.10	0.9-2.2	7	1	21
Total protein g/dL	6.56	6-7.9	9	4	21

Radiological and USG findings

Direct and indirect radiographs with barium sulphate were taken in all patients who presented with the complaint of swallowing FB. Radiographic examination revealed clustered or tortuous small bowel segments, particularly in patients with linear FB ingestion. Depending on the nature and size of the ingested FB, partial or complete obstructions were observed in various parts of the GI tract (Fig. 3). Radiological findings also indicated dilated intestinal segments. Ultrasonographic examination revealed the presence of shadowing in

some regions of the GI tract due to an ingested FB, decreased peristalsis, and gastric and intestinal dilatation in cases of FB causing complete obstruction (Fig. 4; Fig.5).

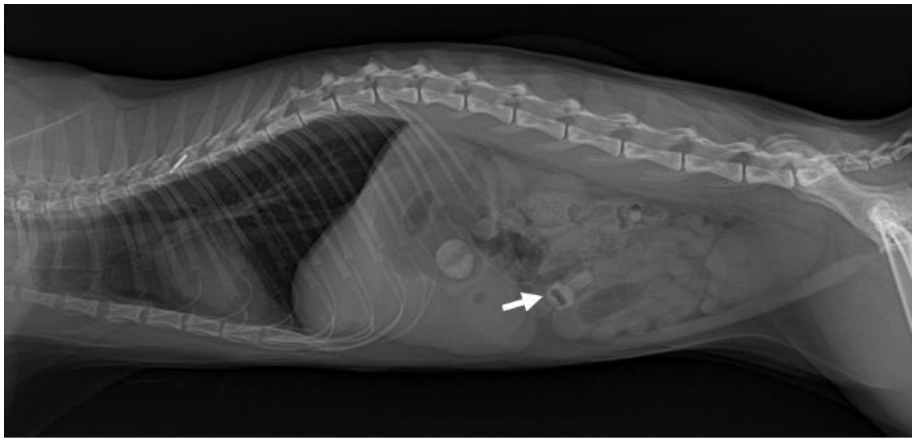

Figure 3. *X-ray image of a FB (white arrows) in the small intestine of a cat.*

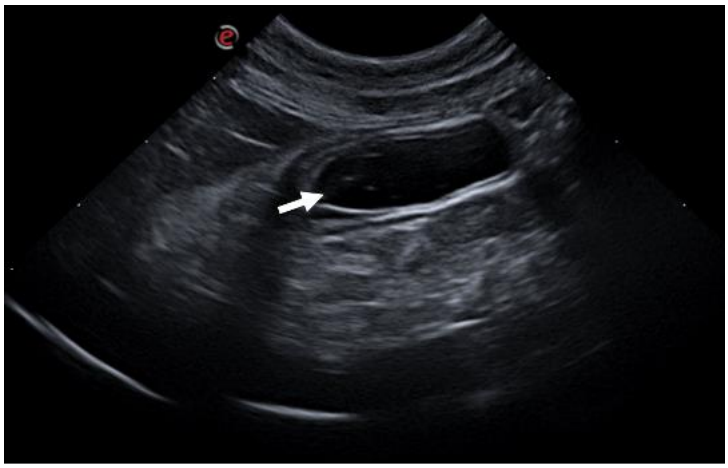

Figure 4. *Longitudinal ultrasonographic image of small intestinal segment dilation (white arrow) secondary to a linear FB in a 5-year-old female mixed-breed cat (Case 18)*

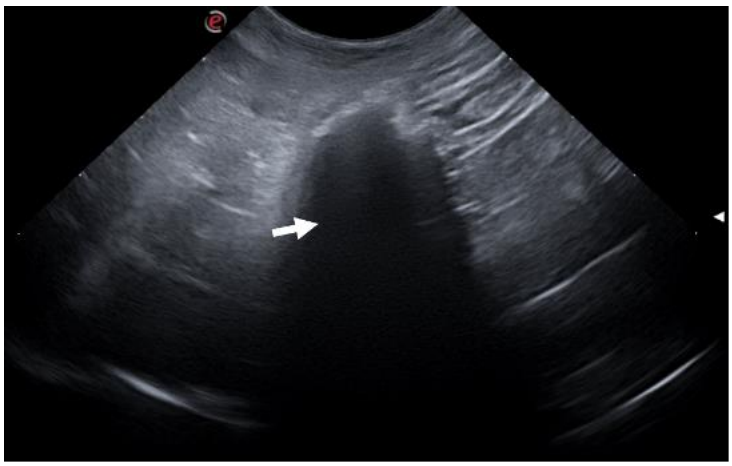

Figure 5. *Oblique sagittal ultrasound image of the jejunum in a 4-month-old female kitten (case 16). A fruit seed causes an acoustic shadow artefact (white arrow) by obstructing deeper sound wave penetration.*

Surgical findings

The nature of the FBs removed from various segments of the GI tract, either through surgery or endoscopy, was analysed. The majority of FBs identified were linear in shape, accounting for 40.5% (n=21) of cases, followed by plastic materials, also representing 40.5% (n=21). Other FBs included needles (5.5%, n=3), bone fragments (5.5%, n=3), fruit stones (4%, n=2), and hairballs (4%, n=2).
Endoscopic removal was performed under general anaesthesia in 4% (n=2) of cases, avoiding the need for surgical intervention. Surgical procedures, including enterotomy and gastrotomy, were required for FB removal depending on their location within the GI tract. The distribution of FBs by anatomical site was as follows: 36.5% (n=19) were multifocal, meaning they were found in multiple locations; 31% (n=16) were located in the duodenum; 13.5% (n=7) in the jejunum; 7.5% (n=4) in the stomach; 5.5% (n=3) in the oesophagus; and 2% (n=1) in the ileum.

Regarding survival outcomes, 23.1% (n=12) of the cases resulted in death, while 76.9% (n=40) of the cases survived to the time of assessment. Among the deceased, 58.3% (n=7) were attributed to linear FBs, 25% (n=3) to plastic objects, 8.3% (n=1) to fruit seeds, and 8.3% (n=1) to hairballs. Upon further analysis of the cases that resulted in death, it was noted that 8.3% (n=1) of deaths occurred intraoperatively. Postoperatively, deaths occurred at varying intervals: 8.3% (n=1) at 6 hours, 8.3% (n=1) at 12 hours, 25% (n=3) on the first day, 16.6% (n=2) on the second day, 8.3% (n=1) on the third day, 8.3% (n=1) on the fourth day, 8.3% (n=1) on the seventh day, and 8.3% (n=1) on the fourteenth day.

Postoperative complications were observed in 21% (n=11) of cases, including minor issues such as anorexia, pyrexia, bloody diarrhoea, paralytic ileus, vomiting, wound infection, and incisional hernia. Major complications, specifically septic peritonitis and sepsis, were documented in 7.6% (n=4) of cases. In cases involving linear FBs, minor complications occurred in 42% (n=3) and major complications in 57% (n=4); all instances of septic peritonitis and sepsis resulted in mortality. For FB cases, the mean time from onset of clinical signs to time of surgery was 67.2 hours for surviving cases and 96 hours for deceased cases. In the postoperative evaluation of the cases; cases without minor or major complications were recorded as “good”, cases with minor complications were recorded as “moderate”, and cases with major complications but still alive were recorded as “worst”.

DISCUSSION

FBs in the GI tract remain a common health problem in cats, and according to our study, 59.6% of the 52 cats with FBs were female. In our study, 40.5% (n = 21) of FB cases were classified as linear FB, while (59.5%, n = 31) were categorised as non-linear FB. Notably, the rate of treatment success was observed to increase significantly (76.9%) with early surgical intervention. However, mortality was predominantly associated with cases involving linear FB. Furthermore, surgical intervention for linear FB cases was typically delayed, with an average time to surgery of 96 hours. These findings underscore the critical importance of prompt diagnosis and early intervention, particularly in cases of linear FB, to improve clinical outcomes and reduce mortality rates. Analyses of studies on FB events showed the majority of events to be in domestic shorthair breeds (95%), with a gender distribution of 70% males (n=7) and 30% females (n=3) (Hayes, 2009; Cola et al., 2009; Miller et al., 2024). In the study by Gülaydın and Akgül (2024) it was reported that 66.6% of the cases were domestic shorthair (n=8) and 33.4% were Scottish breed cats (n=4), and the sex distribution was 75% male (n=9) and 25% female (n=3). In the present study, the breed distribution of GI FB cases revealed that domestic shorthair cats were the most commonly affected breed, accounting for 63.4% of cases (n=33). This finding aligns with the results of previous studies, suggesting a potential predisposition of this breed to GI FB ingestion. However, the data obtained regarding the sex distribution are not compatible with previous findings; 59.6% of the cases in our study were female cats (n=31). This difference may be explained by an excess of female cats in the population. Nevertheless, further extensive and detailed studies are required to validate these hypotheses.

Previous studies have indicated that cats presenting with FB ingestion are predominantly younger than two years of age, a finding supported by the data from our study, in which 48% of affected cats fell within this age group (Hayes, 2009; Pratt et al., 2014; Crinò et al., 2023). The high prevalence observed in younger cats may be attributed to their heightened exploratory behaviour and curiosity about foreign objects. Additionally, the

increased incidence of pica behaviour during the permanent teething period is thought to contribute to the higher risk of FB ingestion in this age group.

The literature indicates that cats exhibit a particular interest in linear FBs and are more prone to swallowing such objects due to the unique anatomical structure of their tongues (Çamkerten and Şahin, 2006; Hayes, 2009; Demirel, 2021; Gülaydın and Akgül, 2024). In our study, an analysis of the types of FBs revealed that 40.4% (n=21) of cases involved linear FBs, while an equal proportion (40.4%, n=21) consisted of plastic materials. The frequent occurrence of linear FBs may be attributed to several factors, including the ease of access to these objects, cats' natural tendency to play with string-like materials, and their anatomical predisposition to engaging with and ingesting such items.

Metabolic alterations caused by GI FBs in cats and dogs have been extensively discussed in the literature. Gollnick et al. (2023) reported that hyponatraemia was the most commonly observed metabolic disturbance in cats with GI lesions, accompanied by decreases in serum chloride and calcium levels in 32% of cases and elevated serum lactate levels in 30% of cases. These findings highlight the impact of GI system damage on electrolyte and metabolite balance. Similarly, Boag et al. (2005) reported hypochloraemia in 51.8%, metabolic alkalosis in 45.2%, hyperlactataemia in 40.5%, hypokalaemia in 25%, and hyponatraemia in 20.5% of dogs with GI injuries, emphasising the need to consider these metabolic changes in clinical management. In contrast, studies focusing on cats and dogs that ingested suture needles suggest more limited changes in metabolic parameters. For instance, in a study by Demirel et al. (2021), sodium, chloride, potassium, haematocrit, total protein, creatinine, and glucose levels were generally within normal limits in both species. This observation suggests that the type and location of the FB may play a significant role in determining the extent of metabolic changes. Supporting this, Parlak et al. (2022) found hypokalaemia in 42%, hypochloraemia in 20%, and hyperlactataemia in 50% of cats with linear FBs. These findings underline the importance of considering FB characteristics in the evaluation of metabolic disturbances associated with GI FB cases.
Sayın (2024) reported hyperlactataemia in 67.3%, hypochloraemia in 43.4%, hyponatraemia in 27.6%, and hypokalaemia in 13% of GI FB cases, further demonstrating the prevalence and clinical importance of these metabolic alterations. These findings highlight the need for careful monitoring of electrolyte and metabolic parameters during the clinical evaluation of GI cases. The data obtained in our study are consistent with findings reported in the literature (Boag et al., 2005; Parlak et al., 2022; Gollnick et al., 2023; Sayın, 2024). Hypochloraemia and hypernatraemia observed in some cases are thought to result from prolonged vomiting and dehydration. Furthermore, hyperlactataemia is likely influenced by decreased tissue perfusion caused by intestinal wall compression by the FB, emphasising the significant local and systemic effects of FBs on metabolic parameters.

In this study, radiographic imaging was an important diagnostic tool, and direct radiography was found to be sufficient for the detection of radiopaque FBs. However, both ultrasonography (USG) and radiography were employed for the diagnosis of radiolucent FBs. In cases where FBs could not be detected using either method, indirect radiography was utilised. In cases with linear FBs, clustering and tortuosity of intestinal segments were readily apparent on direct radiographs, while dilated intestinal segments were noted in non-linear FB cases. These findings align with reports in the literature, which emphasise the utility of radiography in identifying radiopaque FBs, determining obstruction sites, and assessing gas and fluid content within the GI tract (Arıcan, 2011; Finck et al., 2014; Erol et al., 2019). However, as previously noted by Elser et al. (2020), radiographic findings alone can be non-specific, particularly in differentiating FBs from neoplasia, adhesions, or strictures. Additionally, typical radiographic findings for linear FBs are not always present. Ultrasonography, performed immediately after radiography, proved invaluable in accurately identifying FBs, especially non-radiopaque ones. It also provided critical information regarding intestinal wall integrity, mesenteric changes, and free peritoneal fluid, which guided treatment decisions. This aligns with previous studies highlighting the diagnostic value of ultrasonography in GI FB cases (MacPhail, 2002; Penninck, 2002; Tyrrell et al., 2006; Hayes, 2008). The combined use of radiography and ultrasonography expedited the diagnosis and facilitated timely surgical intervention, ultimately improving clinical outcomes.

It has been well established that delayed intervention decreases treatment success in cases of intestinal obstruction in cats and dogs (Hayes, 2009; Kan et al., 2022). Additionally, the literature identifies the most critical complications of GI surgery as disruption of suture line integrity and leakage of intestinal contents into the abdominal cavity (Allen et al., 1992; Evans et al., 1994; Shales et al., 2005; Hayes, 2009). Hayes (2009)

noted no mortality in cats during the postoperative period, with only minor complications such as upper respiratory tract infections reported. Similarly, Gollnick et al. (2023) observed no intestinal perforation or septic peritonitis in cats with GI FBs, although intestinal perforations were more frequently associated with linear FBs. These cases were linked to a higher incidence of postoperative ileus and a higher infection rate at the surgical site (43%) compared to other FB cases. The increased infection rate in linear FB cases may be attributed to factors such as prolonged operative durationss, the requirement for multiple GI incisions, or the risk of incisional contamination during manipulation of the linear FB. These findings underscore the importance of timely surgical intervention and meticulous intraoperative management to optimise outcomes in cats and dogs with GI FBs. In this study, the timing of surgical intervention in cases with GI FBs was evaluated, revealing that surgery was performed after an average of 67.2 hours in surviving cases and 96 hours in cases that succumbed. Among cases with linear FBs that resulted in mortality, the average time to surgery was 76.8 hours. These findings align with those reported by Hayes (2009) and Kan et al. (2022), clearly demonstrating that mortality rates increase with delayed intervention. Particularly in cases involving linear FBs, delayed surgical intervention is thought to exacerbate damage, as linear FBs located in cranial regions of the GI tract (e.g., tongue root) can cause intestinal clustering due to continued caudal peristalsis, cumulatively increasing intestinal damage. The prognosis for cats undergoing surgical removal of FBs is generally favourable, with low rates of postoperative septic peritonitis and mortality (Gollnick et al., 2023). However, cases involving linear FBs are often more complex, and the postoperative care process is typically more challenging. While Miller et al. (2024) reported no significant difference in the occurrence of postoperative complications between linear and other FB cases, they documented two fatalities in the postoperative period. One case was suspected to have developed systemic inflammatory response syndrome (SIRS), and both cases experienced complications such as hypotension, acute kidney injury, and pleural effusion. These findings highlight the critical need for timely surgical intervention and comprehensive postoperative care, particularly in cases involving linear FBs, to optimise outcomes and minimise the risk of severe complications. Of the 52 cases evaluated in this study, 43 (82.69%) were successfully discharged, while 9 cases (17.31%) succumbed to complications during hospitalization. Additionally, 3 cases (6%) were reported to have died due to complications after discharge. When minor and major postoperative complications were analysed, minor complications—such as anorexia, pyrexia, bloody diarrhoea, paralytic ileus, vomiting, wound infection, and incisional hernia—were observed in 21% (n=11) of the cases. Major complications, including septic peritonitis and sepsis, were identified in 7.6% (n=4) of the cases. Among cases with linear GI FBs, minor complications occurred in 42.85% (n=3), and major complications occurred in 57.15% (n=4), with all cases of septic peritonitis and sepsis resulting in mortality. These findings differ from those reported by Hayes (2009), Gollnick et al. (2023), and Miller et al. (2024) regarding the type and frequency of minor and major complications. However, the observed mortality in all cases with peritonitis and sepsis aligns with previous studies (Allen et al., 1992; Evans et al., 1994; Shales et al., 2005; Hayes, 2009). The higher frequency of complications in this study compared to prior literature is likely attributable to the predominance of linear FB cases and prolonged surgical intervention times. The increased complication and mortality rates in linear FB cases appear to be associated with delayed presentation to the clinic and the subsequent development of septic peritonitis due to intestinal perforation. The presence of postoperative complications, such as incisional hernia and wound infection, highlights the critical importance of meticulous postoperative care. Moreover, the fact that most deaths occurred within the first 48 hours post-surgery underscores the need for improved postoperative critical care. While no significant differences were observed in age or breed between survivors and nonsurvivors, mortality was significantly higher among cases with linear FBs (33.3%) compared to non-linear FBs (16.1%). Perforation and peritonitis caused by multifocal localisation of linear FBs in the intestinal system likely explain the increased mortality rate. All linear FB cases resulting in mortality (33.3%) exhibited multifocal localisation, which contributed to longer surgical intervention times and increased contamination.

CONCLUSION

This study highlights the critical importance of early diagnosis and timely intervention in the clinical management of GI FBs in cats. The results show that linear FBs in particular are associated with higher complication rates, and septic peritonitis and mortality are more common in these cases. Mortality rates were found to be higher in cases where surgical intervention was delayed, clearly demonstrating the negative effects of late intervention. Our study supports the necessity of a multifaceted diagnostic approach combining radiographic and ultrasonographic imaging methods to accurately localise FBs and determine the degree of obstruction. In addition, electrolyte imbalances such as hypochloraemia, hyponatraemia, and hyperlactataemia

were observed as important metabolic changes. These changes are thought to be due to prolonged vomiting, dehydration, and impaired intestinal perfusion due to obstruction caused by FBs. Given the increased risk of postoperative complications, meticulous management during surgery and intensive postoperative care are vital to improve clinical outcomes.

CONFLICT OF INTEREST

The authors confirm that they have no potential conflicts of interest related to the research, authorship, or publication of this article.

AUTHOR CONTRIBUTION

N. Z. E., concept, design and writing the manuscript
H. E., S. P., İ. A., data collection and analysis.
K. P., concept, design and writing the manuscript

ETHICAL APPROVAL

This study was conducted with the approval of the Selcuk University Faculty of Veterinary Medicine Experimental Animal Production and Research Center Ethics Committee, dated 30.01.2025 and numbered 2025/13.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

Allen, D. A., Smeak, D. D., & Schertel, E. R. (1992). Prevalence of small intestinal dehiscence and associated clinical factors: a retrospective study of 121 dogs. Journal of the American Animal Hospital Association, 28(1), 70-76. https://www.cabidigitallibrary.org/doi/full/10.5555/19932280396

Arıcan, M. (2011). Veteriner Genel Radyoloji ve Kedi Köpek için Tanısal Radyografi Atlası. Selçuk Üniversitesi Veteriner Fakültesi Cerrahi ABD.

Boag, A. K., Coe, R. J., Martinez, T. A., & Hughes, D. (2005). Acid-base and electrolyte abnormalities in dogs with gastrointestinal foreign bodies. Journal of veterinary internal medicine, 19(6), 816-821. https://doi.org/10.1111/j.1939-1676.2005.tb02770.x

Cola, V., Del Magno, S., Valentini, S., Zanardi, S., Foglia, A., Spinella, G., ... & Pisoni, L. (2019). Deep vegetal foreign bodies in cats: a retrospective study of 10 cases. Journal of the American Animal Hospital Association, 55(5), 249-255. https://doi.org/10.5326/JAAHA-MS-6913

Crinò, C., Humm, K., & Cortellini, S. (2023). Conservative management of metallic sharp-pointed straight gastric and intestinal foreign bodies in dogs and cats: 17 cases (2003-2021). Journal of Small Animal Practice, 64(8), 522-526. https://doi.org/10.1111/jsap.13606

Çamkerten, İ., & Şahin, T. (2006). Kedi ve Köpeklerde Akut Abdomen. Yüzüncü Yıl Üniversitesi Veteriner Fakültesi Dergisi, 17(1), 27-32. https://dergipark.org.tr/tr/download/article-file/146611

Demirel, A. (2021). Kedi ve köpeklerde mide barsak yabancı cisim prevalansı (Master's thesis, Afyon Kocatepe Üniversitesi, Sağlık Bilimleri Enstitüsü). Yükseköğretim Kurulu Ulusal Tez Merkezi. (Dissertation No: 674623).

Elser, E. B., Mai, W., Reetz, J. A., Thawley, V., Bagshaw, H., & Suran, J. N. (2020). Serial abdominal radiographs do not significantly increase accuracy of diagnosis of gastrointestinal mechanical obstruction due to occult foreign bodies in dogs and cats. Veterinary Radiology & Ultrasound, 61(4), 399-408. https://doi.org/10.1111/vru.12870

Erol, H. (2019). Köpeklerde Yabancı Cisme (Kulak Küpesi) Bağlı Şekillenen Mekanik İleus' un Operatif Sağaltım ve Sonuçlarının Değerlendirilmesi: 6 Olgu. Erciyes Üniversitesi Veteriner Fakültesi Dergisi, 16(2), 92-97. https://doi.org/10.32707/ercivet.595651

Evans, K. L., Smeak, D. D., & Biller, D. S. (1994). Gastrointestinal linear foreign bodies in 32 dogs: a retrospective evaluation and feline comparison. Journal of the American Animal Hospital Association, 30(5), 445-450. https://www.cabidigitallibrary.org/doi/full/10.5555/19942216565

Finck, C., D'Anjou, M. A., Alexander, K., Specchi, S., & Beauchamp, G. (2014). Radiographic diagnosis of mechanical obstruction in dogs based on relative small intestinal external diameters. Veterinary radiology & ultrasound, 55(5), 472-479. https://doi.org/10.1111/vru.12153

Gollnick, H. R., Schmiedt, C. W., Wallace, M. L., Sutherland, B. J., & Grimes, J. A. (2023). Retrospective evaluation of surgical treatment of linear and discrete gastrointestinal foreign bodies in cats: 2009–2021. Journal of Feline Medicine and Surgery, 25(6), 1098612X231178140.https://doi.org/10.1177/1098612X23117814

Guilford, W. G., & Strombeck, D. R. (1996). Intestinal obstruction, pseudoobstruction, and foreign bodies, in Guilford WG, Center SA, Strombeck DR, et al (eds): Strombeck's Small Animal Gastroenterology, ed 3. Philadelphia, WB Saunders, pp 487–502. https://www.cabidigitallibrary.org/doi/full/10.5555/19972203983

Gülaydın, A., & Akgül, M. B. (2024). Evaluation of Cases of Foreign Body Ingestion in the Gastrointestinal Tract of Cats: 12 Cases. Harran Üniversitesi Veteriner Fakültesi Dergisi, 13(1), 76-83. https://doi.org/10.31196/huvfd.1468487

Hayes, G. (2009). Gastrointestinal foreign bodies in dogs and cats: a retrospective study of 208 cases. Journal of small animal practice, 50(11), 576-583. https://doi.org/10.1111/j.1748-5827.2009.00783.x

Kan, T., Hess, R. S., & Clarke, D. L. (2022). Clinical findings and patient outcomes following surgical treatment of chronic gastrointestinal foreign body obstructions in dogs and cats: 72 cases (2010-2020). Canadian Journal of Veterinary Research, 86(4), 311-315. https://pmc.ncbi.nlm.nih.gov/articles/PMC9536220/

MacPhail, C. (2002). Gastrointestinal obstruction. Clinical Techniques in Small Animal Practice, 17(4), 178-183. https://doi.org/10.1053/svms.2002.36606

Miller, A. K., Regier, P. J., Ham, K. M., Case, J. B., Fisher, K. J., Rogers, J. M., ... & Colee, J. C. (2024). Linear and discrete foreign body small intestinal obstruction outcomes, complication risk factors, and single incision red rubber catheter technique success in cats. Veterinary Surgery, 53(7), 1256-1265. https://doi.org/10.1111/vsu.14125

Papazoglou, L. G., Patsikas, M. N., & Rallis, T. (2003). Intestinal foreign bodies in dogs and cats. Compendıum on contınuıng educatıon for the practısıng veterınarıan-north amerıcan edıtıon-, 25(11), 830-845 https://www.researchgate.net/publication/282211745

Parlak, K., Akyol, E. T., Uzunlu, E. O., Zamirbekova, N., Çayırlı, Ü. F. B., & Arıcan, M. (2022). Gastrointestinal linear foreign bodies in cats: A retrospective study of 12 cases. Journal of Advances in VetBio Science and Techniques, 7(2), 233-241. https://doi.org/10.31797/vetbio.1131263

Pratt, C. L., Reineke, E. L., & Drobatz, K. J. (2014). Sewing needle foreign body ingestion in dogs and cats: 65 cases (2000–2012). Journal of the American Veterinary Medical Association, 245(3), 302-308. https://doi.org/10.2460/javma.245.3.302

Sayın, M. (2024). Kedilerde gastrointestinal yabancı cisimler; radyografik, endoskopik ve biyokimyasal değerlendirme (Master's thesis, Afyon Kocatepe Üniversitesi, Sağlık Bilimleri Enstitüsü). Yükseköğretim Kurulu Ulusal Tez Merkezi. (Dissertation No: 896074).

Shales, C. J., Warren, J., Anderson, D. M., Baines, S. J., & White, R. A. S. (2005). Complications following full-thickness small intestinal biopsy in 66 dogs: a retrospective study. Journal of Small Animal Practice, 46(7), 317-321. https://doi.org/10.1111/j.1748-5827.2005.tb00326.x

Tyrrell, D., & Beck, C. (2006). Survey of the use of radiography vs. ultrasonography in the investigation of gastrointestinal foreign bodies in small animals. Veterinary radiology & ultrasound, 47(4), 404-408. https://doi.org/10.1111/j.1740-8261.2006.00160.x

Willis, S. E., & Farrow, C. S. (1991). Partial gastrointestinal obstruction for one month due to a linear foreign body in a cat. The Canadian Veterinary Journal, 32(11), 689-691. https://pmc.ncbi.nlm.nih.gov/articles/PMC1481086/

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Research Article

Cichlidae Ailesinden Üç Türün İki Alıştırma Sıcaklığında Termal Tolerans Parametreleri ve Bunların Vücut Büyüklüğüne Göre Değişimi

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ÖZET

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Çalışmada Cihlidae ailesinden sarı prenses (*Labidochromis caeruleus*), şeker pembe (*Aulonocara stuartgranti*) ve yunus ciklit (*Cyrtocara moorii*)'in 20 ve 28 °C alıştırma sıcaklığında (AT) termal tolerans parametreleri ve bunların vücut büyüklüğüne göre değişimleri belirlenmiştir. Balık türleri arasında sıcaklık tolerans değerleri birbirine yakın olup, AT'ye bağlı olarak kritik düşük sıcaklık (CT_{min}) 9,40 – 12,79 °C, kritik yüksek sıcaklık (CT_{max}) 35,40 – 39,87 °C arasında saptanmıştır. Bu verilere göre 208 - 220 °C olarak hesaplanan TTP (thermal tolerance polygon) değeri, bu türlerin ait oldukları ailenin karekterine uygun olarak dar bir sıcaklık aralığına (stenothermik) sahip olduğunu göstermektedir. Üç ciklit türünde AT ile CTM değerleri arasında pozitif bir ilişki gözlenmiştir ($P<0.05$). AT'nin 20°C'den 28 °C'ye çıkması, balıkların CT_{min} değerlerinde 2,56 ile 3,39 °C, CT_{max} değerlerinde 2,42 ile 3,17 °C arasında bir artışa neden olmuştur. Bu değişime bağlı olarak ARR (alıştırma tepki oranı) değerleritürler arasında CT_{min}'de 0,32 ile 0,42, CT_{max}'da 0,30 ile 0,40 arasında bulunmuştur. Nispeten düşük sayılabilecek bu değerler, bu türlerin sıcaklık dalgalanmalarına karşı duyarlı olduğuna işaret etmektedir. Üç ciklit türünde 7-8 kat bir ağırlık farkınınher iki AT'de balıkların ne düşük ne de yüksek sıcaklık toleransı üzerinde herhangi bir etkisinin olmadığı belirlenmiştir ($P > 0,05$). Dolayısıyla, sucul poikiloterm hayvanların küçük boyutlu bireylerinin yüksek sıcaklıklarla baş etmede avantajlı olduklarına dair sav, bu üç ciklit türü üzerinde yapılan gözlemlerde doğrulanmamıştır

Keywords: *Labidochromis caeruleus, Aulonocara stuartgranti, Cyrtocara moorii, termal tolerans, balık büyüklüğü*

Thermal Tolerance Parameters of Three Species from the CichlidaeFamily at Two Acclimation Temperatures and Their Changes According to Body Size

ABSTRACT

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Thermal tolerance parameters of electric yellow cichlid (*Labidochromis caeruleus*), peacock cichlid (*Aulonocara stuartgranti*) and blue dolphin cichlid (*Cyrtocara moorii*) at 20 and 28 °C acclimation temperatures (AT) and their changes according to body size were determined in this study. Depending on AT, the critical low (CT_{min}) and high (CT_{max}) temperatures ranged from 9,40 to 12,79 °C and 35,40 to 39,87 °C, respectively. TTP (thermal tolerance polygon) value calculated as 208 - 220 °C shows that these species have a narrow temperature range (stenothermic). A positive relationship was observed between AT and CTM values ($P < 0.05$). Increasing the AT from 20 to 28 °C caused an increase in the CTmin values of the species between 2.56 and 3,39 °C, and in the CT_{max} values between 2,42 and 3,17 °C. Depending on this change, the ARR (acclimation response rate) values were found between 0,32 and 0,42 in CT_{min} and 0,30 and 0,40 in CT_{max} among species. A 7-8 fold weight difference in three cichlid species did not affect either low or high-temperature tolerance of fish at both AT ($P > 0.05$). Therefore, the argument that small-sized individuals of aquatic poikilotherms have an advantage in coping with high temperatures was not observed in these three species.

Key words: *Labidochromis caeruleus, Aulonocara stuartgranti, Cyrtocara moorii, thermal tolerance, fish size*

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GİRİŞ

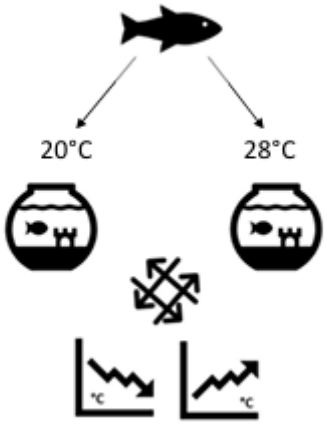
Balık gibi poikloterm hayvanlarda sıcak önemli bir çevresel etmendir (Yoldaş ve Erişmiş, 2022). Sıcaklığa karşı fazla bağımlı olan bu hayvanların sıcaklık tolerans parametrelerinin bilinmesi, bunların yaşamlarında maruz kalacakları ekstrem sıcaklıklara karşı gösterecekleri tepkilerin öngörülmesi, yeni habitatlara adaptasyonları veya iklim değişikliğine karşı gösterebilecekleri hayatta kalma stratejileri ve taktiklerinin kestirilmesi bakımından önemlidir (Yanar ve ark., 2023). Bu bilgiler, yerli habitatlara bulaşmış süs balıkları gibi egzotik türlerin mevcut sıcaklık bariyerlerini aşabilme ve üreme becerileri gösterebilmelerinin öngörülmesi, ayrıca olası ekolojik risklerin tespiti konusunda sağlıklı bir değerlendirme yapılmasına olanak sağlar. Özellikle süs balıkları, küresel çaptaki yoğun ticaretleri nedeniyle yerli habitatlar için potansiyel egzotik türlerdir ve bu balıkların sıcaklık tolerans parametrelerinin tespiti bu açıdan önemlidir. Diğer yandan, sıcaklık tolerans parametreleri balık yetiştiriciliğinde tür tercihi yapılırken dikkate alınan en önemli kriterlerden biridir. Özellikle sıcaklık değişiminin fazla olduğu subtropikal bölgelerdeki tropik balık yetiştiriciliğinde bu parametrelerin bilinmesi önemli fayda sağlar. Bu nedenle gerek sucul ekosistem gerek balık yetiştiriciliği bakımından balık türlerinin sıcaklık toleransı ile ilgili bir veri tabanına gereksinim vardır. Buna ilaveten, hayvanların sıcaklık toleranslarının, diğer çevresel veya içsel etmenlerden nasıl etkilendiğinin de bu veri setine eklenmesi gerekir. Giderek hızla artan endüstrileşme ve kentleşmenin küresel ısınmayı artırdığı bilinmektedir. Bu sıcaklık değişmelerine karşı türlerin vücut boyutlarında geçirecekleri adaptif evrimsel değişiklikler önemli bir araştırma konusu olmuştur. Vücut sıcaklıklarını düzenleme yeteneklerinden yoksun ve çevresel sıcaklığa fazla bağımlı olan poikloterm hayvanların sıcaklık tolerans limitlerinin belirlenmesi, her geçen gün artma eğiliminde olan küresel ısınmaya karşı verebilecekleri yanıtların kestirimi açısından önemlidir. Küresel ısınmanın getirdiği doğal seçilim baskısının poikloterm hayvanların vücut boyutunu küçültmeye zorladığı iddia edilmektedir (Angilletta ve Dunham, 2003; Daufresne ve ark., 2009; Sheridan ve Bickford, 2011; Horne ve ark., 2015). Bunun nedeni, daha küçük boyutlu olma, dolayısıyla daha dar bir yüzey alanına sahip olmanın hayvanın oksijen gereksinimini azaltacağı için, bu formasyonun kritik yüksek sıcaklıklarda bir avantaj olacağına dayandırılmıştır (Atkinson ve ark., 2006; Pouly, 2010; Verberk ve ark., 2011; Leiva ve ark, 2019). Nitekim, sucul poikloterm hayvanlarda yapılan bazı çalışmalarda küçük boyutlu olmanın hayvanın yüksek sıcaklıkla baş etme şansını arttırdığını ileri sürülmüştür (Di Santo ve Lobel, 2016, Brans ve ark., 2017; Turko ve ark., 2020). Ancak bu konu henüz tartışmalı olup, sıcaklık ile vücut büyüklüğü arasındaki negatif ilişki bazı poikloterm hayvanlarda doğrulanmamıştır (Barrionuevo ve Fernades, 1995; Ospinaand Mora, 2004; Recsetar ve ark., 2012). Dolayısıyla bu konunun daha pek çok poikloterm hayvanlarda test edilmesine gereksinim vardır.

Akuatik poikilotermik hayvanların alt (CT_{min}) ve üst (CT_{max}) sıcaklık toleranslar limitlerinin belirlenmesinde en yaygın kullanılan yöntemlerden biri, kritik termal metodolojidir (CTM). İlk olarak Cowles ve Bogert (1944) tarafından çöl reptillerinin sıcaklık tolerans limitlerinin belirlenmesi amacıyla kullanılan bu metot, daha sonra çeşitli araştırmacılar tarafından (Cox, 1974; Spotila ve ark., 1979; Lutterschmidt ve Hutchison, 1997; Beitinger ve ark, 2000) geliştirilerek balıklara ve diğer poikloterm akuatik hayvanlara uygulanmıştır. CTM verileri hayvanların ekstrem sıcaklık toleransları konusunda mutlak bilgiler vermekten ziyade (Selong ve ark., 2001), bu konuda göreceli olarak türler arasında bir karşılaştırma olanağı sağlar (Becker ve Genoway 1979; Beitinger ve ark, 2000). Farklı alıştırma sıcaklıklarında elde edilen CT_{min} ve CT_{max} verilerinden üretilen ARR (alıştırma tepki oranı), hayvanın sıcaklık dalgalanmalarına karşı verdiği tepkiyi (Claussen, 1977; Diaz-Herrera ve ark., 1998), TTP (termal tolerans poligonu) ise hayvanın yaşadığı sıcaklık aralığının genişliğini ifade eder (Bennett ve Beitinger, 1997). Bu parametreler özellikle hayvanların ekolojisi ve yayılışları konusunda sağlıklı bir öngörü ve kavrayış sağlar.

Bu konuda tanınmış süs balığı türlerine ilişkin melek balığı (Pérez vd., 2003), japon balığı (Ford ve Beitinger, 2005), zebra balığını (Cortemeglia ve Beitinger, 2005) içeren az sayıda çalışma literatürde mevcuttur. Termal tolerans parametrelerinin balık büyüklüğüne bağlı değişimleri Cichlid türlerinde çalışılmamıştır. Bu çalışmada termal tolerans parametrelerinin, Cichlidae ailesinden sarı prenses (*L. caeruleus*), şeker pembe (*A. stuartgranti*) ve yunus ciklit (*C. moorii*) türlerinde 20 ve 28 °C alıştırma sıcaklığında termal tolerans parametreleri ve bunların vücut büyüklüğüne göre değişimi belirlenmiştir.

MATERYAL VE YÖNTEM

Bu çalışmada deneysel kurgu Cichlidae ailesinden sarı prenses (*L. caeruleus*), şeker pembe (*A. stuartgranti*) ve yunus ciklit (*C. moorii*) türleri ile gerçekleştirilmiştir. Çalışma Çukurova Üniversitesi Su Ürünleri Fakültesi Dr. Nazmi Tekelioğlu Tatlı Su İşletmesinde yürütülmüştür. Her balık türü, aralarında 7 - 8 kat ağırlık farkı olan iki büyüklük gruba ayrılmış (Tablo 1) ve her grup için 20 ve 28 °C olmak üzere iki alıştırma sıcaklığı temel alınarak balıkların CT_{min}, CT_{max}, ARR ve TTP değerleri tespit edilmiştir.



Şekil 1. *Deneme dizaynı görseli*

Balıkların aklimasyonu

Türlerine ve büyüklüklerine göre ayrılan balıklar 20 ve 28°C sıcaklığına sahip 100 L'lik akvaryumlara kademeli olarak (günde 1°C) alıştırılarak burada 35 gün aklimasyonları (alıştırılmaları) sağlandı. Bu süreçte balıklar günde üç kez serbest yemleme yöntemiyle akvaryum balıklarına özel bir yemle (Tetra - Minflake) beslenmişlerdir. Akvaryumların suları merkezi bir hava motoruyla sürekli havalandırılarak oksijenlendirilmiş, sudaki oksijen düzeyi 6,4 mg / L – 7 mg / L aralığında ölçülmüştür. Akvaryum suları her gün sifonlanarak yem artıkları ve dışkılar ortamdan uzaklaştırılmıştır. Suyun pH değeri 7,7 – 7,9, sertliği ise 305 mg / L $CaCO_3$ olarak ölçülmüştür. Aklimasyon boyunca balıklara 12 saat aydınlık ve 12 saat karanlık periyot uygulanmış, aklimasyon periyodunun sonunda her büyüklük grubundan rasgele 15 adet balık alınarak ortalama boy ve ağırlıkları ölçülerek deneme aşamasına geçilmiştir.

CT_{min} ve CT_{max} denemesi

Aklimasyonun ardından balıklar 24 saat aç bırakılarak denemelerin gerçekleştirileceği, aynı sıcaklıklara sahip 10 L'lik akvaryumlara transfer edilmiştir. CT_{min} ve CT_{max} denemelerinde her bir balık türünden, her bir aklimasyon sıcaklığı ve her bir boy grubu için 5 adet balık kullanılmış ve denemeler üç tekerrürlü yürütülmüştür. Böylece çalışma her bir balık türü için 120, toplam 360 adet balıkla tamamlanmıştır.
Balıkların CT_{min} ve CT_{max} değerleri kritik termal metodoloji (CTM) uygulanarak belirlenmiştir. Akvaryum balıkları küçük boyutlu oldukları için, çalışma Becker ve Genewoy (1979) tarafından küçük balıklar için önerilen 0,3 °C / dk su değişim oranı yöntemiyle gerçekleştirilmiştir. Su balığın motor aktivitesi ve koordinasyonunu yitirdiği ve denge kaybının oluştuğu (LOE) ana kadar ısıtılmış (CT_{max}) ve soğutulmuştur (CTmin). Denge kaybı için balıkların 1 dakikadan fazla dorso - vetral oryantasyonunu sürdürememesi esas alınmıştır (Bennett ve Beitinger, 1997). Test akvaryumsularının sıcaklık seviyeleri, termostatlı su ısıtıcısı (Xilong AT - 700 / China) ve su soğutucusu (Resun 650 – CL / China) cihazlarıyla düzenlenmiştir.
Balıkların bireysel olarak kaydedilen termal tolerans limitlerinin aritmetik ortalaması, grupların termal tolerans limitleri olarak not edilmiştir. CT_{min} veya CT_{max} denemelerinden hemen sonra balıklar bulundukları akvaryumlardan alınıp tekrar aklimasyon akvaryumlarına aktarılmış ve 96 saatlik yaşama oranları kaydedilmiştir. ARR değerlerinin hesaplanmasında ΔCTM / ΔAT formülünden yararlanılmıştır (Claussen, 1977). Bennett ve Beitinger (1997) ve Eme ve Bennett (2009) tarafından geliştirilen TTP, Yanar ve ark. (2019) tarafından önerilen, koordinat sisteminde horizontal (Alıştırma su sıcaklıkları) ve vertikal (CT_{min} ve CT_{max}) aksisler arasında kalan yamuk alan formülüne [(a + c) / 2 x h] göre hesaplanmıştır. Burada "a" ve "c" yamuğun

paralel kenarlarını, "h" yamuğun yüksekliğini sembolize etmektedir. Bu yamuk formülüne göre TTP hesabı "$(CT_{Max1} - CT_{Min1})^a + (CT_{Max2} - CT_{Min2})^c / 2 \times (\Delta AT)^h / 2$" formülü ile hesaplanmaktadır.

İstatistiksel Analiz

Balık türlerinin büyüklük grupları ve termal tolerans değerleri arasındaki istatistiksel farklılıkları SPSS (versiyon 20.0) programında, %5 önem seviyesinde bağımsız t-testi kullanılarak belirlenmiştir. Ayrıca sıcaklık ve CTM değerleri arasındaki korelasyon Pearson testi ile değerlendirilmiştir. Makale metnindeki tüm veriler ortalama ± standart sapma (SD) olarak ifade edilmiştir.

BULGULAR

Test sonrası balıklar tekrar alıştırma su sıcaklığına alındığında yaşama oranı CT_{min} testi sonrasında %100, CT_{max} testi sonrasında ise % 86 – 93 arasında gerçekleşti. Balık türü ve büyüklüğüne bakılmaksızın CTM değerleri AT'den önemli derecede etkilenmiş ve aralarında pozitif bir ilişki gözlenmiştir ($P < 0,05$). AT'nin 20°C'den 28 °C'ye çıkması, türlerin CT_{min} değerlerinde 2,56 ile 3,39 °C, CT_{max} değerlerinde 2,42 ile 3,17 °C arasında bir artışa neden olmuştur (Tablo 1). Alıştırma sıcaklığı ile CTmin ve CTmax değerleri arasında yapılan korelasyon testi anlamlı bulunmuştur (Pearson, $P < 0,05$). AT'ye bağlı CTM değerlerindeki bu değişimin matematiksel ifadesi olan ARR değerleri de bu artışa göre oluşmuştur. ARR değerleri türler arasında CT_{min}'de 0,32 ile 0,42, CT_{max}'da 0,30 ile 0,40 arası gerçekleşmiştir (Tablo 1).

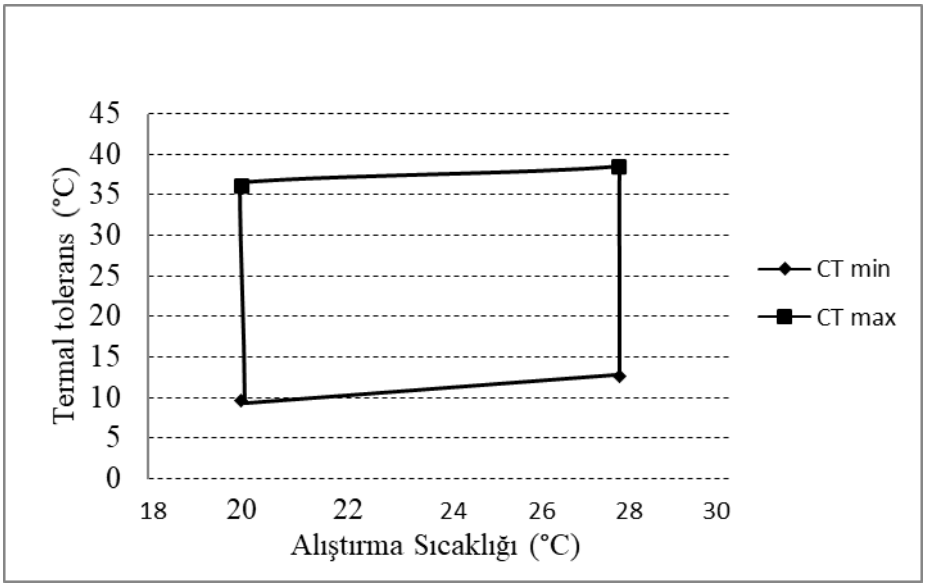
Tablo 1. *Balık büyüklüğü ve alıştırma sıcaklığına bağlı termal tolerans parametreleri*

Türler	Büyüklük grupları	CT_{min}		CT_{max}		ARR		TTP
		20 °C	28 °C	20 °C	28°C	CTmin	CTmax	(C°)
A. stuartgranti	Küçük 6,26±0,28 cm 3,63±0,49 g	9.59 ± 0,62[a]	12.76 ± 0,70[b]	35,96 ± 0,80[a]	38,41 ± 0,72[b]	0,40	0,31	208,08
	Büyük 11,59±0,49cm 28,30±2,81 g	9.81 ± 0,66[a]	12.69 ± 0.67[b]	36,27 ± 0,74[a]	38,66 ± 0,84[b]	0,36	0,30	209,72
	ortalama	9,70	12,72	36,12	38,54	0,38	0,30	208,96
L. caeruleus	Küçük 5,97±0,33cm 3,79±0,44 g	9.43 ± 0,74[a]	12.65 ± 0,65[b]	37.28 ± 0.73[a]	39.89 ± 0,90[b]	0,40	0,33	220,36
	Büyük 10,78±0,32cm 25,39±1,75 g	9,37 ± 0,77[a]	12,93 ± 0,87[b]	37,62 ± 0,92[a]	39,85 ± 0,84[b]	0,45	0,28	220,68
	ortalama	9,40	12,79	37,45	39,87	0,42	0,30	220,52
C. moorii	Küçük 6,10±0,18 cm 3,58±0,24 g	9.48 ± 0.66[a]	12,22 ± 0.84[b]	35,27 ± 0,61[a]	38,49 ± 0,84[b]	0,34	0,40	208,24
	Büyük 11,94±0,55 cm 29,21±3,52 g	9,83 ± 0,65[a]	12,19 ± 0,59[b]	35,53 ± 0,70[a]	38,65 ± 0,82[b]	0,30	0,39	208,64
	ortalama	9,65	12,21	35,40	38,57	0,32	0,40	209,24

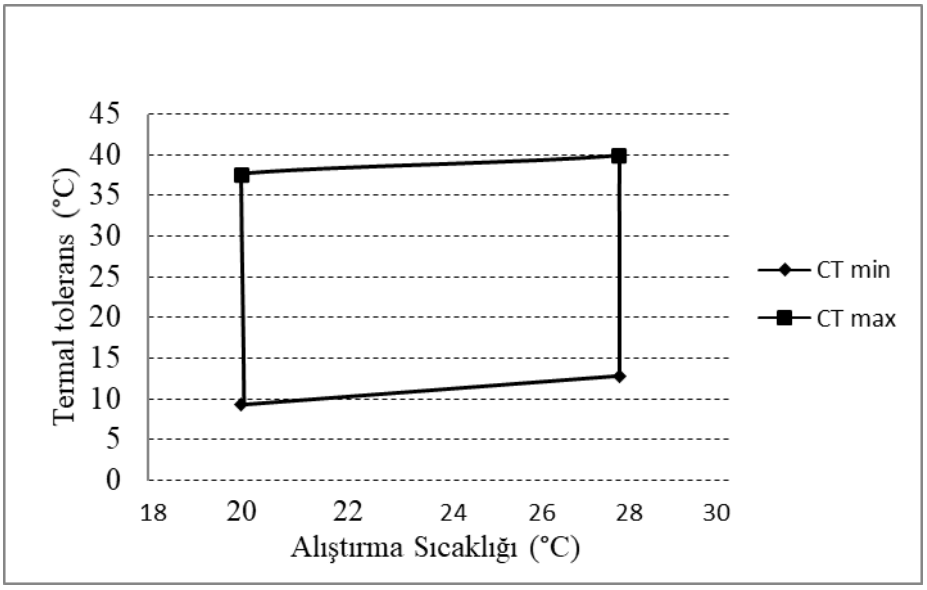
Her satırda her büyüklük grubunun alıştırma sıcaklıkları arasındaki termal tolerans farklılıkları ve her sütunda büyüklük gruplarının arasındaki termal tolerans farklılıklarıfarklı harflerle gösterilmiştir($p < 0.05$).

TARTIŞMA

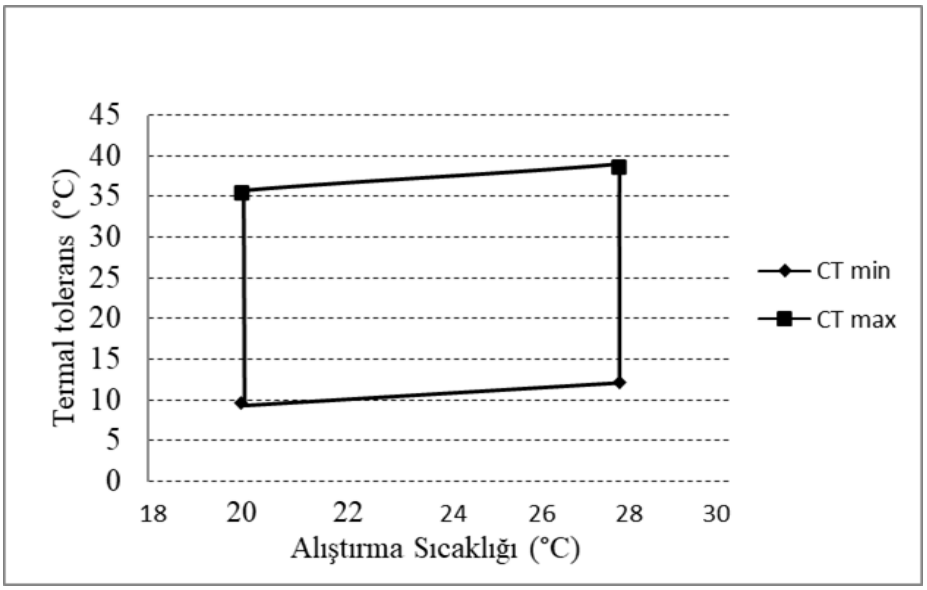
Balıklar CT_{min} ve CT_{max} testlerine benzer olduğu kadar farklı tepkiler de gösterdi. CT_{min} testinde su sıcaklığı düştükçe balıkların hareketlerinde önce yavaşlama ve koordinasyonsuzluk, sonra denge kaybı olurken, CT_{max} testinde su sıcaklığı arttıkça balıklarda hareketlilik arttı, ardından koordinasyonsuz hareketler ve denge kaybı oluşmuştur. Dolayısıyla, ekstrem düşük sıcaklıklara kıyasla, ekstrem yüksek sıcaklıklara maruz kalma daha öldürücü olmuştur. Üst termal limitlerin öldürücü olmalarının mekanizması canlının homeostatik durumundaki kararlılığın bozulması olarak açıklanmaktadır. Bu duruma göre ısı stresi nedeniyle canlı homeostazisinin bozulma hızı ile canlı homeostazisini korumak eyleme geçen biyolojik süreçlerin hızı arasında denge bozulmakta ve organizma ısı stresine karşı kendini koruyamaz hale gelmektedir (Ern ve ark., 2023; Jørgensen ve ark., 2021; Ørsted, 2022). ARR, balığın sıcaklık dalgalanmalarına karşı dayanıklılığını ifade ettiği için, sarı prenses türünün soğuk sulardaki dalgalanmalara (CT_{min}'de ARR, 0,42), yunus ciklit türünün ise sıcak sulardaki dalgalanmalara (CT_{max}'da ARR, 0,40) karşı diğer ciklit türlerine kıyasla görece daha esnek yanıtlar vermeleri beklenir. Bu üç ciklit türünün ARR değerleri diğer balık türlerine göre nispeten düşük seviyededir. Örneğin, farklı ailelerden 13 balık türü üzerinde yapılan bir çalışmada (Yanar ve ark., 2019) ARR değerleri CT_{min}'de 0,18 (*Hypostomus plecostomus*) ile 0.63 (*Branchydanio rerio*), CT_{max}'da ise 0,17 (*Garra rufa)* ile 0,67 (*Puntius tetrazona*) arasında bulunmuştur. Tropik balıklar subtropik balıklara göre bulundukları ortamın klimatik koşullarının bir gereği olarak daha az sıcaklık dalgalanmalarına maruz kaldıkları için daha düşük bir ARR değerine sahip olmaları (Diaz-Herrera ve ark.,1998; Diaz ve ark., 2004; Re ve ark., 2005; Yanar ve ark., 2019) beklenen bir durumdur. Dolayısıyla, ciklit gibi tropik balıkların ARR değerleri nispeten daha düşük olduğu için, subtropikal bölgelerde mevsim geçişlerindeki sıcaklık dalgalanmalarından fazla etkileneceği dikkate alınmalıdır.



Şekil 2. *A. stuartgranti'nin termal tolerans poligon alanı (TTP)*



Şekil 3. *L. caeruleus'un termal tolerans poligon alanı (TTP)*



Şekil 4. *C. moorii'nin termal tolerans poligon alanı (TTP)*

Balık türleri arasındaki sıcaklık tolerans değerleri birbirlerine yakın olup CT_{min}, 20°C AT'de 9,40 – 9,70, 28 °C AT'de 12,21 – 12,79 iken, CT_{max}, 20 °C de 35,40 – 37,45, 28 AT'de 38,54 – 39,87 arasında gerçekleşmiştir. Şeker pembe türünün CTM değerleri ilk olarak bu çalışmada gösterilmiştir. Balıkların CT_{min} ve CT_{max} değerlerinin görece yüksek çıkması, diğer bir ifadeyle yüksek sıcaklıklara karşı dayanıklı, düşük sıcaklıklara karşı dayanıksız olmaları, ciklit gibi tropik balık türlerinde beklenen bir sonuçtur. Benzer koşullarında yapılan bir çalışmada (Yanar ve ark., 2019), 20 ve 28 °C AT'de yunus ciklit türünde CT_{min} sırasıyla 9.20 ve 12,22 °C, CT_{max} 35,75 ve 38,95 °C; sarı prenses türünde CT_{min} 9,77 ve 13,06°C, CT_{max} 37,96 ve 40,00 °C olarak tespit edilmiş olup, bizim bulgularımız bu araştırmanın bulgularına yakındır. En geniş sıcaklık aralığına sahip balık türleri ise 1 – 3 °C CT_{min} ve 40 – 45 °C CT_{max} değerleri ile Cyprinodon'lara aittir (Beitinger ve ark., 2000).

Hayvanın yaşayacağı sıcaklık aralığının genişliğini ifade eden TTP değeri, bu çalışmada türler arasında 208 ile 220 °C arasında hesaplanmıştır (Tablo 1). Bu değerler, özellikle subtropikal balık türleriyle karşılaştırılırsa oldukça düşük seviyededir. Örneğin, Cyprinidlerden japon balığında 281 °C, koi'de 267,2 °C, zebra'da 261,3 °C olarak belirlenmiştir (Yanar ve ark., 2019). Dolayısıyla çalışmamızda da görüldüğü gibi üç ciklit türünün

de sıcaklık aralıkları dar (Şekil 2, 3 ve 4), diğer bir ifadeyle termal plastisiteleri düşük (stenotermal) olduğu için, dünyadaki yayılımları da sınırlı olacaktır.

Bu çalışmanın ana konusu balığın vücut büyüklüğü ile sıcaklık toleransı arasındaki ilişkidir. Her üç ciklit türünde, 7 - 8 kata varan ağırlık farkının her iki AT'de balığın gerek düşük sıcaklık (CT_{min}) gerek yüksek sıcaklık (CT_{max}) toleransı üzerine bir etkisi olmamıştır ($P > 0,05$) (Tablo 1). Cichlidae ailesi türleri üzerinde bu konu ilk defa bu çalışmada araştırılmıştır. Poikloterm hayvanlarda vücut büyüklüğü ile yüksek sıcaklık toleransı arasındaki negatif bir ilişki olduğu iddia edilse de (Kraskura ve ark., 2023) bu konu tartışmalı olup, tüm türlerde henüz kanıtlanmamıştır. Daha dar bir yüzey alana sahip olma hayvanda oksijen tasarrufu sağladığı için (Atkinson ve ark., 2006; Pouly, 2010; Verberk ve ark., 2011; Leiva ve ark., 2019), küresel ısınmanın etkisiyle poikloterm hayvanların vücut boyutunda değişiklikler meydana geldiği, hayvanların boyutlarının küçülme eğiliminde olduğu bildirilmiştir (Angilletta ve Dunham, 2003; Daufresne ve ark., 2009; Sheridan ve Bickford, 2011; Horne ve ark., 2015). Di Santo ve Lobel (2017), *Elacatinus oceanops* ve *E. lobeli* türlerinde küçük boyutlu olmanın hayvanın yüksek sıcaklıkla baş etme şansını arttırdığını ileri sürmüşlerdir. Keza Brans ve ark. (2017), kentsel yaşam alanlarında yaşayan su pirelerinin (*Daphnia magna*) sıcaklığın artmasıyla boyutlarını küçülterek yüksek sıcaklığa karşı toleranslarını yükselttiklerini gözlemlemişlerdir. Turko ve ark. (2020), *Clinostomu selongatus* balık türleri yavruların yetişkinlere göre düşük ve yüksek sıcaklıklara karşı daha dayanıklı olduğunu bildirmişlerdir. Ancak, yukarıda kısaca değinilen yüksek sıcaklık ile vücut büyüklüğü arasındaki negatif ilişki, bizim üç ciklit türünde vardığımız sonuçlara benzer şekilde bazı araştırmacılar tarafından bazı akuatik poikloterm türlerde doğrulanmamıştır. Barrionuevo ve Fernades (1995), *Prochiludos scofra*'da vücut boyutunun CT_{min} üzerinde etkili olduğu, fakat CT_{max} üzerinde etkili olmadığını rapor etmişlerdir. Ospina ve Mora (2004) tarafından Gorgona adasına ait (tropik doğu pasifik okyanusu) 7 resif balık türünde yapılan bir çalışmada, vücut büyüklüğü ile termal tolerans arasında bir ilişki bulunmamıştır. Diğer yandan, Recsetar ve ark., (2012), *Oreochromis niloticus* (35–206-mm), *Ictalurus punctatus* (62–264 mm), *Oncorhynchus mykiss* (41–200 mm) ve *Micropterus salmoides* (72-266 mm) türlerinde balık boyutu ile CTmax arasında anlamlı bir ilişki bulamazken, *O.clarkiivirginalis* (36–181 mm) ile *O.gilaeapache* (40–220-mm) alt türlerinde negatif bir ilişki bulmuşlardır. Ancak bu farklılığın oldukça küçük (yaklaşık 1 °C) olduğu not edilmiştir.

SONUÇ

Sarı prenses, şeker pembe ve yunus ciklit türlerinin sıcaklık tolerans değerleri birbirlerine yakın olup, AT'ye bağlı olarak kritik düşük sıcaklık (CT_{min}) 9,40 - 12,79 °C (CT_{min}), kritik yüksek sıcaklık 35,40 - 39,87 °C civarındadır. CTM verilerine göre hesaplanan termal tolerans poligonigonu (TTP) nispeten düşük olup (208 - 220 °C), her üç balık türü ait olduğu ailenin karakterine uygun olarak, kısmen dar bir sıcaklık aralığına (stenotermik) sahiptir. Bu balıklar subtropikal bölgelerde sıcaklığın 8 - 10 °C ye kadar düştüğü kış mevsimini ilave bir ısıtma desteği olmadan atlatamazlar. Balık yetiştiricileri tür tercihinde bulunurken balıkların bu düşük sıcaklık tolerans değerlerini göz önünde bulundurmalı veya gerekli ısıtma önlemlerini almalıdırlar.

Üç ciklit türünde AT ile CTM değerleri arasında pozitif bir ilişki gözlenmiş olup, AT'nin 20°C'den 28 °C'ye çıkması, türlerin CT_{min} değerlerinde 2,56 ile 3,39 °C, CT_{max} değerlerinde 2,42 ile 3,17 °C arasında bir artışa neden olmuştur. Bu değerlere göre hesaplanan alıştırma tepki oranlarının (ARR) görece düşük olması (0,30 - 0,42), bu türlerin sıcaklık dalgalanmalarına karşı hassas olduğuna göstermektedir. Dolayısıyla bu türler mevsim geçişlerindeki sıcaklık dalgalanmalarından fazla etkilenirler.

Üç ciklit türünde 7 - 8 kata varan ağırlık farkının her iki AT'de balıkların gerek düşük sıcaklık, gerek yüksek sıcaklık toleransı üzerinde bir etkisi olmamıştır ($P > 0,05$). Dolayısıyla, sucul poikloterm hayvanlarda yüksek sıcaklıklarla baş etmede vücut boyutunun küçük olmasının bir avantaj sağlaması savı, bu türlerde görülmemiştir. Sonuç olarak, vücut büyüklüğü ile sıcaklık toleransı arasındaki ilişkinin aydınlatılması için daha pek çok tür üzerinde çalışmalara gereksinim vardır.

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KAYNAKLAR

Angilletta, M.J., Dunham, A.E. (2003). The temperature size rule in ectotherms: simple evolutionary explanations may not be general. *American Society of Naturalist*, 162(3), 332-342.

Atkinson, D., Morley, S.A., Hughes, R.N. (2006). From cellstocolonies: at whatlevels of body does the 'temperature-size rule' apply? *Evolution & Development*, 8(2), 202-214. https://doi.org/10.1111/j.1525-142X.2006.00090.x

Becker, C.D., Genoway, R.G. (1979). Evaluation of the critical thermal maximum for determining thermal tolerance of fresh water fish. *Environmental Biology of Fishes*, 4, 245-256.

Barrionuevo, W.R., Fernandes, M.N. (1995). Critical thermal maxima and minima for curimbata, *Prochilodusscrofa steindachneri*, of two different sizes. *Aquacuture Research*, 26: 447-45. https://doi.org/10.1111/j.1365-2109.1995.tb00934.x

Beitinger, T.L., Bennett, W.A., Mccauley, R.W. (2000). Temperature tolerances of North American fresh water fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes*, 58, 237-275.

Bennett, W.A., Beitinger, T.L. (1997). Temperature Tolerance of the sheeps head Minnow, *Cyprinodon variegatus*. *Copeia*, 1, 77-87. https://doi.org/10.2307/1447842

Brans, K.I., Jansen.M., Vanoverbeke, J., Tuzun, N., Stoks, R., De Meester, L. (2017). The heat is on: Genetic adaptation to urbanization mediated by thermal tolerance and body size, *Global Change Biology*, 23, 5218-5227. https://doi.org/10.1111/gcb.13784

Claussen, D.L. (1977). Thermal acclimation in ambystomatid salamenders. *Comparative Biochemistry and Physiology Part A: Physiology*. 58, 333-340. https://doi.org/10.1016/0300-9629(77)90150-5

Cortemeglia, C., & Beitinger, T. L. (2005). Temperature tolerances of wild-type and red transgenic zebra danios. *Transactions of the American Fisheries Society*, *134*(6), 1431-1437.

Cox, D.K. (1974). Effects of three heating rates on the critical thermal maximum of blue gill.. *In: J.W. Gibbons& R.R. Sharitz (ed.) Thermal Ecology, Nat. Tech. Inform. Service., Springfield*, 158-163.

Cowles, R.B., Bogert, C.M. (1944). A preliminary study of the thermal requirements a desert reptiles. *Bulletin of the American Museum of Natural History*, 13(1), 53-60.

Daufresne, M., Lengfellner, K., Sommer, U. (2009). Global warming benefits the small in aquatic ecosystems. *The Proceedings of the National Academy of Sciences*, 106(31), 788– 12 793. https://doi.org/10.1073/pnas.0902080106

Di Santo, V., Lobel, P.S. (2016). Size affects digestive responses to increasing temperature in fishes: physiological implications of being small under climate change. *Marine Ecology*, 37, 813-820. https://doi.org/10.1111/maec.12358

Di Santo,V., Lobel, P.S. (2017). Body size and thermal tolerance in tropical gobies, *Journal of Experimental Marine Biology and Ecology*, 487, 11-17. https://doi.org/10.1016/j.jembe.2016.11.007

Diaz, F., Re, A.D., Sierra, E., Amador, G. (2004). Behavioral thermoregulation and critical limits applied to culture of red claw crayfish, *Cherax quadricarinatus* (VonMartens). *Freshwater Crayfish*, 14, 90–98.

Diaz-Herrera, F., Uribe, S.E., Ramirez, B.L.F., Mora, G.A. (1998). Critical thermal maxima and minima of *Macrobrachium rosenbergii* (Decapoda: Palemonidae). *Journal of Thermal Biology*, 23(6), 381–385.https://doi.org/10.1016/S0306-4565(98)00029-1

Eme, J., Bennett, W.A. (2009). Critical Thermal Tolerance Polygons of Tropical Marine Fishes from Sulawesi, Indonesia. *Journal of Thermal Biology*, 34(5), 220-225. https://doi.org/10.1016/j.jtherbio.2009.02.005

Ern, R., Andreassen, A. H., Jutfelt, F. (2023). Physiological mechanisms of acute upper thermal tolerance in fish. *Physiology*, *38*(3), 141-158. https://doi.org/10.1152/physiol.00027.2022

Ford, T., Beitinger, T. L. (2005). Temperature tolerance in the goldfish, Carassius auratus. *Journal of Thermal Biology*, *30*(2), 147-152.

Horne, C.R., Hirst, A. AndAtkinson, D. (2015). Temperature size responses match latitudinal-size clines in arthropods, revealing critical differences between aquatic and terrestrial species. *Ecology. Letters*, 18, 327- 335. https://doi.org/10.1111/ele.12413

Jørgensen L. B., Malte H., Ørsted M, Klahn N.A., Overgaard J. (2021). A unifying model to estimate thermal tolerance limits in ectotherms across static, dynamic and fluctuating exposures to thermal stress. *Scientific Reports*, 11: 12840.https://doi:10.1038/s41598-021-92004-6

Kraskura, K., Hardison, E. A., Eliason, E. J. (2023). Body size and temperature affect metabolic and cardiac thermal tolerance in fish. *Scientific Reports*, 13, 17900. https://doi.org/10.1038/s41598-023-44574-w

Lutterschmidt, W.I., Hutchison, V.H. (1997). The critical thermal maximum: history and critique. *Canadian Journal of Zoology*, 75(10), 1561-1574. https://doi.org/10.1139/z97-783

Leıva, P.L., Calosi, P., Verberk, W.C.E.P. (2019). Scaling of thermal tolerance with body mass and genome size in ectotherms: a comparison between water- and air-breathers, 374, 20190035. http://dx.doi.org/10.1098/rstb.2019.0035

Lutterschmidt, W.I., Hutchison, V.H. (1997). The critical thermal maximum: history and critique. *Canadian Journal of Zoology*, 75(10), 1561-1574. https://doi.org/10.1139/z97-783

Ørsted, M., Jørgensen, L.B., Overgaard, J. (2022). Finding the right thermal limit: a frame work to reconcile ecological, physiological and methodological aspects of (CTmax) in ectotherms. *Journal of Experimental Biology*, 225(19), jeb244514. https://doi:10.1242/jeb.244514

Ospina, A.F., Mora, C. (2004). Effect of body size on reef fish tolerance to extreme low and high temperatures, *Environmental Biology of Fishes* 70, 339-343.

Pauly, D. (2010). Gasping fish and panting squids: oxygen, temperature and the growth of water breathing animals. *Excellence in Ecology Series, International Ecology Institute*, 22.

Pérez, E., Díaz, F., & Espina, S. (2003). Thermoregulatory behavior and critical thermal limits of the angelfish Pterophyllum scalare (Lichtenstein)(Pisces: Cichlidae). *Journal of Thermal Biology*, *28*(8), 531-537.

Re, A.D., Diaz, F., Sierra, E., Rodriguez, J., Perez, E. (2005). Effect of salinity and temperature on thermal tolerance of Brown shrimp *Farfantepenaeus aztecus* (Ives) (Crustacea,Penaeidae). *Journal of Thermal Biology*, 30(8), 618–622. https://doi.org/10.1016/j.jtherbio.2005.09.004

Recsetar, M.S., Zeıgler, M.P., Ward, D.L., Bonar, S.A. AndCaldwell, C.A. (2012). Relationship between Fish Size and Upper Thermal Tolerance. *Transactions of the American Fisheries Society*, 141(6), 1433-1438. https://doi.org/10.1080/00028487.2012.694830

Selong, J.H., Mcmahon, T.E., Zale, A.V., Barrows, F.T. (2001). Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. *Transactions of the American Fisheries Society*, 130(6), 1026-1037. https://doi.org/10.1577/1548-8659(2001)130<1026:EOTOGA>2.0.CO;2

Sheridan, J.A., Bickford, D. (2011). Shrinking body size as an ecological response to climate change. *Nature Climate Change*, 1:401-406. https://doi.org/10.1038/NCLIMATE1259

Spotila, J.R., Terpin, K.M., Koons, R.R., Bonati, R.L. (1979). Temperature requirements of fishes from eastern Lake Erie and the upper Niagara River: a review of the literature. *Environmental Biology of Fish*. 4(3), 281–307.

Turko, A.J., Nolan, C.B., Balshine, S., Scott, G.R., Pitcher, T.E. (2020). Thermal tolerance depends on season, age and body condition in imperilled redside dace *Clinostomus elongatus*. *Conservative Physiology*, 8(1), 1-15. https://doi.org/10.1093/conphys/coaa062

Verberk, W.C.E.P., Bilton, D.T., Calosi, P., Spicer, J.I. (2011). Oxygen supply in aquatic ectotherms: partial pressure and solubility together explain biodiversity and size patterns. *Ecology* 92, 1565-1572. https://doi.org/10.1890/10-2369.1

Yanar, M., Erdoğan, E., Kumlu, M. (2019). Thermal tolerance of thirteen popular ornamental fish species. *Aquaculture*, 501, 382-386. https://doi.org/10.1016/j.aquaculture.2018.11.041

Yanar, M., Evliyaoğlu, E., & Tekelioğlu, B. K. (2023). Sex Differences in Thermal Tolerance of Nine Ornamental Fish Species from the Poecilidae, Cichlidae and Cyprinidae Family. *Turkish Journal of Fisheries and Aquatic Sciences*, *23*(6).

Yoldaş, T., Erişmiş, U. C. (2022). Cold Hardiness in Animals: The Cryobiology of Amphibians. *Commagene Journal of Biology*, *6*(2), 242-253.

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Research Article

Determination of Yield and Fruit Characteristics of Some F1 Tomato Variety Candidates in Konya Ecological Conditions

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ABSTRACT

The high economic value of tomatoes in our country, as well as all over the world, has made them the subject of many studies from cultivation to breeding. Breeding programs and new varieties are receiving intense interest in line with changing producer and consumer demands. In the experiment, 20 F1 village tomato variety candidates which were determined to be promising in previous field trials were evaluated. The experiment was established in Selçuk University, Faculty of Agriculture, Department of Horticulture, Department of Vegetable Breeding Research and Application Plot according to the randomised plots experimental design.. In the grown plants; yield per plant, number of fruits per plant, average fruit weight, fruit length, fruit width, pericarp thickness, carpel length, fruit hardness, fruit color and brix measurements were made. Among the candidate varieties, the highest yield per plant was K11 with 5744.50 g/plant, the number of fruits per plant was K11 with 40.00 pieces/plant, the average fruit weight was 242.77 g, the fruit length and width were 67.59 mm and 83.30 mm, respectively, K2, the highest fruit hardness was 4.90 with K11, and the candidate variety was K13 with 6.26% TSS. As a result of the study, it is thought that the candidate varieties K13 and K18 can be taken to yield trials in different locations.

Keywords: *Breeding programs, locations, grown plants*

Bazı F1 Domates Çeşit Adaylarının Konya Ekolojik Koşullarında Verim ve Meyve Özelliklerinin Belirlenmesi

MAKALE BİLGİSİ

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ÖZET

Domatesin tüm dünyada olduğu gibi ülkemizde de ekonomik değerinin yüksek olması, yetiştiriciliğinden ıslahına kadar birçok araştırmaya konu olmasını sağlamıştır. Değişen üretici ve tüketici talepleri doğrultusunda ıslah programları ve yeni çeşitler yoğun bir ilgi görmektedir. Denemede daha önceki arazi denemelerinde ümit var olarak belirlenmiş 20 adet F1 köy domatesi çeşit adayı değerlendirilmeye çalışılmıştır. Selçuk Üniversitesi Ziraat Fakültesi Bahçe Bitkileri Bölümü Sebze Yetiştirme Islahı araştırma ve uygulama parselinde tesadüf parselleri deneme desenine göre kurulmuştur. Yetiştirilen bitkilerde; bitki başına verim, bitki başına meyve sayısı, ortalama meyve ağırlığı, meyve uzunluğu, meyve genişliği, perikarp kalınlığı, karpel uzunluğu, meyve sertliği, meyve rengi ve brix ölçümleri yapılmıştır. Çeşit adaylarında bitki başına verimde 5744,50 g/bitki ile en yüksek K11 çeşit adayı, bitki başına meyve sayısı 40,00 adet/ bitki ile K11, ortalama meyve ağırlığında 242,77 g ile K2, meyve uzunluğu ve genişliğinde sırasıyla 67,59 mm ve 83,30 mm ile K2, meyve sertliği en yüksek 4,90 ile K11 ve % 6,26 SÇKM ile K13 kodlu çeşit adayları ilk sıralarda yer almışlardır. Çalışma sonucunda K11 ve K5 çeşit adaylarının farklı lokasyonlarda verim denemelerine alınabileceği düşünülmektedir.

Anahtar kelimeler: *Islah programları, Lokasyonlar, Yetiştirilen bitkiler*

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INTRODUCTION

Tomato belongs to the Lycopersicon genus of the Solanacea family and is a warm climate vegetable produced and consumed in almost every season in many countries of the world. Tomato is a rich source of minerals, vitamins, organic acids, essential amino acids and dietary fiber. It is also a source of vitamin A, vitamin C and potassium, and also contains minerals such as iron and phosphorus. Due to its content, tomato consumption has been shown to have positive effects on reducing the risk of diseases such as cancer, diabetes and cardiovascular disease (Krauss et al., 2006; Li et al., 2018; Ray et al., 2011; Sönmez & Ellialtıoğlu, 2014). According to FAO statistics, approximately 190 million tonnes of tomatoes are produced in the world (FAO, 2022). Approximately 31.5 million tons of production was realized in Turkey in 2022. The largest share in vegetable production belongs to tomatoes (41-42%). According to the latest data, the amount of tomato production in Turkey is approximately 13 million tons (TUIK, 2022). Although there are differences in tomato production in Turkey over the years, it is understood that 70% of it is done in the open and 30% under cover (Güvenç, 2019).

The F1 hybrid variety is formed as a result of the crossbreeding of two different purified lines and provides higher total yield and earliness than its parents and standard varieties. In addition to their high adaptability, they are also seen to carry more disease and pest resistance genes than their parents (Çelik et al., 2022). Developing hybrid varieties in tomato breeding consists of the following stages: creating a population with a wide genetic diversity, selfing of lines (purifying for homozygosity), determining the morphological, phenotypic and agronomic characteristics of the lines, testing and evaluating the general and specific combination abilities of the lines, setting up field trials, selecting varieties that are equivalent to or higher than commercial varieties on the market, and seed production (Zengin et al., 2015). As with many plant species, producer and consumer demands can change in tomatoes, and genetic diversity must be preserved in order to develop varieties that will adapt to this change. The most important indicator of this diversity is perceived as the diversity in morphological structure. Because it is very important to know the variations found in cultivated species and to apply the distribution of this variation to breeding programs (Bliss, 1981). When aiming to obtain a hybrid variety, it is important to know the variation of the genotypes in the gene pool being studied, however, the presence of genotypes with a very distant degree of relatedness from each other indicates that the chance of achieving hybrid strength is higher (Gözen, 2008).

This study was carried out to determine some yield and yield components of some F1 tomato candidate varieties in the ecological conditions of Konya province

MATERIALS AND METHODS

The study was carried out between May and September 2021 in the research and application area of Selçuk University Faculty of Agriculture and 20 F1 village type tomato variety candidates developed by SELKO ARGE company were used. The research was established according to the randomized plots trial design with 10 plants from each variety and 3 replications. Some climate data of the trial year are given in Table 1. As a result of the soil analysis, it was determined that pH was 7.8, organic matter was 1.2% and the soil had no salinity problem and had a clayey-loamy structure.

Table 1. *Some climate data of the study area*

Months	Max. Heat. (°C)	Min. Heat. (°C)	Average Temp. (°C)	Average Wind Speed (m/s^{-1})	Precipitation (mm)
May	35.9	6.7	18.4	2.4	2.5
June	40.3	11.2	21.6	0.8	1.4
July	36.2	13.1	23.8	2.8	5.8
August	35.2	12.8	23.7	2.4	13.4
September	30.2	4.9	17.3	2.3	14.4

After laying drip irrigation pipes on the land where soil was cultivated in early spring, plots were created on May 5, 2021 with 100 cm between rows and 50 cm between rows. Irrigation was done with drip irrigation system at 5-7 day intervals according to the needs of the plant. When the plants reached a certain height, throat filling process was done and hoeing was done 3 times according to the weed development. During the growing period, 8 kg/da N, 10 kg/da P0O2 and 10 kg/da K2O were applied. In the candidate varieties, fruits that reached harvest size were harvested separately from each parcel. The first harvest was made on July 18, and the trial was terminated after a total of 3 harvests. In order to make measurements and observations on the fruit, 10 fruits representing the genotype were sampled and the necessary measurements and observations were made.

Within the scope of the study; yield per plant (g), number of fruits (piece/plant), fruit weight (g), fruit length (cm), fruit diameter (mm), pericarp thickness (mm), carpel length (cm), fruit hardness, fruit color values (L, a, b), TSS (brix) measurements were carried out.

In the experiment, yield and fruit measurements taken from 20 F1 village tomato variety candidates were subjected to principal components analysis (PCA) in the JMP-17 computer package program. The distinctions between genotypes were determined by examining the Score Plot graph created in line with the components obtained because of the analysis. The standard deviations of the measurements taken were calculated and interpreted, and the data were evaluated.

RESULTS AND DISCUSSION

Yield and fruit measurements of hybrid tomato variety candidates are given in Table 2. While the yields per plant of the candidate varieties varied between 5744 g (K11) and 923 g (K16), the average yield per plant was found to be 2729 g. When the number of fruits per plant of the candidate varieties was examined, the highest number of fruits was measured in the candidate variety K11 with 40 pieces, similar to the yield parameter, while the lowest number of fruits was in the candidate variety K16 (6.40) The average fruit weight of the candidate varieties was measured as 146.14 g. The lowest fruit weight was measured in candidate variety K17, while the highest was measured in candidate variety K2 (72.11 g and 242 g, respectively).. While the average fruit length of the candidate varieties was measured as 54.01 mm; the shortest candidate varieties were K1 (47.21 mm), K8 (49.33 mm), K23 (49.26 mm); the longest was K2 (67.58 mm). Fruit diameter was measured in tomatoes and the average of the variety candidates was found to be 67.59 mm. The candidates with the smallest fruit diameters were found to be K9, K12 and K4 (60.34, 60.87 and 61.72 mm), and the widest fruit diameters were observed for varieties K2 and K18 (83.31 and 80.66 mm, respectively) . The average pericarp thickness of the candidate varieties was measured as 2.95 mm, with candidate number K9 being the smallest (2.19 mm) and candidates numbered K20 and K12 being the largest (3.68, 3.57 mm). In a study, they observed the average fruit weight, total yield, fruit length and fruit width of 20 tomato lines in the F6 generation in order to determine the fruit and quality characteristics. They stated that it was 14.93 t/da, 200.80-384.00 g, 53.68-75.05 mm and 71.95-98.29 mm, 6.60 respectively. In addition, it was found that the fruit flesh firmness values of tomato lines varied between 0.41-1.32 kg/cm^2; brix values were 6.10-9.60%; vitamin C values were between 20.03-25.57 mg/100 g; total phenolic content was between 13.28-30.72 mg/100 g; lycopene content was between 4.69-9.68 mg/100 g, and beta carotene content was between 0.83-2.17 mg/100 g (Demir, 2024). In a study conducted by (Aktaş, 2020), they observed the effects of different rootstocks on plant growth, fruit quality and yield in tomato plants. They stated that the use of rootstock affected the parameters of fruit firmness, distance between bunches, number of leaves, plant height, EC, pH, titratable acidity, TSS, fruit height. (Dar & Sharma, 2011) They observed the effects of genetic variability, heredity and genetic advantage on yield and fruit quality of tomato with 60 tomato genotypes and they clearly saw that heredity had a significant effect on the amounts of β-carotene, vitamin C and lycopene and thus they concluded that these traits could be improved in the lines to be crossed.

Table 2. *Yield and fruit measurements of a variety of candidates*

Candidates	Yield per plant (g)	Number of fruits per plant	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Pericarp thickness (mm)
K1	3119.44	22.78	136.95	47.21±1.50	70.04±0.59	3.05±0.42
K2	2030.45	8.36	242.77	67.58±3.02	83.31±9.58	3.49±0.57
K4	1952.78	14.44	135.19	50.48±2.40	61.72±2.30	3.25±0.82
K5	4637.50	29.60	156.67	50.18±2.95	63.16±2.91	2.72±0.65
K6	2910.56	19.78	147.16	50.67±4.92	65.48±6.19	3.02±0.45
K8	2486.00	18.30	135.84	49.33±1.25	64.86±1.35	2.99±0.33
K9	2423.00	18.80	128.88	57.27±4.64	60.34±10.31	2.19±0.34
K11	5744.70	40.00	143.61	54.26±2.24	72.62±5.99	3.15±0.60
K12	2596.30	21.40	121.32	49.01±3.62	60.87±4.15	3.57±0.66
K13	2837.22	16.78	169.10	57.57±6.08	67.21±5.97	2.78±0.43
K14	3018.33	25.11	120.19	54.18±3.25	66.60±8.05	3.37±0.68
K15	3185.00	26.90	118.40	52.19±1.33	64.37±5.31	2.35±0.68
K16	923.00	6.40	144.21	55.31±3.36	66.08±1.34	2.75±1.35
K17	2366.82	32.82	72.11	54.86±3.74	65.59±4.25	2.65±0.43
K18	3128.50	16.80	186.22	59.41±5.10	80.66±4.91	2.58±0.38
K20	2732.22	19.11	142.96	55.05±4.19	66.17±3.70	3.68±0.47
K21	1632.58	13.84	117.97	57.19±2.95	65.26±5.13	2.49±0.62
K23	2486.50	15.40	161.46	49.26±7.57	68.18±13.98	3.12±0.51
K24	2008.50	13.30	151.01	56.32±2.99	64,83±1,22	2.43±0.87
K25	2364.50	12.40	190.68	54.67±4.02	74.56±4.82	3.37±0.59
Average	**2729.20**	**19.62**	**146.14**	**54.01**	**67.59**	**2.95**

Other fruit measurements of tomato variety candidates are given in Table 3. When the carpel lengths were examined from the table, it was seen that the average was 7.58 mm. Variety candidates K9 and K23 were measured as the shortest with 6.52 mm and 6.55 mm, respectively; while variety candidates K24 and K1 were measured as the longest with 8.58 mm and 8.53 mm, respectively. When fruit firmness was examined, it was seen that the average of the variety candidates was 2.09, while candidates K9 and K20 were determined to have the softest fruits (0.50 and 0.70), and candidates K11 and K5 were determined to have the hardest fruits (4.90 and 4.30). Tomato fruit colour was measured by Konica Minolta CR 200 colourimeter as L, a* and b* values. L indicates the lightness or darkness of the colour from black: 0 to white: 100'a*, while a* and b* determine the colour in a* colour plane perpendicular to L. On the horizontal axis, positive a* indicates red and negative a* indicates green; on the vertical axis, positive b* indicates yellow and negative b* indicates blue.While the average of L values of the variety candidates was determined as 40.94, the lowest L value was measured as 35.27 (K15), and the highest as 45.60 and 45.27 (K2, K23). The average of a* value from the color values was 28.59. It was observed that the K2 variety candidate had the lowest values with 19.79, while the K5 and K8 varieties demonstrated the highest values 32.44 and 32.78, respectively. The average of the color b* value was 26.95, the lowest was measured as 21.35 (K15), and the highest was measured as 33.90 (K2). The average of the TSS amount of the tomato variety candidates in the study was 5.41. In a characterisation study carried out in 14 different genotypes at S2 stage, the L value expressing the lightness-darkness of tomato fruit was the highest in genotype D1 and the lowest in genotype S1. The highest positive a value expressing redness was measured in genotype E1 and the lowest in genotype KH1 (Güngör, 2023). The highest TSS amount was measured in the variety candidates K13, K8 and K6 (6.26, 6.10, 6.08, respectively). In a study conducted in two different places under open field conditions, it was observed that the L value of 7 tomato genotypes varied between 41.29-27.54, a value between 26.81-18.02 and b value between 29.57-12.89 in terms of morphological, physiological, chemical and yield characteristics. It was also stated that the SÇKM values varied between 4.97 and 5.93 (Özbay, 2021). In another study, some morphological and pomological characteristics were examined in 14 tomato genotypes in the S2 stage taken from different regions of Kırşehir province. The obtained data were subjected to cluster analysis and examined in four separate groups. The first group included the K5, K2 and K3 genotypes with red fruit color and standard round, the second group included the red but small-sized P1, S1, A1, AT1 and K4 tomato genotypes. The third group included the genotypes K1, MS1 D1 and K6 beef type with fruit weights over 140 g, and the fourth group included beef type KH1 and E1 tomato genotypes with pink fruit color (Güngör, 2023). (Gölükçü M, 2018) determined that there were significant differences in some physical and chemical properties in a study they conducted to compare the quality traits of six parent and parent lines and three tomato varieties developed as a result of their crossbreeding. As a result of the research, it was determined that variations could be created in quality traits such as sugar composition, lycopene content and color of tomatoes with crossbreeding studies. In the study conducted by (Sönmez, Ellialtıoğlu, & Oğuz, 2015), 37 local tomato populations were examined in terms of

26 traits, and among these traits, perceptual traits such as fruit weight, fruit shape, rind thickness, rind color (Chroma), color tone (Hue) and lycopene content were determined as selection criteria and scored. Five accessions that have the potential to be used in breeding studies in terms of fruit characteristics, color and lycopene content were identified.

Table 3. *Fruit measurements of a variety of candidates*

Candidates	Carpel length (mm)	Fruit firmness	Fruit color L value	Fruit color a* value	Fruit color b* value	TSSC
K1	8.53±1.04	1.18±1.86	42.33±1.72	26.10±2.73	26.65±1.46	5.52±0.93
K2	7.35±0.64	3.82±3.32	45.60±3.68	19.79±4.94	33.90±2.93	5.28±0.08
K4	8.14±1.25	2.10±3.58	44.05±2.13	26.48±3.44	29.40±2.86	4.62±0.84
K5	8.15±0.58	4.30±2.05	39.48±3.35	32.44±2.90	26.32±1.39	5.33±0.20
K6	7.39±0.73	2.90±1.14	38.39±3.64	30.86±3.26	27.61±3.91	6.08±0.84
K8	7.51±0.92	1.50±0.71	43.40±3.12	32.78±2.41	26.57±4.19	6.10±0.32
K9	6.52±1.24	0.50±0.00	39,05±2.43	28.37±0.73	25.82±1.51	6.02±0.51
K11	8.35±0.58	4.90±2.70	39.14±2.46	28.96±4.26	24.75±2.12	5.66±0.23
K12	7.06±0.66	2.20±1.20	44.11±3.45	28.66±1.73	26.25±1.32	5.76±0.48
K13	7.83±0.78	1.70±1.30	39.87±4.90	28.34±3.03	25.91±3.64	6.26±0.55
K14	7.51±0.25	1.50±1.22	38.16±2.60	29.78±5.66	26.05±4.29	5.26±0.21
K15	7.10±0.28	2.30±2.17	35.27±2.26	25.55±1.73	21.35±1.60	5.28±0.64
K16	7.53±1.73	2.30±1.64	39.08±3.83	29.90±6.70	25.88±3.92	5.26±0.17
K17	7.07±1.45	2.70±2.05	42.04±4.32	29.03±1.89	26.41±1.56	4.98±0.29
K18	8.32±1.48	1.10±0.89	37.89±1.87	30.46±3.74	24.73±2.68	5.20±0.19
K20	7.39±1.11	0.70±0.45	41.56±2.70	26.16±2.34	25.34±4.06	5.24±0.36
K21	7.19±1.02	1.50±1.00	37.91±1.56	30.68±1.90	27.04±2.77	4.52±0.76
K23	6.55±1.92	2.10±1.95	45.57±3.49	29.34±2.14	29.55±4.09	4.88±0.51
K24	8.58±0.65	1.30±0.84	42.73±2.55	28.46±2.56	30.98±4.42	5.60±0.51
K25	7.53±0.92	1.10±0.89	43.26±1.93	29.77±3.81	28.55±1.92	5.26±0.39
Average	7.58	2.09	40.94	28.59	26.95	5.41

In the experiment, yield and fruit measurements taken from 20 F1 village tomato variety candidates were subjected to PCA analysis to determine the important measurements that separate the genotypes from each other (Table 4). As a result of PCA, the data was explained at a high rate of %100 in 12 components (Table 4). When the results were examined, the first component explained 31,14% of the study, C,D,E,F,G,I and K parameters were explained positively. The second component explained 19,62% of the study, A and B were the positively explained parameters, while I was the negatively explained parameters. The third component explained 13,49% of the study, A, B, F and H were the positively explained parameters, while C be negatively.

The fourth component explained 9,37% of the study, and A, C and G were the parameters that explained positively, and B and D awere the parameters that explained negatively. When the fifth component was examined, 7,80% of the study was explained, and there were features that explained D in the positive direction, and F and H in the positive direction (Table 4). The sixth component explained 6,104 of the study, with A in the negative direction and C and D in the positive direction. Bhattarai et al. (2016) obtained 5 principal component axes in 71 tomato genotypes and were reported to explain more than 92% of the total variation. In a study, they reported that it explained 63.35% of the total variation (Jin et al., 2019).. Zhou et al. (2015) reported that they explained 78.54% of the total variation. Figàs et al. (2015) reported that the total variation in the first and second components of PCA in tomato genotypes Cherry, Borseta, Cor, Penjar, Plana, Pruna, Redona and Valenciana was 22.6% and 11.8%, respectively.

Table 4. *Principal component analysis of yield, quality and morphological characteristics of Some F1 Tomato Variety Candidatesin Konya ecological conditions*

Number	Eigenvalue	Percent	Cum Percent
1	3,737293	31,144	31,144
2	2,355395	19,628	50,772
3	1,619828	13,499	64,271
4	1,125062	9,376	73,646
5	0,936182	7,802	81,448
6	0,732504	6,104	87,552
7	0,601450	5,012	92,564
8	0,350531	2,921	95,485
9	0,273362	2,278	97,763
10	0,170408	1,420	99,183
11	0,092014	0,767	99,950
12	0,005972	0,050	100,000

Table 5. *Basic declared analysis results basic declared axes*

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10	Prin11	Prin12
A	-0,24748	0,53813	0,05685	0,03270	0,06905	-0,06765	0,06771	0,19733	-0,22175	0,50218	0,04795	-0,53697
B	-0,37069	0,35563	0,13171	-0,23985	0,10599	-0,03578	-0,12668	0,43503	0,12890	0,01890	-0,11536	0,64276
C	0,39928	0,25214	-0,16390	0,27247	0,04925	0,01499	0,26491	-0,19795	-0,42106	0,30897	0,17254	0,51125
D	0,31300	0,08764	-0,50388	-0,19397	0,16900	0,10408	-0,03779	0,18231	0,58733	0,22603	0,36092	-0,04968
E	0,32509	0,34554	-0,25820	-0,01934	-0,08844	-0,24924	0,31283	0,34564	-0,08819	-0,54909	-0,29840	-0,14931
F	0,21026	0,16910	0,51570	-0,01033	0,15166	-0,49770	0,25392	-0,31085	0,46430	0,09544	-0,06571	0,01817
G	0,00170	0,34017	-0,05017	0,38789	-0,64840	-0,12260	-0,46339	-0,13004	0,21400	-0,06669	0,10995	0,04335
H	-0,02739	0,47216	0,13544	-0,29437	0,04230	0,58500	0,08398	-0,44092	0,04148	-0,32911	0,11440	-0,05219
I	0,32239	-0,04294	0,53760	0,09553	0,02166	0,11988	-0,10239	0,45632	-0,12298	-0,18696	0,55564	-0,06087
J	-0,31471	-0,10637	0,03290	0,36406	-0,29871	0,27650	0,67953	0,17028	0,29613	0,02303	0,09575	0,04692
K	0,42255	-0,01429	0,22632	0,06416	-0,11762	0,45998	-0,11889	0,18619	0,13533	0,30991	-0,61389	-0,02171
L	-0,10854	0,11261	-0,06219	0,66795	0,62964	0,11664	-0,19305	-0,00932	0,14127	-0,21451	-0,10512	-0,03287

A:Yield Per Plant; B:Number Of Fruit Per Plant; C:Fruit Weight;D: Fruit Length; E:Fruit Width; F:Thickness Of Pericarp; G:Carpel Length; H:Fruit Firmness; I:Fruit Color L Value; J: Fruit Color a* Value; K:Fruit Color b* Value; L:Brix

It was reported that there was a positive correlation when the angle between the vectors was 90°, but there was no significant correlation when the angle between the vectors was not 90° (Yan and Kang, 2003). When table 5 is analyzed, the highest positive correlation was found between fruit length and fruit width. On the other hand, the highest negative correlation was found between yield per plant and fruit L colour.

The basic method in variety breeding studies is to select plants with the desired characteristics by creating a wide genetic variation. Genetic materials with these characteristics determined as a result of analyses can help to create a heterogeneous gene pool in tomato breeding studies.

It was observed that genotypes K18 and K13, which were in the positive region in both components, showed superior characteristics in terms of yield and fruit quality and could be a promising variety candidate in tomato studies.

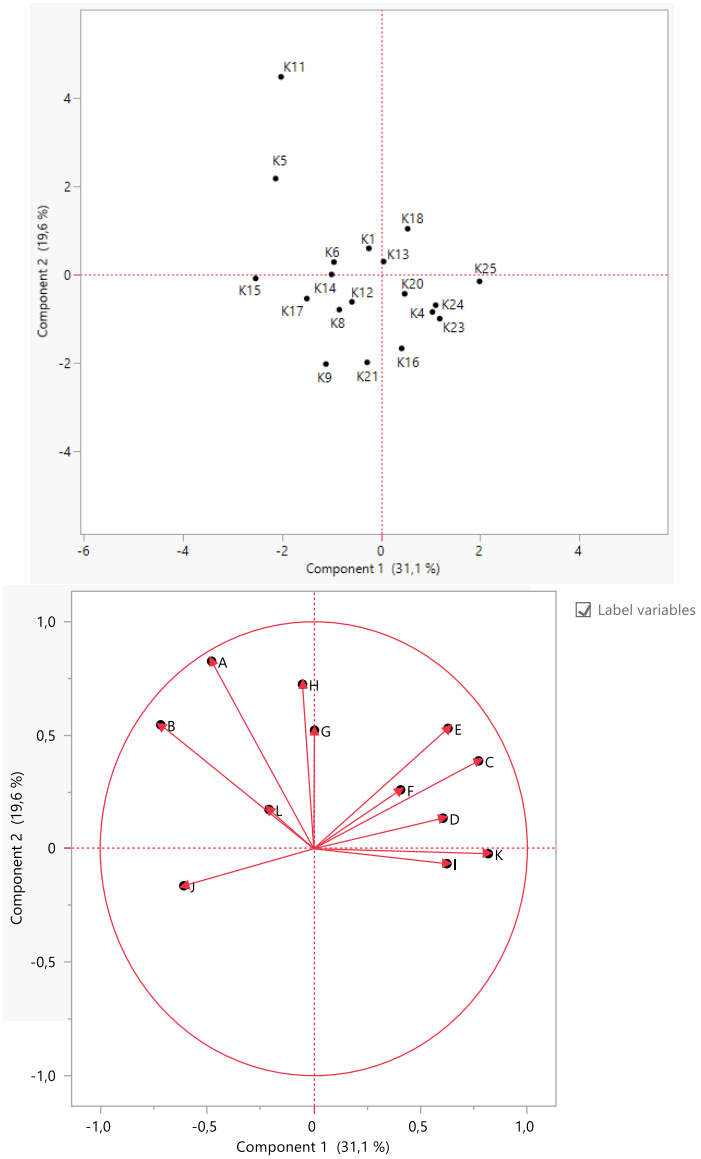

Figure 1. *Score plot and loading plot graph*

CONCLUSION

In this study, the performances of 20 hybrid tomato variety andidates developed by the private sector in terms of fruit quality and yield elements were examined in detail. According to the measurements made, it was seen that the variety candidates had different characteristics in terms of yield and quality parameters. . As a result of the study, it was revealed that the K13, K2 and K18 variety candidates could be taken to yield trials in different locations. According to the results obtained, it is predicted that examining the variety candidates in terms of yield and fruit characteristics will be useful for the development of new varieties. It is thought that these variety candidates can be grown in open field conditions in regions such as Konya ecology and will contribute to the country's agriculture.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

AUTHOR CONTRIBUTION

All authors contributed equally.

ETHICAL APPROVAL

During the writing process of the study titled " **Determination of Yield and Fruit Characteristics of Some F1 Tomato Variety Candidates in Konya Ecological Conditions** ", scientific rules, ethical and citation rules were followed; No falsification has been made on the collected data and this study has not been sent to any other academic media for evaluation. Ethics committee approval is not required.

REFERENCES

Aktaş, H. (2020). Domateste kullanılan farklı anaçların bitki büyümesi, verim ve meyve kalitesi üzerine etkilerinin belirlenmesi. *Ziraat Fakültesi Dergisi, 15*(1), 27-40.

Bhattarai, K., Louws, FJ., Williamson, JD., Panthee, DR. (2016). Diversity Analysis Of Tomato Genotypes Based On Morphological Traits With Commercial Breeding Significance For Fresh Market Production In Eastern USA. *Australian Journal of Crop Science*, 10 (8): 1098-1103.

Bliss. F, A., (1981). Utilization of vegetable germplasm [Ploidy levels]. HortScience.

Çelik, İ., Aydın, S., Kayıkçı, H. C., & Ünlü, A. (2022). Aday Domates Çeşitlerinde Verim Ve Bazi Morfolojik Özelliklerin Belirlenmesi. *Bahçe*, 358.

Dar, R., & Sharma, J. (2011). Genetic Variability Studies Of Yield And Quality Traits In Tomato (Solanum Lycopersicum L.).

Demir, Ö., Ünlü, H., & Ünlü, H. (2024). Determination of Yield And Fruit Quality Characteristics of Some Beef Type Tomato Lines. *Ziraat Fakültesi Dergisi*, 19(1), 55-62.

FAO, (2022). *Food And Agriculture Organization Of The United Nations*. http://www.fao.org/faostat/en/#data/QC. Access date: 15.11.2024.

Figàs, M.R., Prohens, J., Raigón, M.D., Fernández-de-Córdova, P., Fita, A., Soler, S. (2015). Characterization Of A Collection Of Local Varieties Of Tomato (Solanum Lycopersicum L.) Using Conventional Descriptors And The High-Throughput Phenomics Tool Tomato Analyzer. *Genetic Resources and Crop Evolution*, 62 (2): 189-204.

Gölükçü, M., Kabaş, A., Bayır Yeğin, A., Vuran, F.A., Yüksel. K., Tanır, A. (2018). Domatesin bazı fiziksel ve kimyasal kalite özelliklerinin melezleme ile değişimi. *Derim, 35*(2), 152–160.

Gözen, V. (2008). Hıyarda (Cucumis Sativus L.) Örtü Altı Yetiştiriciliğine Uygun Hibrit Çeşit Islahında Morfolojik Karakterizasyon, Hibrit Kombinasyonları Ile Hibrit Tohum Verim Ve Kalitesinin Belirlenmesi. *Derim*. 26(1), 51-59.

Güngör, R. (2023). S2 kademesindeki domates genotiplerinin morfolojik ve pomolojik karakterizasyonu. *Kırşehir Ahi Evran Üniversitesi Ziraat Fakültesi Dergisi, 3*(2), 152-163.

Güngör, R., Başak, H., & Aydın, A. (2023). S2 Kademesindeki Domates Genotiplerinin Morfolojik ve Pomolojik Karakterizasyonu. *Kırşehir Ahi Evran Üniversitesi Ziraat Fakültesi Dergisi*, 3(2), 152-163.

Güvenç, İ. (2019). Türkiye'de Domates Üretimi, Dış Ticareti Ve Rekabet Gücü. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım Ve Doğa Dergisi, 22*(1), 57-61.

Jin, L., Zhao, L., Wang, Y., Zhou, R, Song, L., Xu, L., Cui, X., Li, R., Yu, W., Zhao, T. (2019). Genetic Diversity Of 324 Cultivated Tomato Germplasm Resources Using Agronomic Traits And Indel Markers. *Euphytica*, 215 (4): 1-16.

Khan, T., Rashid, R., Shah, L., Afroza, B., Khan, S., Bhat, M. A., ... & Sun, H. J. (2024). Genetic And Phenotypic Diversity İn Solanum Lycopersicum Genotypes: İnsights From Morpho-Molecular And Biochemical Analyses. *Plant Biotechnology Reports, 18*(2), 207-221.

Krauss, S., Schnitzler, W. H., Grassmann, J., & Woitke, M. (2006). The Influence Of Different Electrical Conductivity Values In A Simplified Recirculating Soilless System On Inner And Outer Fruit Quality Characteristics Of Tomato. *Journal Of Agricultural And Food Chemistry, 54*(2), 441-448.

Li, Y., Wang, H., Zhang, Y., & Martin, C. (2018). Can The World's Favorite Fruit, Tomato, Provide An Effective Biosynthetic Chassis For High-Value Metabolites? *Plant Cell Reports, 37*, 1443-1450.

Özbay, N. (2021). 'Guldar' Domatesinin Coğrafi İşaret Almasına Yönelik Yürütülen Arazi ve Laboratuvar Çalışmaları. *Türk Tarım ve Doğa Bilimleri Dergisi, 8*(2), 492-500.

Ray, R. C., El Sheikha, A. F., Panda, S. H., & Montet, D. (2011). Anti-Oxidant Properties And Other Functional Attributes Of Tomato: An Overview. *International Journal Of Food And Fermentation Technology, 1*(2), 139-148.

Sönmez, K., & Ellialtıoğlu, Ş. (2014). Domates, karotenoidler ve bunları etkileyen faktörler üzerine bir inceleme. *Derim, 31*(2), 107-130.

Sönmez, K., Ellialtıoğlu, Ş. Ş., & Oğuz, A. (2015). Useage of Weighted Scaling Method in The Evaluation of Local Table Tomatoes Germplasm. *Tarım Bilimleri Araştırma Dergisi, 8*(1), 14-19.

TUİK. (2022). Türkiye İstatistik Kurumu (TUİK). Bitkisel Üretim İstatistikleri, (Erişim tarihi: 15.08.2024).

Zengin, S., Kabaş, A., Oğuz, A., Eren, A., & Polat, E. (2015). Determining of general combining ability for yield, quality and some other traits of tomato (Solanum lycopersicum L.) inbred lines. *Akdeniz University Journal of the Faculty of Agriculture*, *28*(1), 1-4.

Zhou, R., Wu, Z., Cao, X., Jiang, F. (2015). Genetic Diversity Of Cultivated And Wild Tomatoes Revealed By Morphological Traits And SSR Markers. *Genetics and Molecular Research*, 14 (4): 13868-13879.

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Research Article

Development of Petal Culture Method in Kalanchoe (*Kalanchoe blossfeldiana* Poelnn.) and Investigation of its Potential Use in *In Vitro* Mutation Breeding Studies

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ABSTRACT

Kalanchoe (*Kalanchoe blossfeldiana* Poelnn.), is an important potted indoor plant as well as an outdoor ornamental plant and cut flower in recent years. Studies are being carried out using different breeding methods in order to develop new varieties suitable for market needs. *In vivo* and *in vitro* mutation breeding studies are important for creating different genetic variations for this species, which is highly prone to mutation breeding. In *in vitro* mutation applications, vegetative propagation methods are of critical importance in mass propagation of mutant single individuals while preserving genetic stability. This study consists of two stages: First, development and optimization of petal culture method in kalanchoe to provide *in vitro* vegetative propagation of mutant individuals, and second, morphological observation of genetic stability in clones obtained by propagation via petal culture from M1V4 kalanchoe mutant single plants obtained by using ionizing radiation. *In vitro* petal culture conditions were determined for kalanchoe and it was determined that Murashige and Skoog (MS) nutrient medium containing 2.0 mg L^{-1} thidiazuron (TDZ), 0.5 mg L^{-1} 1-naphthalenacetic acid (NAA), 30 g L^{-1} sucrose, 6 g L^{-1} agar and pH 5.7 provided the best regeneration. In addition, after *in vitro* physical mutagen application, flowers were observed in mutant individuals propagated up to M1V4 stage in laboratory conditions and transferred to external conditions. Petals from plants with 4 different mutant flowers selected from these were cultured and propagated *in vitro*. As control, petals from a commercial variety were used for micropropagation. The flowers of the clones obtained showed homogeneity depending on whether the mutant flowers used as starting material were homogeneous or chimeric in appearance. Following this study, in which the first findings on petal culture in kalanchoe were obtained, studies are continuing to develop it comprehensively.

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Kalanşo'da (*Kalanchoe blossfeldiana* Poelnn.) Petal Kültürü Yönteminin Geliştirilmesi ve *In Vitro* Mutasyon Islahı Çalışmalarında Potansiyel Kullanımının Araştırılması

ÖZET

Kalanşo (*Kalanchoe blossfeldiana* Poelnn.), önemli bir saksılı iç mekân bitkisi olduğu gibi son yıllarda dış mekân süs bitkisi ve kesme çiçek olarak da öne çıkmaktadır. Pazar ihtiyaçlarına uygun yeni çeşitlerin geliştirilmesi amacıyla farklı ıslah yöntemleri kullanılarak çalışmalar yürütülmektedir. Mutasyon ıslahına oldukça yatkın olan bu tür için farklı genetik varyasyonlar oluşturmak amacıyla *in vivo* ve *in vitro* mutasyon ıslah çalışmaları önem taşımaktadır. *In vitro* mutasyon uygulamalarında vegetatif çoğaltım yöntemleri, mutant tek bireylerin genetik stabiliteyi koruyarak kitlesel çoğaltımının yapılmasında kritik öneme sahiptir. Bu çalışma iki aşamadan oluşmaktadır. Birincisi mutant bireylerin *in vitro* vegetatif çoğaltımını sağlamak üzere kalanşo türünde petal kültürü yönteminin geliştirilmesi ve optimizasyonu, ikincisi ise iyonize radyasyon kullanılarak elde edilmiş M1V4 kalanşo mutant tek bitkilerden petal kültürü yoluyla çoğaltım yaparak elde edilen klonlardaki genetik stabiliteyi morfolojik olarak gözlemlemek. Kalanşo için *in vitro* petal kültürü koşulları belirlenmiş ve 2.0 mg L^{-1} thidiazuron (TDZ), 0.5 mg L^{-1} 1-naphthalenacetic asit (NAA), 30 g L^{-1} sukroz, 6 g L^{-1} agar ve ph 5.7 içeren Murashige ve Skoog (MS) besin ortamının en iyi rejenerasyonu sağladığı saptanmıştır. Ayrıca *in vitro* fiziksel mutagen uygulaması sonrasında laboratuvar koşullarında M_1V_4 aşamasına kadar çoğaltılan ve dış koşullara aktarılan mutant bireylerde çiçekler gözlenmiştir. Bunların arasından seçilen 4 farklı mutant çiçeklere sahip bitkilerden petaller *in vitro* kültüre alınmış ve çoğaltılmıştır. Kontrol olarak, mikroçoğaltım için ticari bir çeşidin taç yaprakları kullanıldı. Elde edilen klonların çiçekleri, başlangıç materyali olarak kullanılan mutant çiçeklerin homojen yapılı veya kimerik görünümlü olup olmadıklarına sağlı olarak homojenlik göstermiştir. Kalanşo'da petal kültürü konusundaki ilk bulguların elde edildiği bu çalışmanın ardından, kapsamlı bir şekilde geliştirilmesi konusunda çalışmalar devam etmektedir.

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INTRODUCTION

Kalanchoe (*Kalanchoe blossfeldiana* Poelnn.), originating from Africa and belonging to the Crassulaceae family, is a species that stands out among the potted plant group because of its different flower color, flower and leaf structure. The Kalanchoe genus is naturally distributed in tropical climate regions, mostly in Madagascar, East and South Africa, South America, India, the Arabian Peninsula, and Southeast Asia (Descoings, 2003). The genus Kalanchoe includes about 140 species. The propagation of the *Kalanchoe blossfeldiana* species and the development of new varieties of this species began in the 1930s (Kahraman and Boyacı, 2021; Bejaoui, 2022). It is an ornamental plant with increasing demand among potted plants. Kalanchoe is a sought-after succulent plant with hardy and long-lasting flowers and low-maintenance, thick, glossy and showy leaves. The genus includes numerous cultivars traded in different flower colors such as red, orange, pink, yellow, white and purple. It also shows a very high tolerance to drought due to its succulent structure. In addition, it has been cultivated as a cut flower in recent years and there is a trend towards its use as an outdoor ornamental plant (Kahraman et al., 2022). In addition to *K. blossfeldina*, which has commercial value as an ornamental plant, some other Kalanchoe species are also used in traditional medicine (Vargas et al., 2022), anti-cancer studies (Stefanowicz-Hajduk et al., 2022) or for their insecticidal effects (Kolodziejczyk-Czepas and Stochmal, 2017) throughout the world, according to literature.

Kalanchoe has taken the first place among indoor ornamental plants whose economic value is increasingly remarkable in Europe and America (Sanikhani et al., 2006; Jain and Ochatt, 2010). Kalanchoe is the most traded ornamental plant after orchids. In the Netherlands, which ranks first in the ornamental plant market in Europe, 87.1 million *K. blosfeldiana* hybrids were sold in 2015 (Kazaz, 2016). In the world's largest flower auction (Royal FloraHolland) in the Netherlands, it ranked second after the *Phanelopsis* orchid in the 2018 potted ornamental plant sales ranking with 87 million units and a turnover of 53 million Euros (AIPH, 2019). According to the Plant Variety Community Office (CPVO), there are over 700 registered cultivars of kalanchoe worldwide. The majority of these are *K. blossfeldiana*, but several species such as *K. marmorata* Baker, *K. humilis*, *K. manginii*, *K. laciniata*, *K. uniflora* and *K. thyrsiflora* are also registered (CPVO, 2017).

Breeding studies in ornamental plants are carried out for different purposes in many species (Balkaya et al., 2021). These purposes can be listed as; determination of resistance levels to biotic and abiotic stress conditions, plant odor, color, changes in flower structure, differences in flowering time, duration of flower retention and post-harvest vase life (İzgi Denli and Balkaya, 2023) or growth types of plants (tall or dwarf). At the beginning of *K. blossfeldiana* breeding programs, producers grew plants obtained from seeds resulting from selfing of plants because the gene pool they had was narrow and they did not perform interspecific hybridization, and they selected from these plants to obtain new varieties. However, since these are generally tall plants, the first selection studies were carried out to develop dwarf kalanchoe plants (Boiteau and Allorge-Boiteau, 1995). Interspecific hybridization is the most used method in new cultivars development studies in ornamental plants. Interspecific hybridization is of great importance in developing new hybrid kalanchoe varieties and increasing the existing variation in gene pools. The first interspecific hybrids were obtained from interspecific crossing between *K. blossfeldiana* and *K. glaucescens* in 1939 (Mackenzie et al., 2018). After this stage, genetic variation was increased by interspecific hybrids, and different flower types, development patterns, double-flowered and abundant flowering plants were developed. As a result of hybridization of different kalanchoe species such as *K. flammea, K. grandiflora, K. pumila, K. kirkii, K. manginii* with *K. blossfeldiana*, varieties with very different characteristics and flowers of various colors and structures have been obtained over the years (Descoings, 2006). But also, there are pre-fertilization and post-fertilization barriers that affect and prevent success in interspecific hybridization methods (Kuligowska et al., 2015). Germination ability may be very low or not at all in seeds obtained from interspecific hybridizations of kalanchoe. Although obstacles that arise as a result of interspecies hybridization can be overcome with embryo rescue techniques (embryo, ovule, ovary) (Mackenzie et al., 2018), there are difficulties in breeding interspecific hybrids. While traditional breeding methods still maintain their importance, tissue culture techniques integrating biotechnological methods with molecular methods (Lütken et al., 2010; Fujimoto et al., 2022; Jácome-Blásquez and Kim, 2023) have also begun to be used in breeding studies in recent years. In addition to breeding studies, the use of tissue culture techniques has increased considerably for the commercial propagation and production of this species (Gümüş and Ellialtıoğlu, 2018). Another technique for creating alternative genetic variations is mutation breeding, one of the classical breeding methods. Kalanchoe is a species prone to natural mutations. For example, Vlielander (2002) registered two varieties called Leonardo and Bromo by taking advantage of the

genetic variation that occurred because of natural mutation in the *K. blossfeldiana* species. In addition, there are many kalanchoe varieties registered with the American Patent Institute (Kahraman and Boyacı, 2021). It has been scientifically proven that the kalanchoe species has a high ability to form shoots by the adventitious bud method and that mutant individuals can be successfully produced by this method (Van Harten, 2002). Physical and chemical mutagens were used to create mutagenic variation in Kalanchoe (Broertjes and Leffring, 1972; Krupa-Malkiewicz, 2010). To date, 4 mutant varieties have been developed in Kalanchoe through mutation breeding (Flores, Lombok, Sumba and Harvest Moon cultivars) (MVD, 2024).

Research on *in vitro* mutant breeding has been widely used to produce various variants and give biotic and abiotic stress tolerance in various plant species (Kantoğlu et al., 2021). *In vitro* mutations that will cause changes in the flower (color, size, flowering period, number of petals) and leaves (form, size, color) of the kalanchoe plant as well as plant structure and other morphological characters too. It is seen that mutation breeding methods are used to obtain both disease resistance and morphological differences in kalanchoe plants (Li et al., 2019). Mutation breeding studies are carried out on the *in vitro* propagation of a plant bearing a different flower characteristic of a single mutant with petals isolated from that mutant flower (Anand et al., 2020). Mutant material from *in vitro* or *in vivo* mutation breeding trials can be clonally propagated using petal cultures (Datta et al., 2005). According to the results presented to date, *in vitro* petal culture in chrysanthemum can be easily used for both the isolation of solid mutants and plant production (Prathyusha et al., 2021). Although there are many publications on different tissue culture applications such as leaf, petiole, node, callus and protoplast culture in kalanchoe species (Bejaoui, 2022; Winiarczyk et al., 2024), no study has been found on plant regeneration from petal. However, vegetative propagation from flower tissues is extremely important in terms of maintaining mutations such as flower structure, petal color, and multi-layer flower formation in a permanent way. Moreover, important outcomes were achieved in terms of exposing hidden somaclonal variations in the *in vitro* propagation process following mutation breeding, in addition to propagating homogeneous clonal material with petal culture (Datta, 2023). The *in vitro* petal culture can be used to identify point mutations also.

The main goal of our breeding program is to make homogeneous clonal propagation from single mutant kalanchoe plants obtained by using physical mutagen applications. The aim of this study was to reveal the feasibility of propagation with *in vitro* petal culture, which was attempted for the first time for the kalanchoe, to shorten the breeding process and ensure that the method can be used in practice specific to this ornamental plant species. For this purpose, the study was carried out in two stages: First, development and optimization of petal culture method in kalanchoe to provide *in vitro* vegetative propagation of mutant individuals, and second, morphological observation of genetic stability in clones obtained by propagation via petal culture from M1V4 kalanchoe mutant single plants obtained by using ionizing radiation.

MATERIAL AND METHODS

Material

A kalanchoe genotype with white flowers ‘Calandiva White Kalanchoe’, obtained from a domestic producer, was used. A variety with white and double flowers was chosen to ensure that the morphological differences that would occur after mutagen application could be easily distinguished. Flowers that differ as a single flower on the same plant were determined in plants belonging to mutant clones that were propagated up to the M1V4 stage by *in vitro* physical mutagen (gamma rays) application. The petals taken from these flowers were propagated by taking the *in vitro* petal culture as an example, which was previously successfully applied by Datta et al. (2005) for chrysanthemum but had no application for kalanchoe. For this purpose, conditions that provide *in vitro* regeneration specific to the petals of kalanchoe species were determined. In the first stage of the study, flowers of ‘Calandiva White Kalanchoe’ plants and their petals were used to optimize the *in vitro* regeneration method (Figure 1a). After determining the most suitable growth regulator content for regeneration, petals from M_1V_1 mutant individuals were used *in vitro* propagation in the second stage to see if there is homogeneity among plants belonging to mutant clones.

The main material used in the mutation stage of our research project was obtained by culturing mature kalanchoe leaves *in vitro* and propagating the plant through shoot regeneration. After regeneration obtained in MS medium containing 1.0 mg L^{-1} BA and 0.5 mg L^{-1} NAA; 0.1 mg L^{-1} GA_3 was added to the same composition to provide shoot elongation. The use of 1.0 mg L^{-1} BA was sufficient for proliferation. Obtaining

in vitro shoots for mutation purposes and their multiplication rates were explained in detail by Bejaoui et al. (2023a). After optimization of micropropagation of the genotype, *in vitro* mutation application was carried out using a Cesium-137 (^{137}Cs) gamma ray source (821 Gy/h dose rate) and irradiating the kalanchoe shoots (1000 pieces) with an effective mutation dose of 119 Gy, which was determined for the same genotype in another study (Kantoğlu et al., 2024a). *In vitro* mutant shoots obtained from gamma ray-treated shoot explants were sub-cultured four times by using MS medium including 1.0 mg L^{-1} BA. They identified at the clone level. Clones at the M1V4 stage were transferred to external conditions, according to Bejaoui et al. (2023b). The plant and flower development were watched and the differences observed in the mutant clones in the M1V4 generation were evaluated in terms of features such as petal shape, petal color, number of colored petals on a branch, growth type, intense of branch, and single or multiple layer formation. Applications and results obtained for mutation breeding are explained by Kantoğlu et al. (2024a).

Methods

Establishment of petal cultures and determination of the regeneration medium composition

In the first stage of the study, fully bloomed flowers of 'Calandiva White Kalanchoe' plants (Fig. 1a) and their petals were used as beginning explant sources. White and layered kalanchoe flowers were collected from potted plants grown in the greenhouse (25 ºC) in early spring. The flowers brought to the laboratory were first kept under running tap water for 10 minutes for the purpose of surface disinfection protocol. Then the petals were separated from the flower tray and washed again with tap water for 1-2 minutes. Following this, the petals were kept for 10 minutes by rinsing them 3–4 times with sterile deionized water in a sterile cabinet. In the next stage, the petals were shaken in 70% ethanol (EtOH) for 10 min. and washed three times with sterile water. Subsequently, the samples were shaken for 10 min. in a sterilization solution of 15% commercial bleach (ACE brand) prepared with 1-2 drops of Tween 20 and then washed three times with sterile distillated water (Fig. 1b). The water in the breaker was poured well. The glass-breakers containing the petals were turned upside down on filter paper, and the remaining excess water was drained to prevent contamination (Figure 1c).

Explants were placed on MS (Murashige and Skoog, 1962) basal medium, which had a pH of 5.7 and contained 30 g L^{-1} sucrose, 6 g L^{-1} agar, with the growth regulator combinations presented in Table 1. In determining plant growth combinations, BA x NAA, recommended for chrysanthemum petal culture (ray florets) by Datta et al. (2005), and TDZ x NAA, which highly stimulates regeneration from kalanchoe leaves (Bejaoui, 2022), were preferred. The nutrient medium without plant growth regulators constituted the control group. 30 ml of nutrient medium was filled into 70 ml glass jars with autoclavable plastic lids, and the nutrient media were sterilized in an autoclave at 121 ºC for 20 minutes. Explants were cultured in 5 glass jars for each medium composition and 10 petal leaves per jar. After the agar nutrient media were solidified in the laminar flow cabinet and brought to room temperature, the sterile petal leaf explants were placed in the jars with the help of forceps under aseptic conditions (Fig. 1d).

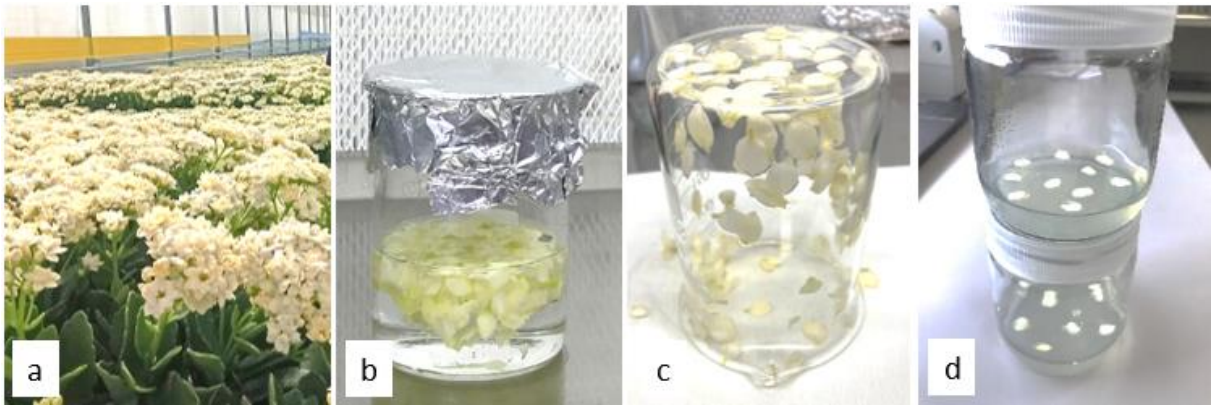

Figure 1. *a. Explant source flowers on the non-irradiated kalanchoe plants in the greenhouse, b. Kalanchoe petals during rinsing by using sterile distillated water, c. Breaker with sterile kalanchoe petals inside, inverted onto sterile filter paper in the laminar flow hood, d. Petals cultured in five different nutrient media contents.*

Table 1. *In vitro petal culture nutrient media combinations*

Medium code	*In vitro* regeneration medium combinations	Sub-culture medium
A1	MS (2 mg L^{-1} TDZ + 0.5 mg L^{-1} NAA)	MS (hormone-free)
A2	MS (1 mg L^{-1} TDZ + 0.5 mg L^{-1} NAA)	MS (hormone-free)
B1	MS (1 mg L^{-1} BAP + 0.5 mg L^{-1} NAA)	MS (hormone-free)
B2	MS (4 mg L^{-1} BAP + 0.5 mg L^{-1} NAA)	MS (hormone-free)
C	MS (hormone-free)	MS (hormone-free)

After the explants were planted on the nutrient medium in petri dishes, the cultures were kept for 3 weeks at 25±2 ºC and in constant darkness (Minas, 2007), then in the same temperature regime, 16 hours of light and 8 hours of darkness were adjusted in the photoperiodic regime in the growing chamber that can provide 8 000 lux of light. In the 8th week of incubation, differentiation began to occur on the tissues, and the petals, which were in 3 jars and 10 in each jar, were transferred to fresh media with hormone- free MS content, 5 petals in each jar (6 jars totally for each treatment). Regeneration formation rates were determined in the 10th week of culture. For this, whether there was shoot differentiation on a total of 30 petals belonging to each medium combination was recorded numerically and proportionated as a percentage. Shoot clusters on the explants were separated into small clusters of 1-1.5 cm and transferred to double-layered media in the 14th week. In these media, 30 g L^{-1} sucrose and 7 g L^{-1} agar were used, and pH was adjusted to 5.7. First, MS nutrient media prepared as semi-solid with agar added to 0.25% activated charcoal were added, then 10 mL of MS nutrient media added to 0.3 mg L^{-1} GA_3 was added to each jar in a sterile cabinet. Liquid nutrient media were sterilized using sterile filters and syringes (Ellialtıoğlu and Yanmaz, 1994). After three weeks, the developing shoots were separated one by one and micro-cuttings with 2 nodes were sub-cultured twice in hormone-free MS media, and then rooted in ½ MS media added with 0.1 mg L^{-1} IBA. The acclimatization phase was carried out as applied in previous studies with 100% success (Bejaoui et al., 2023b). The first phase of the experiment ended here.

In vitro regeneration from petals of mutant kalanchoe plants at the M1V4 stage obtained by gamma irradiation and morphological stability control at the flowering stage

In the second stage of the research, fully bloomed flowers and petals of 4 mutant plants obtained by gamma ray irradiation from the mutation breeding project of Has Biotech were used as initial explant sources. One of the 4 different mutants used in the experiment (No: 44) has flowers showing salmon pink homogeneous color. The second mutant has single-layer flowered and white petaled flowers (No: 129), the third is multi-layered and white petaled (No: 65) and the fourth is a mutant with the flower structure of the control plant with white-dark pink variegated petals (No: 42) (Fig. 2).

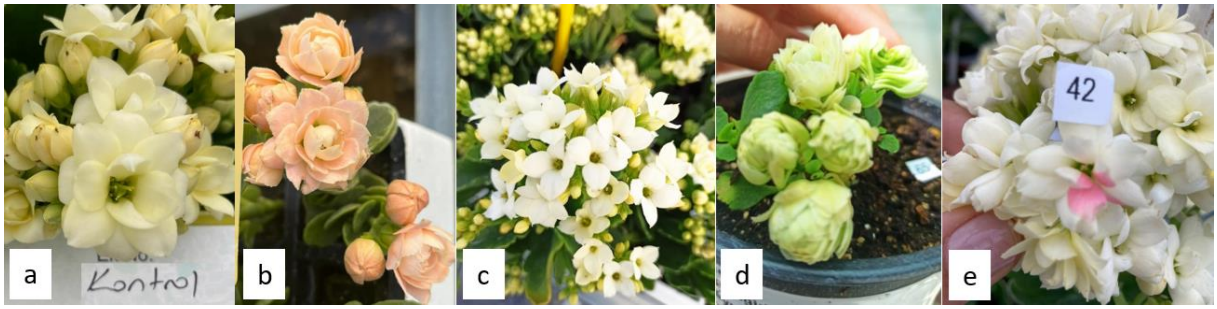

Figure 2. *a. White flowers of control (non-irradiated) plants. b-d: Explant source flowers on the irradiated kalanchoe plants (b. Homogenous salmon pink petals, c. Single layer flowers with white petals, d. Multiple layers flowers with white petals, d. Chimeric heterogenous pink-white petals).*

In the first stage of our study, petals isolated from flowers of 4 different mutants and also petals taken from non-irradiated commercial starting material to form the control group were placed in the most suitable nutrient medium composition determined as MS salts and vitamins included 2 mg L^{-1} TDZ + 0.5 mg L^{-1} NAA, 3% sucrose, 0.6% agar and adjusted pH 5.7 for *in vitro* regeneration from petals. General tissue culture conditions,

sterilization of plant material and incubation of cultures were applied as in the first stage. Figure 3 shows petals prepared for cultivation from mutant clones.

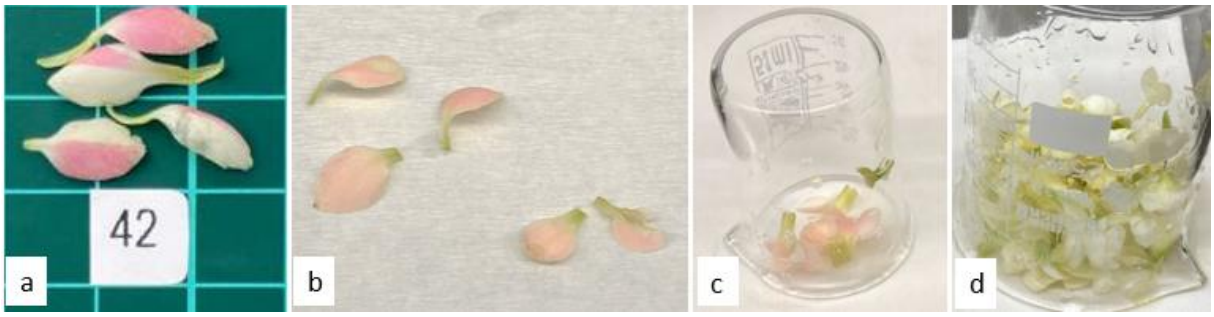

Figure 3. *a. Chimeric leaves of clone number 42, b. Salmon-pink petals of clone number 44, c. Pink mutant petals of clone number 44 before the transfer to culture jars, d. White petals of clone number 65 after the sterilization protocol*

After shoot regeneration was achieved, the petals were transferred to fresh sub-culture media in the 8th week, and the developing clusters were separated in the 14th week and transferred to double layered growth media containing AC (Fig. 4). The developing shoots were sub-cultured twice in hormone-free nutrient media and then transferred to rooting media (0.1 mg L^{-1} + 30 g L^{-1} sucrose + 0.7% agar containing ½ MS medium). The materials that were rooted within a month and continued to form shoots were transferred to peat filled in vials. After irrigation, the seedlings were placed on the benches in the greenhouse and watered twice a day by pulverization for 3 days (Fig. 5). Then, they were acclimated to external conditions by pulverization three times a week and then twice a week.

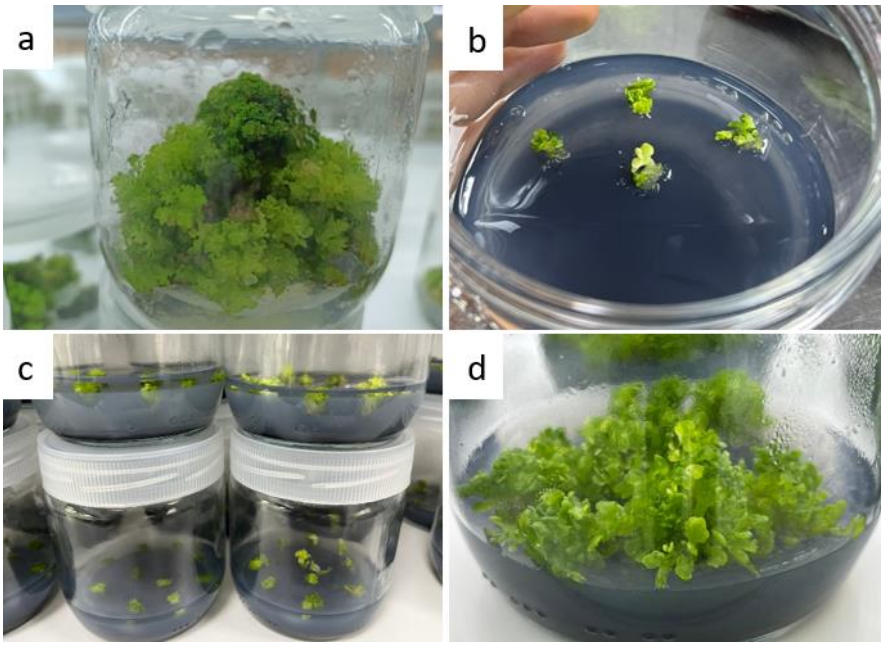

Figure 4. *a. Developed shoot clusters at the 14th weeks of petal cultures, b. Separating the cluster into 10-15 mm pieces and transferring to double layered MS medium, c. Mini plant clusters of mutant clones after transfer into the fresh doubled layered growing medium, d. Growth of healthy shoots from the mini clusters 3 weeks after subculturing.*

Figure 5. *a-c. Transferring kalanchoe mutant clones from in vitro conditions to soil, d. Water pulverization after life water irrigation in the greenhouse.*

During the acclimatization and transfer to the greenhouse of a total of 200 candidate mutant materials within the scope of the project, the plants regenerated from petals in the experiment were planted in vials with 50 plants from each mutant plant. Mutant plants were grown there under optimal conditions at 25 ºC. Flowering occurred after February 20 in the glass greenhouse in Antalya province and observations were made on mutant clones until March 15. Whether flower color was preserved (stability) during the flowering phase in plants regenerated from petal culture was observed under greenhouse conditions. The multiplicity of flowers, petal color and homogeneity rate among 50 plants in total were determined for the plant used as starting material. The breeding program continues and the trials on petal culture were completed with these observations.

Statistical Analysis

To determine the nutrient medium combination that is effective for the regeneration capacity of petals, first stage experiments were set up in three replicates according to a random plot design, with 10 replicates in each repetition. The results were analyzed using MSTACT and MINITAB statistical package programs. The Duncan test was applied for multiple comparisons ($p < 0.01$).

RESULTS and DISCUSSION

Has Biotech Co. has been working on the potential of developing new varieties through kalanchoe breeding since 2019. In this context, it conducts research on developing a mutation breeding protocol. It has carried out pioneering studies in Türkiye on *in vitro* mutation breeding with ^{60}Co-derived gamma ray applications. As is known, breeding studies take a long time. *In vitro* techniques can shorten the time needed for breeding programs. In this study, an *in vitro* petal culture method was applied to mutants with different flower colors on the same plant to propagate mutant individuals with the same color from petals of different colors, as in a previous study conducted in chrysanthemum (Kantoğlu et al., 2024b). Thus, an *in vitro* regeneration protocol through petals specific to the kalanchoe plant was determined. For this purpose, the petal leaves of a commercial kalanchoe variety 'Calandiva White Kalanchoe' used as explants were cultured in A1, A2, B1, B2, and C media. As a result of regeneration studies in the MS medium enriched with four plant growth regulator combinations. In the hormone-free MS medium without any growth regulator additives, no regeneration occurred in the petals at the end of the 14th week. In the study conducted by Bejaoui et al. (2023a; 2024), no development was observed in petiole and leaf explants in hormone-free MS medium, and no shoot formation or callus development occurred in the explants in the 12th week following planting. No callus tissue was formed in the cut areas, and no morphogenesis and shoot or root formation was observed. Indeed, Yuliang et al. (2004), Zhang and Guo (2005), Linjian et al. (2006) also obtained results from nutrient media supplemented with various auxins and cytokinin's for shoot regeneration from leaf explants. Bhuiyan et al.

(2006), in their tissue culture regeneration study from leaf explants not only in *K. blossfeldiana* but also *in K. daigremontiana* species, reported that development was obtained only from explants supplemented with growth regulators, and no development was recorded from hormone-free MS medium. In the cultures with growth regulator additives, color change started to occur from the 4th week onwards, and the white or pink petals started to turn light green and gradually green. In the 8th week, meristematic tissues started to form on the tissues and at their edges, and especially in the A1 and A2 media containing TDZ, compact shoots in the form of clusters were formed (Fig. 6). Data was obtained by counting the meristematic structures formed in the 10th week of culture. However, many shoots could not be expressed numerically due to their compact structure. The tendency to compact cluster formation is less in the media containing BAP and NAA combination. The numerical data obtained are given in Table 2. The control application, in which shoot, and callus formation was not obtained, is not included in the table.

Table 2. *Petal explants' average regeneration values on nutritional media with various growth regulators*

Medium code	Number of flowers isolated	Number of regenerating plants	Regenerated callus number	Mean plantlet number of each explant (petal)
A1	21	191	81	9.10 a
A2	13	84	39	6.46 b
B1	16	0	16	0.00 d
B2	23	6	12	0.26 c

(LSD Val= 0.096, Sx= 0.026, According to the Duncan test, letters define the difference between the means within the limits of $p < 0.01$)

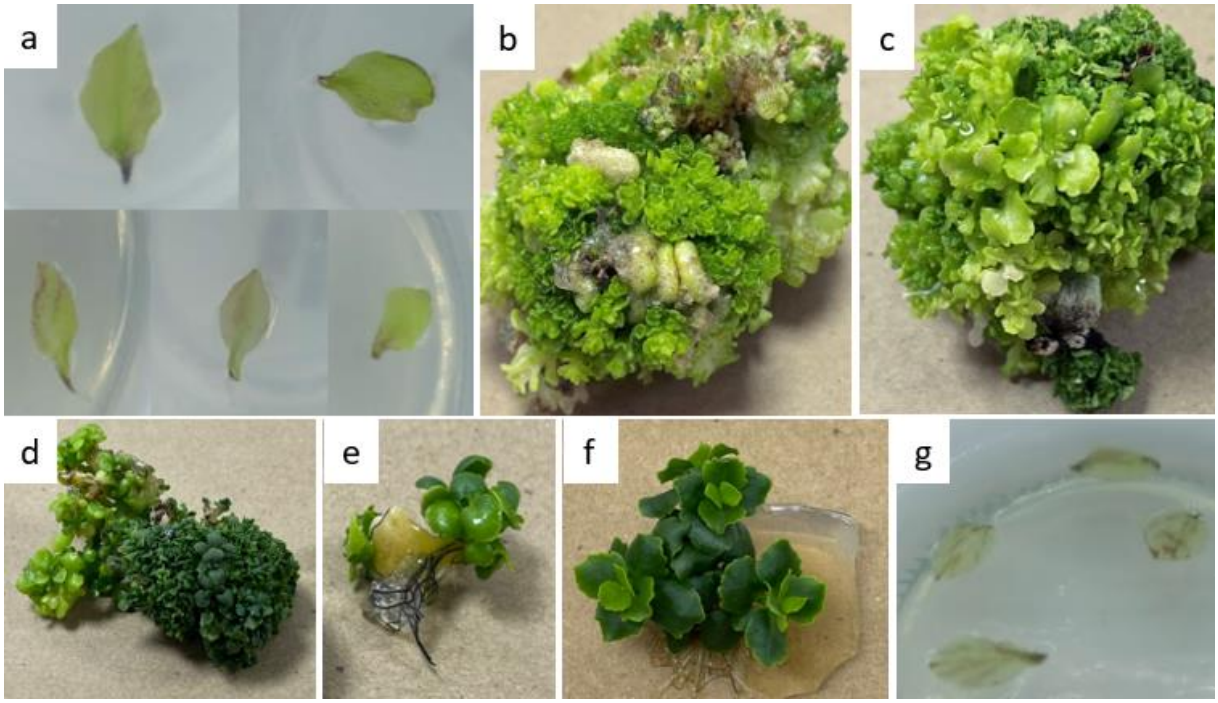

Figure 6. *a. Petal explants starting to turn green in the 8th week of culture, b and c. Shoot organogenesis in the 10th week of culture in A1 medium, d. Meristematic clusters forming in A2 medium, e and f. Shoots and root formation on the explants in B2 medium, g. Petals starting to lose their vitality by necrosis from the 8th week of culture in hormone-free MS medium.*

The best regeneration with an average of 9.10 plantlets per explant was achieved in A1-coded MS nutrient medium containing 2 mg L^{-1} TDZ and 0.5 mg L^{-1} NAA. The study's findings revealed that the A2 nutritional medium was likewise successful in stimulating regeneration, resulting in the growth of 6.46 plantlets per explant. On the other hand, no positive regeneration response was obtained in B1 medium. The combination

of 1 mg L^{-1} BAP + 0.5 mg L^{-1} NAA was insufficient to provide regeneration in kalanchoe petals. The MS medium (B2) to which 4 mg L^{-1} BAP + 0.5 mg L^{-1} NAA was added provided a very low rate of shoot regeneration of 0.26 /petal explants, but these shoots, which were formed in small numbers, developed healthily and strongly during the culture period, indicating that this combination could also be used by increasing the BAP dose. According to the results of the statistical evaluation, the difference between the regeneration capacity provided by the A1 nutrient media and other ones was significant within the error limits of 0.01. After this evaluation made in the 10th week of culture, more than 50 meristematic points and shoot development were detected from each petal starting material that was transferred to fresh media with the same content and kept for development until the 14th week. The development in all explants that reached this period was equalized and no visual or numerical difference was distinguishable between A1 and A2 media (Fig. 4a). After subculturing in double layered media containing activated charcoal, this material was developed healthily and then transferred to media containing IBA as explained in the Method section. The plantlets that were rooted (Fig. 7 a, b) formed healthy kalanchoe plants with 100% success during the acclimatization phase (Fig. 7c). Thus, in addition to the micropropagation method optimized from leaf explants by Bejaoui et al (2023 a, b, c), a successful protocol for kalanchoe plants from petals was presented for the first time in literature with this study. Consequently, it was found that kalanchoes are prone to petal culture and yield good results. Eventually, with the regeneration provided by the cultivated petals, plant production was achieved, and verification could be performed under greenhouse conditions. To date, research on *in vitro* regeneration using petal cultures in kalanchoe species has not been conducted. Although it is not possible to compare the findings for the kalanchoe species, it has been reported that regeneration is achieved in *in vitro* conditions with petal culture in *Chrysanthemum* and *Capparis* plant species; this technique is an effective method, especially in terms of producing a sample plant (Malaure et al., 1991; Datta et al., 2005; Barakat et al., 2010; Carra et al., 2012; Verma et al., 2012; Anand et al., 2020; Asoko et al., 2020; Prathyusha et al., 2021). In Gerbera, which has an important place among ornamental plants, plant regeneration has been achieved from petal explants (Kumar and Kanwar, 2006), and Fritillaria has also entered the literature as a species that can form bulblets directly from its petals (Mohammadi-Dehcheshmeh et al., 2008). Oh and Kim (1994) used *Petunia hybrida* petal explants as starting material for protoplast culture. All of these results demonstrate that *in vitro* petal culture is an alternative technique that makes it possible to reproduce important genetic material (Kantoğlu et al., 2024b). Because it is extremely valuable for breeding work to preserve and propagate the genetic resource that develops only on that plant and cannot be easily reproduced from the flower stem using this method.

Figure 7. *a and b. Rooting of kalanchoe shoots, c. Well acclimatized plants at the flowering stage in the greenhouse.*

Callus development also occurred on explants, although more in media containing TDZ and less in media containing BAP. It was observed that the formed callus was compact and transparent, non-embryogenic, and that the white color turned brown from the 12th week onwards and that it was necrotic at some points. Since the formation of cream-colored embryogenic callus with a fragile and scattered structure did not occur, these structures were not evaluated for breeding or regeneration purposes. In fact, Green and Phillips (1975) reported that different callus types can be induced in plants in tissue culture, i.e. Type I, II and NE callus. Type-I callus is generally white and compact and seems to be a further advanced differentiation step of Type-II callus. This latter type is soft, white or pale yellow, friable, can usually retain totipotency after long periods of time in culture, and is similar to the embryogenic cultures of model plant species (Jiménez and Bangerth, 2001). NE (non-embryogenic) callus is translucent, does not show any sign of organization (Fransz and Schel, 1994). In this study, callus tissue developed from petals did not provide embryogenesis or organogenesis in the media used. It was not planned to obtain regeneration from these structures, which are thought to have a NE callus

appearance. However, in subsequent studies, callus formation from petals and their use in regeneration may be evaluated in the formation of natural or induced somaclonal mutations.

After the gamma irradiation, the kalanchoe plantlets sub-cultured up to the M1V4 stage were transferred to the greenhouse and then observations and evaluations were made within the framework of the mutation breeding program by Has Biotech Co. EMD_{50} (119 Gy) gamma irradiation was successful in creating variations on traits such as flower structure, petal color, plant development and flowering time by providing *in vitro* mutation formation in the studied kalanchoe genotype (Kantoğlu et al., 2024a). Indeed, mutations that will cause changes in the flower (color, size, flowering period, number of petals) and leaves (form, size, color) of the kalanchoe plant as well as plant structure and other morphological characters were observed in previous years too. Broertjes and Leffring (1972) with physical mutagen (200 rad/min X-ray) and Krupa-Malkiewicz (2010) with chemical mutagen (2.0 mM diethyl sulfate (DES) applications, created mutagenic variation in kalanchoe. Fort his study selections of mutant plants were made. In this context, 4 mutant plants were determined to be propagated from petal leaves. These are mutant plants numbered 44, 129, 65 and 42.

Regeneration was provided from petal leaves cultured in A1 medium, 12.20 shoots were determined in the 10th week in plant numbered 44, 10.56 in plant numbered 129, 14.30 in plant numbered 65 and 9.40 in plant numbered 42. The number of shoots consisting of petals taken from the non-irradiated starting material as a control gave a value close to the first stage of the study (11.3/petal explant). However, meristematic regions that continued to develop in the form of numerous green dots in the compact cluster structure were also observed. In the 14th week of culture, a developed cluster structure with over 50 shoot formations was obtained, and these were separated into small clusters as in the first stage and transferred to double layered media containing AC. The plants that went through the rooting and acclimatization stages were allowed to grow in a glass greenhouse in Antalya during the winter period at a minimum temperature of 15 ^{o}C, and they entered the flowering stage in viols at the end of February. The flowers of clones propagated from petals belonging to 4 different mutant plants and the flowers of plants developed from non-irradiated petals were morphologically compared with the flowers of the commercial variety that was the starting plant. In addition, flowering times in the same environment were recorded.

The flowers of the plants obtained from non-irradiated petals were found to have the same morphological structure as the starting material and their flowering times were found to be one-to-one. In the observations made after the mutant clones transferred to the greenhouse had bloomed, four of the five clones produced plants that produced flowers with exactly the same characteristics as the mutant flower in the donor plant. Three of the clones propagated from the petals of the mutant plants (plants no. 44, 129 and 65) had the same flower structures as their mutant donor. While plants no. 44 and 129 did not differ in flowering time from the commercial variety of the starting material, the multi-layer white-flowered mutant no. 65 flowered about a week later. The flowers of the plants resulting from the cultivation of pink-white variegated chimeric leaves also had different colors. These petals were evaluated as chimeric. Pink or pink-white mixed coloration occurred in 8 of 50 plants (16%), and the rest produced white flowers like the starting material (Fig. 8). The results showed that petal culture provides the opportunity to propagate clonally and maintain a single flower mutation. After mutation breeding, studies on the mechanism of the formation of chimeras, especially in flowers, and the mechanisms that stimulate this formation have increased since 2000. Especially in transgenic plants, the change in the gene regions of interest after the application of mutagenesis-inducing chimeras has been among the topics of interest of researchers (Narumi et al., 2008). Applications for tracking chimeric formations for color changes, particularly in liliums, gained prominence following the modeling of Arabidopsis using chimeric repressor gene-silencing technology (CRES-T). Additionally, chimeras were assessed in transgenic technology (Otani et al., 2020). Again, in different studies, cytokinin synthesis on chimeric formations and the functions of the gene regions affected after this synthesis are also examined for transgene technology (Narumi et al., 2008). Therefore, the isolation and reproduction of commercially valuable chimeric formations in mutants is important for breeding studies. Because of this, it is crucial to separate the chimeric forms via petal culture.

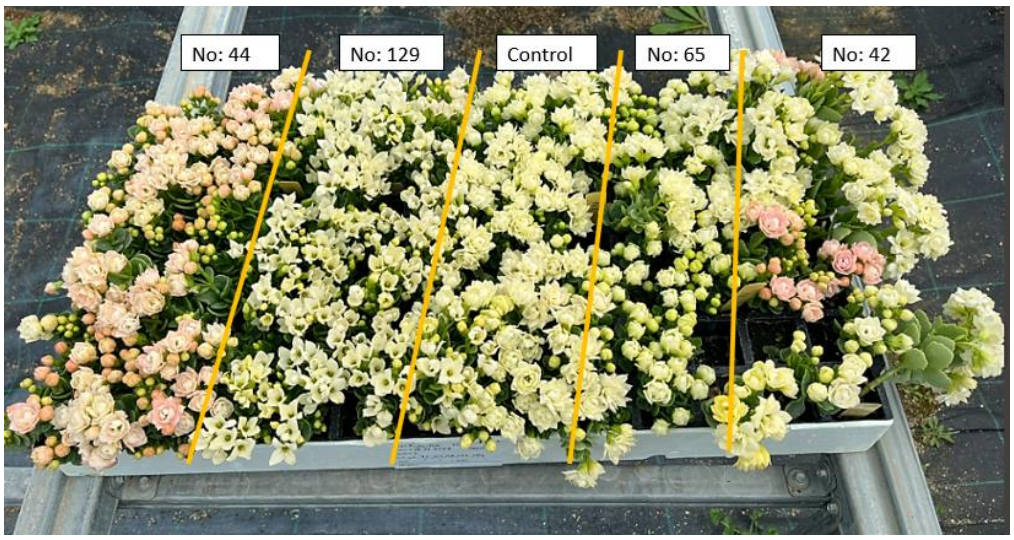

Figure 8. *Stability observation through the clones obtained from petals.*

Regarding *in vitro* mutation applications, Verma et al. (2012) found that petal culture is an effective method for the isolation of solid mutants, whereas in another study conducted on chrysanthemum, mutants selected by this culture multiplied with the same homogeneity at a rate of 98.56%, and 1.44% of somatic mutants were revealed by this method (Kantoğlu et al., 2024b). The results of this research show that it is crucial to introduce petal culture into hybridization or mutation breeding programs for kalanchoe. This research established the viability of ap plying petal culture, particularly in kalanchoe, and showed that a novel explant type could be employed for *in vitro* mutation breeding research studies.

CONCLUSIONS

In vivo and *in vitro* mutation breeding are effective techniques that contribute significantly to the creation of new variations in ornamental plants. Especially in the mutant variation obtained after mutagen application, single flowers with different characters appearing on the same plant are remarkable. It is important to isolate these single flowers, propagate mutant plants with the same structure, and bring them into production as a new variety candidate. As a result of *in vitro* petal leaf culture applications carried out based on this argument in species such as chrysanthemum and capers to date, studies have shown that mutant plants bearing that characteristic can be propagated from petal leaves cultured from flowers with different structures. In this study carried out in kalanchoe, experiments were established based on the argument that the reproduction of single flowers obtained similarly as a result of an *in vitro* mutation breeding study can be done with *in vitro* petal culture. Since petal culture studies have not been carried out for kalanchoe to date, preliminary studies were carried out based on the data previously obtained for chrysanthemum, and different combinations of growth regulators were tried according to the findings obtained. As a result of the treatments, petals regenerated in MS nutrient medium containing 2.0 mg L^{-1} TDZ and 0.5 mg L^{-1} NAA, and plant growth was obtained from explants. The feasibility of *in vitro* petal culture, which was the aim of the research, was revealed in this study. This result shows that it is possible to propagate new mutant clones from single flowers obtained with different characters as a result of mutation or somatic variations in breeding studies carried out in different species. It was found that petal culture is an effective propagation technique that gives results in a short time for *in vitro* mutation breeding studies. With this finding and other successful results obtained for other species in the past, the idea that *in vitro* petal culture may give positive results in other species that have not been tried so far and that preliminary trials should be carried out to adapt it to studies in this context has gained weight.

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AUTHOR CONTRIBUTION

All authors contributed equally.

ETHICAL STATEMENT

During the writing process of the study titled "**Development of Petal Culture Method in Kalanchoe (*Kalanchoe blossfeldiana* Poelnn.) and Investigation of its Potential Use in *In Vitro* Mutation Breeding Studies**", scientific rules, ethical and citation rules were followed; No falsification has been made on the collected data and this study has not been sent to any other academic media for evaluation. Ethics committee approval is not required.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

REFERENCES

AIPH. (2019). International Statistics Flowers and Plants. Hannover, Germany: International Association of Horticultural Producers, Hannover: *Institut für Gartenbauökonomie, Universität Hannover.*

Anand, P., Vanlalruati, V., Kumar, G., & Kumar, S. (2020). *In vitro* isolation of a gamma ray induced mutant in chrysanthemum (*Dendranthema grandiflora*). *The Indian Journal of Agricultural Sciences* 101476. https://doi.org/10.56093/ijas.v90i3.101476.

Asoko, N., Ruamrungsri, S., Yoosumran, V., & Saetiew, K. (2020). Improvement of *Dendranthemum grandiflora* cv. Canter with colchicine *in vitro*. *International Journal of Agricultural Technology 16*(2): 237-246.

Balkaya A., İzgi Saraç Y., & Tütüncü M. (2021). Melezleme ıslahı. In: YY. Mendi, S. Kazaz (Eds). *Süs Bitkileri Islahı Kitabı-2. Klasik ve Biyoteknolojik Yöntemler*. Bölüm: 3, (s: 107-144). Gece Kitaplığı Yayınevi, Ankara.

Barakat, M. N., Fattah, R. S. A., Badr, M., & El-Torky, M. G. (2010). *In vitro* culture and plant regeneration derived from ray florets of *Chrysanthemum morifolium. African Journal of Biotechnology 9*(8):1151-1158.

Bejaoui, R. (2022). *In Vitro* Micropropagation of Kalanchoe (*Kalanchoe blossfeldiana* Poelln.). PhD Thesis. Ankara University, Institute of Natural and Applied Sciences, Department of Horticulture. 103p. Ankara.

Bejaoui, R., Özdemir, G. E., & Ellialtıoğlu, Ş. Ş. (2023b). *In vitro* or *ex vitro* rooting and acclimatization of *Kalanchoe blossfeldiana* Poelln. shoots propagated by tissue culture technique. *Turkish Journal of Agricultural and Natural Sciences (TTDB) 10*(4): 843–853. https://doi.org/10.30910/turkjans.1288919

Bejaoui, R., Gümüş, C., Sönmez, K., Kırbay, E., & Ellialtıoğlu, Ş. Ş. (2023a). The effects of different PGR contents on *in vitro* organogenesis and shoot proliferation in kalanchoe (*Kalanchoe blossfeldiana* Poelln.). In: 11th International Conference on Agriculture, Animal Sciences and Rural Development, 03-05 March 2023, Muş Alparslan University, Muş – Türkiye. *Conference Proceedings Book* (Eds: Karadağ, Y., Seydoşoğlu, S.). pp: 995-1010. ISBN:978-625-7720-91-5.

Bejaoui, R., Ellialtıoğlu, Ş. Ş., & Yanmaz, R. (2024). The effect of different cytokinin and auxin source on micropropagation of *Kalanchoe blossfeldiana*. *Turkish Journal of Agricultural and Natural Sciences 11* (4): 1182–1192. https://doi.org/10.30910/turkjans.1531762.

Bhuiyan, M.S.U., Kim, T., In, J. G., Yang, D. C., & Choi, K. S. (2006). Plant regeneration from leaf explants of *Kalanchoe daigremontiana* Hamet & Perrier. *Korean Journal of Medicinal Crop Science 14*(5): 293-298

Boiteau, P., & Allorge-Boiteau, L. (1995). Kalanchoe (Crassulacées) de Madagascar. *Systématique, écophysiologie et phytochimie*. ICSN, CNRS, 91198 Gif-surYvette, Éditions Karthala, Paris.

Broertjes, C., & Leffring, L. (1972). Mutation breeding of Kalanchoë. *Euphytica 21*(3), 415-423.

Carra, A., Sajeva, M., Abbate, L., Siragusa, M., Sottile, F., & Carimi, F. (2012). *In vitro* plant regeneration of caper (*Capparis spinosa* L.) from floral explants and genetic stability of regenerants. *Plant Cell Tissue and Organ Culture 109*: 373–381. https://doi.org/10.1007/s11240-011-0102-9

CPVO varieties database.2017. Web page. http://cpvo.europa.eu. (Access date: 12.04.2017)

Datta, S. K. (2023). Technology package for induced mutagenesis. *Journal of Biology and Nature, 15*(1), 70-88.

Datta, S. K., Misra, P., & Mandal, A. K. A. (2005). *In vitro* mutagenesis – a quick method for establishment of solid mutant in Chrysanthemum. *Current Science 88*(1): 155-158.

Descoings, B. (2003). Kalanchoe. In: Eggli U, Hartmann HEK (eds) *Illustrated Handbook of Succulent Plants*. Crassulaceae. Springer Verlag, New York, pp 143–181.

Descoings, B. (2006). Le genre kalanchoe structure et définition. Journal de Botanique de la Société Botanique de France, 33, 3-28.

Ellialtıoğlu, Ş., & Yanmaz, R. (1994). Domates ve karnabaharda çift fazlı ortam ve aktif kömürün *in vitro* sürgün verim ve kalitesine etkisi. *KÜKEM Dergisi 16* (1): 19-27.

Fransz, P. F., & Schel, J. H. N. (1994). Ultrastructural studies on callus development and somatic embryogenesis in *Zea mays* L. In: *Maize* (pp. 50-65). Berlin, Heidelberg: Springer Berlin Heidelberg.

Fujimoto, T., Otani, M., & Nakano, M. (2022). Production of colored foliage phenotypes in *Kalanchoe blossfeldiana* by ectopic expression of R2R3 MYB genes. *J. Plant Biochem. Biotechnol. 31*: 665–672. https://doi.org/10.1007/s13562-021-00760-3.

Green, C. E., & Phillips, R. L. (1975). Plant regeneration from tissue cultures of maize L. *Crop Science* 15(3): 417-421.

Gümüş, C., & Ellialtıoğlu, Ş. Ş. (2018). A review on tissue culture studies of *Kalanchoe blossfeldiana* Poelln. *Turkish Journal of Scientific Reviews 11*(1): 18-26. E-ISSN: 2146-0132. (In Turkish).

İzgi Denli, Y., & Balkaya, A. (2023). *Tulipa gesneriana* türü ile yerel lale genotiplerinin (Tulipa spp.) türler arası melez performanslarının belirlenmesi ve melez tohum özelliklerinin incelenmesi. *Manas Journal of Agriculture Veterinary and Life Sciences 13* (2): 164-176. https://doi.org/10.53518/mjavl.1367291

Jácome-Blásquez, F., & Kim, M. (2023). Meristem genes are essential for the vegetative reproduction of *Kalanchoë pinnata*. *Frontiers in Plant Science, 14*: 1157619. https://doi.org/10.3389/fpls.2023.1157619.

Jain, S.M., & Ochatt, S.J. (2010). Protocols for *in vitro* propagation of ornamental plants. Springer Protocols. Humana Press.

Jiménez, V. M., & Bangerth, F. (2001). Hormonal status of maize initial explants and of the embryogenic and non-embryogenic callus cultures derived from them as related to morphogenesis *in vitro*. *Plant Science 160*(2), 247-257.

Kahraman, M. U., & Boyacı, F. (2021). Kalanşo In: In: S. Kazaz, & Y. Mendi Yalçın (Eds.), *Süs Bitkileri Islahı (Türler),* (pp. 239-282). Gece Publishing. ISBN: 978-625-7478-250-2. (in Turkish).

Kahraman, M., U., Yalçın Mendi, Y., Karabıyık, Ş., Lütken, H. V., & Favero, B. T. (2022). Kalanchoë breeding: past, present and future. *Ornamental Horticulture 28*(1): 19-35. doi: https://doi.org/10.1590/2447-536X.v28i1.2403

Kantoğlu, K. Y., Kuşvuran, Ş., & Ellialtıoğlu, Ş. Ş. (2021). Doku kültürü yöntemlerinin stres çalışmalarında kullanımı. In: Ş.Ş. Ellialtıoğlu, H.Y., Daşgan, & Ş. Kuşvuran (Eds.) *Sebzelerde Stres Toleransı ve Islah Stratejileri.* (pp. 708-741). Gece Publishing, Ankara. ISBN 978-625-8449-01-3. (in Turkish)

Kantoğlu, K. Y., Kunter, B., Şenel, Ü., & Haspolat, G. (2024b). Ray-floret based rapid reproduction and detection of somatic variation in selected mutant chrysanthemum individuals. *Yuzuncu Yil University Journal of Agricultural Sciences 34*(4): 549-558.

Kantoğlu, K. Y., Sarıtoprak, O., Akyüz Çağdaş, E., Okutan, E., Aktaş, H., & Ellialtıoğlu, Ş. Ş. (2024a). *In vitro* mutation breeding in kalanchoe (*Kalanchoe blossfeldiana* Poelnn.). *Düzce University Journal of Forestry* (in press).

Kazaz, S. (2016). Dünya süs bitkileri sektöründe ürün deseni, sosyo-ekonomik ve teknoloji alanında yaşanan gelişmeler ile Türkiye'nin gelecek vizyonu. *VI. Süs Bitkileri Kongresi, 19-22 Nisan, Antalya.*

Kolodziejczyk-Czepas, J., & Stochmal, A. (2017). Bufadienolides of *Kalanchoe* species: an overview of chemical structure, biological activity and prospects for pharmacological use. *Phytochem Review 16*(6): 1155-1171. https://doi.org/10.1007/s11101-017-9525-1.

Krupa-Malkiewicz, M. (2010). Influence of chemical mutagens on morphological traits in kalanchoe (Kalanchoe hybrida). *Folia Pomeranae Universitatis Technologiae Stetinensis. Agricultura, Alimentaria, Piscaria et Zootechnica, 15*.

Kuligowska, K., Lütken, H., Christensen, B., Skovgaard, I., Linde, M., Winkelmann, T., & Müller, R. (2015). Evaluation of reproductive barriers contributes to the development of novel interspecific hybrids in the Kalanchoë genus. *BMC Plant Biology 15*, 1-15.

Kumar, S., & Kanwar, J. K. (2006). Regeneration ability of petiole, leaf and petal explants in gerbera cut flower cultures *in vitro. Folia Horticulturae Ann. 18*(2): 57-64.

Li, R., Fan, L., Lin, J., Li, M., Liu, D., & Sui, S. (2019). *In vitro* mutagenesis followed by polymorphism detection using start codon targeted markers to engineer brown spot resistance in Kalanchoe. *Journal of the American Society for Horticultural Science 144*(3): 193-200. https://doi.org/10.21273/JASHS04571-18

Linjian, F., Dongpo, J., & Xinshuan, Z. (2006). Research of different culture conditions on plantlet regeneration from leaves of *Kalanchoe blossfeldiana*. *Chinese Agricultural Science Bulletin, 5*. (Accessed date: 23.04.2024): http://en.cnki.com. cn/Article_en/CJFDTotal ZNTB200605021. htm.

Lütken, H. V., Jensen, L. S., Topp, S. H., Mibus, H., Müller, R., & Rasmussen, S. K. (2010). Production of compact plants by overexpression of *AtSHI* in the ornamental *Kalanchoë*. *Plant Biotechnology Journal 8*(2): 211-222. https://doi.org/10.1111/j.1467-7652.2009.00478.x

Mackenzie, K. K., Lütken, H., Coelho, L. L., Kaaber, M. D., Hegelund, J. N., & Müller, R. (2018). Kalanchoë. *Ornamental Crops* 453-479.

Malaure, R. S., Barclay, G., Power, J. B., & Davey, M. (1991). The production of novel plants from florets of *Chrysanthemum morifolium* using tissue culture. I. shoot regeneration from ray florets and somaclonal variation exhibited by the regenerated plants. *J Plant Physiol. 139*: 8-13.

Minas, G. J. (2007). A rapid protocol for *in vitro* micropropagation of three types of gardenia (*Gardenia* spp. Ellis) for quality produce flowering pot-plants. *International Conference on Quality Management in Supply Chains of Ornamentals 755*, 81-86.

Mohammadi-Dehcheshmeh, M., Khalighi, A., Naderi, R., Sardari, M., & Ebrahimie, E. (2008). Petal: a reliable explant for direct bulblet regeneration of endangered wild populations of *Fritillaria imperialis* L. *Acta Physiologiae Plantarum 30*: 395-399.

Murashige, T., & Skoog, F. (1962). A revised medium for rapid growth and bioassay with tobacco tissue cultures. *Physiologia Plantarum 15*: 473-497.

MVD. (2024). IAEA Mutant Varietiy Database. https://nucleus.iaea.org/sites/mvd/ SitePages/Search.aspx (Access date: 20.10.2024)

Narumi, T., Aida, R., Niki, T., Nishijima, T., Mitsuda, N., Hiratsu, K., Ohme-Takagi, M., & Ohtsubo, N. (2008). Chimeric *AGAMOUS* repressor induces serrated petal phenotype in *Torenia fournieri* similar to that induced by cytokinin application. *Plant Biotechnology 25*(1): 45-53.

Oh, M. H., & Kim, S. G. (1994). Plant regeneration from petal protoplast culture of *Petunia hybrida*. *Plant Cell, Tissue and Organ Culture 36*, 275-283.

Otani, M., Aoyagi, K., & Nakano, M. (2020). Suppression of B function by chimeric repressor gene-silencing technology (CRES-T) reduces the petaloid tepal identity in transgenic *Lilium* sp. *PLoS One 15*(8):e0237176. https://doi.org/10.1371/journal.pone.0237176.

Prathyusha, N., Dorajeerao, A. V. D., Ravindrakumar, K., Aparna, D., & Salomi Suneetha, D. R. (2021). *In vitro* propagation of chrysanthemum (*Chrysanthemum morifolium*) cultivars from ray floret explants. *The Pharma Innovation Journal 10*(10): 415-417.

Sanikhani, M., Frello, S., & Serek, M. (2006). TDZ induces shoot regeneration in various *Kalanchoe blossfeldiana* Poelln. Cultivars in the absence of auxin. *Plant Cell, Tissue and Organ Culture 85:*75–82 https://doi.org/10.1007/s11240-005-9050-6.

Stefanowicz-Hajduk, J., Hering, A., Gucwa, M., Sztormowska-Achranowicz, K., Kowalczyk, M., Soluch, A., & Ochocka, J. R. (2022). An *in vitro* anticancer, antioxidant, and phytochemical study on water extract of *Kalanchoe daigremontiana* Raym.-Hamet and H. Perrier. *Molecules, 27*(7): 2280. https://doi.org/10.3390/molecules27072280.

Van Harten, A. M. (2002). Mutation breeding of vegetatively propagated ornamentals. In *Breeding for ornamentals: classical and molecular approaches* (Vainstein, A. (Ed.)) (pp. 105-127). Dordrecht: Springer Netherlands. Kluwer Academic Publishiers, ISBN: 978-90-481-5975.

Vargas, A., Herrera, I., Nualart, N., Guézou, A., Gómez-Bellver, C., Freire, E., Jaramillo Díaz, P., & López-Pujol, J. (2022). The genus *Kalanchoe* (Crassulaceae) in Ecuador: From gardens to the wild. *Plants 11*(13): 1746. https://doi.org/10.3390/plants11131746.

Verma, A. K., Prasad, V., Singh, S. K., & Kumar S (2012). *In vitro* isolation of red coloured mutant from chimeric ray florets of chrysanthemum induced by gamma-ray. *Indian J. Hort. 69*(4): 562-567.

Vlielander, I. (2002). U.S. Patent Application No. 10/080, 611.

Winiarczyk, K., Czerska, D., Denisow, B., Chrzanowska, E., & Pietrusiewicz, J. (2024). Regenerative potential and its variability in different topophysical zones of *Kalanchoe daigremontiana* leaves in *in vitro* culture conditions. *Acta Scientiarum Polonorum Hortorum Cultus 23*(2):93-101. https://doi.org/10.24326/asphc.2023.5280

Yuliang, C., Xiaogang, Z., & Yanping, Z., & Zhengying, Z. (2004). Isolation leaf disks culture, and high efficient plantlet regeneration of *Kalanchoe blossfeldiana*. *Chinese Agricultural Science Bulletin 20*(5), 33.

Zhang, R., & Guo, X. (2005). Study on regeneration of vitro leaf of *Kalanchoe blossfeldiana.* Shanxi *Forestry Science and Technology, 01*. (Access date: 20.10.2024): http://en.cnki.com.cn/Article_en/CJFDTotal-SXLK200501003.htm.

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Research Article

Effects of Colchicine Applications on Embryo Yield and Spontaneous Chromosome Doubling in Pepper (*Capsicum annuum* L.) Anther Culture

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ABSTRACT

The haploidy technique starts with the production of haploid embryos and continues with the doubling of the chromosome set. Androgenic embryos can be either haploid (H) or spontan doubled haploid (SDH). Since haploid plants are sterile, anti-mitotic agents are applied at appropriate doses and durations to restore diploid status and fertility. Chromosome doubling can be induced in vivo with anti-mitotic agents, but this method is expensive, complex and time consuming. Therefore, spontaneous doubling of chromosomes during culture is preferred. In this study, the effects of colchicine use on embryo yield and embryo development in pepper (*Capsicum annuum* L.) anther culture were investigated. Colchicine is a chemical agent that changes the cell division process by inhibiting microtubule formation in plant cells. Colchicine was applied to pepper anthers at concentrations of 0.3%, 0.4% and 0.6% in semi-solid and double-layer media for 14 and 21 days. Embryo and plant regeneration rates obtained according to media, colchicine dose and application duration were examined. According to the trial results, the highest embryo formation rate (21.03%) was obtained in the group treated with 0.6% colchicine dose for 14 days in semi-solid media. The development rates of embryos into plants varied depending on both colchicine doses and nutrient media used. Plants developed from embryos were grouped as haploid (H) and spontaneous double haploid (SDH) by examining the presence of pollen in flowers, seeds in fruits, stomata number and stomata characteristics. It was observed that the addition of colchicine to the medium had a very significant effect on the SDH plant ratio. The highest SDH plant ratio (74.28%) was obtained from the application of 0.6% colchicine for 21 days in semi-solid medium. On the other hand, the highest SDH plant ratio (69.05%) in double-layer media was determined in the application of 0.6% colchicine dose for 14 days. The SDH plant ratio obtained from embryos grown in colchicine-free medium was found to be 48.89% (14 days) and 44.74% (21 days). It can be concluded that colchicine application significantly enhances the production of SDH plants in pepper anther culture, with the most effective treatment being 0.6% colchicine for 21 days in a semi-solid medium.

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INTRODUCTION

Pepper is one of the vegetables with high economic value worldwide. Various biotechnological methods are used to improve traits such as high yield, disease resistance and quality in pepper production. It requires great effort and time to obtain 100% homozygous pure lines in plant breeding programs. The ability of haploid plants to reach full homozygosity in a single generation by chromosome doubling has become a valuable tool in terms of shortening the time in plant breeding (Yaman & Karaca Sanyürek, 2023). Haploid induction from male gamete (androgenesis) and female gamete (gynogenesis) are prominent methods in this process. Methods such as parthenogenesis are also used, and techniques such as insufficient or irrated pollen use during pollination and chromosome elimination are also preferred approaches in this field (Zhang et al., 2020; Ebrahimzadeh et al., 2021; Marin-Montes et al., 2022; Salehian et al., 2023). Successful results were obtained with the anther culture method in studies conducted specifically on pepper plants.

The first step of the haploidy technique is to obtain haploid embryos and the second step is to double the chromosome set. Androgenic embryos can be haploid (H) or spontaneously doubled haploid (SDH) during culture. Double haploids are very important for plant breeding because they can produce completely homozygous plants within one generation, making qualitative and quantitative phenotypic selection more efficient (Hooghvorst & Nogués, 2021).

Haploid embryos formed during the natural process of androgenesis usually fail to complete their development. Haploid plants are generally smaller and have a weak development compared to their diploid counterparts. Haploid plants are sterile due to the improper pairing of chromosomes during gamete formation and cannot produce pollen and seeds. In order to restore diploid status and fertility in haploids, they should be subjected to some anti-mitotic agents at appropriate doses and durations (Segui-Simarro & Neuz, 2008).

In androgenetic embryos, chromosome doubling is critical for ensuring developmental stability, maintaining genetic balance and creating homozygous lines for research. Obtaining haploid plants with in vitro techniques and transforming them into diploid plants offers an effective way to develop plant varieties with new and superior characteristics. Embryos with diploid chromosome structure are obtained by doubling the chromosomes and these embryos are generally stable and suitable for development.

Spontaneous or in vitro induced chromosome duplication during culture has the advantage of reducing the time and cost of DH production by eliminating the need for in vivo chromosome doubling. One way to increase the viability of haploid embryos and improve plant development in anther culture method is diploidization of embryos at the beginning of culture (Comlekcioglu, 2021) . Although the mechanism of SDH in androgenesis has not been fully explained, three main mechanisms have been mentioned in the literature; endoreduplication, nuclear fusion and c-mitosis (Seguí-Simarro & Nuez, 2008). The use of various antimitotic agents for chromosome doubling in haploid plants is evaluated as c-mitosis mechanism. C-mitosis leads to chromosome doubling by affecting the metaphase stage of cell division with antimitotic agents. Antimitotic agents are generally known as metaphase inhibitors that are effective during metaphase. Colchicine, colcemid, vinblastine, acenaphthene, dintroanilines, phosphoroamidates, pyridines, benzamides, benzoic acid compounds affect the metaphase stage of cell division and cause chromosome doubling. Compounds such as colchicine in particular prevent cell division by altering microtubule dynamics and cause doubling of chromosome number (Dewitte & Murray, 2003; Vaughn, 2006; Dhooghe et al., 2011).

A successful protocol is required for efficient chromosome doubling in haploids induced in vivo by the use of anti-mitotic agents. Multiple factors must be adjusted to maximize the rate of genome duplication. Successful outcomes can vary depending on antimitotic agent application efficiency, especially concentration, exposure time, application method and conditions. It is also critical for plant developmental stage and plant survival. Therefore, SDH is desired during culture. When haploid plants are exposed to colchicine, oryzalin, trifluralin and other chemicals with antimitotic effects in vitro or in vivo, chromosome doubling occurs (Vural et al., 2019). These applications can be done in vitro, at the explant, callus or plantlet periods. Chromosome duplication is difficult in haploid plants with a single chromosome set; usually application of antimitotic agents is used. In vivo application of antimitotic agents is costly, difficult and time-consuming.

During the androgenesis process, in vitro chromosome doubling varies significantly among different species and genotypes. The success rates vary depending on factors such as genotype, culture conditions and

chromosome doubling method, and it is a labor-intensive work (Mishra et al. 2021, da Silva Dias, 2003; Yuan et al., 2015).

Shim et al. (2006) reported that factors such as the concentration of antimitotic agents, temperature during application and exposure time are critical for the species. Kasha (2005) reported that chromosome duplication also depends on the haploidy method, and that the first pollen mitotic division stage of the microspore in androgenesis and Supena et al. (2006) reported that the first week of culture are the ideal times for chromosome duplication. Da Silva Dias (2003) reported that low concentrations (0.01-0.02%) of colchicine only inhibit the cell division cycle for a short time, and then the cells can continue mitosis when they contain a doubled set of chromosomes. The most suitable time for in vitro antimitotic agent application was determined as the first 12 hours after microspore isolation. Therefore, SDH should be intensively investigated in addition to the possibilities of increasing the frequency of embryo formation and transformation into a normally developed plant in the anther culture technique, which has become a routine method in Capsicum breeding studies.

It is stated that factors such as culture conditions, pretreatments, use of colchicine and similar antimitotic substances are determinants of in vitro chromosome doubling (Zhao & Simmonds, 1995). In addition, it is stated that there is a direct relationship between the use of plant hormones in in vitro cultures and DNA duplication (Joubes & Chevalier, 2000). It is stated that the type of explant used in the androgenesis process may also affect the SDH rate (Sato et al., 2005). Comlekcioglu and Ellialtıoğlu (2018) reported that SDH rates obtained from pepper anther culture differed significantly among genotypes. It was emphasized that the gamete developmental stage and culture conditions also affect this process (Segui-Simarro & Nuez, 2008). Niklas-Nowak et al. (2012), as a result of cytometric analysis of 63 regenerated pepper plants, it was determined that 32 plants were haploid (H) and 31 plants were SDH. Keleş et al. (2015) investigated the effect of pepper fruit type on obtaining SDH plants through anther culture and the highest rate was observed in the bell pepper type with 53.4%. Grozeva et al. (2021) reported the SDH formation rate in pepper anther culture as 40.14%, while Misal and Das (2023) determined this rate as 40.70% and Arı et al. (2016) as 51.60%. In his study examining the effect of colchicine, Comlekcioglu (2021) reported that SDH rates were 33.3% in control medium, 57.6% in semi-solid medium and 47.3% in double-layer medium.

Published protocols can be used as a basis for experimental design, but different application methods should be tested for best results. Unfortunately, many published DH protocols do not report antimitotic agent application details and treatment efficiency. The current methods can be used to further refine the genome doubling methodology for major vegetable species. Genome duplication tests will provide other researchers with valuable information for the use and further development of genome doubling protocols.

This study aimed to determine the effects of in vitro colchicine applications on embryo yield, embryo development rates into full plants and the increase in the number of spontaneous dihaploid plants in pepper anther culture.

MATERIAL AND METHOD

Plant material

The study was conducted at Petektar Tohumculuk Seed Company in Antalya. The 45-coded bell pepper genotype in the company's gene pool was selected as the donor plant. Seed sowing was carried out in the autumn growing season. Seedlings were planted in the greenhouse in double rows at 50x50x100 cm intervals in the 2-3 leaf period. Anther culture was started with the buds formed 30 days after planting.

In previous studies, in order to determine the development period suitable for anther culture of pepper genotypes, the acetocarmine staining method was used in the study of Gursoy et al. (2022), as well as the research findings of Comlekcioglu et al. (2001) and Alremi et al. (2014) were taken as reference. Accordingly, the stage was selected when the bud size was 5 mm and the petals were 1-2 mm longer than the sepals, the anther color was cream-yellow, and the tips turned slightly purple with anthocyanin accumulation (Figure 1).

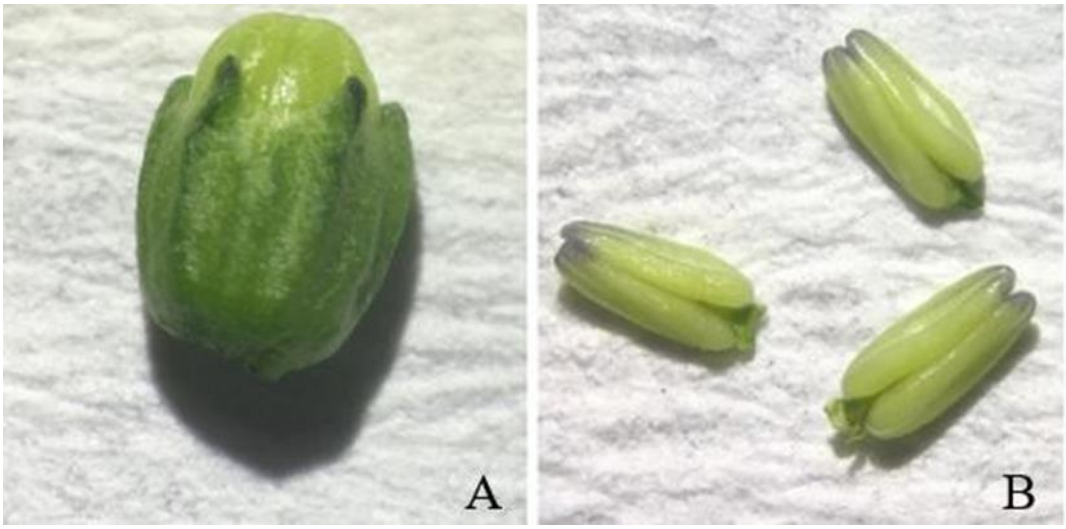

Figure 1. *A; bud at suitable period for anther culture, B; anther at the appropriate period for anther culture*

Sterilization of buds

The buds collected in the morning and brought to the laboratory were shaken in a solution prepared with 15% commercial bleach (approximately 5% sodium hypochlorite content) and 1-2 drops of Twin-20 for 15 minutes. After this process, they were rinsed with sterile distill water 3 times for 5 minutes each.

Nutrient medium

MS (Murashige & Skoog, 1962) containing 4 mg l^{-1} NAA (Naphthalene Acetic Acid), 0.5 mg l^{-1} BAP (Benzyl Amino Purine), 0.25% activated charcoal, 30 g l^{-1} sucrose, 15 mg l^{-1} $AgNO3$ (Silver Nitrate) and 8 g l^{-1} agar was used as the primary culture medium. Regeneration medium was prepared as primary culture medium without activated charcoal and $AgNO_3$. The media coming out of the autoclave were poured into sterile 9 cm diameter glass Petri dishes in a sterile cabinet.

Preparation of colchicine applications

Semi-solid media were created by adding 0.0%, 0.3%, 0.4% and 0.6% colchicine doses to the primary nutrient medium. In double-layer media, while the primary nutrient medium formed the semi-solid phase, 0.3%, 0.4% and 0.6% colchicine doses was added as the liquid phase after anther inoculation. Anthers cultured in the prepared media were transferred to the regeneration medium on the 14th and 21st days of culture (Table 1).

Table 1. *Applications and their contents*

Applications	Contents
Control (Basic medium)	MS + 30 g l^{-1} Sucrose, 0.25% Activated Charcoal, 4 mg l^{-1} NAA, 0.5 mg l^{-1} BAP, 15 mg l^{-1} $AgNO_3$, 8 g l^{-1} Agar
0.3% Colchicine	Control + 0.3% Colchicine (Semi-solid)
0.3% Colchicine	Control + 0.3% Colchicine (Double-layer)
0.4% Colchicine	Control + 0.4% Colchicine (Semi-solid)
0.4% Colchicine	Control + 0.4% Colchicine (Double-layer)
0.6% Colchicine	Control + 0.6% Colchicine (Semi-solid)
0.6% Colchicine	Control + 0.6% Colchicine (Double-layer)
Regeneration medium	MS + 30 g l^{-1} Sucrose, 4 mg l^{-1} NAA, 0.5 mg l^{-1} BAP, 8 g l^{-1} Agar

Placing anthers in the medium

Anthers were cut from their filaments using forceps and scalpels and placed in Petri dishes so that their dorsal surfaces were in contact with the medium (Figure 2). Each Petri dish contained 25 anthers, and 24-27

(600 to 675 anthers) Petri dishes were used for each application. For double-layer applications, after placing the anthers in the Petri dish, filter-sterilized colchicine solutions were added (Figure 3).

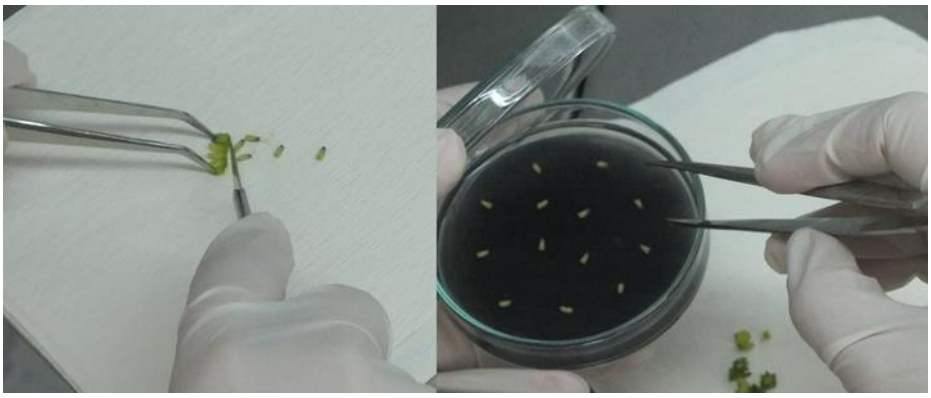

Figure 2. *Cutting the anthers from their filaments and placing them in the nutrient medium*

Figure 3. *Adding filter-sterilized colchicine onto anthers for biphasic applications*

Incubation conditions

Anthers placed in the nutrient medium were exposed to a 35ºC temperature shock in the dark for two days. After being removed from the incubator, they were moved to the climate chamber kept at 25ºC. Anthers kept in the dark in the climate chamber were transferred to the regeneration medium on the 14th and 21st days of culture (Figure 4). After being kept in the dark for 35 days, the cultures were continued to be incubated in the climate chamber with a 16-hour photoperiod at 2300 lux. The embryos developing here were moved into sterile jars filled with hormone-free MS medium.

Figure 4. *Transfer of anthers to regeneration medium*

Acclimatization of plantlets to external conditions

Plantlets were removed from the nutrient medium and planted in small pots (100 ml) filled with a 1:2 peat:perlite mixture. The pots were bagged to maintain humidity and placed in an acclimatization room at 25°C under 2300 lux light and a 16-hour photoperiod. Rooted plants were transplanted into 2.5-liter pots and taken to the greenhouse. The plants, which were kept in pots in the greenhouse for a week, were planted in the greenhouse soil.

Determination of haploid and spontaneous double haploid plants

Pollen in flowers and seed in fruits were examined for this purpose. Stomata count, stomata length and stomata width measurements were made with a microscope (Soptop CX40-T) in the preparations prepared by taking leaves from three different regions of 10 plants of each application. Stomata count and measurements were made in three different regions per unit area (0.08 mm^2) with a 40 magnification objective and a 10 magnification eyepiece.

Data evaluation

Experiments were carried out according to the randomized plot design with three replications (600-675 anthers in total) with 8-9 Petri dishes (200-225 anthers) in each replication. Embryo rate was calculated as the ratio of the number of embryos obtained to the number of anthers cultured. Plantlet rate was calculated as the ratio of the number of plantlets developing from embryos after culture to the number of embryos obtained. The significance level of the differences between the means was determined using the LSD test.

RESULT AND DISCUSSION

In the study, a total of 9100 anthers were cultured and a total of 1022 embryos were obtained (Figure 5.) In 1022 embryos, 495 of the obtained embryos successfully developed into plants (Figure 6). Embryo formation and plant transformation rates varied according to the medium, colchicine dose and application duration (Table 2).

Table 2. *Numbers of anthers, embryos and regenerated plants cultured according to medium, colchicine dose and application time*

Medium	Application Duration (Days)	Colchicine Dose (%)	Anther (Number)	Embryo (Number)	Plantlet (Number)
Semi-solid	14	0,0	650	124	65
		0,3	675	100	59
		0,4	675	80	48
		0,6	675	142	60
	21	0,0	675	96	55
		0,3	650	84	39
		0,4	675	134	54
		0,6	675	104	55
Double-layer	14	0,3	675	26	5
		0,4	600	29	11
		0,6	600	10	1
	21	0,3	675	35	12
		0,4	600	51	29
		0,6	600	7	2

When embryo formation rates were evaluated, it was determined that semi-solid medium was more successful than double-layer medium. While the embryo formation rate in semi-solid medium was 15.91%, it was 4.1% in double-layer medium. The highest embryo formation rate of 21.03% was obtained from anthers cultured in semi-solid medium at a dose of 0.6% colchicine for 14 days. The lowest rate of 1.17% was determined in the application of 0.6% colchicine in double-layer medium for 21 days (Table 3).

Tablo 3. *Embryo formation rate according to different medium structure, colchicine doses and colchicine application duration(%)*

Medium	Colchicine Dose (%)	Application duration (Day)	
		14	**21**
Semi-solid	**0.3**	14.77a	12.40b
	0.4	11.87b	20.00a
	0.6	21.03a	15.40b
Double-layer	**0.3**	3.87a	5.20a
	0.4	4.83b	8.50a
	0.6	1.67a	1.17a
LSD%1	1.693		

The average values indicated with different letters in each line are statistically different from each other.

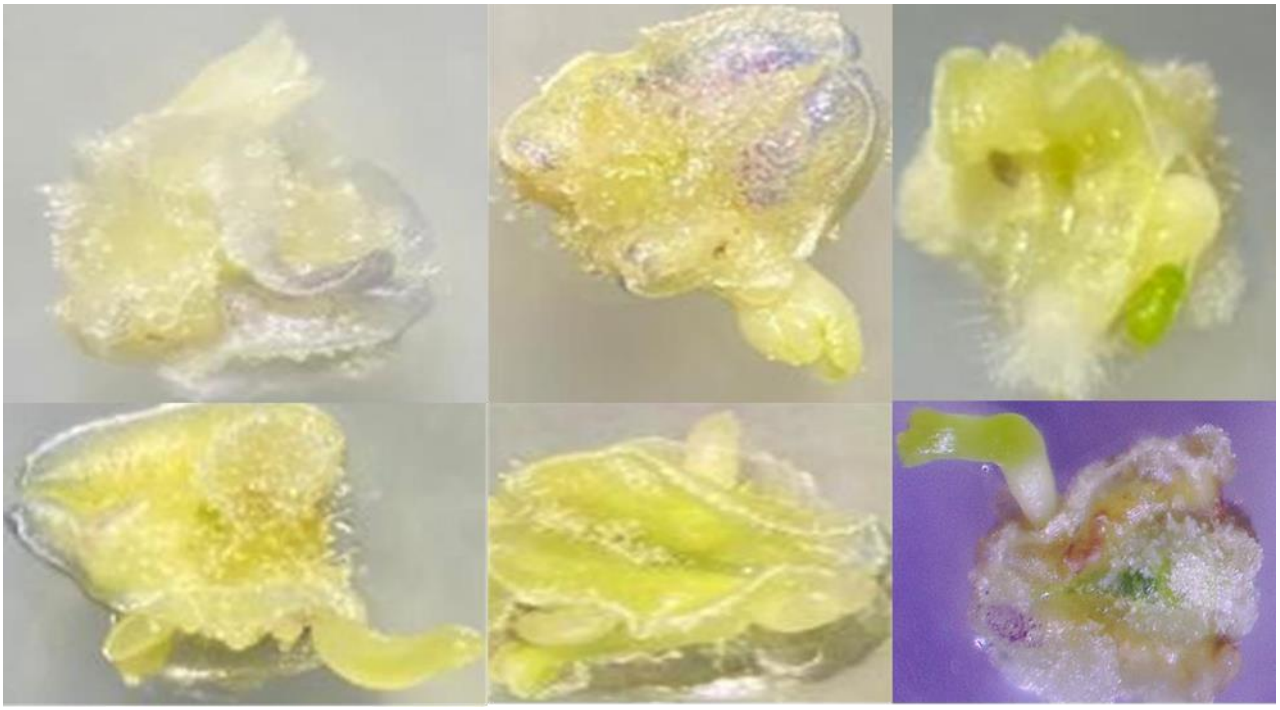

Figure 5. *Some embryos obtained in the study*

Media and colchicine application duration had significant effects on plant regeneration rates. The highest plant regeneration rate was obtained as 53.74% in colchicine application for 14 days in semi-solid medium. This was the most successful plant regeneration result obtained in the study. Application of colchicine for 21 days resulted in similar plant regeneration rates in both media structures (Table 4).

Table 4. *Effect of aplication period X medium on plant regeneration rate (%)*

Application Period (Day)	Medium	
	Semi-solid	**Double-layer**
14	53.74a	27.90b
21	46.68a	45.03a
LSD%1	13.033	

The average values indicated with different letters in each line are statistically different from each other.

In semi-solid medium, the plant regeneration rates varied between 47.56% and 52.75% and the difference was found to be statistically insignificant. In double-layer medium, the highest plant regeneration rate (47.32%) was observed at 0.4% colchicine dose (Table 5).

Table 5. *Effect of medium X dose on plant regeneration rate (%)*

Medium	Colchicine Dose (%)		
	0.3	**0.4**	**0.6**
Semi-solid	52.75a	50.33a	47.56a
Double-layer	27.21b	47.32a	36.11ab
LSD%5	11.626		

The average values indicated with different letters in each line are statistically different from each other.

Figure 6. *Some plantlets developed from the obtained embryos*

Comlekcioglu (2021) determined that the addition of colchicine to the nutrient medium in pepper anther culture increased the embryo formation frequency by 89.5% in semi-solid medium and 36.8% in double-phase medium compared to the control medium. In his study, 19, 36 and 23 embryos were obtained from the control without colchicine, semi-solid and double-layer media containing 0.3% colchicine, respectively. The number of regenerated plants from the embryos was reported as 15, 26 and 19, respectively. In a study

comparing anther culture and shed-microspore culture, it was reported that the anther culture method was a more reliable and successful option than shed-microspore culture to obtain haploid plants in pepper varieties (Kanmaz, 2021).

At the end of the experiment, the plants that were fully developed from the embryos obtainedand transferred to the greenhouse were grouped as H and SDH according to the presence of pollen in the flowers, the presence of seeds in the fruits and the number of stomata on the leaves. 10 plants were evaluated from each application. In the applications made in double-layer medium, 2-7 plants were transferred to the greenhouse and observations were made on these plants. The number of stomata, stomata width and length in donor, H and SDH plants are presented in Table 6 and shown in Figure 7, Figure 8, and Figure 9.

Table 6. *Average stomata number, stomata width and length in donor, haploid and SDH plants*

Ploidy Level	Stomata Number (0.08 mm^2)	Stomata Width (µm)	Stomata Length (µm)
Donor	11.25b	23.83ab	29.78a
Haploid	21.75a	21.73b	25.38b
SDH	13.25b	26.43a	31.38a
LSD%1	3.447	3.374	3.346

The average values indicated with different letters in each line are statistically different from each other.

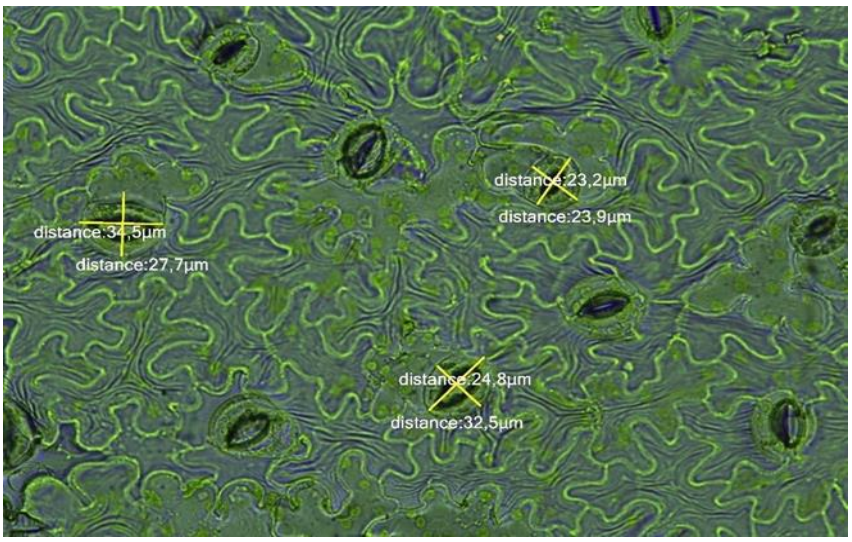

Figure7. *Donor plant stoma image*

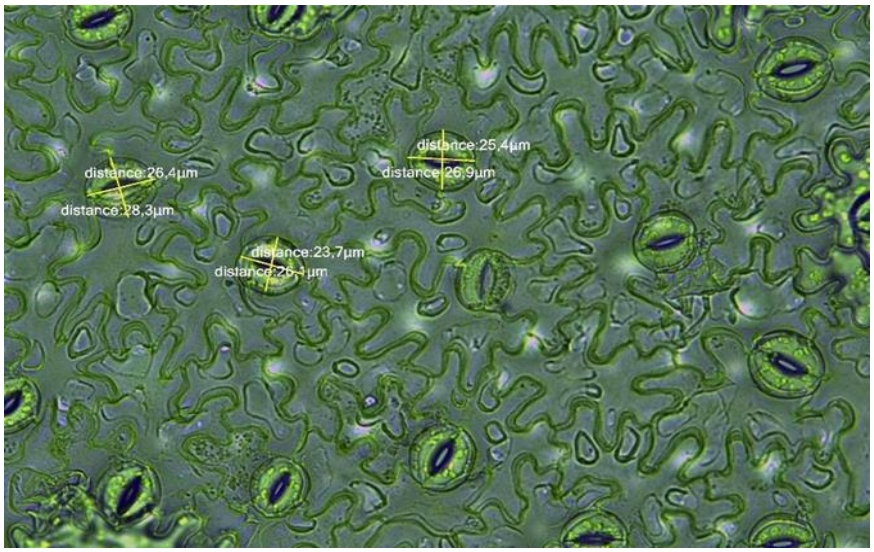

Figure 8. *Haploid plant stoma image*

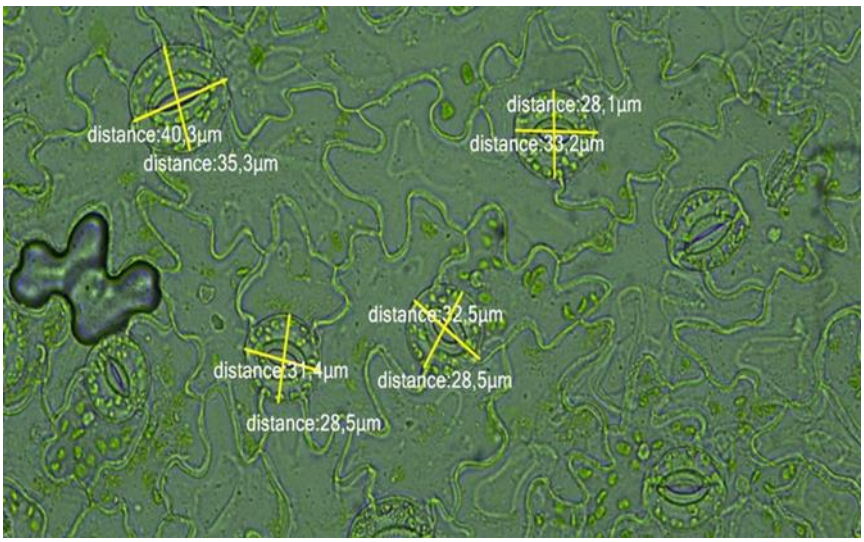

Figure 9. *SDH plant stoma image*

While haploid plants have an average of 21.75 stomata per unit area, this number varies between 11.25 and 13.25 in donor and SDH plants, respectively. Although stomatal width and length in SDH plants are larger than those in haploid plants, considering the turgor status of the plant, the number of stomata is thought to be a more decisive criterion in determining the characteristics of plants. Therefore, the number of stomata has been evaluated as an important indicator in the classification of plants as haploid and SDH. Bat et al. (2021) reported the number of stomata in the same unit area in pepper as 10.71 in haploid and 27.07 in SDH.

In the study, the relationships between variables were evaluated through pairwise correlation analyses, and the resulting correlation coefficients are presented in Table 7. A strong, negative, and statistically highly significant correlation was observed between the embryo rate and the culture media ($r = -0.885$; $P \leq 0.01$). A moderate, negative, and significant correlation was also determined between the plant regeneration rate and the media ($r = -0.528$; $P \leq 0.01$). Furthermore, a moderate, positive, and statistically significant correlation was found between the plant regeneration rate and the embryo rate ($r = 0.519$; $P \leq 0.01$). The correlation coefficients calculated for other variable pairs were not statistically significant ($P > 0.05$).

Table 7. *Correlation analysis between variables*

	Medium	Application Duration	Dose	Embryo rate	Plant regeneration
Medium	1				
Application duration	0.000ns	1			
Dose	0.000ns	0.000ns	1		
Embryo rate	-0.885**	0.058ns	0.047ns	1	
Plant regeneration	-0.528**	0.154ns	-0.160ns	0.519**	1

ns = not significant, * = significant at alfa level %5, ** = significant at alfa level %1

A total of 336 plants were examined in the study conducted to determine haploid and SDH plants. In the application carried out for 21 days at 0.6% colchicine dose in semi-solid medium, the highest SDH rate was found as 74.28% (26 plants). In the application carried out at the same dose for 14 days, the SDH plant rate was determined as 69.05% (29 plants). The SDH plant rate from embryos obtained from medium without colchicine varied between 44.74% and 48.89%. Four plants obtained from the application of 0.3% colchicine for 14 days in double-layer medium were evaluated as SDH. One plant was determined as SDH from the application of 0.6% colchicine for 14 days and two plants were determined as SDH from the application of 21 days. These results show that colchicine is effective in increasing the SDH plant rate and that SDH plant rates change in different medium conditions at different doses and times. In addition, it is understood that different medium conditions also affect the SDH plant rates. In our study, it was determined that the SDH plant rates obtained from media containing colchicine were higher than the control groups without colchicine (Table 8).

Table 8. *Numbers and rates of haploid, SDH plants obtained from applications (%)*

Medium	Application duration (Day)	Colchicine Dose %	Number of Haploid Plant	Haploid Plant Rate %	Number of SDH Plant	SDH Plant Rate %
Semi-solid	14	0.0	23	51.11	22	48.89
		0.3	20	44.44	25	55.56
		0.4	9	36.00	16	64.00
		0.6	13	30.95	29	69.05
	21	0.0	21	55.26	17	44.74
		0.3	13	43.33	17	56.67
		0.4	18	40.91	26	59.09
		0.6	9	25.72	26	74.28
Double-layer	14	0.3	-	00.00	4	100.00
		0.4	1	33.33	2	66.67
		0.6	-	00.00	1	100.00
	21	0.3	2	28.58	5	71.42
		0.4	4	26.67	11	73.33
		0.6	-	00.00	2	100.00

A total of 1020 embryos were obtained from hot pepper anthers and 516 of them developed into normal plants. In the ploidy level analyses performed on 516 regenerative plants, spontaneous chromosome doubling was observed in 40.70% (Misal & Das, 2023). In a study conducted by Keleş et al. (2015), SDH rates were compared in plants obtained by using anther culture in seven Charleston, six bell pepper, eight capia and seven pointed pepper genotypes. It was stated that SDH rates varied among different pepper species. The highest SDH plant rate was observed as 53.4% in bell pepper. 31.9% SDH plant rate was determined in Charleston pepper. 30.4% plant SDH rate was found in capia pepper. 22.2% SDH plant rate was determined in pointed pepper. These data show that SDH plant rates vary in different pepper types, with bell pepper having the highest SDH plant rate. The ability of chromosomes to self-duplicate depends on the genotype. In contrast to pepper, spontaneous chromosome doubling rates were reported as 23% in melon (Hooghvorst et al., 2020) and 63–72% in barley (Mirzaei et al., 2011).

Studies on pepper anther culture show that SDH ratios can vary widely depending on the genotype, culture medium, colchicine dose used and other conditions. SDH ratios have generally been reported ranging from 13% to 65%, and SDH ratios are generally lower than haploid ratios. Mityko et al. (1995) and Gyulai et al. (2000) reported that SDH ratios of regenerated plants varied between 65%; Gemesne et al. (2000), 29.8%; Supena et al. (2006), 13% to 51%; Ercan et al. (2006), all of the 76 plants developed in pepper anther culture were haploid; Niklas-Nowak et al. (2012), approximately 50%; Keleş et al. (2015), 39%; Alremi et al. (2014) reported that 94% of the 40 plants obtained were haploid, while Arı et al. (2016) reported that 51.6% of the 122 plants were SDH, 42.6% were haploid and 5.73% were mixoploid.

Methods to identify haploids and determine spontaneous chromosome doubling in androgenic plants play an important role in plant breeding and genetic research. Chromosome counting from root tip cells under a microscope and measuring the amount of DNA present in the cell nucleus by flow cytometry provide fast and reliable results. Haploids can also be identified using molecular markers.

Morphological and anatomical markers are easy and economical to analyze to determine the success of chromosome folding. SDH allows bypassing laborious treatments with antimitotic agents.

It is known that there is a significant and reliable correlation between stomatal numbers of haploid and SDH plants (Przywara et al., 1988; Cramer, 1999; Aryavand et al., 2003; Yuan et al., 2009; Da Silva et al., 2020; Bat et al., 2021; Tammu et al., 2021; Castañeda-Nava et al., 2023). Studies on stomatal size and stomatal

density per unit area of haploid plants show that haploid plants have smaller stomata than diploids and therefore have more stomata per unit area (Omidbaigi et al., 2010; Głowacka et al., 2010; Hannweg et al., 2013; Widoretno, 2016; Comlekcioglu & Ozden, 2019).

The distinction between haploid and diploid plants in plants obtained from anther culture in *Capsicum annuum* was tested in 170 plants. The results showed that the mean stomatal length and number were 26.4 µm and 7.4 µm in haploid, 35.2 µm and 5.8 µm in diploid, and 33.3 percent (%) and -30% higher in diploid compared to haploid. Thus, haploid and diploid were significantly different in these parameters and measurement of stomatal length is a rapid technique to determine the ploidy level in pepper (Shrestha & Kang, 2016). İlhan and Kurtar (2022) determined the ploidy levels of the plants obtained as a result of anther culture in 12 pepper genotypes by stomatal measurements (stomatal size, chloroplast number and number of stomata per unit area). As a result of stomatal characteristics of 18 plants, 13 plants were haploid and 5 plants were diploid. In the study conducted by Bat et al. (2021), higher stomatal density was found in haploid plants compared to diploid plants. The average number of stomata per unit area was 27.07 in haploid pepper and 10.71 in diploid pepper. It was determined that the average stomatal width was 22.52 µm in haploid pepper and 29.50 µm in diploid pepper and the difference between ploidy levels was significant. Haploid eggplants showed a stomatal density of 29.20 stomata per unit area, whereas doubled haploid (DH) plants had a reduced density of 12.61. The average stomatal lengths were 22.32 µm in haploids and 32.00 µm in DH plants, with corresponding widths of 17.36 µm and 22.32 µm. This suggests that DH plants possess larger but fewer stomata compared to their haploid counterparts. Haploid onion plants had stomatal lengths and widths of 27.2 µm and 25.5 µm, respectively, with a density of 157.6 stomata per mm². Diploid onions displayed larger stomata (39.1 µm in length and 31.0 µm in width) but a lower density of 129.0 stomata per mm². These findings highlight a positive correlation between ploidy level and stomatal size, and a negative correlation with stomatal density (Foshi et al., 2013). It was investigated whether morphological and cytological analyses would be sufficient for ploidy determination of haploid plants obtained by ovary culture in watermelon. For this purpose, stomatal, morphological and cytological characteristics of 15 haploid and 19 doubled haploid plants were determined. Before these analyses, the ploidy level of the plants was determined by flow cytometry. It has been reported that stomatal traits can be used as morphological markers to determine the ploidy level of plants (Kara et al., 2024). Antimitotic agent application efficiency depends on the application conditions, especially its concentration and exposure duration. Furthermore, the plant developmental stage is critical for agent accessibility and plant survival. Current methods can be used to further improve genome doubling methodology for major vegetable species (Fomicheva et al., 2024).

CONCLUSION

In pepper breeding studies, haploid plant production via androgenesis has been focused on. In pepper androgenesis, anther culture is the most effective method widely used by various researchers. The effects of many factors on obtaining haploid plants have been studied. Recently, spontaneous chromosome doubling has become the focus of attention in order to increase the plant production rate by testing and optimizing different procedures. Colchicine is a compound widely used to induce polyploidy in plant tissue culture and can have significant effects on plant development. Colchicine disrupts spindle formation during cell division, leading to an increased chance of chromosome folding. This can lead to the formation of larger and healthier embryos, increased viability and developmental potential of the embryos thus increasing embryo yield and potentially higher yields of viable plants. Since in vitro colchicine application will be carried out in a controlled environment, it minimizes the effect of external factors. It can provide higher efficiency and faster achievement of the desired effect. This is an important advantage in breding studies when time is critical. For these reasons, more experiments on in vitro colchicine applications and adoption of in vitro applications in breeding studies are necessary.

This study shows that embryo formation and plant regeneration rates in pepper anther culture vary significantly depending on the nutrient medium, colchicine dose and application times. The analyses showed that embryo formation and plant regeneration were more successful in semi-solid medium compared to the double-layer medium. It was observed that especially 0.3% and 0.4% colchicine doses were associated with higher regeneration rates. However, it was determined that plant regeneration rates decreased as colchicine dose increased. It was also determined that SDH plant rates varied depending on the duration and dose of colchicine application and that colchicine application increased the SDH rate.

As a result, colchicine applications in anther culture have been found to affect embryo formation and development. In anther culture, spontaneous chromosome doubling may occur due to stress conditions. When colchicine is applied, this may increase the probability of doubling. It has been determined that the effectiveness of colchicine in promoting embryo yield and chromosome doubling depends on the application dose and exposure time. Careful dose adjustment during application is important both to increase embryo yield and to achieve desired polyploidy levels. These applications need to be carefully optimized.

According to the results of this study, the following suggestions can be made to increase the efficiency of future studies and contribute to the wider application of haploidy techniques in pepper plants.

The highest percentage of SDH plants (74.28%) was obtained when 0.6% colchicine was applied for 21 days in semi-solid medium. Future studies could examine the effects of higher or lower colchicine concentrations and different application times on SDH rates. Determining the optimum dose is important to maximize SDH production without negatively affecting plant growth.

Although double-layered media have lower embryo formation rates than semi-solid media, trials could be conducted to improve the efficiency of these media with different nutrient compositions or hormone additions.

Considering that SDH rates vary depending on the genotype, investigating the effectiveness of colchicine applications in different pepper genotypes and conducting studies on a wide genetic base can make an important contribution.

In addition to colchicine, the efficacy of antimitotic agents such as oryzalin and trifluralin on SDH production can be investigated. It should be examined whether these agents have lower toxicity or offer higher success rates.

AUTHOR CONTRIBUTION

All authors contributed equally.

ETHICAL STATEMENT

During the writing process of the study titled "**Effects of Colchicine Applications on Embryo Yield and Spontaneous Chromosome Doubling in Pepper (*Capsicum annuum* L.) Anther Culture** ", scientific rules, ethical and citation rules were followed; No falsification has been made on the collected data and this study has not been sent to any other academic media for evaluation. Ethics committee approval is not required.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

REFERENCES

Alremi, F., Taskin, H., Sonmez, K., Buyukalaca, S., & Ellialtioglu, Ş. (2014). Effects of genotype and nutrient medium on anther culture in pepper (*Capsicum annuum* L.). *Turkish Journal of Agricultural and Natural Sciences*, 1(2), 108-116. https://doi.org/10.30910/turkjans.160702

Arı, E., Yıldırım, T., Mutlu, N., Buyukalaca, S., Gokmen, Ü., & Akman, E. (2016). Comparison of different androgenesis protocols for doubled haploid plant production in ornamental pepper (*Capsicum annuum* L.). *Turkish Journal of Biology*, 40(4), 944-954. https://doi.org/10.3906/biy-1509-36

Aryavand, M., Mozafari, J., & Bagheri, A. (2003). Morphological comparison of haploid and diploid plants in anther culture of pepper (*Capsicum annuum* L.). *Euphytica*, 132(1), 25–30. https://doi.org/10.1023/A:1026088629924

Bat, H., Altındağ, F. N., Yiğit, M. A., Ellialtıoglu, Ş. Ş., & Comlekcioglu, N. (2021). Ploidy estimation in pepper and eggplant via stomata characteristics. *International Journal of Agriculture Forestry and Life Sciences*, 5(2), 139-146.

Castañeda-Nava, J. J., Quiroz-Figueroa, F., & Zavala-García, F. (2023). Chromosome doubling efficiency and morphological variation in doubled haploids of *Capsicum chinense* Jacq. *Scientia Horticulturae*, 312, 111974. https://doi.org/10.1016/j.scienta.2022.111974

Comlekcioglu, N. (2021). Effect of colchicine addition to culture medium on induction of androgenesis in pepper (*Capsicum annuum* L.). *Pak. J. Bot*, 53(3), 1001-1005. http://dx.doi.org/10.30848/PJB2021-3(14)

Comlekcioglu, N., & Ellialtıoglu, Ş. Ş. (2018). Review on the research carried out on in vitro androgenesis of peppers (*Capsicum annuum* L.) in Turkey. *Research Journal of Biotechnology*, 13(6), 75-84.

Comlekcioglu, N., & Ozden, M. (2019). Polyploid induction by colchicine treatment in goldenberry (*Physalis peruviana*), and effects of polyploidy on certain traits. *Journal of Animal & Plant Sciences*, 29(5), 1336–1343.

Comlekcioglu, N., Buyukalaca, S., & Abak, K. (2001). Effect of silver nitrate on haploid embryo induction by anther culture in pepper (*Capsicum annuum* L.). *In XIth EUCARPIA meeting on genetics and breeding of capsicum and eggplant*, (pp. 133-136). Antalya, Turkey.

Cramer, C. S. (1999).Phenotypic comparison of diploid, haploid, and doubled haploid onion (*Allium cepa* L.) lines. *HortScience*, 34(7), 1263–1266.

Da Silva, H. A., Scapim, C. A., Vivas, J. M. S., do Amaral, A. T., Pinto, R. J. B., Mourão, K. S. M., & Baleroni, A. G. (2020). Effect of ploidy level on guard cell length and use of stomata to discard diploids among putative haploids in maize. *Crop Science*, 60(3), 1199-1209.

Dewitte, W., & Murray, J. A. (2003). The plant cell cycle. *Annual Review of Plant Biology*, 54(1), 235-264. https://doi.org/10.1146/annurev.arplant.54.031902.134836

Dhooghe, E., Van Laere, K., Eeckhaut, T., Leus, L., & Van Huylenbroeck, J. (2011). Mitotic chromosome doubling of plant tissues in vitro. *Plant Cell, Tissue and Organ Culture*, 104, 359-373. https://doi.org/10.1007/s11240-010-9786-5

Ebrahimzadeh, H., Lotfi, M., & Sadat-Hosseini, M. (2021). Parthenogenetic haploid plant production in styrian pumpkin by gamma irradiated pollen. *International Journal of Horticultural Science and Technology*, 8(3), 305-314.

Ercan, N., Sensoy, F. A., & Sensoy, A. S. (2006). Influence of growing season and donor plant age on anther culture response of some pepper cultivars (*Capsicum annuum* L.). *Scientia Horticulturae*, 110(1), 16-20.

Fomicheva, M.; Kulakov, Y.; Alyokhina, K.; Domblides, E.(2024). Spontaneous and chemically induced genome doubling and polyploidization in vegetable crops. *Horticulturae*, 10, 551. https://doi.org/10.3390/horticulturae10060551

Gémesné Juhász, A., Petus, M., Venczel, G., Zatykó, L., Gyulai, G., & Cséplö, M. (2000, July). Genetic variability of anther donor versus spontaneous doubled haploid descendents and colchicine induced doubled haploid sweet pepper (*Capsicum annuum* L.) lines. *In IV International Symposium on In Vitro Culture and Horticultural Breeding* 560 (pp. 149-152).

Grozeva, S., Pasev, G., Radeva-Ivanova, V., Todorova, V., Ivanova, V., & Nankar, A. N. (2021). Double haploid development and assessment of androgenic competence of balkan pepper core collection in Bulgaria. *Plants*, 10(11), 2414.

Gursoy, E., Yildiz, B. N., Yapici, B., & Ellialtioglu, S. S. (2022). Genotype effect on obtaining haploid embryos via anther culture in capia pepper gene pool. *Bahce 51* (Special Issue 1): 294–299 ISSN: 1300-8943.

Gyulai, G., Gemesne, J. A., Sági, Z. S., Venczel, G., Pintér, P., Kristóf, Z. & Zatykó, L. (2000). Doubled haploid development and PCR-analysis of F1 hybrid derived DH-R2 paprika (*Capsicum annuum* L.) lines. *Journal of Plant Physiology*, 156(2), 168-174.

Hannweg, K., Sippel, A., & Bertling, I. (2013). A simple and effective method for the micropropagation and in vitro induction of polyploidy and the effect on floral characteristics of the South African iris, *Crocosmia aurea*. *South African Journal of Botany*, 88, 367-372.

Hooghvorst, I., & Nogués, S. (2021). Chromosome doubling methods in doubled haploid and haploid inducer-mediated genome-editing systems in major crops. *Plant Cell Reports*, 40(2), 255-270.

Hooghvorst, I., Torrico, O., Hooghvorst, S., & Nogués, S. (2020). In situ parthenogenetic doubled haploid production in melon "Piel de Sapo" for breeding purposes. *Frontiers in Plant Science*, 11, 378.

İlhan, M., & Kurtar, E. S. (2022). Doublehaploidization efficiency of selected pepper genotypes via in vitro anther culture. *Selcuk Journal of Agriculture and Food Sciences*, 36(2), 253-259. https://doi.org/10.15316/SJAFS.2022.033

Joubès, J., & Chevalier, C. (2000). Endoreduplication in higher plants. *The Plant Cell Cycle*, 191-201.

Kanmaz, M. G. (2021). *Effects of anther and two different shed-microspore cultures on pure line production in capsicum and dolma types in pepper (Capsicum annuum L.) breeding*. [Master's Thesis, Akdeniz University, Institute of Science]. YÖK National Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

Kara, E.; Taskın, H.; Karabıyık, ¸S.; Solmaz, ˙I.; Sarı, N.; Karaköy, T.; Baktemur, G. (2024). Are cytological and morphological analyses sufficient in ploidy determination of watermelon haploid plants. *Horticulturae,* 10, 818. https://doi.org/10.3390/horticulturae10080818

Kasha, K. J. (2005). Chromosome doubling and recovery of doubled haploid plants. *Springer*, In Haploids In Crop Improvement II (pp. 123-152).

Keleş, D., Pınar, H., Ata, A., Taşkın, H., Yıldız, S., & Buyukalaca, S. (2015). Effect of pepper types on obtaining spontaneous doubled haploid plants via anther culture. *HortScience*, 50(11), 1671-1676.

Marin-Montes, I. M., Rodríguez-Pérez, J. E., Robledo-Paz, A., de la Cruz-Torres, E., Peña-Lomelí, A., & Sahagún-Castellanos, J. (2022). Haploid induction in tomato (*Solanum lycopersicum* L.) via gynogenesis. *Plants*, 11(12), 1595.

Mirzaei, M., Kahrizi, D., & Rezaeizad, A. (2011). *Androgenesis and spontaneous chromosome doubling in Hordeum vulgare L*. In Researches of the First International Conference. Babylon and Razı Universities, Euphrates J Agric Sci, 3(9), 248–252.

Misal, S., & Das, A. (2023). *Development of a unique protocol for the production of doubled haploids in hot pepper*. https://doi.org/10.21203/rs.3.rs-3294597/v1

Mishra, A.K., Saini, R., Tiwari, K.N. (2021). *Double haploid production and its applications in crop improvement*. In: Kumar Srivastava, D., Kumar Thakur, A., Kumar, P. (eds) Agricultural Biotechnology: Latest Research and Trends . Springer, Singapore. https://doi.org/10.1007/978-981-16-2339-4_4

Mityko, J., Andrasfalvy, A., Csillery, G., & Fári, M. (1995). Anther-culture response in different genotypes and F1 hybrids of pepper (*Capsicum annuum* L.). *Plant Breeding*, 114(1), 78-80.

Murashige, T., & Skoog, F. (1962). A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiologia Plantarum*,15, 473-497.

Niklas-Nowak, A., Olszewska, D., Kisiała, A., & Nowaczyk, P. (2012). Study of individual plant responsiveness in anther cultures of selected pepper (spp.) genotypes. *Folia Horticulturae*, 24(2), 141-146.

Omidbaigi, R., Yavari, S., Hassani, M. E., & Yavari, S. (2010). Induction of autotetraploidy in dragonhead (*Dracocephalum moldavica* L.) by colchicine treatment.. *J. Fruit Ornam. Plant Res*, 18(1), 23-35.

Przywara, L., Manteuffel, R., & Szczygieł, A. (1988). Induction of haploids and double haploids in anther cultures of *Capsicum annuum* L. *Euphytica*, 40(1), 91-96. https://doi.org/10.1007/BF00034535

Salehian, H., Shahnazi, S., & Nazari, M. (2023). Production of doubled haploid plants in cucumber (*Cucumis sativus* L.) via parthenogenesis. *In Vitro Cellular & Developmental Biology-Plant*, 59(4), 467-474.

Sato, S., Katoh, N., Iwai, S., & Hagimori, M. (2005). Frequency of spontaneous polyploidization of embryos regenerated from cultured anthers or microspores of *Brassica rapa var. pekinensis* L. and *B. oleracea var. capitata* L. *Breeding Science*, 55(1), 99-102.

Seguí-Simarro, J. M., & Nuez, F. (2008). Pathways to doubled haploidy: chromosome doubling during androgenesis. *Cytogenetic and Genome Research*, 120(3-4), 358-369.

Shim Y. S., Kasha K. J., Simion E., Letarte J. (2006) The relationship between induction of embryogenesis and chromosome doubling in microspore cultures. *Protoplasma* 228:79-86

Shrestha, S.L. & Kang, W.H. (2016). Stomata length and Density as an Indicator of Ploidy level in Sweet Pepper (*Capsicum annuum* L.). *Research Journal of Recent Sciences*, 5 (ISC-2015), 4-10.

Supena, E. D. J., Suharsono, S., Jacobsen, E., & Custers, J. B. M. (2006). Successful development of a shed-microspore culture protocol for doubled haploid production in Indonesian hot pepper (*Capsicum annuum* L.). *Plant Cell Reports*, d25, 1-10.

Tammu, R. M., Nuringtyas, T. R., & Daryono, B. S. (2021). Colchicine effects on the ploidy level and morphological characters of katokkon pepper (*Capsicum annuum* L.) from North Toraja, Indonesia. *Journal of Genetic Engineering and Biotechnology*, 19(1), 31.

Vaughn, K. C. (2006). The abnormal cell plates formed after microtubule disrupter herbicide treatment are enriched in callose. *Pesticide Biochemistry and Physiology*, 84(2), 63-71. https://doi.org/10.1016/j.pestbp.2005.03.006

Vural, G. E., Arı, E., Zengin, S., & Ellialtıoğlu, S. S. (2019). Development of androgenesis studies on eggplant (*Solanum melongena* L.) in Turkey from past to present. *Sustainable Crop Production*, 67-90.

Widoretno, W. (2016). In vitro induction and characterization of tetraploid patchouli (*Pogostemon cablin* Benth.) plant. *Plant Cell, Tissue and Organ Culture* (PCTOC), 125, 261-267.

Yaman, H., & Karaca Sanyürek, N. (2023). Obtaining haploid plants by irradiated pollen culture in oil seed crops. *Biotech Studies*, 32(1), 10-16. https://doi.org/10.38042/biotechstudies.1273824

Yuan, S. X., Liu, Y. M., Fang, Z. Y., Yang, L. M., Zhuang, M., Zhang, Y. Y., & Sun, P. T. (2009). Study on the relationship between the ploidy level of microspore-derived plants and the number of chloroplast in stomatal guard cells in *Brassica oleracea*. *Agricultural Sciences in China*, 8(8), 939-946.

Zhang, Z., Conner, J., Guo, Y., & Ozias-Akins, P. (2020). Haploidy in tobacco induced by PsASGR-BBML transgenes via parthenogenesis. *Genes*, 11(9), 1072.

Zhao, J., & Simmonds, D. H. (1995). Application of trifluralin to embryogenic microspore cultures to generate doubled haploid plants in *Brassica napus*. *Physiologia Plantarum*, 95(2), 304-309.

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Research Article

Optimizing Planting Arrangement and Density for Enhanced Oil Yield and Fatty Acid Composition in a Non-Shattering Sesame Cultivar

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ABSTRACT

Sesame (*Sesamum indicum* L.) is a globally significant oilseed crop valued for its high-quality oil, rich in unsaturated fatty acids and antioxidants, yet its production faces challenges such as low yield, shattering losses, and variable oil quality, particularly in semi-arid regions like Iran where domestic demand necessitates enhanced local cultivation. This study aimed to investigate how row spacing (30, 45, 60 cm) and plant density (5, 8, 11, 14 cm) affect oil yield and fatty acid composition in the non-shattering sesame cultivar. Conducted in 2020 at the Moghan Agricultural Research Station in Northwest Iran, the experiment utilized a strip plot design based on a completely randomized block design with four replications. Treatments combined row spacings and plant densities, with oil content and fatty acid profiles analyzed via gas chromatography, and data evaluated using ANOVA, LSD and regression tests. Results revealed that a row spacing of 45 cm with plant spacings of 8–11 cm (20–28 plants/m²) maximized oil content at 55.45% and optimized fatty acid profiles, particularly increasing linoleic acid (up to 48.31%) while maintaining oleic acid levels (up to 40.85%), with significant RS × PS interactions ($P < 0.01$) highlighting their combined influence. These findings provide practical recommendations for Iranian farmers to enhance sesame oil quality and yield, contributing to sustainable production systems in semi-arid regions and reducing reliance on imported edible oils, while suggesting further multi-year studies to address environmental variability in fatty acid biosynthesis.

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INTRODUCTION

Sesame (*Sesamum indicum* L.), one of humanity's oldest oilseed crops, is globally revered for its high-quality oil, which is rich in unsaturated fatty acids, antioxidants, and lignans (Babu et al., 2024; Langyan et al., 2022). Sesame oil is highly valued for its nutritional and health benefits, primarily due to its fatty acid composition and bioactive compounds. It is rich in unsaturated fatty acids, particularly oleic (omega-9) and linoleic (omega-6) acids, which contribute to cardiovascular health (Gouveia et al., 2017; Oboulbiga et al., 2023). The oil also contains important bioactive compounds such as lignans, tocopherols, and phytosterols, which possess antioxidant properties (Oboulbiga et al., 2023; Wacal et al., 2024). Sesame oil's unique composition makes it valuable for both culinary and industrial applications, particularly where oxidative stability is crucial (Kouighat et al., 2025). Global sesame production has increased substantially over the past 60 years, with Asia and Africa as primary producers (Sanni et al., 2024). Globally, sesame is cultivated on approximately 13 million hectares, yielding around 6 million tons of seeds with an average productivity of 520 kg per hectare. In Iran, the 2023 crop year demonstrated the country's growing influence in the sesame market, with over 42,000 hectares dedicated to sesame cultivation, producing an average yield of 690 kg per hectare and resulting in a total seed yield of 29,000 tons (FAOSTAT, 2023). Iran faces a significant challenge in meeting its domestic demand for edible oils, as the country imports approximately 90% of its required oilseeds and vegetable oils to bridge the gap between production and consumption (Mohammadi et al., 2013). This heavy reliance on imports underscores the urgent need to enhance local cultivation of oilseed crops that are well-suited to Iran's climatic conditions, such as sesame. Sesame, being a drought-tolerant crop, is particularly adapted to regions with water scarcity, making it an ideal candidate for expanding agricultural output in Iran's arid and semi-arid landscapes (Gholamhoseini & Dolatabadian, 2024). Despite its economic importance, sesame production faces challenges such as low yield, shattering losses, and variability in oil quality, necessitating innovative agronomic strategies (Rauf et al., 2024; Yadav et al., 2022). Agronomic practices, including planting arrangement (row spacing) and plant density, are critical determinants of sesame crop performance (Ngala et al., 2013). These factors influence light interception, nutrient uptake, and intra-plant competition, ultimately affecting yield and biochemical profiles (Imo, 2012). Optimal row spacing is essential to maximize light interception, nutrient uptake, and plant population density while minimizing competition among plants, particularly in diverse agroecological conditions. For soybeans, row spacings of 25-51 cm have been shown to maximize seed yield and resource use efficiency (Abeje et al., 2020). In rapeseed, narrow row spacings of 15 cm are recommended to achieve higher seed yields (Ozer, 2003). Similarly, for sesame, row spacings of 30 cm combined with intra-row spacings of 5 cm have been found to optimize seed and oil yields (Öztürk & Şaman, 2012). Investigations in sesame under semi-arid regions have demonstrated that narrower row spacings can enhance yield under rainfed conditions, while wider spacings may benefit irrigated systems by reducing plant stress (Ali et al., 2020). Koocheki et al. (2017) reported that the diamond pattern with 50 plants/m² achieved the highest dry matter and seed yield (1100 g/m²), while the same pattern with 30 plants/m² produced the most seeds (47) and capsules (19.2) per plant. Increasing density from 30 to 50 plants/m² reduced 1000-seed weight by 13% and harvest index from 31% to 28%. The diamond pattern with 50 plants/m² was identified as optimal for sesame cultivation in Mashhad, Iran. In contrast, Habibzadeh and Gholamhoseini (2022) reported no significant difference in sesame yield across various planting patterns. The discrepancy in researchers' findings may be attributed to sesame's differing responses to planting patterns, influenced by cultivar characteristics (especially branching type), planting date, irrigation method, soil fertility, and growing season length (Gholamhoseini et al., 2024). Recent advances in sesame breeding have prioritized non-shattering traits to reduce post-harvest losses (Gebremichael, 2017; Rauf et al., 2024). Sesame breeding programs focus on developing cultivars with minimized shattering to achieve high-yielding and shatter-resistant varieties (Gedifew, 2024). Yet, optimal cultivation practices for these cultivars are poorly defined. Wider row spacing improves photosynthetic efficiency and oil content (El Harfi et al., 2021), light penetration and air circulation, reducing fungal diseases and promoting healthy plant growth. However, excessive spacing may lead to reduced competition, potentially lowering yield due to fewer plants per unit area (Khan & Islam, 2023; Öztürk & Şaman, 2012). Closer spacing may be more beneficial as plants can utilize available water efficiently (Ali et al., 2020; Filimon & Worku, 2018). However, these findings may not extrapolate to modern non-shattering genotypes, which exhibit a modified canopy architecture, with curly and larger leaves, which could alter light interception and canopy density compared to traditional varieties (Teboul et al., 2022; Yol et al., 2021). The fatty acid profile of sesame oil is highly sensitive to environmental and agronomic factors. For example, drought stress elevates oleic acid but reduces linoleic acid (Kim et al., 2006; Tas et al., 2024), while this trend is also observed with increasing

nitrogen application (Gholamhoseini, 2022; Tas et al., 2024). Row spacing influences the fatty acid profile of sesame oil. Closer row spacing (37.5 cm) was associated with higher contents of eicosenoic acid and saturated fatty acids compared to wider spacing (75 cm) (Bhardwaj et al., 2015). Additionally, row spacing significantly affected oleic and linoleic acid contents, with interactions between row spacing and irrigation also playing a role (Alpaslan et al., 2001). This study explores how row spacing (30, 45, 60 cm) and plant density (5, 8, 11, 14 cm) affect oil yield and fatty acid profiles in a non-shattering sesame cultivar, aiming to fill existing research gaps. It hypothesizes that wider row spacing boosts oil percentage by reducing competition within rows, while a moderate plant density improves fatty acid composition by optimizing light penetration and photosynthetic efficiency. The findings seek to offer practical recommendations for farmers and breeders to enhance sesame oil quality and yield.

MATERIAL AND METHODS

For finding the optimal planting arrangement and density to enhance oil yield and fatty acid composition in a non-shattering sesame cultivar, an experiment was conducted during the 2020 cropping season at the Agricultural Research and Education Center of Ardabil Province, located at the Moghan Agricultural Research Station in the Moghan Plain, Northwest Iran (N39°39', E47°68', sea level= 78 m). The layout of the experiment was as according to a strip plot design based on a completely randomized block design with four replications. For this purpose, the effect of row spacing (30, 45, and 60 cm) was considered as the vertical factor, and the plant spacing within rows (5, 8, 11, and 14 cm) was considered as the horizontal factor. Based on data from the Iran Meteorological Organization (IRIMO, 2021), this area experiences a semi-humid and moderately warm climate. Over the past 30 years, the average annual precipitation has been 251 mm, with most of it occurring in the autumn and early spring. The region experiences a range of precipitation from a minimum of 72.9 mm to a maximum of 523 mm every year. The average annual maximum temperature is 35°C, while the average annual minimum temperature is 8°C. The mean yearly relative humidity stands around 71%. The weather conditions of the experimental site during the sesame growing season in 2020 are presented in Table 1.

Table 1. *Meteorological data for the moghan region during the sesame growing season in 2020*

	July	August	September	October	November
Minimum Temperature (°C)	19.2	21.5	17.9	14.2	7.1
Maximum Temperature (°C)	33.3	32.5	26.8	23.9	18.8
Average Temperature (°C)	27.6	27.0	22.4	19.1	13.0
Precipitation (mm)	0.1	3.9	43.5	29.2	6.2

Physical and chemical properties of the soil at the experimental site are presented in Table 2.

Table 2. *Physical and chemical properties of the soil at the experimental site*

Silt-Clay-Sand (%)	Organic Matter (%)	Nitrogen (%)	Phosphorus (mg/kg)	Potassium (mg/kg)	Salinity (dS/m)	pH
35-42-23	1.35	0.13	10.52	488	0.56	7.95

After land preparation operations in the spring, including plowing, discing, and ridge formation (based on the experimental treatments and by adjusting the distance between ridges), sesame seeds were manually sown at a depth of 1–2 cm in the third decade of June. Based on soil test results, the field soil had a clay-loam texture, pH of 8, salinity of 0.52 dS/m, and 0.11% nitrogen. Additionally, the levels of phosphorus and potassium in the soil were 7.2 mg/kg and 390 mg/kg, respectively. Fertilization was applied according to the local practices in the Moghan region, consisting of 150 kg/ha of urea and 150 kg/ha of phosphate fertilizer, with an additional 50 kg/ha of urea applied as a top-dressing before the flowering stage. Each experimental plot consisted of six planting rows, each 4 meters long. The distance between plots was 1 meter, and the distance between blocks was 2 meters. The non-shattering sesame cultivar (Mohajer) was used, with a germination rate of 98% and purity of 99%. This cultivar, originating from Iran's sesame breeding programs focused on non-shattering traits, was bred using pureline selection methods. The first irrigation was applied immediately after planting,

with subsequent irrigations performed based on the plant's water needs in a rotational irrigation system. For weed control, 2 liters/ha of the herbicide trifluralin was applied before planting, and manual weeding was conducted during the growing season. To control leaf-eating pests, 250 ml/ha of the insecticide Avaunt was applied in two applications.

Oil content and fatty acid profile analysis

The fatty acid profile of sesame oil was determined using a gas chromatography (Agilent/HP Model 6890) system at the Plant Laboratory of the Research Institute of Forests and Rangelands, Karaj, Iran. First, lipids were extracted from ground sesame seeds using a Soxhlet apparatus with n-hexane as the solvent, followed by drying at 75°C to remove moisture. The extracted oil was then converted into fatty acid methyl esters (FAMEs) through transesterification with methanol and a catalyst (e.g., sodium methoxide or sulfuric acid) at 60–80°C for 30–60 minutes, purified with hexane, and dried with anhydrous sodium sulfate. The FAME sample (1–2 µL) was injected into the GC equipped with a polar capillary column (e.g., DB-23 or BPX-70, 30 m × 0.25 mm × 0.25 µm) and analyzed using a flame ionization detector (FID). The oven temperature was programmed to start at 140°C, ramp at 4–10°C/min to 220–240°C, and hold for 10–15 minutes, with helium as the carrier gas at 1–2 mL/min, injector temperature at 250°C, and detector temperature at 260°C. FAMEs were identified by comparing retention times with known standards, and their percentages were quantified using peak areas relative to the total, processed with software like Agilent ChemStation, ensuring calibration with FAME standards for accuracy and reproducibility.

Data analysis

SAS software (version 9.1) was used to analyze the data after confirming the normality of the experimental data and the homogeneity of variance errors. Furthermore, because of the significant interaction between row spacing and plant spacing, the means comparison for the interaction was conducted using the interaction slicing method combined with the Least Significant Difference (LSD) test, also implemented in SAS. Regression analysis was performed using Excel software, while correlation analysis was conducted using JMP (version 16).

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) demonstrated that row spacing (RS), plant spacing (PS), and their interaction (RS × PS) exerted significant effects on oil content and fatty acid composition in the non-shattering sesame cultivar 'Mohajer' (Table 3). These effects were significant at the 1% probability level ($P < 0.01$) for most traits, with stearic acid showing significance at the 5% level ($P < 0.05$) for RS and PS effects. Block effects were also significant ($P < 0.01$) for oil content, palmitic acid, palmitoleic acid, linoleic acid, α-linolenic acid, and arachidic acid, reflecting spatial variability across experimental units. The low coefficients of variation (CV: 0.007%–4.590%) and minimal error terms indicate high experimental precision and data reliability (Table 3).

Table 3. *Analysis of variance for oil content and fatty acid composition in a non-shattering sesame cultivar*

S.o.V [1]	DF	Oil Content	Palmitic Acid	Palmitoleic Acid	Stearic Acid
B	3	0.077**	0.000**	0.000**	0.018
RS	2	66.140**	0.021**	0.008**	0.123*
Ers	6	0.002	0.000	0.000	0.017
PS	3	8.051**	0.092**	0.002**	0.266**
Eps	9	0.003	0.000	0.000	0.017
RS × PS	6	28.197**	0.101**	0.003**	0.130**
E	18	0.003	0.000	0.000	0.016
CV (%)		0.090	0.030	4.590	2.460

[1]* and ** indicate non-significance and significance at 5% and 1% probability levels, respectively. S.o.V: source of variations; DF: degree of freedom; B: block; RS: row spacing; Ers: error term for row spacing; PS: plant spacing; Eps: error term for plant spacing; RS × PS: row spacing × plant spacing interaction; E: experimental error; CV: coefficient of variations

Table 3. *Continuation of Table 3*

S.o.V [1]	DF	Oleic Acid	Linoleic Acid	α-Linolenic Acid	Arachidic Acid
B	3	0.002	0.001**	0.001**	0.000**
RS	2	7.695**	17.332**	0.013**	0.003**
Ers	6	0.001	0.000	0.000	0.000
PS	3	2.855**	4.360**	0.034**	0.071**
Eps	9	0.000	0.000	0.000	0.000
RS × PS	6	20.633**	6.861**	0.050**	0.012**
E	18	0.000	0.000	0.000	0.000
CV (%)		0.030	0.007	0.590	0.810

[1]* and ** indicate non-significance and significance at 5% and 1% probability levels, respectively. S.o.V: source of variations; DF: degree of freedom; B: block; RS: row spacing; Ers: error term for row spacing; PS: plant spacing; Eps: error term for plant spacing; RS × PS: row spacing × plant spacing interaction; E: experimental error; CV: coefficient of variations

Oil content

Oil content (OC) was significantly influenced by row spacing, plant spacing, and their resulting plant densities (Table 4), with the highest oil content (55.45%) observed at a row spacing of 45 cm, a plant spacing of 11 cm, and a density of 20 plants/m², compared to the lowest (47.52%) at a row spacing of 60 cm, a plant spacing of 5 cm, and a density of 33 plants/m²; moderate row spacings of 45 cm with plant spacings of 8–11 cm (densities of 20–28 plants/m²) consistently yielded higher oil contents (52.73%–55.45%), likely due to optimized light interception and reduced competition, while wider spacings of 60 cm with 5 cm plant spacing (33 plants/m²) reduced oil content, possibly due to fewer plants per unit area, with the significant RS × PS interaction ($P < 0.01$) underscoring their combined effect; additionally, regression analysis (Figure 1) revealed a quadratic relationship where oil content dipped to ~50% at 30–40 plants/m² before peaking at ~55% at 60–70 plants/m², though the low R^2 (0.0926) indicates that plant density alone explains only 9.26% of the variability, suggesting other factors like environmental conditions or genetics also play key roles.

Table 4. *Mean comparisons of interaction effects for oil content and fatty acid composition in a non-shattering sesame cultivar*

Row Spacing (cm) [1]	Plant Spacing (cm)	Density (P/m²)	Oil Content (%)	Palmitic Acid (%)	Palmitoleic Acid (%)	Stearic Acid (%)	Oleic Acid (%)	Linoleic Acid (%)	α-Linolenic Acid (%)	Arachidic Acid (%)
30	5	67	53.77^{b}	9.074^{a}	0.082^{a}	4.998^{a}	36.15^{d}	47.65^{b}	0.292^{d}	0.505^{a}
	8	42	55.10^{a}	8.872^{b}	0.064^{b}	5.053^{a}	36.21^{c}	48.31^{a}	0.419^{a}	0.458^{b}
	11	30	51.30^{c}	8.728^{c}	0.067^{b}	5.025^{a}	37.24^{b}	47.52^{c}	0.342^{c}	0.342^{d}
	14	24	48.87^{d}	8.619^{d}	0.064^{b}	5.178^{a}	40.31^{a}	46.79^{d}	0.386^{b}	0.427^{c}
45	5	44	52.11^{c}	8.775^{b}	0.173^{a}	5.013^{b}	39.43^{b}	47.70^{b}	0.207^{c}	0.622^{a}
	8	28	52.73^{b}	8.664^{d}	0.099^{c}	5.282^{a}	39.57^{a}	45.11^{d}	0.193^{d}	0.470^{b}
	11	20	55.45^{a}	8.703^{c}	0.106^{b}	5.043^{a}	36.05^{c}	47.73^{a}	0.550^{a}	0.324^{d}
	14	16	55.41^{a}	8.949^{a}	0.089^{d}	5.123^{ab}	36.06^{c}	46.82^{c}	0.269^{b}	0.432^{c}
60	5	33	47.52^{d}	8.769^{c}	0.074^{d}	4.837^{c}	37.84^{c}	47.16^{a}	0.350^{b}	0.503^{a}
	8	21	51.32^{b}	8.867^{a}	0.088^{c}	5.195^{b}	36.84^{d}	46.41^{b}	0.268^{d}	0.474^{b}
	11	15	48.31^{c}	8.556^{d}	0.102^{b}	5.649^{a}	40.85^{a}	43.49^{d}	0.299^{c}	0.431^{c}
	14	12	52.35^{a}	8.824^{b}	0.127^{a}	5.271^{b}	39.67^{b}	45.00^{c}	0.384^{a}	0.364^{d}

[1] Within each trait and treatment, means with the same letter are not significantly different (P>0.05)

Fatty acid composition

The fatty acid profiles of sesame oil were significantly influenced by row spacing and plant density, with distinct trends observed for saturated, monounsaturated, and polyunsaturated fatty acids (Table 4 and Figure 1).

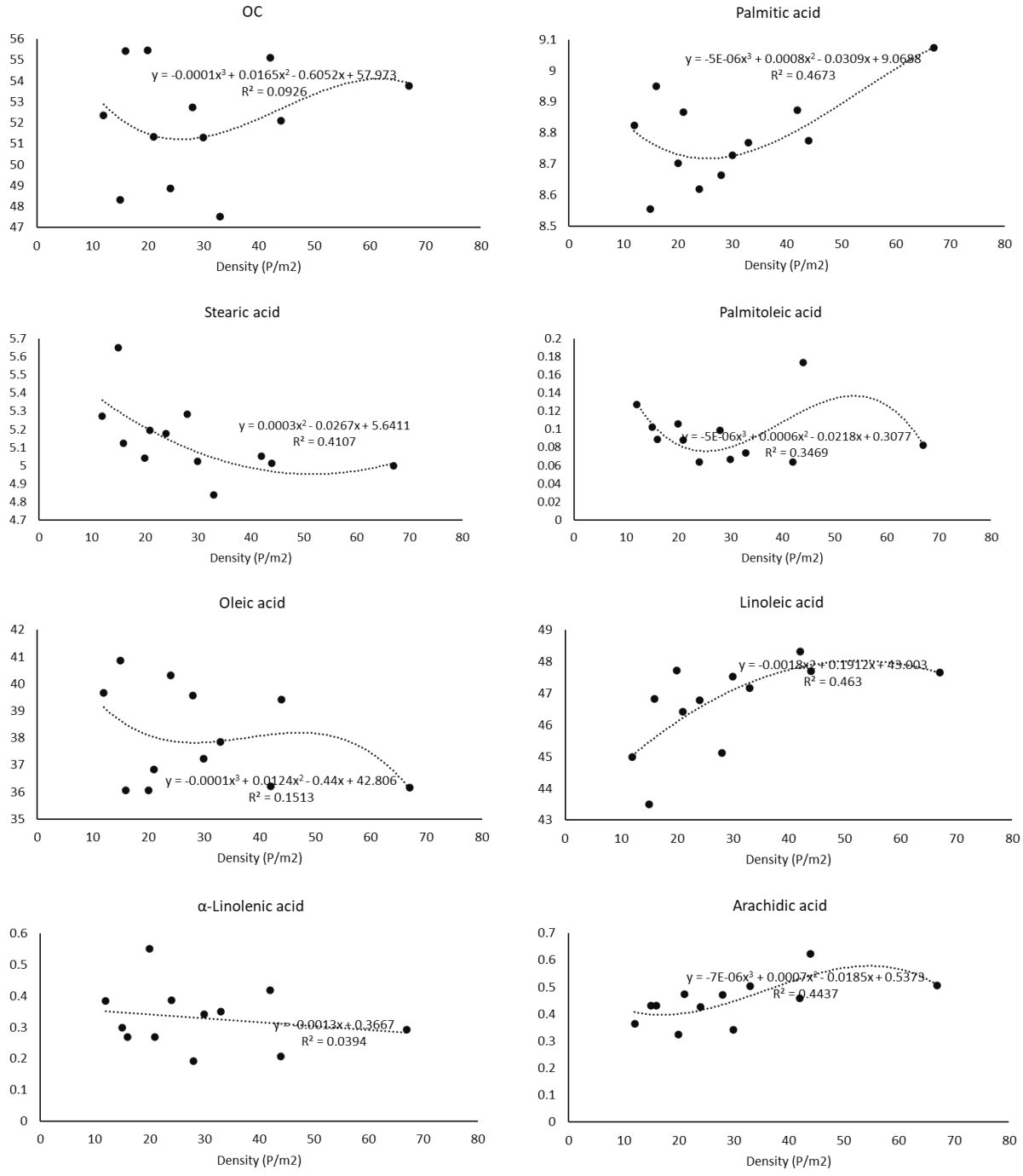

Figure 1. *The effect of different densities on oil content and fatty acid composition in a non-shattering sesame cultivar*

Palmitic Acid (Saturated): Palmitic acid concentrations ranged from 8.556% (row spacing 60 cm, plant spacing 11 cm, 15 plants/m²) to 9.074% (30 cm, 5 cm, 67 plants/m²), showing significant variation with row spacing and plant density (Table 4, Figure 1). The regression trend exhibited a U-shaped pattern, decreasing from 0 to

~30 plants/m² then increasing to 80 plants/m² (R^2 = 0.4673), suggesting moderate density influence possibly due to competition-driven metabolic adjustments. Stearic Acid (Saturated): Stearic acid concentrations varied from 4.837% (row spacing 60 cm, plant spacing 5 cm, 33 plants/m²) to 5.649% (60 cm, 11 cm, 15 plants/m²), influenced significantly by row spacing and plant density (Table 4, Figure 1). The regression trend showed a decrease to ~40 plants/m² followed by a slight increase (R^2 = 0.4107), indicating density sensitivity with potential contributions from unmodeled factors.

Palmitoleic Acid (Monounsaturated): Palmitoleic acid, present in low amounts, ranged from 0.064% (row spacing 30 cm, plant spacing 8 or 14 cm, 42 or 24 plants/m²) to 0.173% (45 cm, 5 cm, 44 plants/m²), with significant effects from row spacing and plant density (Table 4, Figure 1). The regression trend peaked at 20–30 plants/m², declining on either side (R^2 = 0.3469), reflecting high variability and minimal density impact, likely dominated by environmental factors.

Oleic Acid (Monounsaturated): Oleic acid concentrations spanned 36.05% (row spacing 45 cm, plant spacing 11 cm, 20 plants/m²) to 40.85% (60 cm, 11 cm, 15 plants/m²), showing significant variation with row spacing and plant density (Table 4, Figure 1). The regression trend increased slightly to ~20 plants/m² then gradually declined (R^2 = 0.1513), suggesting complex interactions with factors like irrigation or soil nutrients.
Linoleic Acid (Polyunsaturated): Linoleic acid concentrations ranged from 43.49% (row spacing 60 cm, plant spacing 11 cm, 15 plants/m²) to 48.31% (30 cm, 8 cm, 42 plants/m²), significantly affected by row spacing and plant density (Table 4, Figure 1). The regression trend showed a consistent increase with density from 0 to 80 plants/m² (R^2 = 0.4633), likely due to enhanced photosynthetic efficiency or stress responses.
α-Linolenic Acid (Polyunsaturated): α-Linolenic acid, present in trace amounts, ranged from 0.193% (row spacing 45 cm, plant spacing 8 cm, 28 plants/m²) to 0.550% (45 cm, 11 cm, 20 plants/m²), with significant effects from row spacing and plant density (Table 4, Figure 1). The regression trend decreased sharply with increasing density (R^2 = 0.0394), indicating minimal density influence and high variability from other factors.
Arachidic Acid (Saturated): Arachidic acid concentrations varied from 0.324% (row spacing 45 cm, plant spacing 11 cm, 20 plants/m²) to 0.622% (45 cm, 5 cm, 44 plants/m²), showing significant variation with row spacing and plant density (Table 4, Figure 1). The regression trend decreased to ~40 plants/m² and then slightly increased (R^2 = 0.4437), suggesting moderate density influence with contributions from additional factors.
The significant RS × PS interaction ($P < 0.01$) affected all fatty acid profiles, emphasizing the importance of optimizing row spacing and plant spacing for specific fatty acid outcomes (Table 4). Low coefficients of variation (CV: 0.007%–4.590%) indicate high measurement precision. Moderate row spacings (45 cm) with plant spacings of 8–11 cm (20–28 plants/m²) optimized fatty acid profiles, particularly oleic and linoleic acids, critical for sesame oil's nutritional value. However, variable R^2 values from Figure 1 suggest additional environmental or genetic factors influence fatty acid composition, warranting further investigation.

Comparison of oil content (OC) correlations with fatty acids

The correlation matrix reveals distinct relationships between oil content (OC) and the fatty acid composition of sesame seeds, providing insights into how planting arrangements influence oil quality (Figure 2). OC exhibits a moderate positive correlation with linoleic acid (0.42**), indicating that higher oil yields are associated with increased levels of this essential omega-6 polyunsaturated fatty acid, which is nutritionally beneficial for cardiovascular health. This suggests that agronomic practices favoring higher oil production, such as denser planting arrangements (e.g., row spacing of 30 cm and plant spacing of 8 cm), may also enhance linoleic acid content, reflecting shared metabolic or environmental responses. In contrast, OC shows a strong negative correlation with oleic acid (-0.66**), highlighting a significant trade-off where higher oil content corresponds to lower oleic acid levels, crucial for oil stability and oxidative resistance. This inverse relationship, observed with oleic acid peaking at 40.85% under wider spacing (row spacing 60 cm, plant spacing 11 cm), suggests that maximizing oil yield might compromise oil shelf life. OC also shows a moderate positive correlation with palmitic acid (0.55**), indicating a slight increase in this saturated fat with higher oil content, though the effect is less pronounced than with linoleic acid. Weaker correlations include a negligible negative relationship with stearic acid (-0.10), a minor positive association with α-linolenic acid (0.19), and weak negative correlations with palmitoleic acid (0.13) and arachidic acid (-0.17), suggesting these fatty acids are less directly influenced by oil content variations or respond differently to planting density.

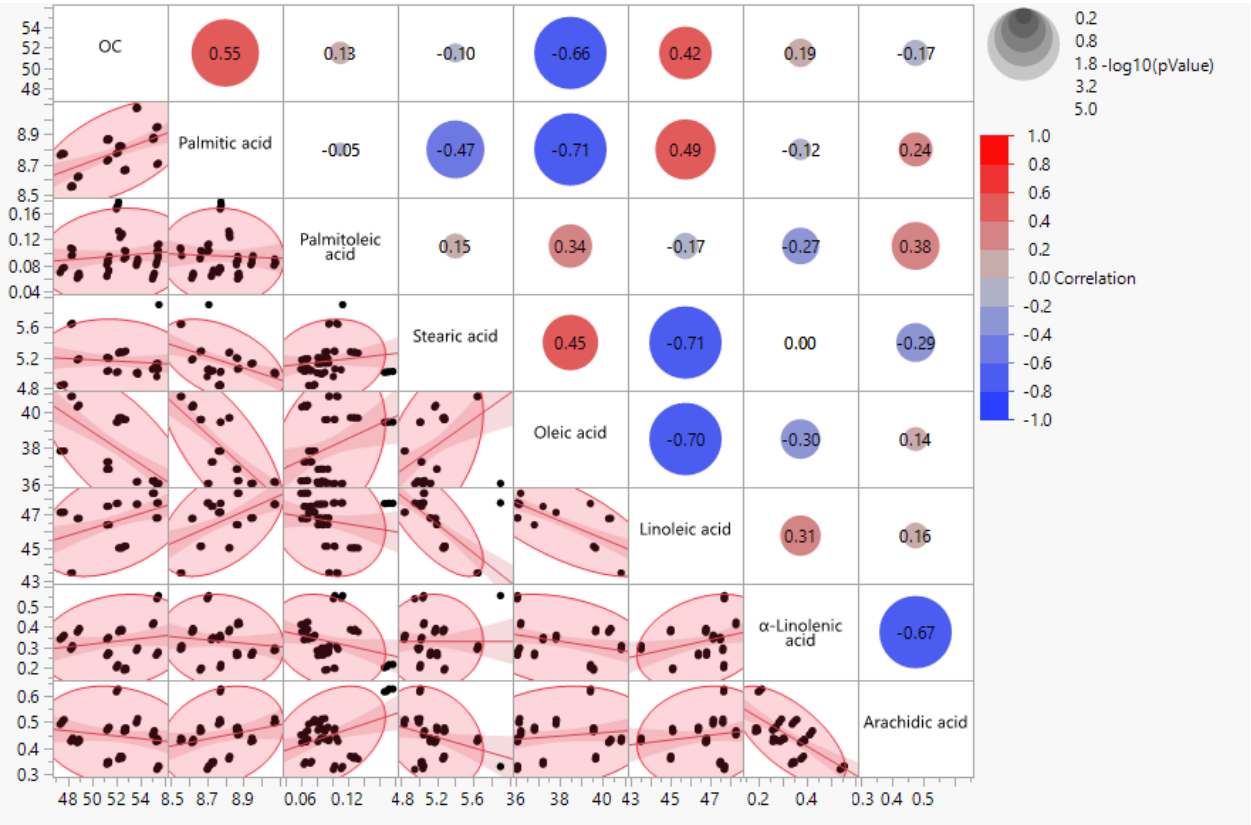

Figure 2. *Correlation heatmap of oil content and fatty acid composition in a non-shattering sesame cultivar*

Comparison of saturated, monounsaturated, and polyunsaturated fatty acids

The correlation matrix highlights complex interrelationships among saturated, monounsaturated, and polyunsaturated fatty acids, reflecting their competitive or complementary metabolic pathways in sesame oil under varying planting densities. Saturated fatty acids, such as palmitic (highest at 9.074% with row spacing 30 cm, plant spacing 5 cm), stearic (5.649% at row spacing 60 cm, plant spacing 11 cm), and arachidic (0.622% at row spacing 45 cm, plant spacing 5 cm), show mixed correlations with monounsaturated and polyunsaturated fats. Palmitic acid exhibits a strong negative correlation with oleic acid (-0.71**), a monounsaturated fat (peaking at 40.85% with row spacing 60 cm, plant spacing 11 cm), indicating a trade-off, while it shows a moderate positive correlation with linoleic acid (0.49**), a polyunsaturated fat (highest at 48.31% with row spacing 30 cm, plant spacing 8 cm), suggesting some alignment. Stearic acid, another saturated fat, has a moderate positive correlation with oleic acid (0.45**) but a strong negative correlation with linoleic acid (-0.71**), indicating competition with polyunsaturated fats but synergy with monounsaturated fats. Arachidic acid, a minor saturated fat, shows a moderate positive correlation with palmitoleic acid (0.38*), another monounsaturated fat (highest at 0.173% with row spacing 45 cm, plant spacing 5 cm), but a strong negative correlation with α-linolenic acid (-0.67**), a polyunsaturated fat (peaking at 0.55% with row spacing 45 cm, plant spacing 11 cm), highlighting distinct metabolic dynamics. Monounsaturated fats, like oleic and palmitoleic, show a moderate positive correlation (0.34*), suggesting alignment, but both have strong negative correlations with linoleic acid (-0.70** for oleic, -0.17 for palmitoleic), indicating a clear trade-off with polyunsaturated fats. Polyunsaturated fats, linoleic and α-linolenic, exhibit a moderate positive correlation (0.31*), reflecting their shared nutritional role, but both face competition from saturated and monounsaturated fats, particularly oleic acid, underscoring the need for strategic planting to balance these fatty acid profiles for nutritional and industrial purposes.

The results of the current work offer important new perspectives on how plant density and row spacing affect oil yield and fatty acid composition in a non-shattering sesame cultivar. The findings highlight areas for more research and line up with and expand current knowledge by providing useful advice for best sesame growing practices. The observed optimal combination of 45 cm row spacing and 8–11 cm plant spacing for maximizing oil content (55.45%) is consistent with prior research emphasizing the importance of moderate planting

densities. For instance, Koocheki et al. (2017) demonstrated that a diamond planting pattern with 50 plants/m² enhanced dry matter and seed yield, while Öztürk and Şaman (2012) reported that narrower spacings (30 cm) combined with intra-row spacings of 5 cm maximized seed and oil yields in second-crop sesame. Similarly, Ali et al. (2020) found that narrower spacings improved performance under rainfed conditions, though wider spacings were better suited for irrigated systems. These findings corroborate the current study, which demonstrates that moderate row spacings (45 cm) combined with intermediate plant densities (8–11 cm) optimize oil content and maintain favorable fatty acid profiles. This underscores the need for region-specific planting strategies to balance resource use and productivity. The U-shaped response of palmitic acid to plant density, where concentrations initially decreased then increased at higher densities, presents a novel finding that complements earlier work by Bhardwaj et al. (2015) on shatter-resistant dwarf sesame. While their focus was primarily on oil yield characteristics, present research reveals how metabolic adjustments under varying competition levels specifically affect saturated fatty acid biosynthesis. This observation gains additional significance when compared with findings from Alpaslan et al. (2001), who demonstrated row spacing effects on sesame seed composition but did not explore the complex density-dependent relationships documented here. Current results regarding linoleic acid's consistent increase with density (43.49%–48.31%) corroborate and expand upon Ali et al. (2020) work in semi-arid regions, where narrower row spacings enhanced sesame performance under rainfed conditions. The moderate positive correlation between oil content and linoleic acid ($r = 0.42^{**}$) suggests a physiological mechanism where increased photosynthetic efficiency at higher densities directly influences polyunsaturated fatty acid biosynthesis. This relationship is particularly relevant given linoleic acid's crucial role in cardiovascular health, as emphasized by Gouveia et al. (2017). The strong negative correlation between oleic and linoleic acids ($r = -0.70^{**}$) documented in this study provides empirical support for the competitive nature of fatty acid biosynthesis pathways previously suggested by Kim et al. (2006) and Tas et al. (2024). Their work on drought stress and nitrogen application effects showed similar inverse relationships, though current findings specifically attribute these dynamics to planting arrangement variations. This insight has practical implications for breeding programs aiming to develop sesame varieties with specific fatty acid profiles, as noted by Rauf et al. (2024) in their comprehensive review of sesame breeding achievements. The observed decrease in α-linolenic acid with increasing density, despite showing poor model fit ($R^2 = 0.0394$), contrasts with findings from Tas et al. (2024), who demonstrated significant effects of drip irrigation and nitrogen levels on sesame oil composition. This discrepancy suggests that while agronomic practices like irrigation and fertilization significantly influence α-linolenic acid levels, planting arrangements may have minimal direct impact. The low variability explained by the present model indicates other environmental or genetic factors might play more substantial roles in determining this nutritionally important omega-3 fatty acid's concentration. Results of arachidic acid's response to planting density, showing a decreasing trend followed by a slight increase, provide new data that complements earlier work by El Harfi et al. (2021) on genetic diversity in Moroccan sesame. The moderate R^2 value (0.4437) suggests that while density influences arachidic acid levels, other genetic or environmental factors also contribute significantly. This finding aligns with observations from Filimon and Worku (2018) regarding optimum inter-row spacing for sesame production under irrigation, though our study offers more precise data on how specific planting arrangements affect individual fatty acids. The complex interrelationships among different fatty acids revealed through current correlation analysis, particularly the strong negative correlations between stearic and linoleic acids ($r = -0.71^{**}$) and between oleic and linoleic acids ($r = -0.70^{**}$), highlight fundamental trade-offs in fatty acid biosynthesis. These findings complement earlier work by Koocheki et al. (2017) on planting patterns and density effects but provide more detailed biochemical insights. The observed relationships have significant ramifications for sesame breeding programs and agricultural policy development, especially considering Iran's emerging influence in the global sesame market, as discussed by Gholamhoseini and Dolatabadian (2024). The practical applications of present findings are particularly relevant for regions facing similar semi-humid, moderately warm climatic conditions as this study site. Present recommendations for 45 cm row spacing and 8–11 cm plant density offer clear guidelines for maximizing oil yield and quality, extending beyond general suggestions from Ngala et al., (2013) about inter-row spacing and plant density effects in Nigerian Sudan Savanna conditions. Furthermore, the documented relationships between planting arrangements and fatty acid profiles can inform processing industries about expected oil characteristics based on cultivation practices, supporting sustainable sesame production systems as emphasized by Sanni et al. (2024). The study's limitations, particularly regarding environmental factors not fully controlled during the experimental period, suggest avenues for future research. While meteorological data was recorded and soil properties analyzed, variations in microclimate conditions and subtle differences in field management could have influenced results. Future research should incorporate multi-year and multi-location trials to account for these variables, building

on methodological approaches suggested by Abeje et al. (2020) in their soybean spacing studies. Additionally, molecular approaches could help elucidate the genetic mechanisms underlying observed responses to planting arrangements, complementing recent advances in sesame genomics documented by Yol et al. (2021) and Teboul et al. (2022). The implications of these findings extend to economic analyses of recommended practices under different market conditions. As noted by Mohammadi et al. (2013) regarding Iran's edible oil imports, optimizing local sesame cultivation could significantly impact national food security and economic sustainability. Results of the current study provide concrete data to support strategic decisions in expanding sesame cultivation, particularly in arid and semi-arid regions where water-efficient crops are crucial, as emphasized by Gholamhoseini (2022) in his work on irrigation and nitrogen optimization. Future research directions should focus on integrating obtained findings with broader agronomic strategies. Long-term studies incorporating multiple environmental variables, as suggested by Khan and Islam (2023) in their row spacing performance analysis, would provide more comprehensive optimization strategies. Additionally, exploring the interactions between planting arrangements and other agronomic factors such as irrigation scheduling and nutrient management could build upon current findings and contribute to developing sustainable sesame production systems, as emphasized by Wacal et al. (2024) in their comprehensive review of sesame's potential benefits

CONCLUSION

This study demonstrates that optimizing planting arrangements, specifically moderate row spacings combined with plant spacings, significantly enhances oil content and maintains desirable fatty acid profiles, particularly oleic and linoleic acids, in the non-shattering sesame cultivar 'Mohajer' under semi-humid conditions in Moghan, Iran. The significant interaction between row spacing and plant density underscores their combined impact on oil yield and composition, with regression analyses revealing density-dependent trends, though variable values suggest additional environmental or genetic influences. These findings offer practical recommendations for Iranian farmers to improve local sesame production, reducing reliance on imported edible oils, while highlighting the need for further multi-year and molecular studies to refine cultivation strategies and address variability in fatty acid biosynthesis, ultimately supporting sustainable agriculture and food security in arid and semi-arid regions.

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CONFLICT OF INTEREST

The Authors declares that there are no conflicts of interest.

AUTHOR CONTRIBUTION

Conceptualization: HZT; Data collection: HZT, FS; Analysis and interpretation of results: HZT, FS; Writing - original draft: HZT, FS;Writing - review & editing: HZT, FS, AP. All authors reviewed and approved the final version of the manuscript.

ETHICAL APPROVAL

This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in MJAVL belongs to the author(s).

REFERENCES

Abeje, Y., Tadesse, T., & Ousman, Y. (2020). Effects of inter and intrarow spacing on yield and yield components of soybean (*Glycine max* L.) under rain fed condition in North western Ethiopia. *Journal of Biology, Agriculture and Healthcare, 10*(8), 38-44. https://doi.org/10.7176/JBAH/10-8-05

Ali, A. Y. A., Guisheng, Z., Hassan, A., Yagoub, S. O., Farah, G. A., Ahamed, N. E., Ibrahim, E., Ibrahim, M. E. H., Suliman, M., & Elradi, S. B. (2020). Sesame seed yield and growth traits response to different row spacings in semi-arid regions. *Univers. J. Agric. Res*, *8*(4), 88-96. https://doi.org/10.13189/ujar.2020.080402

Alpaslan, M., Boydak, E., Hayta, M., Gerçek, S., & Simsek, M. (2001). Effect of row space and irrigation on seed composition of Turkish sesame (*Sesamum indicum* L.). *Journal of the American Oil Chemists' Society*, *78*(9), 933-935. https://doi.org/10.1007/s11746-001-0366-0

Babu, S. G., Saraswathi, R., Mahalingam, A., Paramasivan, M., & Manivannan, N. (2024). Outlook on nutritional importance and breeding strategies for oil and quality improvement in sesame (*Sesamum indicum* L.). *Plant Science Today*. https://doi.org/10.14719/pst.4216

Bhardwaj, H. L., Hamama, A. A., Kraemer, M. E., & Langham, D. R. (2015). Characterization of oil yield and quality in shatter-resistant dwarf sesame produced in Virginia, USA. *Journal of Agricultural Science*, *7*(4), 87. https://doi.org/10.5539/jas.v7n4p87

El Harfi, M., Charafi, J., Houmanat, K., Hanine, H., & Nabloussi, A. (2021). Assessment of genetic diversity in Moroccan sesame (*Sesamum indicum*) using ISSR molecular markers. *OCL*, *28*, 3. https://doi.org/10.1051/ocl/2020066

FAOSTAT. (2023). Agriculture Organization of the United Nations Statistics Division (2023). *Available online at: http://www.fao.org/faostat/en/#data. Accessed Jenuary 2023*.

Filimon, Y., & Worku, W. (2018). Determination of optimum inter-row spacing and phosphorus level for sesame production (*Sesamum indicum* L) under irrigation at Arbaminch Zurya District, Southern Ethiopia. *Food Sci. Quality Manag*, *75*: 24-29.

Gebremichael, D. E. (2017). Sesame (*Sesamum indicum* L.) breeding in Ethiopia. *International Journal of Novel Research in Life Sciences*, *4*(1), 1-11.

Gedifew, S. (2024). Multivariate analyses of shattering and seed yield related morphological traits reveal high yielding sesame genotypes exhibit low degree of shattering. *Middle East Research Journal of Biological Sciences*, *4*(3): 58-71. https://doi.org/10.36348/merjbs.2024.v04i03.002

Gholamhoseini, M. (2022). Optimizing irrigation and nitrogen fertilization of Iranian sesame cultivars for grain yield and oil quality. *Journal of Food Composition and Analysis*, *108*, 104448. https://doi.org/10.1016/j.jfca.2022.104448

Gholamhoseini, M., & Dolatabadian, A. (2024). Sesame renaissance: Iran's emerging influence in the global sesame market. *OCL*, *31*, 24. https://doi.org/10.1051/ocl/2024024

Gholamhoseini, M., Zeinalzadeh-Tabrizi, H., Abbasali Andarkhor, S., Mansouri, S., Shariati, F., & Parchami-Araghi, F. (2024). The Effect of planting arrangement and plant density on the yield of non-dehiscent sesame in Sari and Moghan. *Journal of Plant Production Research*, *31*(1), 171-188. https://doi.org/10.22069/jopp.2023.21410.3045

Gouveia, L., Zago, L., & Moreira, A. (2017). Physical-chemical characterization and nutritional quality of sesame oil (*Sesamum indicum* L.). *Journal of Nutritional Health & Food Science*, *5*(3), 1-7. https://doi.org/10.15226/jnhfs.2017.00100

Habibzadeh, F., & Gholamhoseini, M. (2022). Selection of the best planting method and plant density for two sesame (*Sesamum indicum* L.) cultivars with different growth types in Karaj region. *Journal of Plant Production Research*, *29*(1), 191-207. https://doi.org/10.22069/jopp.2021.19024.2808

Imo, M. (2012). Analysis of nutritional interactions in cropping systems. *Crop Production Technologies*. https://doi.org/10.5772/28508

IRIMO. (2021). Iranian Meteorological Office Data Processing Center. *Islamic Republic of Iran Meteorological Office*.

Khan, M. A. H., & Islam, M. (2023). Performance of row spacing on the yield of sesame varieties. *Bangladesh Agronomy Journal*, *26*(1), 28-31. https://doi.org/10.3329/baj.v26i1.47645

Kim, K.-S., Ryu, S.-N., & Chung, H.-G. (2006). Influence of drought stress on chemical composition of sesame seed. *Korean Journal of Crop Science*, *51*(1), 73-80.

Koocheki, A., Mahallati, M., Nourbakhsh, F., & Nehbandani, A. (2017). The effect of planting pattern and density on yield and yield components of sesame (*Sesamum indicum* L.). *Iranian Journal of Field Crops Research*, *15*(1), 31-45. https://doi.org/10.22067/gsc.v15i1.33089

Kouighat, M., Guirrou, I., El Antari, A., El Fechtali, M., Bouchyoua, A., & Nabloussi, A. (2025). Exploring fatty acid composition, bioactive compounds, and antioxidant properties in oils of newly developed sesame mutant lines in Morocco. *Journal of the American Oil Chemists' Society*, *102*(2), 223-237. https://doi.org/10.1002/aocs.12879

Langyan, S., Yadava, P., Sharma, S., Gupta, N. C., Bansal, R., Yadav, R., Kalia, S., & Kumar, A. (2022). Food and nutraceutical functions of sesame oil: An underutilized crop for nutritional and health benefits. *Food Chemistry*, *389*, 132990. https://doi.org/10.1016/j.foodchem.2022.132990

Mohammadi, M., Hajeb, P., Seyyedian, R., Hossein Mohebbi, G., & Barmak, A. (2013). Evaluation of oxidative quality parameters in imported edible oils in Iran. *British Food Journal*, *115*(6), 789-795. https://doi.org/10.1108/bfj-feb-2011-0035

Ngala, A. L., Dugje, I. Y., & Yakubu, H. (2013). Effects of inter-row spacing and plant density on performance of sesame (*Sesamum indicum* L.) in a nigerian Sudan Savanna. *Science International (Lahore)*, *25*(3), 513-519.

Oboulbiga, E. B., Douamba, Z., Compaoré-Sérémé, D., Semporé, J. N., Dabo, R., Semde, Z., Tapsoba, F. W.-B., Hama-Ba, F., Songré-Ouattara, L. T., & Parkouda, C. (2023). Physicochemical, potential nutritional, antioxidant and

health properties of sesame seed oil: a review. *Frontiers in Nutrition*, *10*, 1127926. https://doi.org/10.3389/fnut.2023.1127926

Ozer, H. (2003). The effect of plant population densities on growth, yield and yield components of two spring rapeseed cultivars. *Plant Soil and Environment*, *49*(9), 422-426. https://doi.org/10.17221/4151-pse

Öztürk, Ö., & Şaman, O. (2012). Effects of different plant densities on the yield and quality of second crop sesame. *International Journal of Agricultural and Biosystems Engineering*, *6*(9), 800-805.

Rauf, S., Basharat, T., Gebeyehu, A., Elsafy, M., Rahmatov, M., Ortiz, R., & Kaya, Y. (2024). Sesame, an underutilized oil seed crop: breeding achievements and future challenges. *Plants*, *13*(18), 2662. https://doi.org/10.3390/plants13182662

Sanni, G. B., Ezin, V., Chabi, I. B., Missihoun, A. A., Florent, Q., Hamissou, Z., Niang, M., & Ahanchede, A. (2024). Production and achievements in sesamum indicum industry in the world: past and current state. *Oil Crop Science*. https://doi.org/10.1016/j.ocsci.2024.06.006

Tas, I., Akcura, S., Kaplan, M., Jagosz, B., Atılgan, A., Kocięcka, J., Rolbiecki, R., Liberacki, D., & Rolbiecki, S. (2024). The effect of drip irrigation and nitrogen levels on the oil and fatty acid composition of sesame and its economic analysis. *Agronomy*, *14*(9), 2092. https://doi.org/10.3390/agronomy14092092

Teboul, N., Magder, A., Zilberberg, M., & Peleg, Z. (2022). Elucidating the pleiotropic effects of sesame kanadi1 locus on leaf and capsule development. *The Plant Journal*, *110*(1), 88-102. https://doi.org/10.1111/tpj.15655

Wacal, C., Musinguzi, S. P., Ewaju, E., Atibo, C., Alowo, D., Alipa, J., & Basalirwa, D. (2024). Unravelling the potential benefits of sesame (*Sesamum indicum* L.) in cropping systems, nutritional, health, and industrial uses of its seeds–a review. *Cogent Food & Agriculture*, *10*(1), 2360766. https://doi.org/10.1080/23311932.2024.2360766

Yadav, R., Kalia, S., Rangan, P., Pradheep, K., Rao, G. P., Kaur, V., Pandey, R., Rai, V., Vasimalla, C. C., & Langyan, S. (2022). Current research trends and prospects for yield and quality improvement in sesame, an important oilseed crop. *Frontiers in Plant Science*, *13*, 863521. https://doi.org/10.3389/fpls.2022.863521

Yol, E., Basak, M., Kızıl, S., Lucas, S. J., & Uzun, B. (2021). A high-density SNP genetic map construction using ddRAD-seq and mapping of capsule shattering trait in sesame. *Frontiers in Plant Science*, *12*, 679659. https://doi.org/10.3389/fpls.2021.679659

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Research Article

Interfacial Mechanisms of O-O Type Chelating Collectors in the Flotation of Copper Minerals: A Density Functional Study

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ABSTRACT

Flotation is a widely used separation technique in mineral processing that relies on surface chemistry to recover valuable metals from low-grade ores. This study presents a theoretical evaluation of O-O type chelating collectors in the selective flotation of copper minerals, emphasizing their interactions at the colloidal and interfacial levels. Using advanced computational methods, key surface chemistry parameters—including adhesion mechanisms, electron density distributions, and binding energies—were analyzed to assess the efficiency and selectivity of these collectors. The findings demonstrate that O-O type chelating collectors establish strong and specific interactions with copper mineral surfaces, enhancing hydrophobicity and improving attachment to air bubbles. Among the studied collectors—Cupferon, Neocupferon, 2-nitroso-1-naphthol, 2,4-pentanedione, Octyl hydroxamate, and 2-Acetyl-acetanalid—Octyl hydroxamate exhibited the highest stability and affinity for Cu^{2+} ions, while 2-Acetyl-acetanalid showed the weakest performance. This study provides fundamental insights into the interfacial mechanisms governing flotation efficiency and offers guidance for optimizing reagent selection. By contributing to the design of more selective and sustainable collectors, these findings support advancements in mineral processing, environmental technologies, and interfacial science.

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INTRODUCTION

Flotation is one of the most common methods of beneficiation, which uses differences in the surface properties of minerals for their separation in water. It is significant in the metal mining and mineral processing industries, especially for the economic recovery of valuable metals from low-grade ores (Atak, 1990; Yekeler and Yekeler, 2005). Flotation is considered one of the most critical processes. developments in mining and metallurgy in the 20th century. This method has enabled the economical processing of solid fuel resources and ores. In addition to the flotation methods widely used in the mining industry for ore and coal beneficiation, flotation methods are also applied in fields such as chemical, food and environmental engineering (Chia et al., 2019). Flotation is widely used in the mineral industry, but it is also used in many other fields (Peleka et al., 2018).

The flotation process allows collectors, known as surfactants, to adsorb on the surface of certain minerals, allowing these minerals to bind to air bubbles and be transported to the surface. This method utilizes the different surface properties of the grains and the air bubbles created in the pulp. Separation of the grains is achieved by the upward movement of the grains that are in contact with the air bubble (hydrophobes) and the downward movement of the grains that are not in contact (hydrophiles) (Hacıfazlıoğlu, 2007; Valderrama and Rubio, 2008). This method has been widely applied for the recovery of copper (Gupta et al., 2023), zinc (Chen at al., 2024), lead (Kee and Shoparwe, 2024) and precious metals (Fuerstenau, 2000).

Chelating agents are organic ligands that form coordination complexes with metal ions and change their solubility, stability and reactivity. O-O-type chelating agents have functional groups containing two oxygen atoms in their structure and form chelate structures by binding to metal ions through these atoms. They are used in purification processes by selective precipitation or complexation of metal ions (Dwyer, 2012). It increases the yield of reactions by acting as a ligand in transition metal catalysts. Some O-O type chelates with antioxidant properties are used in medical treatments and drug design. It is used in the paper, textile and detergent industries to prevent unwanted reactions by binding metal ions (Torres and Kremer, 2023).

Collectors used in the flotation of copper minerals are generally compounds that change the surface chemistry and make the minerals hydrophobic. Collectors are divided into different categories according to their chemical structure. O-O type chelating collectors play a strong and important role in dealing with metal ions. In the future, more selective and efficient chelating agents can be designed by developing O-O type ligands containing new functional groups.

The main feature of such collectors is that they show a high affinity for metal ions and form stable complexes (Brooks and Fleming, 1989). Some of the O-O type chelating collectors are. Cupferone (N-nitrosofenylhydroxylamine) is a selective collector for copper minerals in an acidic solution. Neocupferon acts as a collector with its two aromatic rings in an acidic solution. Another chelating reagent for copper minerals is 2,4-pentanedione. Octyl hydroxamate is a perfect collector for copper oxide and natural copper minerals. The use of this reagent as a collector of copper oxide mineral is because it forms stable copper chelate. High solubility in water. The long chain structure helps to retain the reaction product on the surface (Fuerstenau, 2000). 2-Acetyl-acetanalite is also one of the essential collectors used in the flotation of copper minerals.

The main factors determining flotation efficiency include pH, reagent concentration, solvent medium, temperature and surface-tension relations (Marabini et al., 1988). In particular, the and ionic componentssolvent medium's dielectric constant and ionic composition directly affect the collector-mineral surface interaction (Rai, 2003). Highly efficient flotation processes depend on the collector'scollectors' adhesion force to the mineral surface. The size of the hydrophobic area formed by the collectors on the surface is one of the main parameters that increase flotation efficiency (Ackerman et al., 1999).

Computational chemistry methods are necessaryessential in understanding flotation reagents' effectiveness. Density Functional Theory (DFT) has emerged as a reliable method to determine chemical systems electronic and structural properties (Zhang et al., 2022).

In this study, the flotation efficiency of O-O type chelators were investigated using DFT. Calculations at the B3LYP/6-31G** level and then the frequency values of the O-O type chelators optimized with the

B3PW91/LANL2DZ basis set calculated were calculated in this study. The complex structures formed by O-O type chelators with Cu+2 were optimized with the B3PW91/LANL2DZ basis set, and parameters such as frequency values, relative energy (ΔE), atomic charges, and parameters such as frequency values, relative energy (ΔE), atomic charges, and HOMO-LUMO energies were evaluated.

The main objective of this study is to determine the effectiveness of O-O type chelating collectors in the flotation of copper minerals and to theoretically investigate their usability in the flotation of copper minerals. The results obtained will contribute to optimizing the choice of reagents in flotation processes, the development ofoptimizing the choice of reagents in flotation processes, and the development of more environmentally sustainable collectors.

MATERIAL AND METHODS

All calculations of isolated complexes were executed using Gaussian 98W and GaussView 6 program package (Chen et al., 1998). The optimized structures of Cu-complex were found at B3LYP functional in the gas phase. In the study, LANL2DZ and 6-311++G(d,p) basis sets were used for Cu atom and rest atoms in complexes, respectively. Geometric optimization was performed using Becke's three-parameter hybrid three-parameter exchange function (B3LYP) within the Density Functional Theory (DFT) framework. This function, which considers electron correlation and exchange interactions, is recognized as an effective method to accurately describe the electronic structure of chemical systems (Becke, 1993).

In the calculations, the 6-31G basis set was used to provide sufficient accuracy to represent the wave function of the system. To verify whether the optimized molecular structures reach a stable minimum energy conformation, the harmonic vibrational frequencies were calculated at the same level. This analysis was performed to determine whether each optimization point is a true minimum energy configuration and to detect virtual frequencies, if any.

In addition, zero-point vibrational energy (ZPE) corrections were calculated and their contribution to the total relative energy (ΔE) values was evaluated. For the ZPE corrections, a scaling factor of 0.9804, which is widely used in the literature (Tantirungrotechai et al., 2006), was applied to improve the agreement between theoretical calculations and experimental data.

To better understand the reactivity and electron distribution properties of molecules, Mulliken charge analysis was performed. The atomic charge values calculated using the Mulliken scheme (Mulliken, 1955) provide an important reference for evaluating the electrostatic properties, bond formation mechanisms and chemical reactivity of molecules.

These calculations are a reliable method for understanding molecular systems' electronic and geometrical structures and provide a fundamental source of data for predicting the interaction of flotation agents with metal surfaces.

RESULTS AND DISCUSSION

Developing and designing new chemical reagents for froth flotation remains an active area of research aimed at improving the efficiency of mineral separation processes. The use of selective, economical and highly efficient reagents plays a critical role in optimizing flotation processes. In this context, Marabini et al synthesized new compounds with chelating properties for flotation studies. The effectiveness of new flotation reagents is based on evaluating donor-acceptor interactions between donor atoms (N, S, O, etc.) in functional groups in the reagent molecule and metal surfaces. The structures of some O-O type chelating collectors Cupferon, Neocupferon, 2-nitroso-1-naphthol, 2,4-pentanedione, Octyl hydroxamate and 2-Acetyl-acetanalide are given in Fig. 1.

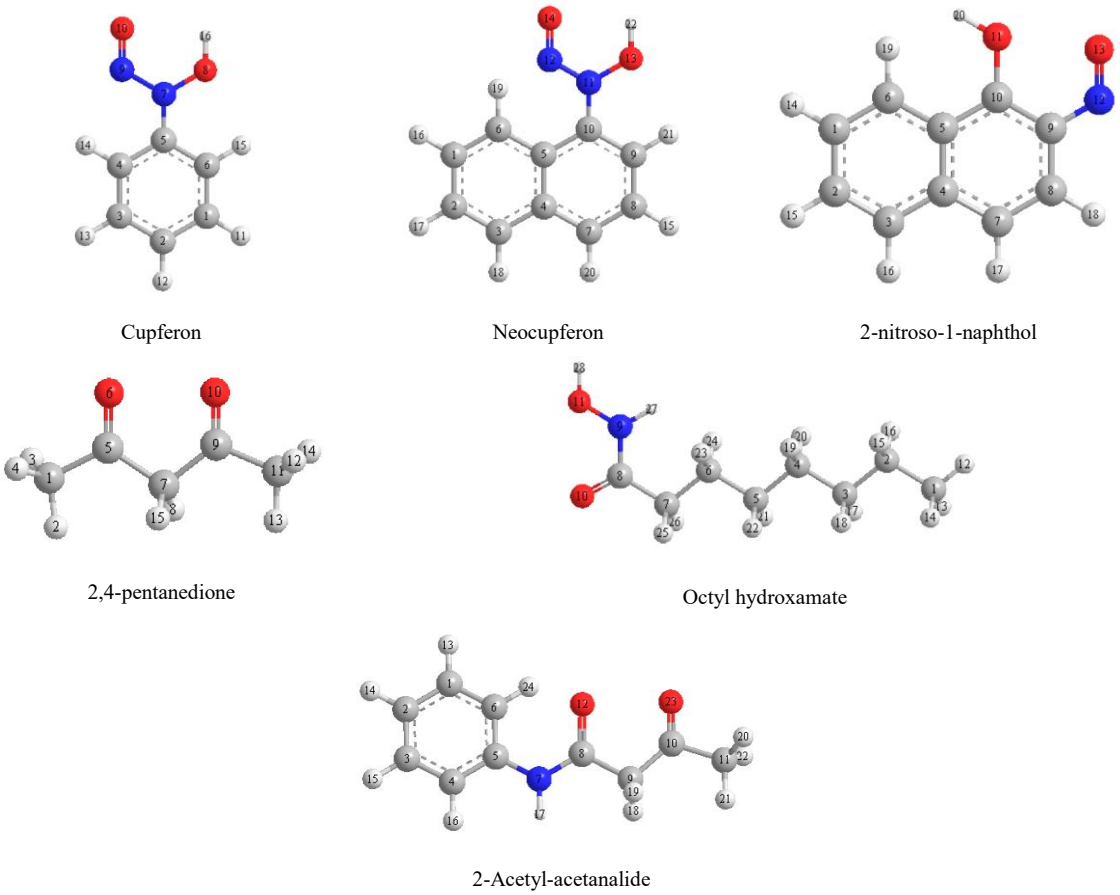
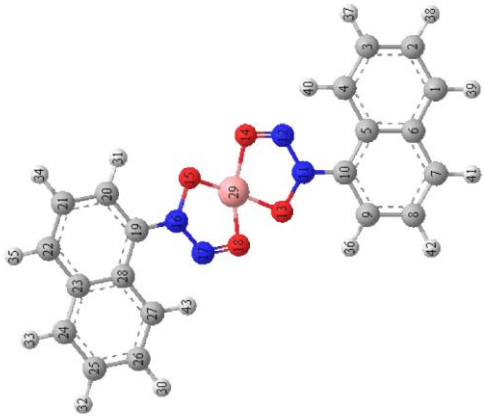


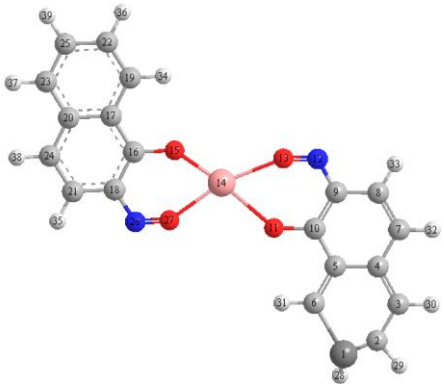
Figure 1. *Structures of Cupferon, Neocupferon, 2-nitroso-1-naphthol, 2,4-pentanedione, Octyl hydroxamate and 2-Acetyl-acetanilide*

Chelate rings are ringed structures formed by a multi-toothed ligand bonded to the central metal with at least two donor atoms. Chelate compounds show high selectivity and efficiency in flotation. For a ligand to form a chelate with a metal, it must have appropriate functional groups and form a closed heterocyclic structure with the metal through N, O, S or P atoms in these groups. The O-O type chelating agents examined in this study, Cupferon Neocupferon, 2-nitroso-1-naphthol, 2,4-pentanedione, octyl hydroxamate and 2-acetyl-acetanalide form ring complexes with Cu^{2+} ion via oxygen atoms. The efficiency of an organic compound as a flotation collector varies depending on the chemical and structural properties of the layer formed on the metal surface. The complex structures formed by O-O type chelating agents with copper minerals are given in Fig. 2.

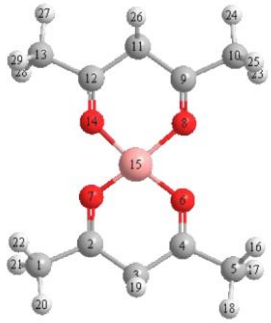
Cupferon-Cu complex



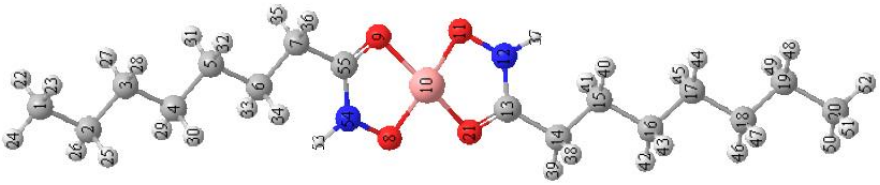
Neocupferon-Cu complex



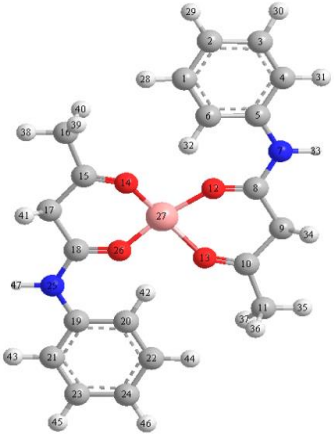
2-nitroso-1-naphthol - Cu complex



2,4-Pentanedione - Cu complex



Octyl hydroxamate - Cu complex



2-Acetyl-acetanalide - Cu complex

Figure 2. *Complex structures formed by Cupferon, Neocupferon, 2-nitroso-1-naphthol, 2,4-pentane-dione, Octyl hydroxamate and 2-Acetyl-acetanilide with copper mineral*

The calculated bond lengths for the 2-nitroso-1-naphthol molecule, one of the O-O type chelators, were determined as C-O 1.276 Å, N-O 1.290 Å and C-C-N-O tetrahedral angle 0.001°, respectively. have measured in experimental studies as 1.238 Å, 1.362 Å, and 0.6°. In this study, the calculated structural parameters of the Cu-2-nitroso-1-naphthol complex were Cu-O_1 1.924 Å, Cu-O_2 1.975 Å, C-O 1.299 Å and O-C-Cu bond angle 129.308°. The experimental data were reported as 1.927 Å, 1.975 Å, 1.305 Å and 127.090°, respectively (Odabaşoğlu et al., 2006).

The calculated bond lengths for another O-O type chelating agent, 2,4-pentanedione molecule, were determined as O-C 1.279 Å, C-C 1.429 Å and O_2-C_2 1.279 Å. Experimental studies showed these values as 1.295 Å, 1.411 Å and 1.282 Å, respectively. In the Cu-2,4-pentanedione complex, Cu-O bond lengths were equal and calculated as 1.941 Å, while experimental studies measured 1.93 Å (Hummel et al., 2009).

For octyl hydroxamate, another O-O type chelating agent, the bond lengths calculated in this study were C=O 1.285 Å, C-N 1.355 Å and N-O 1.373 Å. While the experimental data are 1.22 Å, 1.37 Å and 1.37 Å, ab initio calculations are reported as 1.22 Å, 1.34 Å and 1.44 Å, respectively. In experimental studies, these values were 1.285 Å, 1.355 Å and 1.373 Å.

All these data show that the calculated values largely agree with the experimental findings. The efficiency of flotation reagents can be related to certain quantum chemical parameters. Among these, the energy of the highest occupied molecular orbital (HOMO), which determines the electron-donating capacity of a molecule, stands out as an important parameter. The HOMO and LUMO orbitals are referred to as boundary molecular orbitals and play a critical role in determining chemical reactivity. ZPE, ΔE, ΔH, ΔG, HOMO-LUMO energy values and dipole moment values of O-O type chelators are given in Table 1.

Table 1. *ZPE, ΔE, ΔH, ΔG, HOMO-LUMO energy values and dipole moment values of Cupferon, Neocupferon, 2-nitroso-1-naphthol, 2,4-pentane-dione, Octyl hydroxamate and 2-Acetyl-acetanilide*

	B3PW91/LANL2DZ					B3LYP/6-31G**				
	Dipol moment	HOMO	LUMO	ΔE	ZPE	Dipol moment	HOMO	LUMO	ΔE	ZPE
Cupferon	9.339	-0.263	-0.173	-491.150	0.105	3.192	0.008	0.125	-491.399	0.105
Neocupferon	11.047	-0.263	-0.197	-644.66	0.153	3.281	-0.004	0.0851	- 644.995	0.151
2-nitroso-1-naphthol	9.497	-0.266	-0.203	-589.41	0.136	4.307	-0.013	0.0929	- 589.726	0.135
2,4-pentanedione	5.912	-0.316	-0.161	-344.93	0.109	5.014	-0.004	0.179	- 345.107	0.108
Octyl hydroxamate	20.864	-0.307	-0.100	-519.161	0.237	3.208	0.055	0.166	-519.436	0.235
2-Acetyl-acetanalide	9.912	-0.298	-0.164	-591.840	0.181	3.400	-0.022	0.120	-592.155	0.179

Since chemical bond formation is usually shaped by the interactions of valence electrons (Zhang et al., 2009), the HOMO orbital, which determines the spatial distribution of these electrons, is considered an important indicator in identifying regions prone to electrophilic attacks. Since flotation agents act as electron-donating species (Mohammadi-Jam et al., 2014), especially HOMO orbitals are considered in this study. The HOMO plots are given in Figure 3 and it is seen that the charge density is generally on the functional groups. However, the charge density is also distributed in the annular structure for some molecules. This is due to the participation of π electrons in the resonance in the annular structure.

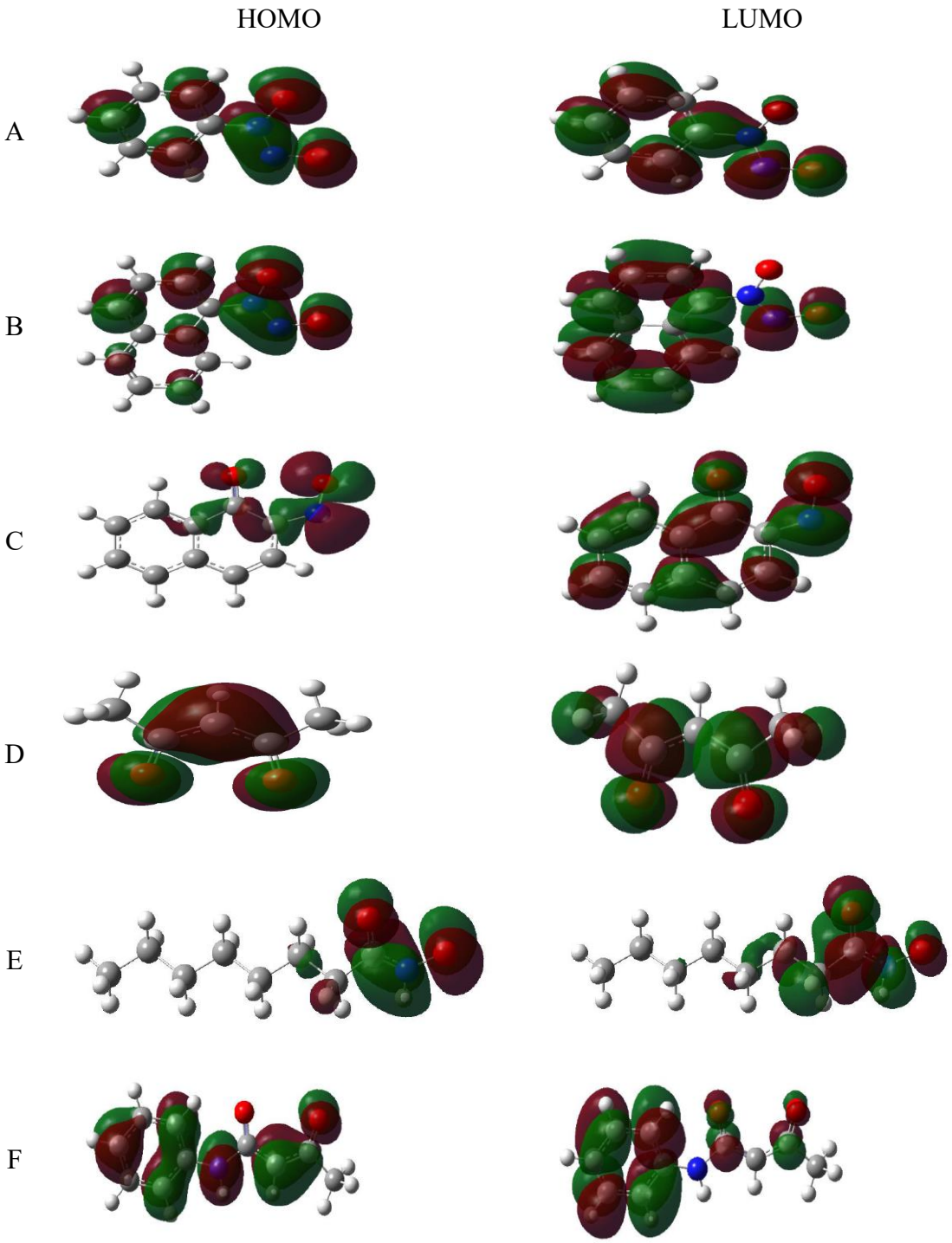


Figure 3. *HOMO-LUMO structures of Cupferon (A), Neocupferon (B), 2-nitroso-1-naphthol (C), 2,4-pentane-dione (D), Octyl hydroxamate (E) and 2-Acetyl-acetanilide (F).*

By looking at the Mulliken charge densities, we can predict which atoms the metal atom will prefer for complex formation (Lu et al., 2006). Moreover, since chemical reactions take place with valence electrons, the HOMO and LUMO orbitals, their shape and energy values in molecules also provide information about the activity of molecules. The chelating capacity of a molecule is directly related to the electronic charge distribution of the donor atoms on the ligand. Since metal atoms are electrophilic, the electron density of the electron donor atoms in the ligand compound is important for chelation. Since metal atoms are electrophilic, they prefer to bind to atoms with high electron density. The electronegativity of the O atom significantly affects the formation of the complex. Therefore, Mulliken population analysis was performed to determine the atomic charge distributions and relevant parameters were evaluated to better understand ligand-metal interactions.

Table 2. *Mulliken Charge Densities of Cupferon, Neocupferon, 2-nitroso-1-naphthol, 2,4-pentanedione, Octyl hydroxamate and 2-Acetyl-acetanalide*

	Cupferon			**Neocupferon**	
	B3PW91/LANL2DZ	B3LYP/6-31G**		B3PW91/LANL2DZ	B3LYP/6-31G**
7 N	-0.096	-0.106	11 N	-0.105	-0.074
8 O	-0.505	-0.419	12 N	-0.057	0.136
9 N	-0.068	0.155	13 O	-0.485	-0.420
10 O	-0.379	-0.320	14 O	-0.361	-0.426
	2-nitroso-1-naphthol			**2,4-pentanedione**	
	B3PW91/LANL2DZ	B3LYP/6-31G**		B3PW91/LANL2DZ	B3LYP/6-31G**
11 O	-0.334	-0.545	6 O	-0.372	-0.406
12 N	-0.068	-0.090	10 O	-0.372	-0.407
13 O	-0.345	-0.372			
	Octyl hydroxamate			**2-Acetyl-acetanalide**	
	B3PW91/LANL2DZ	B3LYP/6-31G**		B3PW91/LANL2DZ	B3LYP/6-31G**
9 N	-0.274	-0.324	7 N	-0.554	-0.653
10 O	-0.439	-0.464	12 O	-0.366	-0.601
11 O	-0.573	-0.406	23 O	-0.369	-0.532

When the Mulliken charge densities are analyzed, it is seen that the O atom is more electronegative. Mulliken charge values of octyl hydroxamate molecule were calculated as N -0.274 D, O1 -0.439 D, O2 -0.573 D. In the literature, these values were found as -0.305 D, -0.595 D, -0.588 D, respectively [15]. Atoms with a more negative charge generally have a higher electron density and a higher tendency to bond to metal ions. The most negative oxygen and nitrogen atoms have the potential to form strong coordination bonds with metal ions. Octyl hydroxamate molecule has oxygens carrying relatively strong negative charges such as (-0.573, -0.406). This suggests that it can form a stronger coordination bond with Cu^{2+} ions and be more effective in flotation. Octyl hydroxamate may show the highest binding interaction to the metal surface compared to other collectors. Although the most negative charges (-0.653, -0.601, -0.532) in the 2-Acetyl-acetanilide collector appear high for some atoms, the distribution of these values may be less symmetrical compared to Octyl hydroxamate. It is conceivable that the molecule is weak in binding ability and has a lower capacity to form a stable complex with Cu^{2+}. The nitrogen and oxygen charge distributions of Cupferon (-0.505, -0.419, -0.068, 0.155) and Neocupferon (-0.485, -0.420, -0.057, 0.136) are similar. This similarity suggests that the performance of the two compounds in flotation may also be close. 2-Nitroso-1-Naphthol carries relatively low negative charges on its oxygens (-0.334, -0.545, -0.345). 2,4-Pentanedione, on the other hand, has a charge distribution of (-0.372, -0.407) and can interact moderately with metal ions. Although these compounds do not bind as strongly as Octyl hydroxamate, they may show a certain selectivity in the flotation process. Octyl Hydroxamate is the collector that provides the strongest interaction with Cu^{2+} ions. 2-Acetyl-acetanilide was evaluated as the weakest collector. Other collectors (Cupferon, Neocupferon, 2-Nitroso-1-Naphthol, 2,4-Pentanedione) have moderate selectivity and binding capacity. The theoretical calculations agree with the experimental findings and show that computational chemistry can be effectively used in the design of flotation collectors. According to both studies, it is seen that the metal, Cu+2, will form a chelate with the O atom. Because the electron density is even higher. When the structures of the collectors are examined, it can be predicted that this structure will form a chelate with the O atom instead of the N atom. This predicted situation has also been confirmed in the studies.

The energy values required for complex formation of O-O type chelating agents are Cupferon (-646,6064966 kcal/mol), Neocupferon (-640,8290166 kcal/mol), 2 -Nitroso-1-naphthol (-632, 3733261 kcal/mol), 2,4-Pentanedione (-668,263732 kcal/mol), Octyl hydroxamate (-677,0413349 kcal/mol), 2-Acetyl-acetanalide (-

654,6166554 kcal/mol). When the energy values are ranked from higher to lower, we can say that 2-Nitroso-1-naphthol, Neocupferon, cupferon, 2-acetyl-acetanalide, 2,4-pentanedione and octyl hydroxamate are ranked. Octyl Hydroxamate (-677.0413 kcal/mol) stands out as the collector that forms the most stable complex with Cu^{2+} ions as it has the lowest (most negative) energy value. This result means it has a high electron density and exhibits strong chelation ability. It can be said that Octyl Hydroxamate will show high efficiency and selectivity in the flotation process. 2,4-Pentanedione (-668.2637 kcal/mol) and 2-Acetyl-Acetanalide (-654.6167 kcal/mol) 2,4-Pentanedione has a stability close to Octyl Hydroxamate and its flotation efficiency can be high. 2-Acetyl-Acetanalide was reported as the weakest collector in this study but its energy value is intermediate with -654,6167 kcal/mol. This indicates that it can form stable complexes in some cases but will be less effective than other collectors. Octyl hydroxamate has the strongest binding and highest flotation efficiency. 2,4-Pentanedione and 2-Acetyl-Acetanalide can form moderately stable complexes. Theoretical calculations show that Octyl hydroxamate is the best collector for flotation and provides the strongest binding to metal ions.Considering this ranking, the octyl hydroxamate collector with low energy value has a more stable structure. In the experimental study, the activity order was found to be octyl hydroxamate, cupferon, Neocupferon and 2,4- pentanedione in the order from largest to smallest. In this study, we see that the ranking between the energy values for these four collectors agrees with the experimental study.

When attention is paid to the molecules examined, five- or six-membered rings are formed during chelate formation. Cupferon, Neocupferon and octyl hydroxamate formed five-membered rings, while 2-nitroso-1-naphthol, 2,4-pentanedione and 2-acetyl-acetanalide formed six-membered rings. Accordingly, we would expect the stability of Cupferon and Neocupferon molecules to be higher, but this is not the case. Because in case of resonance in the chelate ring, the six-membered ring gives a more stable complex. For Cupferon and Neocupferon complexes forming five-ring chelates, Cupferon is more stable. Because π electrons resonate on a single benzene ring in Cupferon and on a double benzene ring in Neocupferon. Therefore, Cupferon will be more active than Neocupferon. Among the O-O type chelators, octyl hydroxamate and 2-acetyl-acetanalide contain similar functional groups. In the 2-acetyl-acetanalide molecule, electrons on the O atom will be attracted due to the resonance effect. In octyl hydroxamate, the electron density of O atoms will increase due to the inductive effect. Therefore, we expect octyl hydroxamate to be more stable than 2-acetyl-acetanalide. This shows that the values calculated in this study agree with those in the experimental studies.

CONCLUSION

This study provides a theoretical framework for understanding the interfacial mechanisms governing the flotation efficiency of O-O type chelating collectors in the selective recovery of copper minerals. By employing computational approaches, key chemical parameters—including HOMO energies, atomic charges, and binding energies—were analyzed to evaluate the stability and selectivity of different collectors. The results demonstrate that Octyl hydroxamate exhibits the highest reactivity and strongest interaction with Cu^{2+} ions, forming a stable chelate, whereas 2-Acetyl-acetanilid shows the weakest binding affinity. The strong correlation between theoretical predictions and experimental findings highlights computational techniques' reliability in characterizing flotation reagents' activity. These insights contribute to the rational design of more effective and environmentally sustainable collectors, aligning with colloid and interface science advancements, adsorption processes, and interfacial chemistry. The ability to predict and optimize collector performance at the molecular level offers valuable implications for industrial flotation processes, mineral beneficiation, and broader applications in catalysis, environmental remediation, and nanomaterials. Future studies can further refine these approaches by integrating experimental validations with advanced molecular dynamics simulations, expanding the scope of computational chemistry in optimizing reagent selection and improving flotation technologies.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTION

Adem Necip: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. Hülya Yekeler: Writing – review & editing, Methodology, Investigation, Data curation Conceptualization.

REFERENCES

Ackerman, P., Harris, G., Klimpel, R., & Aplan, F. (1999). Use of chelating agents as collectors in the flotation of copper sulfides and pyrite. *Mining, Metallurgy & Exploration, 16*(1), 27–35.

Atak, S. (1990). *Flotasyon ilkeleri ve uygulaması*. ĐTÜ Vakfı.

Becke, A. D. (1993). Density-functional thermochemistry. III. The role of exact exchange. *The Journal of Chemical Physics, 98*(7), 5648–5652.

Brooks, M., & Fleming, I. (1989). Modernization of the Nchanga Flotation plant: A comparison of flotation cells and columns. *Mining Magazine, 160*(7), 34–35.

Chen, W., Wong, M., Andres, J., Head-Gordon, M., Replogle, E., & Pople, J. (1998). *Gaussian 98, revision A.7*. Gaussian, Inc.

Chen, Y., Sun, Y., & Han, Y. (2024). Efficient flotation separation of lead–zinc oxide ores using mineral sulfidation reconstruction technology: A review. *Green and Smart Mining Engineering, 1*(2), 175–189.

Chia, S. R., Mak, K. Y., Khaw, Y. J., Suhaidi, N., Chew, K. W., & Show, P. L. (2019). An efficient and rapid method to extract and purify protein–Liquid triphasic flotation system. *Bioresource Technology, 294*, 122158.

Dwyer, F. (2012). *Chelating agents and metal chelates*. Elsevier.

Fuerstenau, D., Herrera-Urbina, R., & McGlashan, D. (2000). Studies on the applicability of chelating agents as universal collectors for copper minerals. *International Journal of Mineral Processing, 58*(1–4), 15–33.

Gupta, M., Huang, K., Noble, A., & Yoon, R.-H. (2023). Improving the performance of a low-grade porphyry copper ore flotation plant using a simulator that can predict grade vs. recovery curves. *Minerals Engineering, 202*, 108243.

Hacıfazlıoğlu, H. (2007). Alternatif flotasyon yöntemlerinin tanıtılması. *Bilimsel Madencilik Dergisi, 46(3)*, 23-41.

Hummel, M., Rubatscher, E., Wurst, K., Laus, G., Jaitner, P., & Schottenberger, H. (2009). Crystal structure of 3-(4-azidophenyl) pentane-2, 4-dione, C11H11N3O2. *Zeitschrift für Kristallographie-New Crystal Structures, 224*(1–4), 699–701.

Kee, L. C., & Shoparwe, N. F. (2024). Advances in membrane technology for gold extraction: A comprehensive review. *Malaysian Journal of Bioengineering and Technology, 1*(2), 121–129.

Lu, H., Dai, D., Yang, P., & Li, L. (2006). Atomic orbitals in molecules: General electronegativity and improvement of Mulliken population analysis. *Physical Chemistry Chemical Physics, 8*(3), 340–346.

Marabini, A., Alesse, V., & Barbaro, M. (1988). New synthetic collectors for selective flotation of zinc and lead oxidized minerals. In *XVI International Mineral Processing Congress* (pp. 1197–1208). Elsevier.

Mohammadi-Jam, S., Burnett, D., & Waters, K. (2014). Surface energy of minerals–Applications to flotation. *Minerals Engineering, 66*, 112–118.

Mulliken, R. S. (1955). Electronic population analysis on LCAO–MO molecular wave functions. I. *The Journal of Chemical Physics, 23*(10), 1833–1840.

Odabaşoğlu, C. M., Albayrak, O., & Büyükgüngör, O. (2005). 2,6-Dimethyl-1,4-benzoquinone 4-monooxime. *Crystal Structure Communications, 61*(4), o240–o242.

Peleka, E. N., Gallios, G. P., & Matis, K. A. (2018). A perspective on flotation: A review. *Journal of Chemical Technology & Biotechnology, 93*(3), 615–623.

Rai, B. (2003). Molecular modeling and rational design of flotation reagents. *International Journal of Mineral Processing, 72*(1–4), 95–110.

Tantirungrotechai, Y., Phanasant, K., Roddecha, S., Surawatanawong, P., Sutthikhum, V., & Limtrakul, J. (2006). Scaling factors for vibrational frequencies and zero-point vibrational energies of some recently developed exchange-correlation functionals. *Journal of Molecular Structure: THEOCHEM, 760*(1–3), 189–192.

Torres, J., & Kremer, C. (2023). Coordination chemistry of lanthanide ions with X-(CH2-COO-)2 (X= O, NH, S) ligands: The leading role of X as carboxylate-connecting group. *Coordination Chemistry Reviews, 494*, 215347.

Valderrama, L., & Rubio, J. (2008). Unconventional column flotation of low-grade gold fine particles from tailings. *International Journal of Mineral Processing, 86*(1–4), 75–84.

Yekeler, M., & Yekeler, H. (2005). Molecular modeling study on the relative stabilities of the flotation products for arsenic-containing minerals: Dixanthogens and arsenic (III) xanthates. *Journal of Colloid and Interface Science, 284*(2), 694–697.

Zhang, H., Sun, W., Zhang, C., He, J., Chen, D., & Zhu, Y. (2022). Adsorption performance and mechanism of the commonly used collectors with oxygen-containing functional group on the ilmenite surface: A DFT study. *Journal of Molecular Liquids, 346*, 117829.

Zhang, L., Ying, F., Wu, W., Hiberty, P. C., & Shaik, S. (2009). Topology of electron charge density for chemical bonds from valence bond theory: A probe of bonding types. *Chemistry–A European Journal, 15*(12), 2979–2989.

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Research Article

0900 Ziraat ve Starks Gold Kiraz Çeşitlerinde Mineral Madde Kompozisyonunun Yıllara ve Farklı Bitki Kısımlarına Göre Değişimi

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ÖZET

Bu çalışma kapsamında, '0900 Ziraat' ve 'Starks Gold' kiraz çeşitlerinde, birbirini takip eden 2019 ve 2020 yıllarında yaprak, meyve ve meyve sapının bazı mineral maddelerce kompozisyonu tayin edilerek; yıllar, çeşitler ve farklı bitki kısımları arasındaki farklılıklar araştırılmıştır. Çalışma sonucunda, kirazın önemli mineral kaynağı olduğu kanaatine ulaşılırken, mineral kompozisyonun başta çeşit olmak üzere, yetiştiricilik yapılan sezonun iklim şartlarına ve bitki kısımlarına göre değişkenlik gösterdiği tespit edilmiştir. 'Starks Gold' çeşidi; N (%1.69), P (2484.82 mg kg^{-}), K (32484.15 mg kg^{-}), Ca (7998.63 mg kg^{-}) ve Zn (48.95 mg kg^{-}) mineralleri yönüyle öne çıkarken, '0900 Ziraat' ise Na (1065.02 mg kg^{-}) birikimiyle dikkat çekici bulunmuştur. İncelenen mineraller genel olarak miktar yönüyle; yaprak> meyve > sap şeklinde sıralanmıştır. Bu durum, yaprakların temel üretim merkezi konumunda olduğunu doğrularken, meyvelerin taşınım merkezi ve sapların ise aracı pozisyonunda olduğunu göstermiştir. Hasada yakın dönemde, hava ve toprak neminde görülen düşüşün, mineral birikimini tetiklediği ve yıllar arasında farklılığa sebep olduğu düşünülmektedir. Temel bileşen analizi kullanılarak üretilen Bi-plot grafiğinde toplam varyasyonun %97.5'i açıklanırken, incelenen minerallerin tamamı değişen seviyelerde birbirleri ile pozitif ilişki içerisinde tespit edilmiştir.

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Anahtar kelimeler: *Prunus avium, Pedisel, Mineraller, PCA, Korelasyon*

Mineral Composition Variation of 0900 Ziraat and Starks Gold Sweet Cherry Varieties According to Years and Different Plant Parts

ABSTRACT

This study aimed to determine the mineral content of the leaves, fruits, and fruit stalks of the cherry varieties "0900 Ziraat" and "Starks Gold" in the consecutive years 2019 and 2020 by revealing the variations among the years, varieties, and plant parts. The study's results indicated that cherries are a significant source of minerals but the mineral composition changes depending on the plant parts, growing seasons, and variety. 'Starks Gold' was discovered to be exceptional with its accumulation of N (%1.69), P (2484.82 mg kg-), K (32484.15 mg kg-), Ca (7998.63 mg kg-), and Zn (48.95 mg kg-) minerals, whereas '0900 Ziraat' stands out with its Na (1065.02 mg kg-) accumulation. The analyzed minerals generally were ranked as follows: leaf > fruit > stalk regarding the quantity. This demonstrated that the leaves were the main production center, while the fruits were the transport center and the stalks were the intermediary positions. It is thought that the decrease in air and soil moisture in the period close to harvest triggers mineral accumulation and causes differences between years. The Bi-plot graph created by principal component analysis explained 97.5% of the total variation and examined minerals were positively correlated with each other at varying levels.

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GİRİŞ

Tüketicilerin sağlık üzerine pozitif etkiler barındıran, fonksiyonel gıdalara eğilimi giderek artmaktadır (Baker ve ark., 2022). Bu bağlamda çeşitli ve zengin biyokimyasal içeriğe sahip türlerden birisi olan kiraza, günlük diyet içerisinde yer verilmesinin oksidatif stresi baskıladığı, kronik rahatsızlıklara iyi geldiği, diyabetik, kardiyovasküler ve kanser türevlerini engellemek üzere pozitif etki gösterdiğinin altı çizilmektedir (Gonçalves ve ark., 2019; Fonseca ve ark., 2022; Arbizu ve ark., 2023).

Son yıllarda Avrupa ülkelerinde şiddet ve sıklığını arttıran yaz yağışları, kiraz meyvelerinde çatlamalara sebep olmakta ve bu ülkelerde kiraz yetiştiriciliğinden kaçışlar görülmektedir (Quero-García ve ark., 2021). Nitekim, 2015 yılında (535.000 ton), %20'sini tek başımıza karşıladığımız kiraz türünde, 2021 yılında Dünya üretimindeki payımız %25'e yükselmiş durumdadır (690.000 ton). Ancak, ihracat miktarımız henüz 70.000 ton dolaylarında olup, potansiyelimizin oldukça altındadır (FAO, 2021). Kiraz üretiminde Dünya'ya liderlik eden ülkemizin, kiraz pazarında da lider olabilmesi için, üretilen kirazların taze olarak pazarlanmasına ek olarak, katma değer kazandırılmış formlarda da pazarlanması, kirazda arzu edilen dış gelirin yakalanmasında önemli olabilir. Bu bağlamda, meyve haricinde kalan kısımlarının da değerlendirilmesi ön plana çıkabilir. Kiraz bitkisine ait yapraklar sarma olarak değerlendirildiği gibi farklı gıdaların içerisine tat ve aroma düzenleyici olarak da ilave edilmektedir. Sapları ise özellikle diüretik etki yönüyle alternatif tıpta uzun yıllardır değerlendirilmektedir (Faienza ve ark., 2020; Maxiselly ve ark., 2022). Ayrıca bu kısımlar, antioksidan ve anti-inflamatuar etkilere sahip zengin fenolik bileşikler içerdiği için yaşlanma karşıtı ve detoksifikasyon özelliklerinde olup, kozmetik ürünlere ilave edilmektedir (Švarc-Gajić ve ark., 2018; Gonçalves ve ark., 2022; García-Villegas, 2024).

Yapılan bir çalışmada, kirazda on sekiz mineral madde bulunduğu vurgulanırken (Nunes ve ark., 2022), minerallerin bitki dokularının yapılarında yer almasına ilave olarak, metabolizma ve bağışıklık sistemi enzimlerinin aktivasyonları için önemine değinilmiştir. Fotosentetik pigmentlerin yapısında yer alan mineraller, stoma hareketlerini regüle ederek, bitkilerin su dengesinde kilit rol oynarlar (Kelebek ve Selli, 2011; Morhart ve ark., 2016; Şimşek ve Süfer, 2021). Bitkiler vasıtası ile alınan mineraller, canlılarda; kemik ve diş gibi organların yapısında direk bulunurken, sinir ve kas sistemlerinin düzgün çalışmasını sağlar. Homeostazinin devamlılığında, hormon üretiminde, bağışıklığın sağlanmasında, enerji ve antioksidan mekanizmalarının etkinliğinde önemli görevler üstlenirler (Quintaes ve Diez-Garcia, 2015). Bu yönleriyle öne çıkan kirazın taze tüketimine ek olarak farklı formata sahip ürünlerin içerisinde kullanım potansiyelinin oldukça yüksek olduğu belirtilmiştir (Nunes ve ark., 2022). Bu bağlamda, farklı bitki organlarında miktarlarının bilinmesi hem beslenme hem de taşınım fizyolojisinin bilinmesi bakımından önemlidir.

Bu çalışmada, ülkemizin en popüler, yerli ve dış pazarda "Türk kirazı" olarak tanınan 0900 Ziraat ve bu çeşide tozlayıcı olarak kullanılan, meyveleri taze tüketimden daha çok işlenerek tüketilen Starks Gold çeşidinin farklı kısımları bazı minerallerce karakterize edilerek, kompozisyonlarına, taşınımlarına ve aralarındaki ilişkilere dair bilgilere yer verilmiştir.

MATERYAL ve YÖNTEM

Çalışma 2019 ve 2020 yıllarında yürütülmüş olup, materyal olarak, 2011 yılında, MaxMa-14 anacına aşılı, 5m*4m dikim mesafelerine sahip '0900 Ziraat' ve 'Starks Gold' çeşitleri kullanılmıştır. Damla sulama yöntemi kullanılan parselde, yıllık bakım işlemleri rutin şekilde yürütülmüştür. Materyal olarak kullanılan bitkiler, Eskişehir (Merkez) ekolojik koşullarında yetiştirilmiştir. Deneme yerinin genel iklimsel özelliklerine ait bilgiler Tablo 1'de verilmiştir. Deneme dönemini içine alan Mart-Temmuz döneminde; 2019 ve 2020 yılları uzun yıllar ortalamasına göre genellikle daha az yağışlı ve daha kurak geçmiştir. Özellikle 2020'de yağışların ve nemin düşük olması, bu dönemin kurak geçtiğini düşündürmektedir. Sıcaklıklar ise her iki yılda da uzun yıllar ortalamasına yakın seyretmiştir.

Tablo 1. *Deneme alanına ait iklimsel özellikler*

YAĞIŞ (mm)													
	Ocak	**Şubat**	**Mart**	**Nisan**	**Mayıs**	**Haziran**	**Temmuz**	**Ağustos**	**Eylül**	**Ekim**	**Kasım**	**Aralık**	**Toplam**
Uzun Yıllar	38.7	32.5	**33.4**	**35.0**	**44.8**	**30.6**	**14.0**	7.8	14.4	27.0	29.2	45.1	352.4
2019	60.2	50.1	**13.4**	**26.7**	**42.2**	**45.7**	**33.5**	2.4	5.0	18.3	33.9	74.1	405.5
2020	52.7	43.3	**20.0**	**13.0**	**38.0**	**73.3**	**1.2**	1.0	6.0	37.6	1.4	9.8	299.2
ORTALAMA SICAKLIK (°C)													
	Ocak	**Şubat**	**Mart**	**Nisan**	**Mayıs**	**Haziran**	**Temmuz**	**Ağustos**	**Eylül**	**Ekim**	**Kasım**	**Aralık**	**Ortalama**
Uzun Yıllar	0.3	4.7	**9.3**	**13.1**	**16.5**	**20.4**	**23.3**	22.9	20.0	12.9	7.5	3.6	12.8
2019	4.3	3.4	**6.3**	**9.5**	**16.5**	**20.9**	**21.3**	22.3	18.1	14.2	7.9	2.9	12.3
2020	0.3	4.1	**8.2**	**10.9**	**16.3**	**19.5**	**23.2**	23.4	21.5	16.1	6.3	5.7	13.0
ORTALAMA NEM (%)													
	Ocak	**Şubat**	**Mart**	**Nisan**	**Mayıs**	**Haziran**	**Temmuz**	**Ağustos**	**Eylül**	**Ekim**	**Kasım**	**Aralık**	**Ekstrem**
Uzun Yıllar	98.2	92.6	**81.6**	**67.8**	**86.1**	**83.3**	**75.8**	74.1	68.1	79.6	80.3	93.6	81.8
2019	91.0	79.6	**64.5**	**69.3**	**65.1**	**67.9**	**62.3**	61.0	62.1	70.1	76.2	89.9	71.6
2020	78.7	70.8	**63.5**	**57.2**	**58.0**	**60.5**	**58.0**	52.1	59.9	73.8	72.7	77.2	65.5

Kaynak: *Her metriğe ait aylık ortalamalar Türkiye Cumhuriyeti Çevre Şehircilik ve İklim Değişikliği Bakanlığı, Devlet Meteoroloji İşleri Genel Müdürlüğü tarafından sağlanmaktadır.*

Örneklemeler, Meyvelerin olgunlaştığı Temmuz ayı içerisinde yapılmıştır. Meyvelerin hasat edilmesinde; tat ve renklenme kriter olarak dikkate alınmıştır. Sap örnekleri, meyve analizi yapılan meyvelerin sapı olacak şekilde seçilmiştir. Aynı gün alınan yaprak örneklerinde ise gelişimini tamamlamış en genç yapraklar seçilmiştir. Tüm örnekler zaman kaybetmeden laboratuvar ortamına aktarılarak, analizler için hazırlanmaya başlanmıştır. Saf suyla muamele edilen bitki kısımları, filtre kâğıdı ile kurutulup, havalandırıldıktan sonra sabit ağırlığa ulaşıncaya kadar 65 °C'ye ayarlanmış etüve alınmıştır. Kurutulan örnekler, öğütme değirmeni kullanılarak un kıvamına getirildikten sonra 0.2 g'mı nitrik asit (HNO_3) ve hidrojen peroksit (H_2O_2) (2:3) ile yaş yakma yöntemine göre mikrodalga fırında çözündürülmüştür. Ekstraksiyonu yapılan numunelerde; (potasyum (K), fosfor (P), çinko (Zn), demir (Fe), bakır (Cu) ve magnezyum (Mg) konsantrasyonları İndüktif Eşleşmiş Plazma Kütle Spektrometrisi (ICP-MS) (Agilent 7500ce, Agilent Technologies, Santa Clara, ABD) kullanılarak belirlenmiştir (Dağhan ve ark., 2020). Azot tayini Kacar ve Inal (2008) tarafından önerilen Kjeldahl metodunda bazı modifikasyonlar yapılarak ölçülmüştür. Gerçekleştirilen mineral analizlerinin doğrulaması aynı analitik yöntemler ile referans örneğin (domates yaprağı; 1573a-NIST, Gaithersburg, MD, ABD) element içerikleri belirlenerek yapılmıştır.

Araştırma, tesadüf parselleri faktöriyel deneme desenine göre tasarlanarak, beş tekerrürlü olarak yürütülmüştür. İncelenen özelliklerin, yıllar, çeşitler ve farklı bitki kısımları arasında istatistiksel olarak önemli farklılıklar gösterip göstermediği Minitab-17 paket programında, GLM prosedürü kullanılarak tespit edilmiştir. Faktörler arası farklılıkların ortaya çıkarılmasında, Tukey çoklu karşılaştırma testi kullanılmıştır. Özellikler arasındaki ilişkilerin ortaya çıkarılmasında, korelasyon analizinden faydalanılmıştır. Veri setinin, faktörlere göre dağılımını görsel olarak şematize etmede, temel bileşen analizi kullanılmıştır (Zar, 2013).

BULGULAR VE TARTIŞMA

Varyans analizi sonuçları

Yapılan çalışmada, '0900 Ziraat' ve 'Starks Gold' kiraz çeşitlerinin meyve, pedisel ve yaprak örneklerinin mineral madde içerikleri birbirini takip eden iki yıl boyunca incelenmiştir. Her bir faktörün (yıllar, çeşitler, bitki kısımları) ve faktörler arası interaksiyonların mineral madde içerikleri üzerindeki etkileri değerlendirilmiş olup, sonuçlar Çizelge 2'de verilmiştir. Bulgular, incelenen minerallerin büyük kısmında; yıllar, çeşitler ve bitki kısımları arasında anlamlı farklılıklar olduğunu göstermiştir (Tablo 1). Yıl*çeşit interaksiyonu incelenen tüm mineraller üzerine önemli bulunurken, çeşit*bitki kısımları interaksiyonu da Cu hariç tüm minerallerin

miktarı üzerine oldukça önemli düzeyde etkili belirlenmiştir. Yıl*bitki kısımları interaksiyonu ise N, K, Mg, Na, Fe ve Mn miktarlarına anlamlı etkide bulunmuştur.
Yılların minarel madde içerikleri üzerine etkisi anlamlı bulunurken, 2019 ve 2020 yılları arasında mineral madde kompozisyonu değişim göstermiştir. Bu bağlamda, azot (N), fosfor (P), potasyum (K), kalsiyum (Ca), magnezyum (Mg), sodyum (Na) ve mangan (Mn) mineralleri yıllar arasında anlamlı değişimler gösterirken, Çinko (Zn), Demir (Fe), bakır (Cu) ve bor (B) mineralleri ise istatistiksel olarak önemsiz bulunmuştur (Tablo 1). N, P, K, Ca, Mg ve Mn mineralleri çalışmanın ilk yılında sırası ile %1.54, 2277.77 mg kg^{-}, 30988.21 mg kg^{-}, 7336.23 mg kg^{-}, 1437.24 mg kg^{-} ve 32.09 mg kg^{-} düzeylerinde ölçülürken, takip eden yılda sırası ile %1.65, 2493.53 mg kg^{-}, 32013.97 mg kg^{-}, 8027.10 mg kg^{-}, 1528.46 mg kg^{-} ve 36.40 mg kg^{-} seviyelerine yükselmiştir. Tersi olarak Na 2019 yılında (1073.92 mg kg^{-}), 2020 yılına (993.41 mg kg^{-}) göre daha yüksek bulunmuştur (Tablo 1).

'0900 Ziraat' ve 'Starks Gold' kiraz çeşitlerinin mineral madde içerikleri karşılaştırıldığında, Fe, Mn, Cu ve B ve hariç incelenen tüm mineraller çeşitler arasında önemli farklılıklar göstermiştir (Tablo 1). 'Starks Gold' çeşidi; N (%1.69), P (2484.82 mg kg^{-}), K (32484.15 mg kg^{-}), Ca (7998.63 mg kg^{-}) ve Zn (48.95 mg kg^{-}) mineralleri yönüyle öne çıkarken, '0900 Ziraat' ise Na (1065.02 mg kg^{-}) birikimiyle dikkat çekici bulunmuştur.

Yapılan çalışmada, bitki kısımlarının (meyve, meyve sapı ve yaprak) mineral madde içerikleri incelenmiş ve ölçülen miktarların tüm mineraller maddeler için istatistiksel olarak anlamlı farklılıklar gösterdiği belirlenmiştir. Yapraklar, azot (%1.93), fosfor (2642.39 mg/kg), potasyum (35044.08 mg/kg), magnezyum (1673.66 mg/kg), sodyum (1198.99 mg/kg), çinko (64.54 mg/kg), demir (141.43 mg/kg), mangan (43.36 mg/kg), bakır (40.37 mg/kg) ve bor (38.25 mg/kg) içeriklerinde en yüksek değerlere sahip olup, bu durum yaprakların besin depolama kapasitesinin yüksek olduğunu göstermektedir. Kalsiyum (8466.75 mg/kg) bakımından ise meyve öne çıkarken, genel olarak yapraklardan daha düşük, ancak meyve saplarından daha yüksek mineral içeriklerine sahiptir. Meyve sapları ise tüm minerallerde en düşük değerlere sahiptir, bu da sapların besin depolama kapasitesinin meyve ve yaprağa göre daha sınırlı olduğunu göstermektedir.
Minerallere ait varyasyon katsayıları (CV) incelendiğinde; bor (%43.67), bakır (%42.35), çinko (%38.55) ve Mangan (%35,54) minerallerinde yüksek katsayılar elde edilirken, diğer minerallerde faktörlere bağlı varyasyonların daha düşük seviyelerde olduğu görülmüştür.

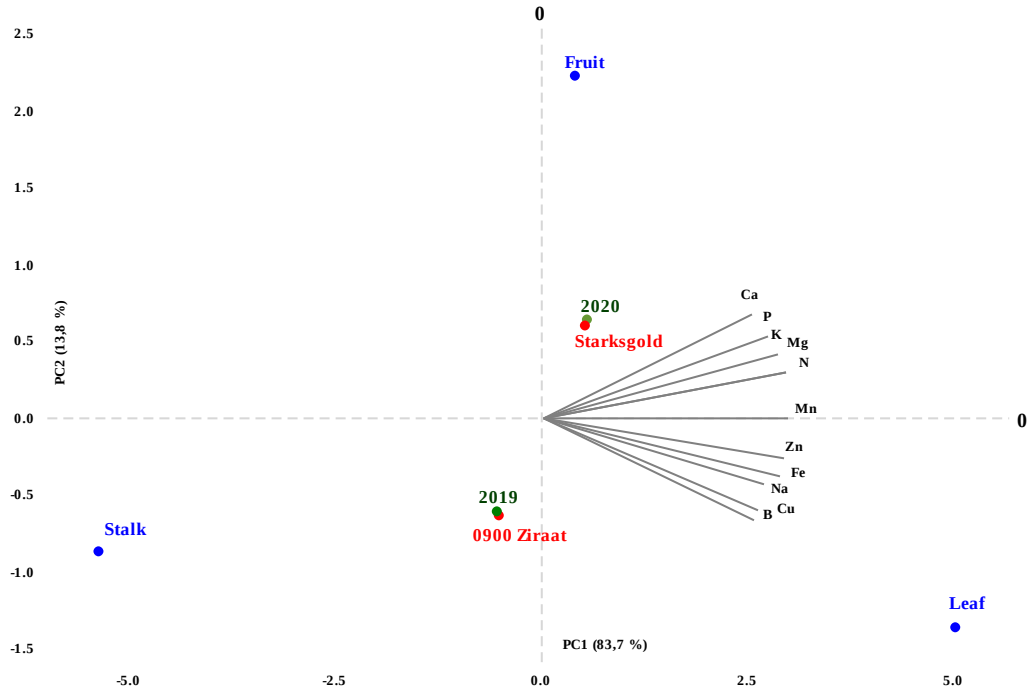
Tablo 2. *İncelenen minerallerin farklı yıllara, çeşitlere ve farklı bitki kısımlarına göre dağılımı (mg kg^{-1}).*

	N (%)	P	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	B
					Yıllar						
2019	1.54 **B**	2277.77 **B**	30988.21 **b**	7336.23 **B**	1437.24 **B**	1073.92 **A**	4410 **NS**	109.59 **NS**	32.09 **B**	25.56 **NS**	26.05 **NS**
2020	1.65 **A**	2493.53 **A**	32013.97 **a**	8027.10 **A**	1528.46 **A**	993.41 **B**	4573	113.99	36.40 **A**	27.00	24.43
					Çeşitler						
0900 Ziraat	1.50 **B**	2286.48 **B**	30518.03 **B**	7364.71 **B**	1420.58 **b**	1065.02 **A**	4062 **B**	114.87 **NS**	35.44 **NS**	25.49 **NS**	25.54 **NS**
Starks Gold	1.69 **A**	2484.82 **A**	32484.15 **A**	7998.63 **A**	1545.37 **a**	1002.30 **B**	4895 **A**	108.72	33.85	27.15	24.96
					Bitki Kısımları						
Meyve	1.740 **B**	2614.47 **A**	34016.94 **B**	8466.75 **A**	1553.94 **B**	1010.88 **B**	4066 **B**	105.64 **B**	35.54 **B**	19.87 **B**	19.39 **B**
Meyve sapı	1.11 **C**	1900.09 **B**	25442.25 **C**	6348.71 **B**	1221.32 **C**	891.11 **C**	29.15 **C**	88.31 **C**	25.04 **C**	18.72 **B**	18.12 **B**
Yaprak	1.93 **A**	2642.39 **A**	35044.08 **A**	8229.55 **A**	1673.66 **A**	1198.99 **A**	64.54 **A**	141.43 **A**	43.36 **A**	40.37 **A**	38.25 **A**
% CV	28.938	19.648	18.568	20.888	17.964	24.017	38.545	25.149	35.544	42.350	43.669
LSD	**Y:**0.079 **C**:0.073 **PP**:0.077	**Y:**106.237 **C**:160.794 **PP**:109.678	**Y:**1004.458 **C**:1267.063 **PP**:109.678	**Y:**321.039 **C**:246.125 **PP**:425.322	**Y:**54.101 **C**:88.109 **PP**:54.937	**Y:**21.553 **C**:42.770 **PP**:46.784	**C**:7.578 **PP**:3.852	**PP**:8.221	**Y:**2.021 **PP**:2.924	**PP**:4.917	**PP**:5.453
					F Değeri						
F$_{Yıl}$	183.747**	406.305**	19.306*	85.734**	277.684**	1374.528**	9.503**ns**	6.281**ns**	55.729*	2.436**ns**	3.194**ns**
F$_{Çeşit}$	146.419**	32.253**	51.040**	140.620**	15.464*	45.582**	25.567**	3.623**ns**	1.274**ns**	4.543**ns**	0.135**ns**
F$_{Yıl\ x\ Çeşit}$	58.666**	37.933**	98.549**	98.549**	41.401*	308.594**	2.883**ns**	3.393**ns**	1.362**ns**	5.393**ns**	8.296*
F$_{Bitki\ Kısımları}$	523.179**	251.090**	521.402**	127.019**	310.555**	187.778**	374.754**	105.393**	180.737**	104.759**	72.945**
F$_{Yıl\ x\ Bitki\ Kısımları}$	11.275**	3.400**ns**	21.553**	0.371**ns**	27.067**	77.075**	1.004**ns**	26.890**	5.111*	0.759**ns**	0.107 **ns**
F$_{Çeşit\ x\ Bitki\ Kısımları}$	170.065**	58.352**	229.575**	124.909**	60.147**	113.418**	31.946**	28.466**	5.482*	1.056**ns**	8.328**

*%5'te anlamlı, **%1'de anlamlı, **ns** %5'te anlamsız; **a** %5'e anlamlı, **A** %1'e anlamlı

Faktör ve PCA analizi

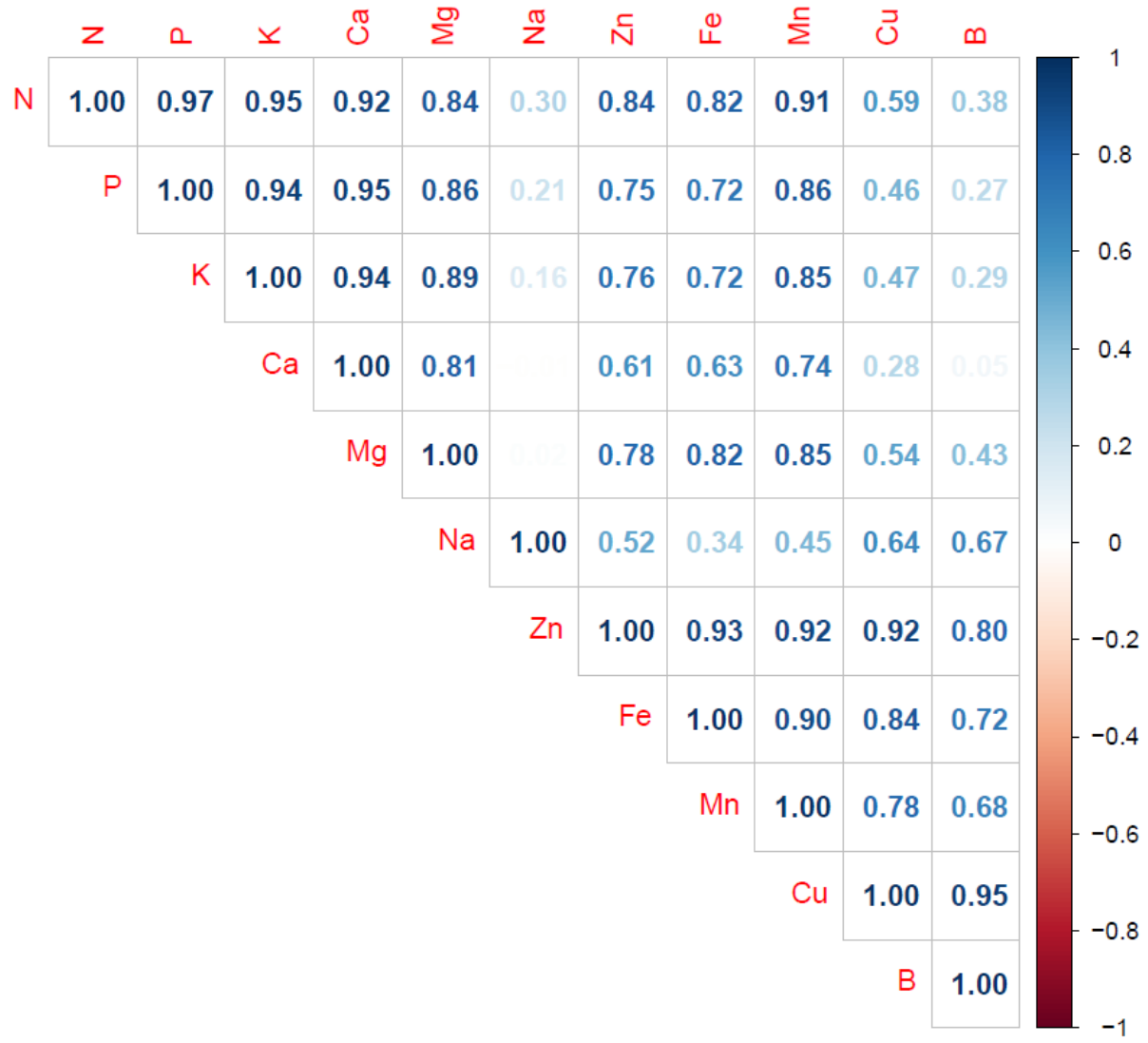
Çalışmada incelenen minerallerin; faktörlere (yıllar, çeşitler ve bitki kısımları) göre dağılımını görsel olarak şematize eden Bi-plot analizi Şekil 1'de verilmiş olup, ilk iki ana bileşen (PC1 ve PC2) ekseninde verilerin dağılımı incelenmiştir. İlgili iki bileşen toplam varyasyonun %97.5'ini kapsamakta olup, verideki değişkenliğin neredeyse tamamını yakaladığını ve bu nedenle iyi bir model olduğunu göstermektedir. PC1, toplam varyasyonun %83.7'sini tek başına oluştururken; N, K, Mg, Zn, Fe ve Mn mineralleri bu faktörde hem en yüksek hem de pozitif yükler göstermiştir (sırasıyla 0.32, 0.31, 0.32, 0.32, 0.31 ve 0.32). Benzer şekilde PC2, varyasyonun %13.8'ine karşılık gelirken, P (0.36) ve Ca (0.45) bu faktörle pozitif, Cu (-0.39) ve B (-0.44) ise, yüksek negatif korelasyon içerisinde tespit edilmiştir. Yaprakların, PC1'de en sağda yer alarak yüksek mineral içeriğine sahip olduğu, meyve saplarının ise en solda yer alarak daha düşük mineral içeriğine sahip olduğu belirlenmiştir. PC2, kalsiyum ve fosforun yüksek olduğu, ancak sodyum, çinko, bakır ve borun düşük olduğu örnekleri ayırt etmektedir. Meyve örneklerinin, bu eksende üstte yer alarak kalsiyum ve fosfor açısından zengin olduğu tespit edilmiştir. Çeşit ve yıllar incelendiğinde, 'Starks Gold' çeşidi ve 2020 yılının daha sağda ve yukarıda yer aldığı, genel olarak daha yüksek mineral içeriğine sahip oldukları belirlenmiştir. Tersi şekilde, '0900 Ziraat' çeşidinin 2019 yılında daha solda ve aşağıda yer alarak daha düşük mineral madde içerdiği tespit edilmiştir.



Şekil 1. *Kiraz çeşitlerinin meyve, sap ve yaprak örneklerinde, yılların incelenen mineral madde içeriklerine göre nasıl gruplandığı gösteren temel bileşenler (PCA) biplot analizi.*

Çalışmada incelenen mineral maddeler arasındaki korelasyonlara ait bulgular Şekil 2'de verilmiştir. İncelenen mineral maddelerin çoğunun birbiriyle yüksek düzeyde pozitif korelasyon gösterdiği tespit edilmiştir. N ile P (0.97), K (0.95), Ca (0.92), Mg (0.84), Zn (0.82), Fe (0.82) ve Mn (0.91) arasında yüksek düzeyde pozitif; Cu (0.59) ile orta düzeyde pozitif, Na ve B ile ise düşük düzeyde pozitif bir ilişki olduğu belirlenmiştir. Bu durum, bu minerallerin birlikte artma eğiliminde olduğunu göstermektedir. P ile K (0.94), Ca (0.95), Mg (0.86), Zn (0.75), Fe (0.72) ve Mn (0.86) arasında yüksek düzeyde pozitif; Na (0.21), Cu (0.46) ve B (0.27) ile ise düşük düzeyde pozitif bir ilişki belirlenmiştir. K ile Ca (0.94), Mg (0.89), Zn (0.76), Fe (0.72) ve Mn (0.85) arasında yüksek düzeyde pozitif; Cu (0.47) ile orta düzeyde, Na (0.16) ve B (0.29) ile ise düşük düzeyde pozitif bir ilişki olduğu tespit edilmiştir. Ca ile Mg (0.81) ve Mn (0.74) arasında yüksek düzeyde pozitif; Zn (0.61) ve Fe (0.63) ile orta düzeyde, Cu (0.28) ile ise düşük düzeyde pozitif bir korelasyon belirlenmiştir. Mg ile Zn (0.78), Fe (0.82) ve Mn (0.85) arasında yüksek düzeyde pozitif; Cu (0.54) ve B (0.43) ile ise orta düzeyde pozitif bir ilişki olduğu tespit edilmiştir. Na ile Zn (0.52), Fe (0.34), Mn (0.45), Cu (0.64) ve B (0.67) arasında orta düzeyde pozitif bir korelasyon olduğu, ancak Na'nın Ca ve Mg ile bir ilişkisinin olmadığı belirlenmiştir. Zn ile

Fe (0.93), Mn (0.92), Cu (0.92) ve B (0.80) arasında oldukça yüksek düzeyde pozitif korelasyon tespit edilmiştir. Benzer şekilde, Fe ile Mn (0.90), Cu (0.84) ve B (0.72) arasında yüksek düzeyde pozitif bir ilişki bulunmuş; Cu ile B (0.95) arasında da yüksek düzeyde pozitif bir ilişki belirlenmiştir.



Şekil 2. *İncelenen mineraller arasındaki korelasyonlar*

Varyans analizi

Mineraller bitkilerde regüle ettikleri fizyolojik döngüler yönüyle oldukça önemlidir. Kalsiyum (Ca) ve magnezyum (Mg) da bitki hücrelerinin yapısal bütünlüğü ve enzimatik işlevler için önemlidir. Kalsiyum özellikle hücre duvarı stabilitesi için önemlidir ve çeşitli fizyolojik süreçleri düzenleyen sinyal yollarında yer almaktadır (Morhart ve ark., 2016). Magnezyum ise klorofilin merkezi bir bileşenidir ve fotosentez için gereklidir. Bu besin maddelerindeki eksiklikler meyvelerde çiçek ucu çürüklüğü ve zayıf meyve tutumu gibi fizyolojik bozukluklara yol açabilir (Usenik ve ark., 2015). Çinko (Zn), demir (Fe), mangan (Mn), bakır (Cu) ve bor (B) gibi mikro besinler daha az miktarlarda gereklidir, ancak bitki sağlığı için eşit derecede önemlidir. Çinko, enzim fonksiyonu ve protein sentezi için çok önemliyken, demir fotosentezde klorofil sentezi ve elektron taşınması için gereklidir (Şimşek ve Süfer, 2021). Manganez fotosentez ve azot metabolizmasında rol oynar ve bakır çeşitli enzimatik süreçlerde yer alır. Bor, hücre bölünmesi ve üreme yapılarının gelişimi için önemlidir (Kelebek ve Selli, 2011). *Prunus avium*'da mineral eksikliklerinin, meyve verimini ve kalitesini düşürdüğü, ayrıca abiyotik ve biyotik stres kaynaklarına karşı dayanıklılığı azalttığı ifade edilmektedir (Usenik ve ark., 2015; Lamichhane, 2014; Guan ve ark., 2018; Wang ve ark., 2018). Bu sebeplere istinaden, mineral kompozisyonuna ve miktar tayinlerine sıklıkla başvurulmaktadır. Elde edilen sonuçlar hem bitkinin beslenme fizyolojisinin yorumlanması hem de insanlara tüketim materyali olarak servis edilmesi bakımından önem taşımaktadır.

Ikinci ve Aldanmaz (2022), *P. mahalep* üzerine aşılı '0900 Ziraat' çeşidi üzerine farklı yaprak gübresi uyguladıkları çalışmada, kontrol grubu kiraz ağaçlarının yaprak azot içeriğini %2.03 olarak bulduklarını bildirmişlerdir. Araştırmacılar ayrıca yapraklarda makro ve mikro besin elementlerini; P (3.000 mg/kg), K (20.100 mg/kg), Ca (16.000 mg/kg), Mg (5.400 mg/kg), Fe (117.33 mg/kg), Cu (12.90 mg/kg), Zn (21.35 mg/kg), Mn (34.25 mg/kg) ve B (36.05 mg/kg) olarak bildirmişlerdir. Benzer şekilde yürütülen farklı bir çalışmada ise 'Gisela 6' anacı üzerine aşılı '0900 Ziraat' çeşidinin kontrol gurubunda yaprak N içeriği %2.28 olarak raporlanırken, diğer mineral maddeler ise P (2.900 mg/kg), K (19.800 mg/kg), Ca (16.700 mg/kg), Mg (3.600 mg/kg), Fe (71.07 mg/kg), Cu (11.01 mg/kg), Mn (26.82 mg/kg), Zn (13.14 mg/kg) ve B (53.87 mg/kg) seviyelerinde ölçülmüştür (Uçgun ve Cansu, 2024). Benzer şekilde Demirer (2019), 'Gisela 6' anacı üzerine aşılı '0900 Ziraat' çeşidi ile yaptığı çalışmada, kontrol grubunun yapraklarında N (%2.863), P (2.660 mg/kg), K (21.430 mg/kg), Ca (12.700 mg/kg), Mg (3.330 mg/kg), Fe (23.130 mg/kg), Cu (9.650 mg/kg), Zn (15.323 mg/kg) ve Mn (33.590mg/kg) olarak tespit emiştir. Gonçalves ve ark (2022) 23 kiraz çeşidi üzerinde yaptıkları çalışmada, meyve örneklerinin mineral madde içeriklerini şu şekilde tespit etmişlerdir; P (683-2219 mg/kg), K (11.774-19.524 mg/kg), Ca (73-373 mg/kg), Mg (320-679 mg/kg), Na (2.32-10.7 mg/kg), Zn (1.08-6.92 mg/kg), Fe (2.44-12.2), Mn (1.64-7.30 mg/kg) ve Cu (2.12-5.22 mg/kg). Mahleple yürütülen farklı bir çalışmada ise meyve saplarının mineral madde içeriği incelenmiş ve P (3054 mg/kg), K (21458 mg/kg), Ca (13851 mg/kg), Mg (1166 mg/kg), Na (91,2 mg/kg), Fe (211,8 mg/kg), Cu (7,2 mg/kg), Mn (10,0 mg/kg), Zn (31,0 mg/kg) ve B (19,4 mg/kg) olarak tespit edildiği bildirilmiştir (Sekeroglu ve ark, 2012).

Çalışma bulguları, literatür ile uyumluluk gösterirken, ürünlerin nihai kompozisyonunun; çeşit, ekolojik faktörler, kültürel işlemler ve izlenen yetiştiricilik modellerinin kümülatif etkisi altında şekillendiği bilinmektedir. Bu bağlamda, gözlemlenen farklılıkların; verim, anaç/çeşit kombinasyonu, ekolojik faktörler, kültürel işlemler, bitki yaşı ve analiz yöntemlerindeki farklılıklardan ileri geldiği düşünülmektedir (Hu ve Schmidhalter, 2005; Lacerda ve ark., 2018; Uçgun ve ark., 2020; Maatallah ve ark., 2022; Nunes ve ark., 2022; Dziadek ve ark., 2018; Gonçalves ve ark., 2022; Danzomo ve ark., 2024; Ross ve ark., 2020; Legua ve ark., 2017; Papapetros ve ark., 2019).

PCA analizi

Çalışmamızda, kiraz çeşitlerinin mineral madde içeriklerine göre gruplandırılmasında, PC1 ve PC2'nin toplam varyansın %97.5'ini açıklaması, analizimizin yüksek bir açıklayıcılığa sahip olduğunu göstermektedir. Gonçalves ve ark. (2022) çalışmasında ise, PC1 ve PC2'nin toplam varyansın %46.5'ini; Ross ve ark. (2020), yaprak mineral içeriği için toplam varyansı ~%55, meyve içinse ~%57 bildirmiştir. Benzer şekilde Nunes ve ark. (2022), kiraz meyvesi, kökleri ve çiçeklerinin mineral içeriğini incelediği çalışmada, PCA'nın toplam varyansın %54.7'ini açıklaması, bizim çalışmamızın önceki çalışmalardan daha fazla varyansı kapsadığını ve dolayısıyla kiraz çeşitlerinin mineral içeriklerine göre daha belirgin bir şekilde ayrılabildiğini ortaya koymaktadır. Bu durum, çalışmamızın kiraz çeşitlerinin mineral profillerine dayalı olarak sınıflandırılmasında daha güçlü bir model sunduğunu düşündürmektedir. Ayrıca, bu bulgular, farklı yıllar ve kiraz yan ürünleri arasında mineral içeriklerinin tutarlılığını ve çeşitliliğini daha iyi anlamamıza olanak tanımaktadır.

Korelasyon analizi

Araştırmalar, çeşitli bitki türlerinde fosfor ve potasyum seviyeleri arasında güçlü bir pozitif korelasyon olduğunu göstermiştir (Edelstein ve ark., 2016). Bir başka çalışmada, kalsiyum mevcudiyetindeki artışın magnezyum alımını olumlu yönde etkileyebileceği ve böylece genel bitki sağlığını iyileştirebileceği bildirilmektedir (López-Lefebre ve ark., 2001). Zeytinin besin içeriğini inceleyen bir çalışmada, azot (N), fosfor (P) ve potasyum (K) gibi makro besin maddelerinin seviyelerinin birbiriyle ilişkili olduğu ve fosforun potasyum seviyeleri ile pozitif bir korelasyon gösterdiği raporlanmıştır (Zincircioğlu, 2018). Yine şeftali ağaçlarında besin maddesi bölünmesine odaklanan bir çalışmada, meyvelerin varlığının kaynaklar için rekabet nedeniyle yaprak besin maddesi konsantrasyonlarını etkilediği ve özellikle azot (N) ve potasyum (K) arasında pozitif korelasyon olduğu vurgulanmıştır (Zhou ve Melgar, 2018). Delfini ve ark. (2020), özellikle demir (Fe), çinko (Zn), bakır (Cu) ve fosfor (P) olmak üzere çeşitli mikro besinler arasında olumlu bir korelasyon olduğunu bildirmiştir. Vera-Vega ve ark. (2022), manganez (Mn) ile çinko (Zn) arasında önemli bir pozitif korelasyon olduğunu belirtmiştir. Fallahi ve ark. (2010) çalışmasında, 'Redchief Delicious'da yaprak N ve K, yaprak K ve Mg ile meyve Ca ve yaprak K arasında negatif korelasyonlar bildirmiştir. Araştırmacı ayrıca, yaprak N ve meyve N, meyve K ve yaprak K gibi birçok mineral arasında önemli ve pozitif korelasyonlar olduğunu tespit etmiştir. Bulgularımız, önceki çalışmalarla büyük oranda paralellik göstermektedir. Mineraller arası rekabet, bazı durumlarda negatif korelasyonu beraberinde getirmektedir Fallahi ve ark., (2010). Ancak, çalışmada

ölçülen mineral konsantrasyonlarının, büyük oranda düşük olması bu tip rekabetin önüne geçtiğinden, incelenen tüm mineraller arasında pozitif korelasyon ortaya çıktığı düşünülmektedir.

SONUÇ

Yapılan çalışmada, '0900 Ziraat' ve 'Starks Gold' kiraz çeşitlerinin mineral madde içerikleri, yıllar, çeşitler ve farklı bitki kısımları bakımından kapsamlı şekilde incelenmiştir. Mineral kompozisyonunun her üç faktör tarafından da etkilendiği gözlemlenirken, mineral içerikleri yaprak> meyve > sap şeklinde sıralanmıştır. 'Starks Gold' mineral birikimi bakımından '0900 Ziraat' çeşidine göre daha üstün bulunmuştur. Yetiştiricilik yapılan sezonda hüküm süren iklim şartları da mineral kompozisyonu üzerine belirleyici olup, hasada yakın kurak koşulların, mineral birikimini tetiklediği görülmüştür.

ÇIKAR ÇATIŞMASI

Yazarlar, herhangi bir çıkar çatışması olmadığını tasdik ederler.

YAZAR KATKISI

Yazarlar eşit oranda katkı sağlamışlardır.

ETİK BEYAN

"**0900 Ziraat ve Starks Gold Kiraz Çeşitlerinde Mineral Madde Kompozisyonunun Yıllara ve Farklı Bitki Kısımlarına Göre Değişimi** " başlıklı çalışmanın yazım sürecinde bilimsel kurallara, etik ve alıntı kurallarına uyulmuş; toplanan veriler üzerinde herhangi bir tahrifat yapılmamış ve bu çalışma herhangi başka bir akademik yayın ortamına değerlendirme için gönderilmemiştir. Çalışmamızda herhangi bir canlıya ait veri bulunmadığından etik kurul izni gerekmemektedir.

KAYNAKLAR

Arbizu, S., Mertens-Talcott, S. U., Talcott, S., & Noratto, G. D. (2023). Dark sweet cherry (*Prunus avium*) supplementation reduced blood pressure and pro-inflammatory interferon gamma (IFNγ) in obese adults without affecting lipid profile, glucose levels and liver enzymes. *Nutrients*, *15*(3), 681.

Baker, M. T., Lu, P., Parrella, J. A., & Leggette, H. R. (2022). Consumer acceptance toward functional foods: A scoping review. *International Journal of Environmental Research and Public Health*, *19*(3), 1217.

Dağhan, H., Gülmezoğlu, N., Köleli, N., & Karakaya, B. (2020). Impact of titanium dioxide nanoparticles (TiO_2-NPs) on growth and mineral nutrient uptake of wheat (*Triticum vulgare* L.). *Biotech Studies*, *29*(2), 69-76.

Danzomo, I. M., Yunusa, A., Adamu, A. U., Danjaji, H. I., Dalhatu, M. M., Usman, I. M., & Lawan, U. (2024). Phytochemicals, mineral elements and antioxidants evaluation of some commonly consumed desert fruits. *Sahel Journal of Life Sciences FUDMA*, 2(1), 118-131. https://doi.org/10.33003/sajols-2024-0201-014

Delfini, J., Moda-Cirino, V., Neto, J. d. S., Buratto, J. S., Ruas, P. M., & Gonçalves, L. S. A. (2020). Diversity of nutritional content in seeds of brazilian common bean germplasm. *Plos One*, 15(9), e0239263. https://doi.org/10.1371/journal.pone.0239263

Demirer, T. (2019). Effect of leonardite application on leaf nutrient content and fruit chemical parameters of cherry (*Prunus avium* L.). *Journal of Plant Nutrition*, 42(19), 2532-2538. https://doi.org/10.1080/01904167.2019.1659352

Dziadek, K., Kopeć, A., & Tabaszewska, M. (2018). Potential of sweet cherry (Prunus avium L.) by-products: bioactive compounds and antioxidant activity of leaves and petioles. European Food Research and Technology, 245(3), 763-772. https://doi.org/10.1007/s00217-018-3198-x

Edelstein, M., Cohen, R., Elkabetz, M., Pivonia, S., Maduel, A., Sadeh-Yarok, T., … & Ben-Hur, M. (2016). The potential of enriched fertilization in overcoming nutritional deficiency in grafted melons. *HortScience*, 51(4), 435-438. https://doi.org/10.21273/hortsci.51.4.435

Faienza, M. F., Corbo, F., Carocci, A., Catalano, A., Clodoveo, M. L., Grano, M., ... & Portincasa, P. (2020). Novel insights in health-promoting properties of sweet cherries. *Journal of functional foods*, *69*, 103945.

Fallahi, E., & Simons, B. R. (2010). Interrelations among leaf and fruit mineral nutrients and fruit quality in 'Delicious' apples. *Journal of Tree Fruit Production*, 1(1), 15-25. https://doi.org/10.1300/J072v01n01_02

FAO, 2021, Food and Agricultural Organization, Erişim tarihi 01.12.2024.

Fonseca, L. R., Silva, G. R., Luís, Â., Cardoso, H. J., Correia, S., Vaz, C. V., ... & Socorro, S. (2021). Sweet cherries as anti-cancer agents: From bioactive compounds to function. *Molecules*, *26*(10), 2941.

García-Villegas, A., Fernández-Ochoa, Á., Alañón, M. E., Rojas-García, A., Arráez-Román, D., Cádiz-Gurrea, M. d. l. L., … & Segura-Carretero, A. (2024). Bioactive compounds and potential health benefits through cosmetic applications of cherry stem extract. *International Journal of Molecular Sciences*, 25(7), 3723. https://doi.org/10.3390/ijms25073723

Gonçalves, A. C., Bento, C., Silva, B., Simões, M., & Silva, L. R. (2019). Nutrients, bioactive compounds and bioactivity: The health benefits of sweet cherries (*Prunus avium* L.). *Current Nutrition & Food Science*, *15*(3), 208-227.

Gonçalves, A. C., Campos, G., Pinto, E., Oliveira, A. S., Almeida, A., de Pinho, P. G., ... & Silva, L. R. (2022). Essential and non-essential elements, and volatile organic compounds for the discrimination of twenty-three sweet cherry cultivars from Fundão, Portugal. *Food Chemistry*, 367, 130503. https://doi.org/10.1016/j.foodchem.2021.130503

Gonçalves, A. C., Costa, A. L. S., Flores-Félix, J. D., Falcão, A., Alves, G., & Silva, L. (2022). Anti-inflammatory and antiproliferative properties of sweet cherry phenolic-rich extracts. *Molecules*, 27(1), 268. https://doi.org/10.3390/molecules27010268

Guan, J., Wang, J., & Lv, X. (2018). Pn-par and CO_2 responses of *Prunus avium* to drought stress during hard nucleus stage. Proceedings of the 2018 7th International Conference on Energy, *Environment and Sustainable Development* (ICEESD 2018). https://doi.org/10.2991/iceesd-18.2018.72

Hu, Y., & Schmidhalter, U. (2005). Drought and salinity: A comparison of their effects on mineral nutrition of plants. *Journal of Plant Nutrition and Soil Science*, 168(4), 541–549. https://doi.org/10.1002/jpln.200420516

Ikinci, A., & Aldanmaz, S. (2022). The effect of boron and zinc containing foliar fertilizer applications on leaf mineral content of '0900 Ziraat' cherry (*Prunus avium* L.) cultivar. *Journal of Tekirdag Agricultural Faculty*, 19(2), 283-295. https://doi.org/10.33462/jotaf.939675

Kacar, B., & Inal, A. (2008). Plant analysis. *Nobel Pres*, *1241*, 891.

Kelebek, H., & Selli, S. (2011). Evaluation of chemical constituents and antioxidant activity of sweet cherry (*Prunus avium* L.) cultivars. *International Journal of Food Science & Technology*, 46(12), 2530-2537. https://doi.org/10.1111/j.1365-2621.2011.02777.x

Lacerda, C. F. D., Ferreira, J. F. D. S., Suarez, D. L., Freitas, E. D., Liu, X., & Ribeiro, A. D. A. (2018). Evidence of nitrogen and potassium losses in soil columns cultivated with maize under salt stress. *Revista Brasileira de Engenharia Agricola e Ambiental*, 22(8), 553–557. https://doi.org/10.1590/1807-1929/agriambi.v22n8p553-557

Lamichhane, J. R. (2014). *Xanthomonas arboricoladiseases* of stone fruit, almond, and walnut trees: progress toward understanding and management. *Plant Disease*, 98(12), 1600-1610. https://doi.org/10.1094/pdis-08-14-0831-fe

Legua, P., Domenech, A., Martínez, J. J., Sánchez-Rodríguez, L., Hernández, F., Carbonell-Barrachina, A. A., & Melgarejo, P. (2017). Bioactive and volatile compounds in sweet cherry cultivars. *Journal Of Food and Nutrition Research*, 5(11), 844-851. https://doi.org/10.12691/jfnr-5-11-8.

López-Lefebre, L. R., Rivero, R. M., García, P. C., Sánchez, E., Ruiz, J. M., & Romero, L. (2001). Effect of calcium on mineral nutrient uptake and growth of tobacco. *Journal of the Science of Food and Agriculture*, 81(14), 1334-1338. https://doi.org/10.1002/jsfa.948

Maatallah, S., Dabbou, S., Castagna, A., Guizani, M., Hajlaoui, H., Ranieri, A. M., & Flamini, G. (2020). *Prunus persica* by-products: A source of minerals, phenols and volatile compounds. *Scientia Horticulturae*, 261, 109016. https://doi.org/10.1016/j.scienta.2019.109016

Maxiselly, Y., Anusornwanit, P., Rugkong, A., & Chiarawipa, R. (2022). Phytochemical analysis of leaves and cherries of coffee and sensory evaluation of tea products of robusta coffee in Songkhla, Thailand. *AGRIVITA, Journal of Agricultural Science*, *44*(3), 470-478.

Morhart, C., Sheppard, J., Schuler, J., & Spiecker, H. (2016). Above-ground woody biomass allocation and within tree carbon and nutrient distribution of wild cherry (*Prunus avium* L.) – a case study. *Forest Ecosystems*, 3(1). https://doi.org/10.1186/s40663-016-0063-x

Nunes, A. R., Gonçalves, A. C., Pinto, E., Amaro, F., Flores-Félix, J. D., Almeida, A., ... & Silva, L. R. (2022). Mineral content and volatile profiling of *Prunus avium* L. (sweet cherry) by-products from Fundao region (Portugal). *Foods*, *11*(5), 751.

Papapetros, S., Louppis, A., Kosma, I., Kontakos, S., Badeka, A., Papastephanou, C., & Kontominas, M. G. (2019). Physicochemical, spectroscopic and chromatographic analyses in combination with chemometrics for the discrimination of four sweet cherry cultivars grown in northern Greece. *Foods*, 8(10), 442. https://doi.org/10.3390/foods8100442.

Quero-García, J., Letourmy, P., Campoy, J. A., Branchereau, C., Malchev, S., Barreneche, T., & Dirlewanger, E. (2021). Multi-year analyses on three populations reveal the first stable QTLs for tolerance to rain-induced fruit cracking in sweet cherry (*Prunus avium* L.). *Horticulture Research*, *8*.

Quintaes, K. D., & Diez-Garcia, R. W. (2015). The importance of minerals in the human diet. *Handbook of mineral elements in food*, 1-21.

Ross, K. A., Toivonen, P. M. A., Godfrey, D. V., & Fukumoto, L. (2020). Pre-harvest conditions associated with Staccato sweet cherry fruit quality: mineral status in leaves and fruitlets and orchard growing factors. *Canadian Journal of Plant Science*, 101(2), 262-267. https://doi.org/10.1139/cjps-2020-0115

Sekeroglu, N., Meraler, S. A., Özkutlu, F., & Kulak, M. (2012). Variation of mineral composition in different parts of mahaleb. *Asian Journal of Chemistry*, *24*(12).

Švarc-Gajić, J., Cerdà, V., Clavijo, S., Suárez, R., Mašković, P., Cvetanović, A., … & Novakov, V. (2018). Bioactive compounds of sweet and sour cherry stems obtained by subcritical water extraction. *Journal of Chemical Technology & Biotechnology*, 93(6), 1627-1635. https://doi.org/10.1002/jctb.5532

Şimşek, M. and Süfer, Ö. (2021). Effect of pretreatments on refractance window drying, color kinetics and bioactive properties of white sweet cherries (*Prunus avium* L. Starks Gold). *Journal of Food Processing and Preservation*, 45(11). https://doi.org/10.1111/jfpp.15895

Uçgun, K. and Cansu, M. (2024). Sınırlandırılmış alanlara uygulanan ph düşürücü bazı materyallerin bazı toprak özellikleri, kiraz ağaçlarının beslenmesi ve meyve özelliklerine etkisi. *Harran Tarım ve Gıda Bilimleri Dergisi*, 28(1), 165-179. https://doi.org/10.29050/harranziraat.1264307

Uçgun, K., Ferreira, J. F. D. S., Liu, X., Filho, J. B. D. S., Suarez, D. L., Lacerda, C. F. D., & Sandhu, D. (2020). Germination and growth of spinach under potassium deficiency and irrigation with high-salinity water. *Plants*, 9(12), 1–19. https://doi.org/10.3390/plants9121739

Usenik, V., Štampar, F., Mikulič-Petkovšek, M., & Kastelec, D. (2015). The effect of fruit size and fruit colour on chemical composition in 'Kordia' sweet cherry (*Prunus avium* L.). *Journal of Food Composition and Analysis*, 38, 121-130. https://doi.org/10.1016/j.jfca.2014.10.007

Vera-Vega, M., Jimenez-Davalos, J., & Zolla, G. (2022). The micronutrient content in underutilized crops: The *Lupinus mutabilis* sweet case. *Scientific Reports*, 12(1). https://doi.org/10.1038/s41598-022-19202-8

Wang, J., Guan, J., & Lv, X. (2018). Effects of drought stress on leaf gas exchange parameters in development of sweet cherry fruit. Proceedings of the 2018 7th International Conference on Energy, *Environment and Sustainable Development* (ICEESD 2018). https://doi.org/10.2991/iceesd-18.2018.71

Zar, JH. 2013. Biostatistical Analysis: Pearson New International Edition. Pearson Higher Ed.

Zhou, Q. and Melgar, J. C. (2018). Ripening season affects tissue mineral concentration and nutrient partitioning in peach trees. *Journal of Plant Nutrition and Soil Science*, 182(2), 203-209. https://doi.org/10.1002/jpln.201800304

Zincircioğlu, N. (2018). Domat zeytin çeşidinde meyve - yaprak besin elementleri değişimlerinin incelenmesi. *Ege Üniversitesi Ziraat Fakültesi Dergisi*. https://doi.org/10.20289/zfdergi.352207

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Research Article

Tıbbi Sülük Türlerinin Bulunduğu Türkiye'de Sülükler ile İlgili Çalışmaların Yetersizliği: Bibliyometrik Bir Çalışma

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ÖZET

Bu çalışmanın amacı tıbbi sülüklerle ilgili ülkemizde yapılmış çalışmaların bibliyometrik incelemesini yaparak çalışmaların hangi seviyede olduğunu nicel verilerle göstermektir. Literatür veri setini oluşturmak için akademisyenler tarafından sıklıkla tercih edilen Web of Science Core Collection (WoSCC) elektronik veri tabanı kullanılmıştır. Bilimsel yayınlardan elde edilen verileri sunmak için tanımlayıcı istatistiksel teknikler kullanılmıştır. Bibliyometrik analiz için Biblioshiny (sürüm 2.0) kullanılmıştır. WOS verilerine göre 1975-2024 yılları arasında Dünya genelinde toplam 7565 tane çalışma yapılmıştır. Türkiye'de ise ilk yayının yapıldığı 1997 yılından 2024 yılına kadar toplamda 155 çalışma yapılmıştır. Bu verilere göre Dünya genelinde sülük üzerine yapılan çalışmaların sadece %2.05'i Türkiye'de yürütülmüştür. Türkiye bu çalışma sayısıyla Dünya sıralamasında 11. sırada yer almaktadır. Ayrıca çalışma sayısının son yıllarda artış eğiliminde olduğu ve en fazla çalışmanın ise 2021 yılında yapıldığı tespit edilmiştir. Bu alandaki en aktif üniversitenin 18 yayınla Fırat üniversitesi olduğu saptandı. Her ne kadar son yıllarda bu alanda yapılan çalışmaların sayısı artmış olsa da Türkiye gibi tıbbi sülüklere ev sahipliği yapan bir ülkede, bu alanda yapılan çalışmaların az olduğu ve daha fazla çalışma yapılması gerektiği kanaatine varıldı.

MAKALE BİLGİSİ

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Inadequacy of Studies on Leeches in Turkey, Where Medicinal Leech Species Occur: A Bibliometric Study

ABSTRACT

This study aims to show quantitatively the level of research on medicinal leeches conducted in our country by conducting a bibliometric review. The Web of Science Core Collection (WoSCC) electronic database, which is frequently preferred by academics, was used to create a literature dataset. Descriptive statistical techniques were used to present the data obtained from scientific publications. Biblioshiny (version 2.0) was used for bibliometric analysis. According to WOS data, a total of 7565 studies were conducted worldwide between 1975 and 2024. A total of 155 studies were conducted In Turkey, from 1997, when the first publication was made, to 2024. According to the data, only 2.05% of the studies conducted on leeches worldwide were carried out in Turkey. It was also determined that the number of studies has tended to increase in recent years and the most studies were conducted in 2021. It was determined that the most active university in this field is Fırat University with 18 publications. Although the number of studies in this field has increased in recent years it was concluded that the studies in this field is low in a country like Turkey which hosts medical leeches and that more studies should be conducted.

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GİRİŞ

Tıbbi sülükler omurgalıların kan emen geçici ektoparazitleridirler. Bu sülükler, milattan önce 1500 yılından itibaren birçok medeniyette hekimler tarafından çeşitli hastalıkların tedavisinde kullanılmıştır. Tıbbi sülükler Avrupa'da 17. ve 18. yüzyıllarda neredeyse her hastalık için kullanılmıştır. Bundan dolayı 19. yüzyılın başlarında Avrupa'da sülüklerin popülasyonu endişe verici seviyelere inmiştir. Tıbbi sülüklerin tıbbi tedavide kullanım cazibesi, 19.yüzyılın sonlarında ve 20. yüzyılın başlarında deneysel yöntemlere yönelimle birlikte azalmıştır. Sülüklerin ağız salgılarındaki biyoaktif maddelerin tanımlanmasıyla birlikte son zamanlarda kullanımı hem halk arasında hem de bilimsel camiada yeniden önem kazanmıştır (Vera ve Blu, 2005; Okka, 2013).

Sülükler, Annelida filumunun Hirudinea sınıfına ait hermafrodit parazitlerdir. Sülüklerin 680 türü tanımlanmıştır. Çoğunluğu sucul ortamlar olmak üzere sülükler çok çeşitli habitatlarda bulunabilir. Sülüklerin 480 türü tatlı sularda yaşarken geriye kalanların bir kısmı denizlerde bir kısmı da karalarda yaşarlar. Sülük denince akla kanla beslenen omurgasız canlılar gelebilir ama bazı sülük türleri yırtıcıdır ve küçük hayvanların özellikle omurgasızların etleri ile beslenirler (Sket ve Trontelj, 2008).

Sülüklerin çok az bir kısmı tıbbi amaçlı kullanılmaktadır. Sulak alanlar bakımından zengin olan ülkemizde yapılan çalışmalarda biri H. medicinalis diğeri H. verbana olmak üzere 2 tür tıbbi sülük saptanmıştır (Özbek ve Sarı, 2007). Yakın zamanda yapılan bir çalışmada yeni bir tıbbi sülük türü olan H.suluki'nin saptanmasıyla beraber bu sayı üçe çıkmıştır. H. sulukii Türkiye'nin sadece Güney Doğu Anadolu Bölgesi'ndeki sulak alanlarda saptandığı için endemik bir tür olabileceği düşünülmektedir (Sağlam ve ark., 2016).

Hastalıkların tedavisinde tıbbi sülüklerin kullanılmasına hirudoterapi denir. Tıbbi sülükler 20.yüzyıla kadar birçok hastalığın tedavisinde flebotomi işlemi için kullanılmıştır. Daha sonra 20.yüzyılın sonlarına doğru tıbbi sülükler, ağız salgılarındaki biyoaktif maddelerin terapötik etkisi için kullanılmaya başlanmıştır (Alaama ve ark., 2024). ABD İlaç ve Gıda Dairesi (FDA) tarafından 2004 yılında hirudoterapinin mikro cerrahi ve plastik cerrahide uygulanmasına onay verilmiştir (Rados, 2004). Ülkemizde de 2014 yılında yayımlanan Geleneksel ve Tamamlayıcı Tıp Uygulamaları Yönetmeliği ile hirudoterapinin, sertifikaya sahip hekimlerce resmi sağlık kuruluşlarında uygulanabilmesinin önü açılmıştır (Sağlık Bakanlığı [SB], 2014).

Tıbbi sülüklerin ağız salgılarında 100 farklı biyoaktif madde bulunmaktadır. Bu maddelerden en yaygın olarak bulunanı, kanın pıhtılaşma sürecini baskılanmasında rol alan hirudindir. Sülüklerin tükürük bezlerinden salgılanan salgılar ayrıca antiinflamatuar, bakteriyostatik, analjezik ve vazodilatör madde içerir. Bu maddelerin mikro-dolaşım bozukluklarını ortadan kaldırdığı, hipoksiyi engellediği, kan basıncını düşürdüğü ve bağışıklığı artırdığı bildirilmiştir (Singh, 2010; Liu ve Barkley, 2015). Tıbbi sülüklerin ağız salgıları ile ilgili çalışmalar devam etmektedir. Son zamanlarda yapılan bir çalışmada, bu salgıların içinde hirudinin dışında güçlü bir antikoagülan protein keşfedilmiştir (Manuvera, 2024).

Günümüzde Tıbbi sülükler modern tedaviyi destekleyici bir metot olarak plastik cerrahlar tarafından özellikle rekonstrüktif cerrahide kullanılmaktadır. Yeni nakledilen dokularda venöz tıkanıklık ciddi bir tehdit olup staza, trombüs oluşumuna ve sonuçta doku nekrozuna neden olabilir. Tıbbi sülükler, emme eylemiyle aktif kan drenajı sağlar. Bununla birlikte tıbbi sülüklerin salgılarındaki etkisi uzun süren antikoagülan maddelerden dolayı sülük ayrılmasından sonra meydana gelen pasif sızıntı da hekimleri venöz tıkanıklığı hafifletmek için sülük kullanmaya teşvik eder. Kopmuş olan kafa derisine, kulağa, burun ucuna, alt dudağa ve başka vücut parçalarına yapılan replantasyon işlemleri sonrası tamamlayıcı tedavi olarak hirudoterapi uygulanmış ve başarılı sonuçlar elde edilmiştir. Bu nedenle doktorlar, venöz tıkanıklığın hafifletilmesinde hirudoterapinin etkili olduğunu ve dokuları kurtarmak için hayati bir adım olduğunu savunmuştur (Abdualkader ve ark., 2013).

Bilden ve ark.'nın (2025) yaptıkları deneysel bir çalışmada hirudoterapinin kesik yaralar üzerinde olumlu etki gösterdiği saptanmıştır.

Ekstravasyon yaralanması tedavisinde temel amaç doku içine sızan farmakojik ajanların azaltılması veya seyreltilmesidir. Yapılan deneysel bir çalışma, ekstravazasyon hasarının erken döneminde uygulanan hirudoterapinin dokudaki nekrozu azalttığını ispatlamıştır (Eroğlu ve ark., 2004). Hirudoterapinin osteoartrit, varis, dermatit, hematom egzama, hipertansiyon, gingival ödem, diyabet ve diyabetik ülser gibi birçok hastalık

ve semptomların tedavisinde olumlu sonuç verdiği bildirilmiştir (Ayhan ve Mollahaliloğlu, 2018; Küçük ve Yaman, 2019).

Sülük tedavisi sonrası enfeksiyon, alerji, uzun süren kanamalar gibi olası komplikosyonlar görülebileceği vurgulanmıştır. Tıbbi olmayan sülüklerle yapılan tedavi daha fazla komplikasyona neden olabilir. Sülük türleri dikkatlice seçilmeli ve doğru ve güvenilir ticari kaynaklardan satın alınmalıdır (Pourrahimi ve ark., 2020).

Tıbbi sülüklerle ilgili ülkemizde yapılmış çalışmaların hangi seviyede olduğunu nicel verilerle göstermek için bibliyometrik analiz yöntemi kullanılarak bir bibliyografik inceleme (retrospektif çalışma) gerçekleştirilmiştir.

MATERYAL VE YÖNTEM

Literatür veri setini oluşturmak için, dışa aktarım için eksiksiz ve standartlaştırılmış bir veri koleksiyonu sunan ve akademisyenler tarafından sıklıkla kullanılan Web of Science Core Collection (WoSCC) elektronik veri tabanı kullanılmıştır. Sağlık bilimleri, mühendislik, ve teknoloji alanlarında geniş bir içeriğe sahip olan WoSCC, biyomedikal araştırmalar için güvenilir bir kaynak olarak köklü bir geçmişe sahiptir. Ayrıca kapsamlı atıf verileri sağlayabilmesinden dolayı sağlam ve güvenilir bir temel sağladığı için çalışmanın birincil veri kaynağı olarak kullanılmıştır (Chen ve ark., 2015; Pranckutė, 2021).

Veri elde etmek için arama terimleri olarak “Sülük” OR “leech” OR “hirudo” OR “hirudotherapy” OR “leech therapy” OR “medicinal leech” OR “medicinal leech therapy” (Topic) kullanılmıştır. Veri tabanının sıklıkla güncellendiği dikkate alındığında hata payını minimize etmek ve önyargıdan kaçınmak için literatür taraması bir günde gerçekleştirildi (5 Aralık 2024).

WoSCC'de anahtar kelimeleri kullanılarak yapılan kapsamlı aramada sonrasında “Countries/Regions” sekmesinden “Türkiye” ve “Turkey” seçilerek arama daraltılmıştır. Biri birincil yazar olarak belirlenen iki yazar bağımsız olarak arama yapmış ve herhangi bir tutarsızlık birincil yazar tarafından çözülmüştür. Plain text ve tabdelimted formatlarında çıkarılan veriler belge başlıkları, yayın yılları, dergi adları, yazarların adları, anahtar kelimeler, kurumlar ve ülkeleri içermektedir. Toplam yayın sayısı ve atıflar da dahil olmak üzere çıkarılan tüm veriler WoSCC veri tabanından alınmıştır.

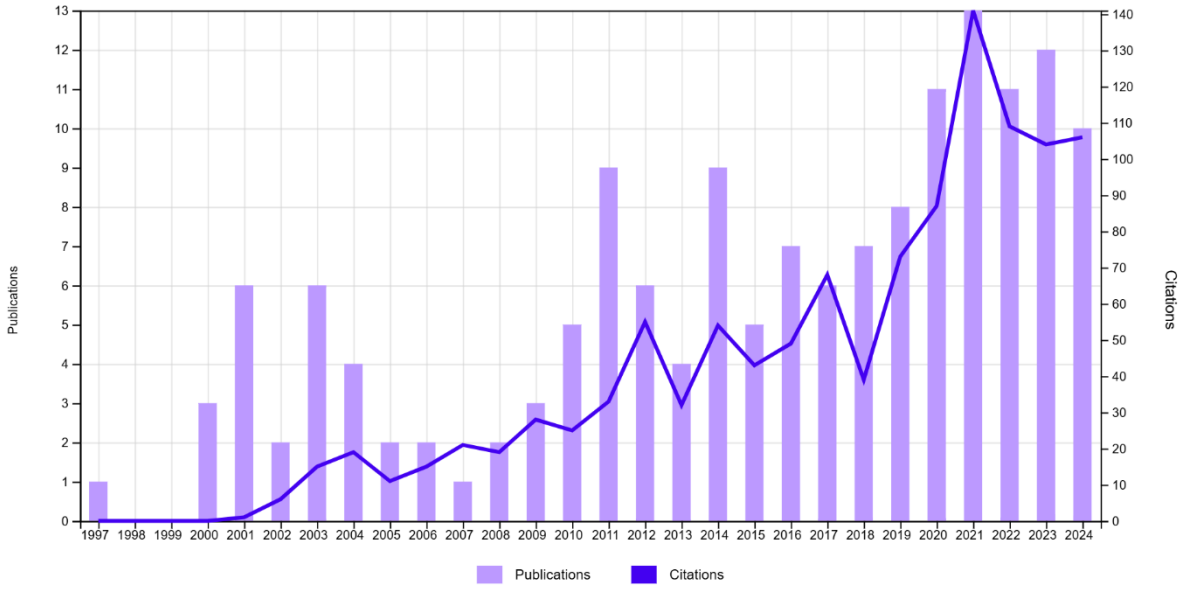
Bilimsel yayınlardan elde edilen verileri sunmak için tanımlayıcı istatistiksel teknikler kullanılmıştır. Bibliyometrik analiz için bir web arayüzü uygulaması olan R-Studio (R sürüm 4.2.2) ile erişilen Biblioshiny (sürüm 2.0) kullanılmıştır (https://www.bibliometrix.org/home/index.php/layout/biblioshiny). R dili ortamı, Bibliometrix ve Biblioshiny ücretsiz kaynak araştırma yazılım paketlerini çalıştırmaktadır. Biblioshiny, kullanıcıların bibliyometrik ve görsel analizler yapmasına olanak tanıyan etkileşimli bir çevrimiçi veri analiz platformu oluşturur (Aria ve Cuccurullo, 2017).

Araştırmanın Sınırlılıkları: Bu çalışma, yalnızca WoSCC veri tabanında yer alan makalelerin kullanılması, çalışmanın sınırlılıklarındandır.

BULGULAR

T WOS verilerine göre 1975-2024 yılları arasında dünya genelinde 7565 tane çalışma yapılmıştır. Türkiye’de ise ilk yayın 1997 yılında yapılmış olup, 2024 yılına kadar toplamda 155 çalışma yapılmıştır. Bu verilere göre dünya genelinde sülük alanında yapılan çalışmaların sadece %2.05’i Türkiye’de yapılmıştır ve bu oranla Türkiye sülük alanında çalışma yapan ülkeler arasında 11. sırada yer almaktadır.

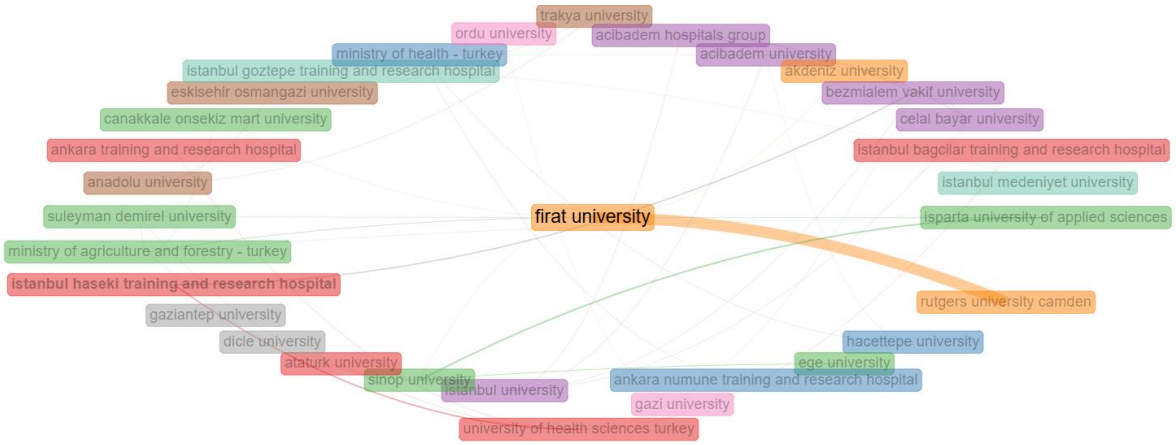
WOS verilerine göre Türkiye’de sülük ile ilgili çalışmalar son yıllarda bir artış eğilimindedir ve 13 (%8.39) yayın ile en fazla yayın 2021 yılında yapılmıştır (Şekil 1). Ayrıca Türkiye’de yapılan çalışmalar toplam 977 atıf almış (kendi yayınlarına atıf hariç) olup H indeksi 19’dur.



Şekil 1: *Türkiye'de Yapılan Yayın Sayılarının Yıllara Göre Dağılımı*

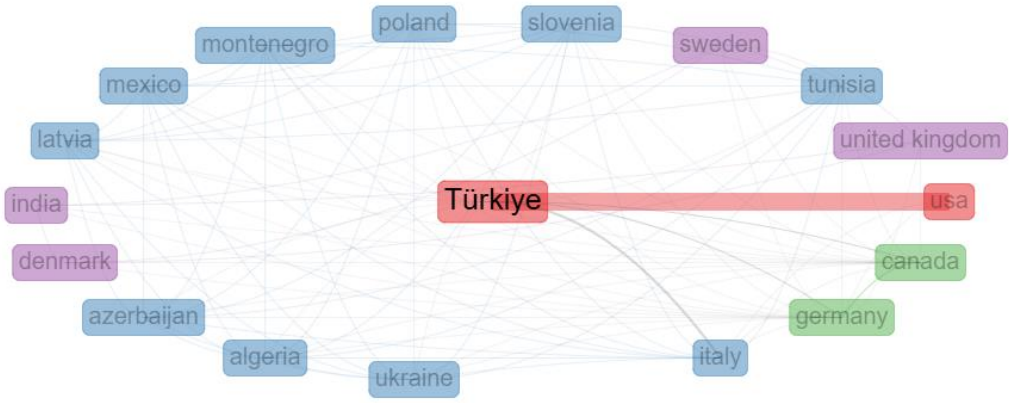
Türkiye'de yapılan yayınların türleri incelendiğinde çalışmaların 138'nin (%89,03) makale ve 11'nin (%7.1) editöre mektup olduğu belirlenmiştir.

Türkiye'de yapılan çalışmalara farklı 164 üniversiteden 458 yazarın dahil olduğu saptandı. Türkiye'de sülükler ile ilgili, 18 (%11.61) yayın ile en fazla Fırat Üniversitesinden yayın üretildiği ve bunu 9 (%5.81) yayın ile Hacettepe Üniversitesinin takip ettiği belirlendi. Üniversiteler arası iş birliği haritasında Fırat Üniversitesinin Türkiye'den diğer üniversitelerle en fazla iş birliği içinde olduğu belirlendi. Ayrıca Fırat Üniversitesinin en fazla Rutgers Üniversitesi (ABD) ile iş birliği yaptığı saptandı (Şekil 2).



Şekil 2: *Üniversiteler Arası İş Birliği Haritası*

Türkiye'nin sülük ile ilgili yayınlarda diğer ülke yazarları ile yaptığı iş birliği haritasına (Şekil 3) bakıldığında, 17 farklı ülkeden yazarlarla iş birliği yapıldığı ve iş birliğinin en fazla ABD ile yapıldığı belirlendi.



Şekil 3: *Türkiye - Ülkeler İş Birliği Haritası*

Yayınlarda therapy, hirudo medicinalis, survival anahtar kelimelerinin en fazla kullanıldığı belirlendi (Şekil 4).

Şekil 4: *Yayınlarda Kullanılan Anahtar Kelimelerin Sıklık Haritası*

TARTIŞMA

Bibliyometrik terimi ilk olarak 1934'te Paul Otlet tarafından kullanılmıştır. Daha sonra 1969'da Alan Pritchard bu terimi yeniden tanımlamıştır (Rousseau, 2014). Bibliyometrik çalışmaların son yılarda akademik camiada popülerliği artmıştır. Bu artışta VOSviewer gibi bibliyometrik araçların ve Scopus ve Web of Science gibi bilimsel veri tabanlarının etkisi vardır (Passas, 2024). Günümüzde hemen hemen her bilim dalının ilgisini çeken bibliyometrik analizde nihai amaç, bir araştırma alanın güncel durumu hakkında nicel veriler elde edebilmektir (İri ve Ünal, 2024). WoS ve Scopus, bibliyometrik araştırmalar için kullanılabilecek iki literatür veri tabanıdır ve her iki veri tabanı da alıntı yapılan yayınları ve referansları gösterme konusunda şeffaftır (Leydesdorff ve ark., 2016). ilk geniş kapsamlı uluslararası bibliyografik veritabanı olan WoS, zamanla dergi seçimi, araştırma değerlendirmesi, bibliyometrik analizler ve diğer görevler için geleneksel olarak kullanılan en etkili bibliyografik veri kaynağı haline gelmiştir (Pranckutė, 2021).

Binlerce yıldır tıp alanında çeşitli hastalıkların tedavisinde başvurulan hiroduterapi günümüzde genel olarak mikro dolaşımın ve damarların, venöz kanın yeterli drenajını sağlayamadığı kritik ameliyat sonrası dönemde endike olup rekonstrüktif cerrahi alanında kullanımı yaygındır (Heinz ve ark., 2020; Brauer ve ark., 2024).

Tıbbi sülükler; solunum sistemi rahatsızlıkları, üriner sistem rahatsızlıkları, kas iskelet sistemi rahatsızlıkları, sindirim sistemi rahatsızlıkları, kardiyovasküler sistem rahatsızlıkları, jinekoloji ve obstetrik rahatsızlıklar, dermatolojik rahatsızlıklar, kulak burun boğaz hastalıkları, göz hastalıkları, nörolojik hastalıklar, diş hekimliği ve cerrahi alanda olmak üzere tedavide bir çok alanda kullanılmaktadır (Ayhan ve Mollahaliloğlu, 2018).

Son yıllarda gelişmiş ülkeler bazı hastalıkların tedavisinde tamamlayıcı tıp uygulaması olarak hiroduterapiye ağırlık vermektedir. Almanya, Fransa, İngiltere, Rusya ve ABD gibi ülkelerde yaygın olarak kullanılmaktadır. Hirudoterapi tıbbi ilaç uygulamalarına göre hem daha düşük maliyetli hem de daha az komplikasyona sahip olmasından dolayı daha çok tercih edilmektedir. Dünya genelinde Hiroduterapi literatürünün %33.57'sinin ABD'ye ait olması ve onu sırasıyla İngiltere, Almanya ve Fransa'nın takip etmesi gelişmiş ülkelerin hiroduterapiye olan ilgisinin ne boyutta olduğunu göstermektedir. Yapılan çalışmaların çoğu zooloji, farmakoloji, biyokimya, kardiyoloji ve cerrahi alanında yapılmaktadır (Şenel ve ark., 2020).

Ülkemiz tıbbi sülük ihracatı konusunda söz sahibi bir ülkedir. Ülkemizde tıbbi sülükler, 1960 yılından beri belli bölgelerden kontrollü bir şekilde toplanarak ABD, Almanya, Fransa, İngiltere ve İsveç'e ihraç edilmektedir. Yapılan çalışmalar, üçüncü ülkelere tekrar satılması da hesaba katıldığında Türkiye'nin 2008 yılında dünya sülük piyasasındaki payının %86,54 olduğu göstermektedir (Gödekmerdan ve ark., 2011; Sağlam, 2011).

Ülkemizde bir tıp fakültesinde görevli öğretim üyelerinin %61.9 u (110) üzerinde yapılan bir çalışmada katılımcıların %19.1'inin hayatında hiç sülük görmediği ve %13.6'sının ise "Hirudoterapi" kelimesini hiç duymadığı saptanmıştır. Yine aynı çalışmada doktor öğretim üyesi ve araştırma görevlilerinin sadece %7.8'i, profesör ve doçentlerin ise sadece %20'sinin hirudoterapi uygulamaları ile ilgili bilgilerinin olduğu tespit edilmiştir (Bilden ve ark., 2024). Ülkemizde bir eğitim araştırma hastanesinde çalışan araştırma görevlisi hekimlerin geleneksel ve tamamlayıcı tıp uygulamaları ile ilgili düşünce, tutum ve davranışlarının değerlendirildiği bir çalışmada hekimlerin %51.4'ü (168) bu uygulamaların kullanılması için daha fazla bilimsel kanıta ihtiyaç olduğunu söylemiştir. Aynı çalışmada hekimlerin %79.5'i sülük tedavisini bilmesine rağmen sadece 19.6'ı sülük tedavisini önermektedir (İkiışık ve ark., 2021). Yapılan bu çalışmayla, dünya genelinde tıbbi sülük alanında yapılan çalışmaların sadece %2.05'inin Türkiye'de yapıldığı saptanmıştır. Son yıllarda Hiroduterapinin tekrardan önem kazanmasına ve ülkemizde de bol miktarda tıbbı sülük bulunmasına rağmen ülkemizde tıbbi sülük ile ilgili çalışmaların yeterli seviyede olmamasının nedeni hirudoterapi ile ilgili bilginin ve farkındalık düzeyinin az olduğu kanaatine varıldı.

Yapılan çalışmalar, araştırmacılar arasındaki iş birliğinin zamanla daha yaygın hale geldiğini ve bilimsel çalışmaların önemli bir parçası olduğunu göstermektedir. Araştırma verimliliğini arttırmak için akademik iş birliği gerekmektedir. Uluslararası, ulusal veya kurum içi yapılan iş birliği, üniversitelerin araştırma kalitesini ve miktarını artırmaktadır (Aldieri ve ark., 2018). Şenel ve ark. (2020) tarafından yapılan bir çalışmada bu alanda yayın yapan ülkeler arasında bir ilişki ağı oluşturulmuş ve ABD'yi merkez alan doğrusal bir iş birliği ağı ortaya çıkmıştır. Yaptığımız bu çalışmada da ülkemizdeki yazarların bu konuda en fazla ABD'li yazarlarla iş birliği yaptığı saptanmıştır. Elde edilen bu bulgunun Şenel ve ark.'nın yaptığı çalışma ile uyumlu olduğu saptandı. Bu alanda çalışma yapacak bilim insanlarının ABD'li yazarlarla iş birliği yapması gerektiği kanaatine varıldı. Çalışmamızda Türkiye'de bu alanda 18 (%11.61) yayın ile en fazla Fırat Üniversitesinden yayın üretildiği belirlendi. Çalışmamızda oluşturulan Üniversiteler arası iş birliği haritası incelendiğinde bu alanda Fırat Üniversitesinin Türkiye'den diğer üniversitelerle en fazla iş birliği içinde olduğu görülmüştür. Ülkemizde bu alanda çalışma yapacak araştırmacıların Fırat Üniversitesiyle işbirliği yapması önerilir.

Anahtar kelimelerin doğru seçilmesi literatür tarama sürecinde önemli bir rol oynar. Bu, sonuçları alaka düzeyine göre sıralayan veritabanları için önemlidir. İlgili literatürde sıklıkla kullanılan tanınabilir anahtar kelimleri kullanmak, bir makalenin görünürlüğünü önemli ölçüde artırabilir (Pottier ve ark., 2024). Hirudinidae familyasının isim babası olan Hirudo medicinalis, tıbbi kullanım için en sık referans alınan tür olarak görüldüğünden (Phillips ve Siddall, 2009) dolayı yaptığımız çalışma bu alanda en çok kullanılan anahtar kelimenin Hirudo medicinalis olduğu saptandı. Sülükle ilgili araştırma yapacak bilim insanlarının anahtar kelimelerden olan Hirudo medicinalis'i kullanmaları gerektiği kanaatine ulaşıldı.

SONUÇ

Sonuç olarak hirudoterapi olarak isimlendirilen tıbbi sülük tedavisi bazı hastalıklarda doğrudan tedavi edici özelliğe sahipken bir çok hastalıkta tıbbi tedaviye destek olarak kullanıldığı için her geçen gün daha da önem kazanmaktadır. Yapılan bu bibliyometrik çalışma ile bu alandaki çalışma sayısı, alıntı sıklığı, uluslararası bilimsel iş birliği, üniversitelerimizin çalışmaları ve anahtar kelimelerin kullanımı WoSCC veri tabanı kullanılarak açıklığa kavuşmuştur. Elde edilen objektif veriler bu alanda yapılacak çalışmalara yol gösterici olacaktır. Geleneksel ve Tamamlayıcı Tıp Uygulamaları içerisinde hirudoterapinin gelişmiş ülkelerdeki gibi hak ettiği değeri kazanması ve profesyonel sağlık personelleri tarafından uygulanmasının artması için ülkemizde hirudoterapi ile ilgili daha fazla bilimsel çalışmalar yapılarak farkındalığın artırılması gerektiği kanaatine varıldı.

Etik Standart ile Uyumluluk Çıkar çatışması

Bu araştırma çalışması, araştırma ve yayınlama etiğine uygun bir şekilde yürütülmüştür. MJAVL'de yayınlanan makalelerin bilimsel ve hukuki sorumluluğu yazar(lara) aittir.

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Bu çalışma için etik kurul onayı gerekmemektedir.

KAYNAKLAR

Abdualkader, A. M., Ghawi, A. M., Alaama, M., Awang, M. & Merzouk, A. (2013). Leech therapeutic applications. Indian Journal of Pharmaceutical Sciences, 75(2), 127–137.

Alaama, M., Kucuk, O., Bilir, B., Merzouk, A., Ghawi, A. M., Yerer, M. B., & Helaluddin, A. B. M. (2024). Development of leech extract as a therapeutic agent: A chronological review. Pharmacological Research-Modern Chinese Medicine. 10;100355.

Aldieri, L., Kotsemir M., Vinci, C.P. (2018) The impact of research collaboration on academic performance: An empirical analysis for some European countries. Socio-Economic Planning Sciences. 6;213-30.

Ariaa, M. & Cuccurullo, C. (2017). An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11, 959–975.

Ayhan, H. ve Mollahaliloğlu, S. (2018). Tıbbi sülük tedavisi: Hirudoterapi. Ankara Medical Journal, 18(1), 141-148.

Bilden, A., Çakır, F., Kahraman, M. ve Çiçek, M. (2024). Tıp fakültesi öğretim elemanlarının hirudoterapiye bakış açısının araştırılması. Mersin Üniversitesi Tıp Fakültesi Lokman Hekim Tıp Tarihi ve Folklorik Tıp Dergisi, 14(1), 109-116.

Bilden, A., Kara, Ö., Kahraman, M., Çağlayan, N., & Çiçek, M. (2025). Efficiency of medical leech on experimentally induced incisional wound healing in rats. *Journal of complementary & integrative medicine*, 10.1515/jcim-2024-0351. Advance online publication. https://doi.org/10.1515/jcim-2024-0351

Brauer, P. R., Saadah, M., Fritz, M. A., Wu, S. S. & Lamarre, E. D. (2024). Analysis of antibiotic resistant infections associated with hirudotherapy. American Journal of Otolaryngology, 45(6), 104500.

Chen, H., Jiang, W., Yang, Y., Yang, Y. & Man, X. (2015). Global trends of municipal solid waste research from 1997 to 2014 using bibliometric analysis. Journal of the Air & Waste Management Association, 65(10), 1161–1170.

Eroğlu, L., Orak, İ. ve Şimşek, T. (2004). Ekstravazasyon yaralanmasının tedavisinde tıbbi sülük kullanımı: ön çalışma. Türk Plastik Rekonstrüktif ve Estetik Cerrahi Dergisi, 12(3), 208-211.

Gödekmerdan, A., Arusan, S., Bayar, B. ve Sağlam, N. (2011). Tıbbi sülükler ve hirudoterapi. Türkiye Parazitoloji Dergisi, 35(4), 234-239.

Heinz, P., Tvrdý, P., Pink, R, Dvořák, Z. & Michl, P. (2020). Hırudotherapy in reconstructıve surgery: case-reports and revıew. Acta Chirurgiae Plasticae,62(3-4),95-102.

İkiışık H., Yılmaz FK., Baltalı O., Direk Ş., Yaycı S., Tahmazoğlu E. & Maral, I. (2021). Thoughts, attitudes and behaviors of research assistant doctors regarding traditional and complementary medicine practices: a cross-sectional research. Journal of Traditional Medical Complementary Therapies,4(2),246-55.

İri, R. & Ünal, E. (2024). Bibliometric Analysis Bibliometric Analysis of Research (1980-2023). Ahi Evran Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 10(2), 386-403.

Küçük, M. ve Yaman, O. (2019). Tıbbi Sülük Terapisi (Hirudoterapi). Journal of Biotechnology and Strategic Health Research,3,29-46.

Leydesdorff, L., Wouters, P. & Bornmann, L. (2016). Professional and citizen bibliometrics: complementarities and ambivalences in the development and use of indicators-a state-of-the-art report. Scientometrics, 109(3), 2129–2150.

Liu, C. & Barkley, T. W. Jr. (2015). Medicinal leech therapy: New life for an ancient treatment. Nursing, 45(11), 25–31.

Okka, B. (2013). Hirudotherapy from Past to Present. European Journal of Basic Medical Sciences, 3(3),61-65.

Özbek, M. ve Sarı, H. M. (2007). Batı Karadeniz Bölgesi'ndeki bazı göllerin Hirudinea (Annelida) faunası. Ege Journal of Fisheries and Aquatic Sciences, 24(1), 83-88.

Passas, I. (2024). Bibliyometrik analiz: ana adımlar. Ansiklopedi, 4 (2), 1014-1025.

Phillips, A. J. & Siddall, M. E. (2009). Poly-paraphyly of Hirudinidae: many lineages of medicinal leeches. BMC evolutionary biology, 9, 246.

Pottier, P., Lagisz, M., Burke, S., Drobniak, S. M., Downing, P. A., Macartney, E. L., Martinig, A. R., & Mizuno, A. (2024). Title, abstract and keywords: a practical guide to maximize the visibility and impact of academic papers. Proceedings. Biological sciences, 291(2027), 20241222. https://doi.org/10.1098/rspb.2024.1222

Pourrahimi, M., Abdi, M. & Ghods, R. (2020). Complications of leech therapy. Avicenna journal of phytomedicine, 10(3), 222–234.

Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World. *Publications*, *9*(1), 12. https://doi.org/10.3390/publications9010012.

Rados, C. (2004). Beyond bloodletting: FDA gives leeches a medical makeover. FDA consumer, 38(5).

Rousseau, R. (2014). Library science: Forgotten founder of bibliometrics. Nature, 510(7504), 218.

Manuvera, V. A., Kharlampieva, D. D., Bobrovsky, P. A., Grafskaia, E. N., Brovina, K. A., & Lazarev, V. N. (2024). New anticoagulant protein from medicinal leech. Biochemical and Biophysical Research Communications, 696, 149473.

Sağlam, N. (2011). Protection and sustainability, exportation of some spe-cies of Medicinal Leeches (Hirudo medicinalis L., 1758 and Hirudo verbana Carena, 1820). Journal of Fisheriessciences.com, 5, 1-15.

Sağlam, N., Saunders, R., Lang, S.A. & Shain, D.H. (2016). A new species of Hirudo (Annelida: Hirudinidae): historical biogeography of Eurasian medicinal leeches. BMC Zoology, 1, 1-12.

Sağlık Bakanlığı, (2014). Geleneksel ve Tamamlayıcı Tıp Uygulamaları Yönetmeliği. 27 Ekim 2014. Sayı: 29158. Başbakanlık Basımevi. Ankara

Singh A. P. (2010). Medicinal leech therapy (hirudotherapy): a brief overview. Complementary Therapies in Clinical Practice, 16(4), 213–215.

Sket, B. & Trontelj, B. (2008). Global diversity of leeches (Hirudinea) in freshwater. Hydrobiologia 595,129-137.

Şenel, E., Taylan Özkan, A. & Mumcuoglu, K. Y. (2020). Scientometric analysis of medicinal leech therapy. Journal of Ayurveda and İntegrative Medicine, 11(4), 534–538.

Vera, C., Blu, A. & Torres, M. (2005). Sanguijuelas, parásitos presentes ayer y hoy [Leeches, today and yesterday present parasites]. Revista chilena de infectología,22(1),32-37.

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Review Article

Bitkisel Tarımda Kullanılan Ürün İzleme Teknolojilerinin İncelenmesi

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ÖZET

MAKALE BİLGİSİ

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Hızla artan nüfus, iklim krizi ve gıda güvenliği sorunları, tarımsal üretimde dijitalleşme ve ürün izleme teknolojilerinin önemini her geçen gün artırmaktadır. Dijitalleşmenin, gıda güvenliği, sürdürülebilirlik ve verimlilik gibi kritik alanlara önemli katkılar sağladığı bilinmektedir. Özellikle ürün izleme teknolojileri, verimliliği artırma, kaynak kullanımını optimize etme ve çevresel etkileri azaltma açısından büyük bir potansiyele sahiptir. Bu çalışmada, ürün izleme teknolojileri; otomasyon ve robotik, görüntüleme ve sensörler, büyük veri ve veri analitiği başlıkları altında incelenmiştir. GPS, IoT ve yapay zeka gibi ileri teknolojilerin tarım sektöründe kullanımının yaygınlaşmasıyla birlikte, tarımsal süreçlerin daha verimli hale geldiği, üretimden tüketiciye kadar izlenebilirliğin ve şeffaflığın sağlandığı ortaya konulmuştur. Ayrıca, yakın gelecekte dijital ikiz teknolojisinin tarımda uygulanmasıyla tarımsal verimliliğin artacağı ve daha sürdürülebilir bir üretim yapılacağı öngörülmektedir.

Anahtar kelimeler: *Ürün İzleme, Otomasyon ve Robotik, Görüntüleme ve Sensörler, Büyük Veri ve Veri Analitiği*

Analysis of Crop Monitoring Technologies Used in Crop Agriculture

ABSTRACT

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The rapidly growing population, climate crisis, and food security issues are increasingly highlighting the importance of digitalization and product tracking technologies in agricultural production. It is well-known that digitalization provides significant contributions to critical areas such as food safety, sustainability, and efficiency. In particular, product tracking technologies hold great potential for enhancing efficiency, optimizing resource use, and reducing environmental impacts. In this study, product tracking technologies are examined under the categories of automation and robotics, imaging and sensors, big data, and data analytics. With the widespread use in advanced technologies such as GPS, IoT, and artificial intelligence in the agricultural sector, it has been demonstrated that agricultural processes have become more efficient, and traceability and transparency have been ensured from production to the consumer. Furthermore, it is anticipated that the application of digital twin technology in agriculture in the near future will enhance agricultural productivity and enable more sustainable production.

Keywords: *Crop Monitoring, Automation and Robotics, Imaging and Sensors, Big Data and Data Analytics*

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GİRİŞ

Dünya nüfusunun giderek artması, iklim krizi, savaşlar, küresel ısınma, küresel göç hareketliliği gibi bütün dünyayı etkileyen faktörler sebebiyle insanlık gıdaya erişim problemi ve kaynakların hızlıca tükenmesi riskiyle karşılaşmaktadır. Birleşmiş Milletler tarafından "Dünya Nüfus Tahmini" raporunda Dünya nüfusunun 2030'da 8,6 milyar, 2050'de 9,8 milyar ve 2100'de 11,2 milyarı geçmesinin beklendiği açıklanmıştır (O'Sullivan, 2023). Gıda ve Tarım Örgütü ise 2050'de dünya nüfusunun 9,1 milyara ulaşacağı ve dünya nüfusunun gıdaya ulaşımının ve beslenmesinin ciddi bir sorun olacağını ve bunun ile ilgili tüm ülkelerin politikalar geliştirmesi gerektiğini vurgulamaktadır. Aynı şekilde 2050'de gıda ihtiyacında artışın ise %60'dan daha yüksek olacağından hareketle küresel tarım ve gıda arzının artması gerektiğini ifade etmektedir (Le Mouël ve Forslund, 2017) Artan nüfusun gıda ihtiyacını karşılamak için verim artışının yanı sıra ülkelerin tarımsal Ar-Ge alanına yatırımlarını artırması ve bu doğrultuda politikalar geliştirmesi gerekmektedir. Bu doğrultuda gıda değer zincirinin tüm aşamalarında ortaya çıkabilecek risklere karşın gelişmiş dijital çözümlerin ortaya konulması önemlidir.

Dünyada olduğu gibi Türkiye'de de bu durum tüm yetkili otoriteler tarafından tartışılmakta ve çözümler aranmaktadır. Onuncu Kalkınma Planı döneminde (2014-2018) tarım sektöründe yapısal dönüşümün sağlanması amacıyla tarımsal desteklerin çeşitlendirilmesi, gıda güvenilirliği, toprak ve su kaynaklarının sürdürülebilir kullanımı, araştırma geliştirmenin artırılması, tarım işletmelerinin modernizasyonu, bitki ve hayvan sağlığı ile ıslahı başta olmak üzere çeşitli çalışmalar yürütülmüştür (T.C. Kalkınma Bakanlığı, 2013). On Birinci Kalkınma Planı döneminde (2019-2023) benzer şekilde çalışmaların ivme kazanarak devam edeceği belirtilmektedir. On Birinci Kalkınma Planında, Küresel Gelişmeler ve Eğitimler başlığında İklim Değişikliği, Gıda Güvenliği ve Suyun Etkin Kullanımına ilişkin tespitler yer almaktadır. Belirtilmekte olan tespit ve değerlendirmeler arasında; artan gıda talebi, iklim değişikliği, şehirleşme, toprak ve su kaynakları ile tarımsal ürünler ve üretici üzerinde baskı oluşturması; değişen iklime uygun bitki ve hayvan türlerinin geliştirilmesi, çevre ve biyolojik çeşitliliğin korunmasının önemi, daha az kaynakla gıda talebinin karşılanabilmesi için nitelikli işgücü ve teknolojiye ihtiyaç duyulması yer almaktadır. Ayrıca giderek önemi artan toprak ve su kaynaklarının sürdürülebilir kullanımı, gıda güvenliği, tarımda daha fazla teknoloji / bilgi kullanımı ile girdi kullanımın etkinleştirilmesi ve pazarlama kanallarının çeşitlendirilerek üretimin talebe uygun olarak yönlendirilmesi çabalarının artmakta olduğu ortaya konulmuştur (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2019). On İkinci Kalkınma Planı döneminde (2024-2028) ise akıllı tarım uygulamaları, tarımsal arazilerin korunması, planlı bitkisel ve hayvansal üretim, gıda güvenliği, sürdürülebilir tarım, üretici kayıt sistemleri ve ilgili bilgi sistemlerinin geliştirilmesi, dijitalleşme ve yapay zeka kullanımının yaygınlaştırılması gibi başlıklar öne çıkmaktadır (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2023). Buna göre Türkiye'de yakın zamanda tarımsal üretimde dijitalleşme ve yapay zekâ kullanımını yaygınlaştırmak amacıyla, akıllı tarım uygulamaları teşvik edilecek ve bu doğrultuda tarımsal üretici kayıt sistemleri diğer kayıt sistemleriyle entegre edilerek iyileştirilecektir. Bu entegrasyon, tarım sayımı ve kapsamlı bir tarım envanterinin oluşturulmasını destekleyecek, aynı zamanda ürün izlenebilirliğini sağlayacaktır. Tarım istatistiklerinin derlenmesi, işlenmesi, analizi ve kontrolü için geliştirilecek bilgi sistemleri, üretim süreçlerinin izlenmesini, erken uyarı sistemlerini, piyasa kontrollerini ve üretim planlamasını kolaylaştıracaktır. Ayrıca tarım arazilerinin korunması, sürdürülebilir kullanımı ve etkin yönetimi sağlanacak, arazi toplulaştırma çalışmaları sulama yatırımlarıyla entegre edilerek verimliliği artırırken, ürün izleme ve izlenebilirliğini destekleyen bir altyapı oluşturulacaktır.

Ürün izleme; verimlilik artışı, sürdürülebilirlik, gıda güvenliği, izlenebilirlik, karar destek sistemleri gibi birçok açıdan ilerlemeyi sağlamaktadır (Gomiero, 2019). Ürün izleme teknolojileri çiftçilere tarımsal faaliyetlerini daha verimli bir şekilde yürütmesine yardımcı olmaktadır. Uzaktan algılama, IoT (Nesnelerin İnterneti) sensörleri ve yapay zeka gibi teknolojiler, ürünlerin gelişim aşamalarını anlık veya belirli periyotlar ile izleme imkanı sunmaktadır. Bu sayede çiftçiler verimliliklerini artırmak için doğru kararları zamanında alabilmekte ve kaynaklarını daha etkin bir şekilde kullanabilmektedir. Sürdürülebilir tarım uygulamaları, tarımsal üretimin çevresel etkilerini azaltmayı amaçlarlar. Ürün izleme teknolojileri, toprak sağlığı, su kullanımı ve hava koşulları gibi çevresel faktörleri izleyerek tarımsal faaliyetlerin sürdürülebilirliğini sağlamaktadır (Aydın Eryılmaz ve Kılıç, 2018). Bu da çiftçilerin uzun vadede doğal kaynaklarını koruyarak üretim yapmalarına olanak tanımakta ve girdilerini azaltmaktadır. Ürün izleme teknolojileri, tarladan sofraya uzanan tüm tedarik zinciri boyunca ürünlerin her aşamada doğru ve etkin bir şekilde izlenmesini sağlamaktadır.

Özellikle tüketicilerin ürünlerin menşei ve üretim süreçleri hakkında daha fazla bilgi sahibi olması açısından geliştirilen izlenebilirlik sistemleri için de ürün izleme önemlidir. Ayrıca üretim sürecinde ortaya çıkabilecek sorunların konumunu tespit etmek için izleme gereklidir. Ürün izleme sistemleri, yapay zeka ve büyük veri analitiği ile entegre edilerek tarımda daha hassas ve öngörücü analizler yapılmasına olanak tanımaktadır (Kumar ve ark., 2022). Çiftçiler, elde edilen veriler doğrultusunda tarımsal süreçleri optimize edebilmekte, olası hastalık ve zararlıları önceden tespit edebilmekte ve hatta iklim değişikliklerine göre planlama yapabilmektedir

Ürün izleme teknolojisi, ürünlerin çiftlik düzeyinde izlenmesini içeren hassas tarımın bir parçasıdır. IoT'ye dayalı bağlantılı bir ekosistemle birlikte ürün sağlığı, zararlıların ve hastalık istilasının belirlenmesi, hava koşulları, toprak izleme, sulama izleme, verim tahminleri, stres tespiti vb. ile ilgili önemli bilgileri toplamak için sensörlerin, İHA'ların ve kamera sistemlerinin kullanılması bu pazarın büyümesinin önünü açmıştır. Ürün izleme, çiftçilerin ektikleri ve hasat ettikleri tarımsal ürünlerin verimini artırmak ve çevresel kaynakları daha verimli kullanan bir tarım modeli geliştirmek amacıyla başvurdukları çeşitli teknolojileri ifade etmektedir. Yapay zeka, makine öğrenmesi, uydu görüntüleme ve veri analitiği gibi bu teknolojiler, küçük ölçekli üreticilerin dahi ürün durumunu izlemelerine ve daha yüksek verim elde etmelerine olanak sağlamaktadır. (Ennouri ve ark., 2021). Halihazırda yaygın olarak kullanılan GPS teknolojisi, çiftçilere girdilerin daha verimli kullanılması ve tarımsal işlemlerin hassas bir şekilde yürütülmesi açısından önemli avantajlar sunmaktadır. GPS ile donatılmış tarım makineleri, belirlenen hatlar üzerinde minimum sapma ile çalışarak gereksiz tohum, gübre ve ilaç kullanımını önlemekte; bu sayede ürün izleme süreçlerine yüksek doğrulukta konumsal veri sağlamaktadır. (Torres-Torriti ve Burgos, 2023) Örneğin, GPS destekli gübreleme sistemleri yalnızca ihtiyaç duyulan alanlara uygulama yaparak hem maliyetleri azaltmakta hem de çevresel sürdürülebilirliğe katkı sunmaktadır. Bu entegrasyon ürün izleme altyapısının daha hassas ve etkin çalışmasına olanak tanımaktadır. Bu altyapının bir diğer önemli bileşeni ise sensörler ve uzaktan algılama teknolojileridir. Birçok sensör, toprakta bulunan besin maddeleri, nem, pH ve çevresel faktörler gibi çeşitli parametreleri izlemek ve ölçmek amacıyla kullanılmakta; bu veriler gerçek zamanlı olarak çiftçiler, ziraat mühendisleri ve araştırmacılar tarafından karar destek amacıyla değerlendirilmektedir (Paul ve ark., 2022). Aynı şekilde özellikle tarım için programlanmış ve geliştirilmiş İHA'lar ve uydularla elde edilen tarla görüntüleri, gelişmiş görüntü işleme teknikleriyle analiz edilerek hastalık tespiti, zararlı istilası, düzensiz büyüme ve bitki örtüsü indeksine dair önemli öngörüler sunmakta ve özellikle gelişmiş ülkelerde bu yöntemlerin hızlı bir şekilde yaygınlaştığı görülmektedir. (Barnes ve ark., 2019)

Ürün izleme sektörünün büyümesini sağlayan en önemli faktör, yapay zeka ve IoT tabanlı ürün izleme cihazlarının önder çiftçiler veya kooperatifler tarafından benimsenmesi ve bunun üzerine özellikle verimliliğin artması ile iyi örneklerin ortaya çıkmasıdır. Algılama teknolojileri ile birlikte yapay zeka kullanımı, gerçek zamanlı veya geçmiş veriler üzerinden analiz ile izleme sağlayarak insan müdahalesini ve bağımlılığı azaltmıştır. Ürün izleme pazarı, tarım sektöründe gerçek zamanlı bilgi toplama ve buna göre harekete geçme ihtiyacı arttıkça önemli bir potansiyele sahip olup, henüz gelişme aşamasındadır. Sensörlerin kullanımı, yenilikler ve sensör maliyetlerinin düşmesi sayesinde tarım arazilerinde daha yaygın hale gelmiştir. Ayrıca, birçok şirket tarım teknolojisi sektörüne büyük yatırımlar yapmış olup, 2019 yılında çiftlik teknolojisi girişimlerine toplam 4.7 milyar dolar yatırım yapılmıştır. Ürün izleme pazarının 2020'de 2.1 milyar dolardan 2025'te 4.4 milyar dolara büyümesi öngörülmektedir. (Markets and Markets, 2020).

Ürün izleme sektöründe Amerika kıtası, ürün izleme pazarında en büyük payı alan bölgedir. Bunun nedeni, Topcon, AgLeader, Trimble ve PrecisionHawk gibi büyük pazar oyuncularının bu bölgede bulunmasıdır. Bu şirketler, yenilikçi ürünler ve hizmetler sunarak ve Ar-Ge çalışmalarına büyük yatırımlar yaparak pazarın büyümesine katkıda bulunmuştur. ABD ve Kanada gibi ülkeler, uzaktan algılama ve görüntüleme teknolojilerinin yanı sıra otomasyon ve robotik alanında da erken benimseyenler arasında yer almaktadır (Research And Markets, 2025). Avrupa kıtasında -özellikle batı tarafında- iş gücü kıtlığı ve tarımsal üretimde kendine yeterlilik ihtiyacı nedeniyle tarımda uzaktan algılama ve otomasyon teknolojilerini erken benimsemiştir. Asya-Pasifik bölgesi ise algılama, görüntüleme ve değişken oran teknolojileri açısından gelecek vadeden pazarlardan biridir. Bölgedeki yüksek nüfus artışı ve tarımsal üretime olan talep, pazarın hızlı büyümesine katkıda bulunmaktadır (Markets and Markets, 2020). Hindistan, Avustralya, Çin ve Japonya bu bölgede önemli pazar payına sahip ülkeler olup, Asya-Pasifik pazarının 2020'den 2025'e kadar hızlı bir büyüme oranıyla gelişmesi beklenmektedir (Markets and Markets, 2020). Ürün izleme pazarındaki başlıca büyük şirketler CropX Technologies (İsrail), Topcon (ABD), Trimble (ABD), CropIn (Hindistan), Resson (Kanada),

Gamaya (İsviçre), AtFarm (Norveç), Bosch (Almanya) ve Telit (İngiltere) gibi şirketlerdir. Şirketlerin her biri yüksek teknoloji ürünleri geliştirerek tarım ile buluşturmuşlardır. İsrail merkezli CropX Technologies, toprak sensörleri ve veri analitiği yazılımları ile tarla bazlı karar destek sistemleri sunarken; Topcon ve Trimble (ABD) hassas GPS tabanlı ekipmanlar, otomatik sürüş sistemleri ve veri analiz platformları ile entegre çözümler üretmektedir. Hindistan'dan CropIn, yapay zeka destekli dijital tarla yönetimi platformları geliştirerek üreticilere gerçek zamanlı izleme imkânı sunmaktadır. Resson (Kanada) görüntü işleme ve makine öğrenmesi ile tarla sağlığını tespit eden çözümler üretirken, Gamaya (İsviçre) hiperspektral görüntüleme teknolojisi ile hastalık, zararlı ve besin eksikliklerini tespit etmektedir. Norveçli AtFarm, uydu görüntüleri üzerinden azot yönetimi ve bitki sağlığı izleme hizmeti sunarken, Bosch (Almanya) tarım makinelerine entegre edilebilen IoT tabanlı sensör çözümleri geliştirmektedir. Telit (İngiltere) ise bağlantılı tarım çözümleri için IoT modülleri ve veri iletişim altyapıları sağlamaktadır.

Öte yandan, dünya genelinde çiftçiler arasında dijital ve tarımsal teknolojilere yönelik okuryazarlığın artması, bu teknolojilerin benimsenmesini hızlandırmakta (Deichmann ve ark., 2016); tarımsal teknoloji ve girişim sermayesi yatırımlarındaki artış ile sağlanan kamu ve özel sektör teşvikleri de ürün izleme pazarının genişlemesine katkıda bulunmaktadır (Birner ve ark., 2021). Bu gelişmelerle birlikte, ürün izleme sistemleri sadece büyük ölçekli üreticilerin değil, küçük ve orta ölçekli çiftçilerin de erişebileceği bir yapıya dönüşmektedir. Ancak özellikle gelişmekte olan ülkelerde ileri tarım teknolojilerinin mekanizasyon altyapısına entegre edilebilirliğinin sınırlı olması ve kırsal alanlardaki yetersiz internet altyapısı, bu yaygınlaşmanın önündeki önemli engeller arasında yer almaktadır. Ayrıca bazı geleneksel üreticilerin yeni teknolojilere karşı isteksiz tutumu da benimsenme sürecini yavaşlatabilmektedir. Tüm bu unsurlar, ürün izleme teknolojilerinin yaygınlaşması ve etkili kullanımı için sadece teknik değil, aynı zamanda sosyal ve altyapısal düzeyde bütüncül yaklaşımlar geliştirilmesi gerektiğine işaret etmektedir.

MATERYAL VE YÖNTEM

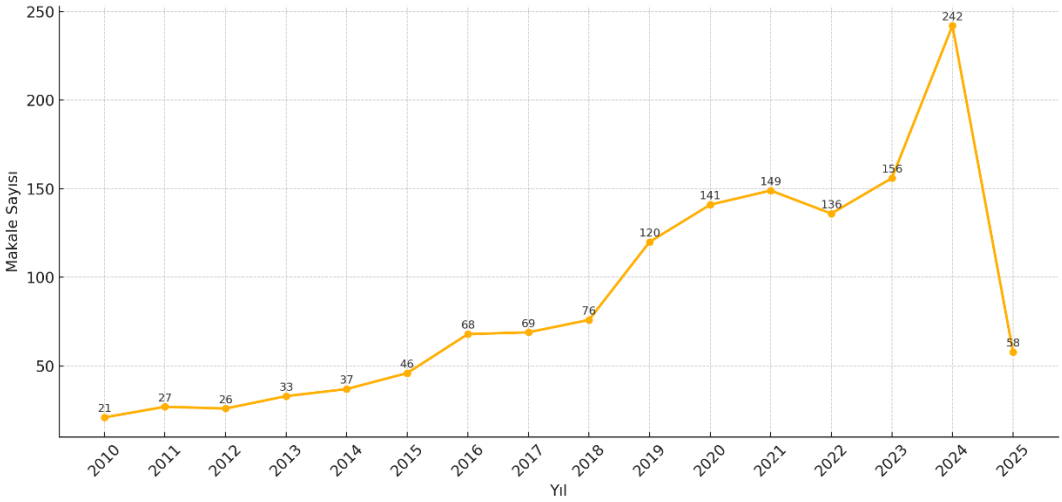
Bu çalışmada, ürün izleme teknolojilerine ilişkin kapsamlı bir bakış açısı sunmak amacıyla pazar raporları, bilimsel çalışmalar ve ilgili diğer kaynaklar bibliyometrik şekilde incelenmiştir. Bibliyometrik analiz bilimsel yayınların istatistiksel yöntemlerle incelenmesini sağlayan sistematik, şeffaf ve tekrarlanabilir bir literatür tarama yöntemidir. Bu analiz, hızla artan yayın hacmi karşısında bilgi birikimini anlamlandırmak, bilimsel alanların yapısını ve gelişimini haritalamak, en etkili çalışmalar ve yazarları belirlemek amacıyla kullanılır. Ayrıca bu yöntem araştırma önceliklerini belirlemeye yardımcı olurken, nesnel ve güvenilir bir inceleme sunar. Bu nedenle bibliyometrik analiz hem akademik değerlendirmelerde hem de politika yapım süreçlerinde önemli bir araçtır. (Aria ve Cuccurullo, 2017).

Bilimsel yayın taramaları için Clarivate Analytics Web of Science veri tabanı kullanılmış, Ocak 2010 ile Ocak 2025 tarihleri arasını kapsayan literatür incelenmiştir. Bu zaman dilimi, hem alanın temellerini hem de en güncel gelişmeleri değerlendirmeye olanak tanımaktadır. Tarama kriterleri, tarım, tedarik zinciri yönetimi ve dijital inovasyon gibi alanlarda ürün izleme teknolojilerine odaklanan çalışmaları belirlemek üzere oluşturulmuştur. Ayrıca, akademik yayınların yanı sıra önde gelen sektör analistlerinin hazırladığı pazar raporları, beyaz kitaplar, bildiriler ve patentler de analiz edilmiştir. Bu belgeler, teknolojilerin pratikteki uygulamaları, benimsenme düzeyleri, karşılaşılan zorluklar ve ekonomik etkilerine dair kapsamlı veriler sunmuştur. Bu çok boyutlu yaklaşım sayesinde, ürün izleme sistemlerinin güncel uygulamaları, karşılaştığı temel sorunlar ve sürdürülebilirlik, kaynak verimliliği ile izlenebilirlik gibi konularda sunduğu potansiyel katkılar derinlemesine incelenmiştir. Pazar raporları, mevcut pazar dinamiklerini ve gelecek projeksiyonlarını ortaya koyarken; bilimsel çalışmalar ise teorik çerçeve ve deneysel bulgular aracılığıyla çalışmanın akademik temellerini desteklemiştir. Ayrıca, benzer çalışmalardan elde edilen yöntem ve bulguların karşılaştırmalı analizi, metodolojinin sağlamlığını ve elde edilen sonuçların güvenilirliğini artırmıştır.

ARAŞTIRMA BULGULARI VE TARTIŞMA

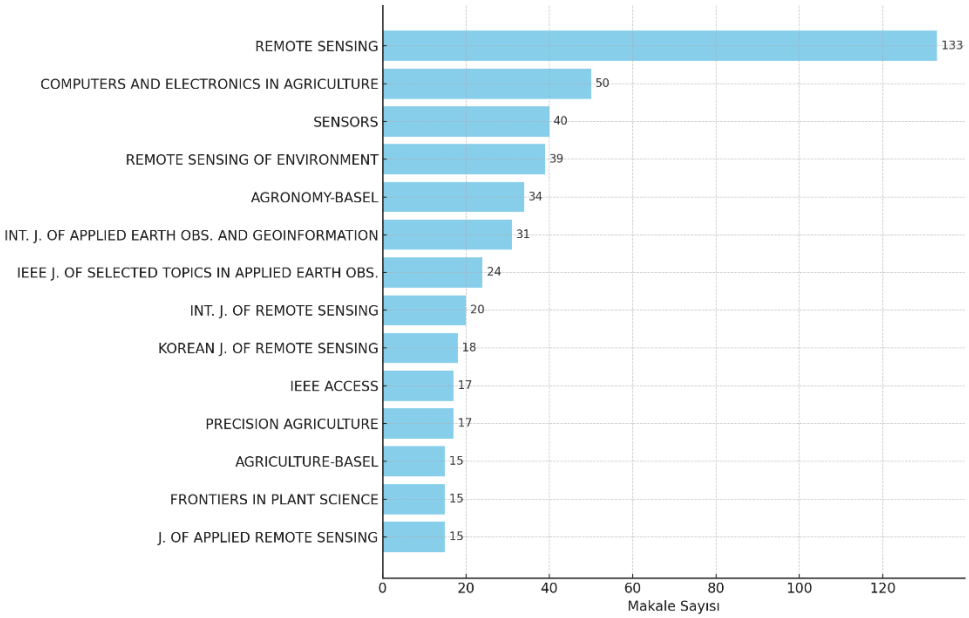
Web of Science taraması sonucunda belirtilen kriterlere uygun 1405 çalışma tespit edilmiştir. Bu çalışmalar, 615 farklı kaynakta yayımlanmış olup, toplamda 5902 yazar tarafından katkı sağlanmıştır. Yazarların %30,75'i uluslararası ortak yazarlık ile çalışmalar yürütmüştür. Çalışmalarda toplam 45231 farklı kaynak kullanılmıştır ve yayın başına ortalama atıf sayısı 21,46 olarak hesaplanmıştır. Yıllara göre bakıldığında her yıl bu alanda yapılan çalışmaların artış gösterdiği Şekil 1'de gösterilmiştir. 2010'dan 2025'e kadar yıllara göre ürün izleme konulu bilimsel yayınların sayısal dağılımı gösterilmektedir. Özellikle 2016 yılından itibaren

belirgin bir artış eğilimi görülmektedir. 2019 sonrası dikkat çekici bir yükseliş yaşanmış, 2024 yılında zirveye ulaşarak 242 yayına kadar çıkmıştır. 2025 verisi ise sadece yılın ilk çeyreğini kapsadığı için düşük görünmekte (58 yayın) ancak genel eğilim, bu alandaki akademik ilginin sürekli arttığını açıkça ortaya koymaktadır.



Şekil 1: *Yıllara göre ürün izleme konusundaki WOS yayın sayıları*

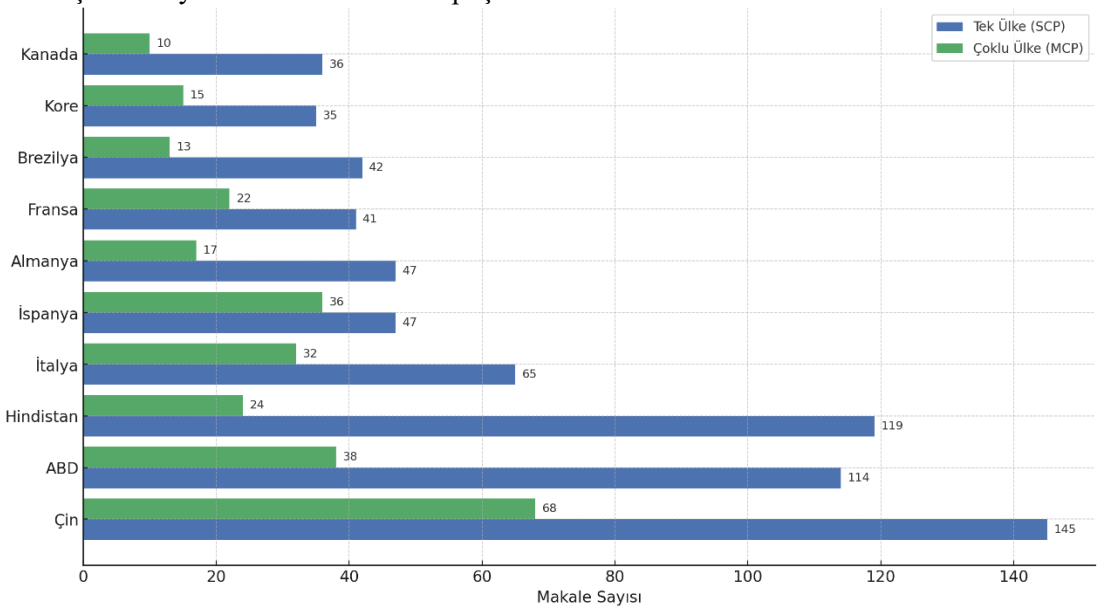
Şekil 2'de, ürün izleme teknolojileri üzerine 15 ve üzeri yayın yapan akademik dergiler görselleştirilmiştir. En çok yayını yapan dergi Remote Sensing olup, 133 makale ile açık ara öndedir. Bu dergiyi sırasıyla Computers and Electronics in Agriculture (50), Sensors (40) ve Remote Sensing of Environment (39) takip etmektedir. Liste ağırlıklı olarak uzaktan algılama, hassas tarım, sensör teknolojileri ve elektronik tarım uygulamaları odaklı dergilerden oluşmaktadır. Bu durum, ürün izleme konusunun disiplinlerarası yapısını ve özellikle uzaktan algılama ile sensör sistemlerinin bu alandaki merkezi rolünü ortaya koymaktadır.



Şekil 2: *Çalışmaların Yayınlandığı Dergilere göre Dağılımı*

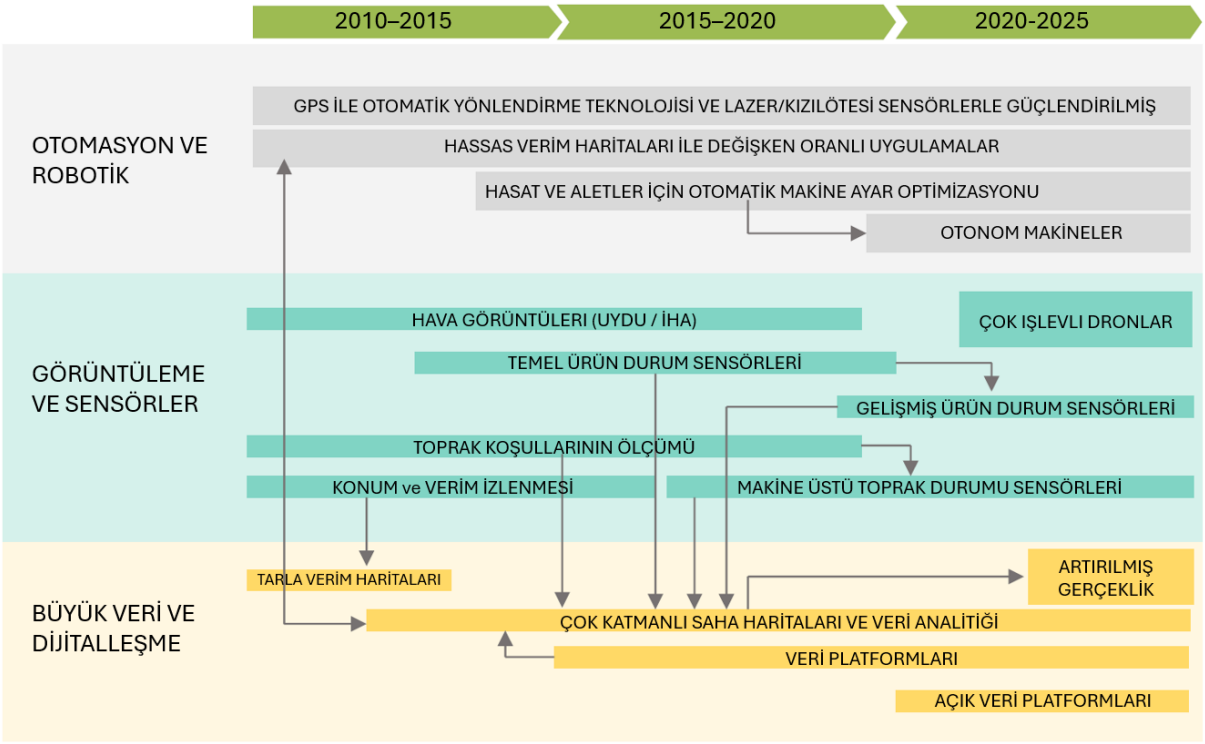
Şekil 3'te ürün izleme teknolojileri alanında en fazla bilimsel yayına sahip ilk 10 ülkeyi, toplam yayın sayılarına göre büyükten küçüğe sıralı olarak göstermektedir. Her ülkenin yayınları, tek ülke ortaklığı (SCP) ve çok uluslu ortaklık (MCP) olmak üzere iki kategoride sunulmuştur. En fazla yayını gerçekleştiren ülke 213 yayınla Çin olurken, onu 152 yayınla ABD ve 143 yayınla Hindistan takip etmektedir. Bu üç ülke, toplam yayın sayısında açık farkla öndedir. Onları sırasıyla İtalya (97), İspanya (83), Almanya (64), Fransa (63), Brezilya (55), Kore (50) ve Kanada (46) izlemektedir. Avrupa ülkeleri olan İtalya, İspanya, Almanya ve Fransa'nın yayın sayıları orta düzeydedir; ancak bu ülkelerde çok uluslu ortaklığa dayalı yayın oranlarının görece yüksek olduğu görülmektedir. Özellikle İspanya, tek ülke ve çoklu ortaklı yayınlar arasında dengeli bir

dağılıma sahiptir. Buna karşılık, Çin, Hindistan ve ABD gibi ülkelerde yayınların büyük kısmı yerel araştırmacılar tarafından üretilmiştir. Bu farklılıklar, ülkelerin araştırma iş birliği stratejileri ve uluslararası bilimsel etkileşim düzeyleri hakkında önemli ipuçları sunmaktadır.



Şekil 3: *Çalışmaların Ülkelere göre Dağılımı*

Çalışmada ürün izleme sistemleri 3 kategoride incelenmiştir. Bunlar sırası ile otomasyon ve robotik, görüntüleme ve sensörler, büyük veri ve veri analitiğidir. İncelenen alışmalar arasında, Görüntüleme ve Sensörler kategorisi %46,31 ile en yüksek orana sahiptir. Otomasyon ve Robotik kategorisi %45,64 oranıyla bunu yakından takip ederken, Büyük Veri ve Veri Analitiği kategorisi %8,05 oranıyla düşük paya sahiptir. 2010-2025 yılları arasında ürün izleme teknolojilerindeki gelişmeleri ve hangi dönemlerde hangi teknolojilerin öne çıktığını zaman çizelgesi şeklinde **Şekil** 'de göstermektedir. Üç ana kategoriye ayrılan bu süreçte ilk olarak otomasyon ve robotik alanında, 2010-2015 yılları arasında GPS (Küresel Konumlama Sistemi) ile otomatik yönlendirme teknolojisi ve lazer/kızılötesi sensörlerin kullanımı öne çıkmıştır. 2015-2020 yıllarında hassas tarım verim haritaları ve değişken oranlı uygulamalarla birlikte makinelerde otomatik ayar optimizasyonu sağlanmış, 2020-2025 döneminde ise otonom tarım makineleri bu alanda önemli bir yer edinmiştir. Görüntüleme ve sensörler kategorisinde, 2010-2015 yılları arasında hava görüntüleri ile temel ürün durumu sensörleri kullanılmaya başlanmış, 2015-2020 döneminde toprak koşullarının ölçümü ve gelişmiş ürün durumu sensörleri devreye girmiştir. 2020-2025 yılları arasında ise çok işlevli İHA'lar ve makine üstü toprak durumu sensörleri bu alandaki gelişimi sürdürmektedir. Büyük veri ve dijitalleşme ise 2010-2015 yılları arasında tarla verim haritalarıyla başlamış, 2015-2020 döneminde çok katmanlı saha haritaları ve veri analitiği, veri platformları ile daha karmaşık hale gelmiş ve 2020-2025 yılları arasında artırılmış gerçeklik ve açık veri platformlarının gelişimiyle daha ileri bir düzeye taşınmıştır. Şekil 4 ürün izleme dijitalleşmenin ve otomasyonun zamanla nasıl geliştiğini ve gelecekte hangi teknolojilerin öne çıkacağını ortaya koymaktadır.



Şekil 4: *Ürün İzleme Pazarındaki Mevcut ve Gelecek Teknolojileri (Markets and Markets raporu kullanılarak yazarlar tarafından oluşturulmuştur)*

Otomasyon ve Robotik

Otomasyon ve robotik, ürün izleme ve karar destek süreçlerinde GPS veya benzeri konumlandırma teknolojilerini kullanan gelişmiş otomatik dümenleme sistemleri ile tarım robotlarının kullanımını kapsamaktadır. Otomatik dümenleme sistemleri, traktörler ve otonom tarım makinelerini hassas bir şekilde yönlendiren navigasyon sistemleridir. Bu sistemler; sürüş, ekim ve hasat işlemlerinde doğruluğu artırmanın yanı sıra, enerji tüketimini azaltmak, verim kayıplarını en aza indirmek ve tarım girdilerinin daha verimli kullanılmasını sağlamak gibi birçok avantaj sunmaktadır (Fountas ve ark., 2020). Mevcut durumda bazı tarım makinelerinde, ürün izleme tekniklerinin bir parçası olarak yönlendirme teknolojisini veya otomatik dümenleme cihazlarını kullanmaktadır. Ürün izlemede, GPS cihazları tarla haritalama, toprak örnekleme, ekim/biçim yönlendirme teknolojisi, ürün keşfi, değişken oranlı gübreleme uygulamaları ve verim haritalama için çiftliklerde traktörlere ve otonom araçlara yerleştirilmektedir. Otomasyon ve robotik kategorisi içinde ilaçlama yapan İHA'lar, yabancı ot biçiminde kullanılan robotlar ve benzeri birçok makine sayılabilmektedir (Hasan ve ark., 2021).

Yapılan bibliyometrik araştırmada bu alanda ciddi bir kümelenmenin olduğu olduğu tespit edilmiştir. Bu konuda incelenen çalışmalardan en fazla atıf alan çalışmalardan bir tanesinde tarla bitkilerinin büyüme ve gelişimini yüksek doğruluk ve tekrarlanabilirlikle izlemek için, üç boyutlu hareket edebilen, sabit raylara monte edilmiş tam otomatik bir robotik fenotipleme platformu geliştirilmiş ve çeşitli sensörlerle bitki performansı yoğun şekilde izlenmiştir (Virlet ve ark., 2017 Başka bir çalışmada ise hassas tarımda mahsul izleme ve güvenlik için düşük maliyetli, enerji tasarruflu ve video gözetim özelliklerini entegre eden bir WSN (Kablosuz Sensör Ağı) platformu/otomasyonu geliştirilmiş, bu platformun enerji tüketimi, çerçeve çakışma olasılığı ve uçtan uca gecikme açısından etkinliği simülasyon ve saha testleriyle doğrulanmıştır (Garcia-Sanchez ve ark., 2011). Benzer şekilde seralarda marul bitkilerinde kalsiyum eksikliğini, insan gözüyle görülebilir belirtilerden bir gün önce tespit edebilen, bitki morfolojik, renk ve doku özelliklerini analiz eden bir makine görüş sistemine dayalı otomatik izleme ve algılama yöntemi robotik olarak geliştirilmiştir (Story ve Ark., 2010).

Milella ve ark. (2024), hizmet olarak robotic (RaaS- Robotics as a Service) yaklaşımının hassas tarımda yeni bir paradigma olarak nasıl uygulanabileceğini ATLAS projesi çerçevesinde incelemiştir. Tarımda robotik ve çoklu sensör teknolojilerinin yaygınlaşmasına rağmen, üreticiye özgü kapalı sistemler ve birlikte çalışabilirlik eksikliği, sistemlerin esnek uyarlanmasını ve bilgi paylaşımını zorlaştırmaktadır. Bu sorunu çözmek üzere

geliştirilen ATLAS projesi, sensör sistemleri, makineler ve veri analiz araçları arasında açık ve dağıtık bir birlikte çalışabilirlik ağı sunmaktadır. Çalışmada, bağ bozumu alanlarında bitki ölçekli izleme yapan RGB-D ve konumlandırma sensörleriyle donatılmış yenilikçi bir tarım robotu tanıtılmış, bu robotla entegre çalışan yazılım bileşenleri aracılığıyla renk ve derinlik verileri kullanılarak bitki örtüsü indeksleri ve morfolojik parametrelerin ölçüldüğü bir hizmet sunulmuştur. Sistem, iki farklı bağda test edilerek ATLAS ağına başarıyla entegre edildiği gösterilmiştir. Modüler yapısıyla çoklu robot yapılandırmalarına ve diğer hassas tarım uygulamalarına (örneğin meyve sayımı, seçici gübreleme ve hasat) kolayca uyarlanabilmektedir. ATLAS ile geliştirilen bu teknoloji, geleneksel tarım ortamlarında robot kullanımını mümkün kılarak, genç ve teknolojiye yatkın kuşakları tarıma çekmeyi hedeflemekte ve nitelikli iş gücü eksikliğine karşı çözüm sunmaktadır (Milella ve ark., 2024). Wei ve ark (2024), tarımsal alanlarda otonom veri toplama ve izleme amacıyla geliştirilen mobil bir kara robotunu tanıtmıştır. Robot, GPS, IMU ve tekerlek enkoderlerinden gelen verileri birleştiren genişletilmiş Kalman filtresi ile hassas konumlandırma sağlamakta ve yönlendirme için yapay elektrik potansiyel alanı temelli yeni bir yöntem kullanmaktadır. Dört tekerlekli yapıya entegre edilen sistem, geleneksel Nav2 algoritmasına kıyasla daha hızlı veri işleme performansı göstermiştir. Robot, tarla sıralarında otonom şekilde hareket ederken RGB ve derinlik görüntüleri toplayabilmekte, bu da sistemin tarımsal izleme için etkinliğini ortaya koymaktadır. Kullanıcıların hedef bölgeleri tanımlamasını ve robotu gerçek zamanlı izlemesini sağlayan grafik arayüz de geliştirilmiştir. ROS2 (Robot Operating System 2) tabanlı mimari ile çalışan sistem, tekli robot uygulamalarının ötesinde çoklu robot yapılarına genişletilmek üzere planlanmış ve Unity arayüzleri ile birlikte değerlendirilmiştir (Wei ve ark., 2024).

Çalışmalar ve rapor incelendiğinde otomasyon ve robotik açısından 2010-2015 yılları arasında, GPS ile otomatik yönlendirme teknolojisi ve lazer/kızılötesi sensörlerin kullanımı öne çıkmıştır. Bu dönemde, çiftçiler tarımsal araçları daha hassas şekilde yönlendirebilmek için GPS teknolojisinden yararlanmaya başlamışlardır. Ayrıca lazer ve kızılötesi sensörler, tarım makinelerine entegre edilerek daha verimli bir çalışma sağlamıştır. Bu teknolojiler, tarımsal süreçlerin doğruluğunu artırmış ve operasyonel hataları en aza indirmiştir. 2015-2020 yılları arasında, hassas tarım verim haritaları ve değişken oranlı uygulamaların yanı sıra hasat makineleri ve tarımsal aletler için otomatik makine ayar optimizasyonu yapılmaya başlanmıştır. Bu dönemde tarımsal verimliliği artırmak için makinelerin verileri analiz edip kendilerini optimize etme yeteneği gelişmiştir. Özellikle değişken oranlı uygulamalar sayesinde gübreleme, sulama ve ilaçlama gibi işlemler daha verimli hale gelmiş ve kaynak kullanımı optimize edilmiştir. 2020-2025 yılları arasında ise otonom tarım makineleri devreye girmeye başlamaktadır. Bu makineler, herhangi bir insan müdahalesine gerek duymadan tarımsal işlemleri gerçekleştirebilecek şekilde programlanmaktadır. Otonom tarım makineleri, tarlada tamamen kendi kendine çalışan sistemler olarak tarımda büyük bir dönüşüm sağlayacaklardır. Bu teknoloji, iş gücü sorunlarını çözmekte ve tarımsal süreçlerin daha etkin, hızlı ve düşük maliyetle yönetilmesine imkan tanımaktadır.

Ürün izlenebilirliği açısından değerlendirildiğinde, 2010-2025 yılları arasındaki teknolojik gelişmeler, tarım sektöründe izlenebilirliğin etkinliğini önemli ölçüde artırmıştır. 2010-2015 yılları arasında GPS ile otomatik yönlendirme teknolojisi ve lazer/kızılötesi sensörlerin kullanımı, tarımsal faaliyetlerin daha hassas ve doğru bir şekilde yapılmasına olanak sağlamıştır. Bu, tarla ve ürün yönetimi süreçlerinde daha doğru verilerin elde edilmesi ve bu verilerin izlenebilirlik sistemlerine entegre edilmesi açısından büyük bir adım olmuştur. Lazer ve kızılötesi sensörlerle sağlanan veriler, ürünlerin yetiştirilme sürecinde hangi alanlarda ne tür işlemler yapıldığını daha net bir şekilde takip etmeye olanak tanımıştır. Bu sayede, üretim sürecinde hangi adımların atıldığına dair daha kapsamlı ve doğruluğu yüksek izlenebilirlik bilgileri elde edilmiştir. 2015-2020 yılları arasında, hassas tarım kapsamında verim haritalarının kullanımı ve değişken oranlı uygulamaların yaygınlaşmasıyla birlikte izlenebilirlik süreçleri önemli ölçüde gelişmiştir. Tarımsal makineler, analiz edilen veriler doğrultusunda çalışmaya başlayarak gübreleme, sulama ve ilaçlama gibi işlemleri değişken oranlı teknolojiyle daha hassas ve verimli şekilde gerçekleştirmiştir. Bu gelişmeler, ürünlerin yetiştirilme sürecindeki kaynak kullanımının izlenmesini ve her bir ürünün hangi çevresel ve tarımsal koşullar altında üretildiğinin daha ayrıntılı olarak takip edilmesini mümkün kılmıştır. Özellikle otomatik makine ayarlarının optimize edilmesi sayesinde, üretim sürecinin tüm adımları sistematik biçimde izlenebilir ve belgelenebilir hale gelmiştir. 2020-2025 yılları ise otonom makinelerin tarımda devreye girmesiyle, izlenebilirlik açısından yeni bir dönemi başlatmıştır. Otonom makineler, insan müdahalesi olmadan ürün yetiştirme süreçlerini yönettiği için, her aşamanın dijital ortamda kaydedilmesi ve izlenmesi daha da kolaylaşmıştır. Bu makineler, hangi alanlarda hangi işlemlerin yapıldığını, ne kadar kaynak kullanıldığını ve ürünlerin hangi koşullarda yetiştirildiğini otomatik olarak raporlayabilmektedir. Bu durum, tarladan sofraya kadar tüm süreçlerin şeffaf

bir şekilde izlenebilmesine olanak tanıyarak, tüketicilere güvenli ve sürdürülebilir gıda sağlama açısından büyük avantajlar sunmaktadır.

Görüntüleme ve Sensörler

Yapılan bibliyometrik araştırmada en büyük kümelenmenin bu alanda olduğu tespit edilmiştir. Hatta HLS (Uyumlaştırılmış Landsat ve Sentinel) veri setinin tarımsal ürün izleme gibi uygulamalarda yüksek potansiyel sunduğu vurgulanmış ve bu konuda örnek zaman serileri sunulan çalışma (Claverie ve ark., 2018) en çok atıf alan çalışmadır. İkinci atıf oranı yüksek çalışmada ise tarımsal ürün izleme için Sentinel-1 ve benzer optik verilerle farklı ürün türlerinin uzaktan algılama sinyallerindeki zamansal değişimleri analiz ederek, özellikle Sentinel-1'in VH/VV (vertical-horizontal/vertical-vertical) oranının potansiyelini vurgulamaktadır (Veloso ve ark., 2017). Üçüncü çalışmada yazarlar arpa yetiştiriciliğinde İHA ile elde edilen yüksek çözünürlüklü RGB görüntülerinden türetilen bitki verilerini kullanarak biyokütle tahmini yöntemlerini değerlendirip tarımsal uygulamalarda potansiyelini ortaya koymuşlardır (Bendig ve ark., 2014). Diğer bir çalışmada ise tarımsal üretimi artırırken çevresel etkileri azaltmayı hedefleyen hassas tarım uygulamalarında, uydu görüntüleme, İHA'lar, büyük veri analitiği ve yapay zeka gibi teknolojilerin kullanımını ve bunların güncel uygulamalarını kapsamlı bir şekilde inceleyerek, uzaktan algılamanın daha geniş ölçekli benimsenmesi için basit ve güvenilir iş akışlarının geliştirilmesinin önemini vurgulamaktadır (Sishodia ve ark., 2020). Çalışmalar ve rapor incelendiğinde görüntüleme ve sensörler açısından, 2010-2025 yılları arasında teknolojinin gelişimi üç ana dönemde incelenmektedir. 2010-2015 yılları arasında hava görüntüleme (uydu ve İHA) ve temel ürün durumu sensörleri kullanılmaya başlanmıştır. Bu teknolojiler, tarla genelinde genel veriler sağlamıştır. 2015-2020 döneminde, toprak koşullarının ölçümü ve daha gelişmiş ürün durumu sensörleri kullanılmaya başlanmış, bu sensörler toprak ve bitki sağlığı hakkında daha detaylı bilgi sunmuştur. 2020-2025 yılları arasında ise çok işlevli İHA'lar ve makine üstü toprak durumu sensörleri gibi daha gelişmiş sistemler devreye girmiştir. Bu sistemler, bitki ve toprak sağlığına dair daha hassas ve gerçek zamanlı veriler sağlayarak tarımın verimliliğini artırmayı amaçlamaktadır. Tarımda uzaktan algılama ve görüntüleme teknolojileri, tarlaya fiziksel olarak erişim gerektirmeden ürün veya arazi durumunun izlenmesine olanak tanımaktadır. Bu teknoloji toprak nemi, sıcaklık, besin durumu, sıkışma ve stres gibi çeşitli tarımsal parametrelerin belirlenmesinde etkili bir araç olarak kullanılmaktadır (Karmakar ve ark., 2024). Uydu, İHA ve yersel kameralar aracılığıyla elde edilen görüntüler sayesinde çiftçiler, sahaya sensör yerleştirmeden ürün gelişimini uzaktan takip edebilmekte ve belirli alanları detaylı olarak analiz edebilmektedir (Olson ve Anderson, 2021). Bu görüntüler, gelişmiş analiz yazılımları ile işlenerek ürün stresinin yeri, yayılımı ve nedenleri hakkında bilgi sunmaktadır. Uzaktan algılama sistemleri aynı zamanda ürün ve toprak değişkenliğini haritalamak, verim haritaları oluşturmak ve zararlı ya da hastalık kaynaklı sorunları tespit etmek gibi işlevlerde yaygın olarak kullanılmaktadır. Bu sayede tarım girdilerinin optimize edilmesi sağlanmakta; verimlilik artışı ve çevresel etkilerin azaltılması gibi sürdürülebilir üretim hedeflerine katkıda bulunulmaktadır. Ancak bu teknolojilerin sağlıklı şekilde uygulanabilmesi için cihaz kalibrasyonu, atmosferik düzeltmeler ve görüntü işleme gibi teknik süreçlerin dikkatle yürütülmesi gerekmektedir. Güvenilir ve anlamlı sonuçlar elde etmek adına gelişmiş veri işleme tekniklerinin kullanımı kaçınılmazdır. Bu aşamada ise yapay zeka ve veri analitiği kavramları devreye girmektedir (Javaid ve ark., 2023). Uydu görüntüleme veya uzaktan algılama, ürünlerin biyofiziksel parametrelerini haritalamak için kullanılan çok bantlı bir görüntüleme tekniğidir. Hava araçları, bitki örtüsü miktarını ölçerek ekinleri yabancı otlardan ayırt edebilmekte ve bu veriler CBS (Coğrafi Bilgi Sistemi) yazılımı yardımıyla haritalara dönüştürülebilmektedir. Bu teknoloji, geniş alanlarda tarla ve ürün durumunu neredeyse gerçek zamanlı olarak izlemek için değerli bilgiler sunmaktadır. Ancak, verilerin güvenilirliği ve zamanında teslimi hala önemli bir endişe kaynağıdır. Uydu görüntüleme, karmaşık dijital sensörler sayesinde dünya yüzeyini hızlı ve kaliteli bir şekilde tarayabilmektedir. Klorofilin radyasyonu emmesini ölçen NDVI (Normalized Difference Vegetation Index) gibi analiz yöntemleri, gübre ve su gibi girdilerin yönetilmesi ile ürün verimi tahmini için kullanılmaktadır. Bu analizler, çiftçilerin tarım faaliyetlerini optimize etmelerine ve gelecekteki üretimi planlamalarına yardımcı olmaktadır (Wu ve ark., 2015). İHA'lar, tarımda maliyetleri azaltma ve değişken oranlı uygulamalarda daha hassas veri sağlama avantajları sayesinde ürün izleme amacıyla yaygın şekilde kullanılmaktadır. Geleneksel yöntemlerle çiftçilerin tarlayı fiziksel olarak gezip veri toplaması günler sürebilirken, İHA'lar kısa sürede geniş alanların yüksek çözünürlüklü görüntülerini toplayarak önemli bir zaman ve emek tasarrufu sağlamaktadır. Elde edilen bu görüntüler, görüntü işleme yazılımları ve analiz sistemleri aracılığıyla işlenerek bitki sayımı, bitki boyutu ve tarladaki stresli alanların ya da sorunlu bölgelerin tespiti gibi çıktılara dönüştürülmektedir (Cuaran ve Leon, 2021). İHA'lar, bitki homojenliğini ve verimini

erken aşamada tespit edebilme yeteneğine sahiptir. Hiperspektral kameralar ve görüntüleme sensörleri ile donatılan bu cihazlar, çiftçiler tarafından kiralanabilmekte veya satın alınabilmektedir. İHA'dan çekilen görüntüler, bulut tabanlı yazılım çözümleri yardımıyla düzeltme işlemine tabi tutularak tek bir perspektif sunacak şekilde birleştirilebilmektedir. Bu işlem sonucunda coğrafi referanslı haritalar oluşturulabilmekte ve yabancı ot tespiti, ürün sağlığı izleme, hasat izleme ve verim tahmini gibi görevler için kullanılabilmektedir.

Yersel sensörler, ürün ve tarla verilerini toplamak amacıyla kullanılan uzaktan algılama cihazlarıdır. Bu sensörler, el tipi cihazlara entegre edilebildiği gibi tarım makinelerine monte edilerek de kullanılabilmektedir. El tipi sensörler; besin düzeyi, toprak yapısı ve iklim koşullarını ölçmeye yönelik farklı kategorilere ayrılmaktadır. Toprak nemi, sıcaklık ve besin maddeleri gibi kritik tarımsal parametreleri sahadan doğrudan ölçen bu sensörler, uydu tabanlı sistemlere kıyasla hem daha uygun maliyetli hem de uygulamaya özel esnek çözümler sunmaktadır (Ali ve ark., 2022) Bu nedenle özellikle verim izleme ve toprak haritalama gibi ürün izleme uygulamalarında yaygın olarak tercih edilmektedir. Yer tabanlı sensörlerin kullanım kolaylığı ve teknik bilgi gereksiniminin az olması, çiftçiler açısından erişilebilirliğini artırmaktadır. Öte yandan telemetri teknolojileri de giderek önem kazanan bir alan olmaya başlamıştır. Tarımda telemetri teknolojileri, tarla ekipmanlarından gerçek zamanlı veri toplanmasını, bu verilerin kablosuz ağlar ya da uydu sistemleri aracılığıyla bulut tabanlı platformlara iletilmesini ve sonrasında analiz edilerek anlamlı bilgilere dönüştürülmesini sağlayan entegre bir sistemdir. Bu sistem sayesinde; traktör, biçerdöver ve ilaçlama makineleri gibi ekipmanların çalışma saatleri, konum bilgileri, hızları, yakıt tüketimleri ve mekanik durumları uzaktan izlenebilmektedir. Özellikle hassas tarım uygulamalarında, telemetri aracılığıyla toplanan veriler, makinelerin operasyonel verimliliğini artırmak, bakım süreçlerini planlamak, enerji tüketimini azaltmak ve karar destek sistemlerini güçlendirmek amacıyla kullanılmaktadır. Araştırmalar, bu teknolojilerin tarımsal otomasyonun önemli bir bileşeni haline geldiğini ve dijital tarımın temel taşlarından biri olarak değerlendirildiğini göstermektedir. (Marques ve ark., 2022).

Büyük veri ve Veri Analitiği

Tarımda büyük veri platformları, tarımsal faaliyetlerden çeşitli teknolojiler ile elde edilen verileri toplayan, işleyen ve analiz eden dijital sistemlerdir. Bu platformlar, çiftçilerin ve tarımsal işletmelerin toprak, hava koşulları, ürün durumu, sulama, gübreleme, zararlı izleme gibi çeşitli alanlardan veri toplayarak daha bilinçli kararlar almalarına yardımcı olmaktadır. Büyük veri, uydu görüntüleri, sensörler, hava durumu verileri, traktör ve diğer tarım makinelerinden gelen telemetri verileri gibi kaynaklardan sağlanmaktadır. Büyük veri platformları ayrıca tedarik zinciri yönetimi ve izlenebilirlik açısından da önemli avantajlar sunmaktadır. Ürünlerin çiftlikten sofraya kadar izlenmesini sağlayarak, tarımsal üretimde şeffaflığı artırır ve gıda güvenliği sorunlarını çözmeye yardımcı olmaktadır (Chergui ve Kechadi, 2022). Çiftçiler, tedarik zincirindeki her adımı izleyerek, hangi aşamada ne tür işlemler yapıldığını kayıt altına alabilmektedir. Bu izlenebilirlik hem tüketicilere ürün güvenliği sağlamakta hem de sürdürülebilir tarım uygulamalarını desteklemektedir. Öte yandan tarımda veri analitiği, çeşitli kaynaklardan elde edilen büyük miktarda tarımsal verinin toplanması, işlenmesi ve analiz edilmesi sürecidir. Bu veriler arasında toprak sağlığı, hava durumu, ürün büyümesi, sulama düzeyleri, gübre kullanımı ve zararlı izleme gibi tarımsal faaliyetler yer almaktadır. Veri analitiği, bu verileri analiz ederek çiftçilere tarımsal süreçlerini optimize etmeleri için eyleme geçirilebilir bilgiler sunmaktadır. Tarımda veri analitiği, ürün verimliliğini artırmak, maliyetleri düşürmek ve çevresel sürdürülebilirliği sağlamak amacıyla kullanılmaktadır. Veri analitiği uygulamaları arasında verim tahmini, kaynak yönetimi (su, gübre ve pestisit kullanımı), toprak sağlığı analizi, iklim ve hava durumu tahmini, zararlı ve hastalık izleme ve hasat zamanlaması yer almaktadır. Bu uygulamalar, çiftçilere daha bilinçli kararlar alabilme imkanı sağlamaktadır. Örneğin, hava durumu verileriyle yapılan analizler, çiftçilere sulama ve gübreleme zamanlamasını optimize etme konusunda rehberlik edebilmektedir. Ayrıca, zararlıların ve hastalıkların erken tespiti ile verim kayıpları önlenebilmektedir. Veri analitiği sayesinde çiftçiler, maliyetleri düşürüp verimliliği artırarak hem ekonomik hem de çevresel fayda sağlayabilir.

Yapılan bibliyometrik araştırmada bu alanda düşük bir orada kümelenmenin olduğu olduğu tespit edilmiştir. Çalışmalar incelendiğinde genellikle yapay zeka tekniklerinin ürün izlenebilirliği alanında kullanıldığı görülmüştür. Örneğin bir çalışmada araştırmacılar Landsat 8 OLI'den (Operational Land Imager) elde edilen NDVI zaman serileri kullanılarak mısır verim tahmini için ileri makine öğrenimi yöntemleri (BRT (Boosted Regression Trees), RFR (Random Forest Regression), SVR (Support Vector Regression), GPR (Gaussian Process Regression)) değerlendirilmiş ve BRT'nin üstün performans gösterdiği, RFR'nin ise verim tahmininde

en istikrarlı yöntem olduğu belirlenmiştir (Aghighi ve ark., 2018). Başka bir çalışmada ise Sentinel-1 radar verilerinin kullanımıyla pirinç boyu ve kuru biyokütle tahmini için makine öğrenimi yöntemleri (SVR, RFR, MLR (Multiple Linear Regression)) değerlendirilmiş, özellikle RFR yöntemiyle yüksek doğruluk sağlanarak Sentinel-1'in pirinç biyofiziksel parametrelerinin tahmininde etkili olduğu gösterilmiştir (Ndikumana ve ark., 2018). Görüleceği gibi bu alan henüz erken dönemini yaşamakta ve mevcut yapay zeka tekniklerinin alana uygulanması ve optimize edilmesi aşamasındadır.

Kum ve ark. (2024), geniş ölçekli akıllı tarım uygulamaları için bulut-yerel mimariye sahip bir yapay zeka platformu önermiştir. Derin öğrenme tabanlı analizlerin kırsal alanlardaki sınırlı bilişim kaynaklarıyla entegrasyonu zor olduğundan, önerilen yapı, uç kaynakları cihaz değil, yönetilebilir kaynaklar olarak ele almakta ve Kubernetes ile bu kaynakların entegrasyonunu sağlamaktadır. Sistem, yapay zeka uygulamalarının kapsayıcılar aracılığıyla dağıtımını, RESTful API'lerle kontrolünü ve kullanıcı dostu arayüzü üzerinden görsel yönetimini mümkün kılmaktadır. Kamera destekli gömülü sistemlerle test edilen platform, farklı çiftlik alanlarına ve ürünlere yönelik yapay zeka uygulamalarının kolayca konuşlandırılmasını, kaynakların paylaşılmasını ve hizmetlerin otomatik ölçeklenmesini desteklemektedir. Çilek tarlasında gerçekleştirilen ürün izleme senaryosu, sistemin bulut-uç sürekliliğinde dikey uygulamalara uygun olduğunu göstermiştir. (Kum ve Ark., 2024).

Ahmed ve ark. (2025), IoT tabanlı tarım uygulamalarında yapay zeka ve büyük veri teknolojilerinin bitki izleme süreçlerine entegrasyonunu incelemiştir. Çalışmada, görüntü sensörleri ile toplanan yaprak verileri, derin öğrenme ve akıllı hesaplama algoritmalarıyla işlenerek bitki hastalıklarının erken tespiti sağlanmıştır. Bu sistem, hastalık sınıflandırması, gerçek zamanlı uyarılar ve tarımsal karar destek önerileri sunarak sulama, ilaçlama ve gübreleme gibi uygulamaların optimize edilmesine olanak tanımaktadır. Sağlıklı ve hastalıklı yaprakları sınıflandırmak için geliştirilen derin öğrenme modelinin %98 doğruluk oranı elde ettiği belirtilmiş, modelin veri kümesi ve parametreleri ayrıntılı biçimde doğrulanmıştır. IoT tabanlı akıllı tarım sistemlerinin kaynak verimliliğini artırdığı, çevresel etkiyi azalttığı ve sürdürülebilirliği güçlendirdiği vurgulanmıştır. Ayrıca, tarımda AI ve büyük veri uygulamalarının karşılaştığı gizlilik, güvenlik, birlikte çalışabilirlik ve kaynak yönetimi gibi zorluklara da değinilmiştir. (Ahmed ve ark., 2025).

Çalışmalar ve rapor incelendiğinde Büyük Veri ve Dijitalleşme kategorisinde 2010-2025 yılları arasındaki teknolojik gelişimleri şu şekilde incelenebilir. 2010-2015 döneminde, tarla verim haritaları kullanımı yaygınlaşmıştır. Bu haritalar, tarımsal faaliyetlerin daha verimli hale getirilmesi ve kaynakların optimum kullanımı için önemli bilgiler sağlamıştır. Bu dönemde veri toplama ve işleme süreçleri henüz başlangıç aşamasında olup, verimlilik artışına odaklanılmıştır. 2015-2020 döneminde ise çok katmanlı saha haritaları ve veri analitiği ön plana çıkmış, bu sayede daha derinlemesine veri analizi yapılarak tarım süreçleri optimize edilmiştir. Veri platformları, çiftçilere daha doğru ve detaylı bilgi sunarak karar alma süreçlerini kolaylaştırmıştır. 2020-2025 yılları arasında ise artırılmış gerçeklik ve açık veri platformları gibi daha ileri dijital teknolojiler tarıma entegre edilmiştir. Son dönemlerde, verilerin daha erişilebilir ve kullanışlı hale gelmesiyle çiftçiler, tarımsal faaliyetlerinde daha etkin ve verimli bir yol izleme imkânına sahip olmuştur. Bu teknolojiler, tarımda dijitalleşmenin önemli bir aşamaya geldiğini göstermektedir.

Bu dijital dönüşüm süreci, tarım sektöründe dijital ikiz (digital twin) kavramının da giderek daha fazla önem kazanmasına neden olmaktadır. Dijital ikiz, fiziksel bir tarım arazisinin veya tarımsal sürecin dijital bir kopyasının oluşturulması anlamına gelir. (van Dinter ve ark., 2022) Bu sistem; sensörler, uydu görüntüleme, IoT cihazları ve yapay zeka algoritmaları ile elde edilen veriler sayesinde, tarladaki anlık durumu dijital ortamda eş zamanlı olarak yansıtabilmektedir. Böylece çiftçiler, tarlada fiilen bulunmaksızın dijital model üzerinden sulama, gübreleme, ilaçlama ve hasat gibi kararları veri odaklı biçimde alabilmektedir. Dijital ikiz teknolojisi sayesinde geçmiş veriler analiz edilerek geleceğe yönelik tahminler yapılabilir; potansiyel riskler önceden tespit edilerek erken önlem alınabilir. Bu da üretim süreçlerinin daha verimli, sürdürülebilir ve izlenebilir hale gelmesini sağlamaktadır. Sonuç olarak, tarımda dijitalleşme yalnızca veri toplamayı değil, bu verilerle gerçek zamanlı ve dinamik karar destek sistemleri oluşturmayı da mümkün kılmakta ve dijital ikiz teknolojisi ise bu dönüşümün en ileri aşamalarından birini temsil etmektedir.

SONUÇ VE ÖNERİLER

Tarımda dijitalleşmenin önemi, tarımsal üretimde verimlilik, sürdürülebilirlik ve karar verme süreçlerini optimize etme yeteneğinde yatmaktadır. Dijitalleşme, çiftçilerin tarım arazilerinden, ürünlerden ve çevresel

faktörlerden toplanan verileri daha hızlı ve doğru bir şekilde analiz etmelerini sağlar. Bu sayede kaynak kullanımı, ürün izleme, sulama, gübreleme ve hasat gibi kritik tarımsal faaliyetler daha verimli hale gelir. Dijital teknolojiler, özellikle büyük veri analitiği, yapay zeka, sensörler, İHA'lar ve IoT gibi araçlarla, çiftçilerin sahadaki gerçek zamanlı verilere dayalı olarak daha bilinçli kararlar almasına olanak tanır. Bu da hem üretim maliyetlerini düşürmekte hem de su ve enerji gibi kaynakların daha verimli kullanılmasını sağlamaktadır. Aynı zamanda, ürün izlenebilirliğini artırarak tedarik zincirindeki şeffaflığı güçlendirir ve tüketici güvenini artırır. Dijitalleşme, gıda güvenliği, iklim değişikliği ve kaynakların sürdürülebilir kullanımı gibi küresel tarımsal zorluklarla başa çıkmak için kritik bir rol oynamaktadır.

Ürün izlemenin önemi, tarımsal üretimin her aşamasının izlenebilir ve yönetilebilir olmasını sağlamasından gelmektedir. Çiftçiler, tedarik zincirindeki ürünlerin üretiminden tüketiciye ulaşmasına kadar olan süreci takip edebilmekte ve herhangi bir sorun veya aksaklık olduğunda hızlı bir şekilde müdahale edebilmektedirler. Bu izlenebilirlik, gıda güvenliği açısından büyük önem taşır; ürünlerin kaynağı, üretim koşulları ve hasat sonrası işlemleri hakkında detaylı bilgi sunarak tüketiciye güven vermektedir. Ayrıca, ürün izleme teknolojileri sayesinde hastalık, zararlı istilası veya iklimsel faktörler gibi sorunlar anında tespit edilerek verim kaybı ve maliyetler minimize edilebilir. Ürün izleme, sürdürülebilir tarım uygulamalarının geliştirilmesine de katkıda bulunmaktadır. Bu şekilde kaynak kullanımı optimize edilerek çevresel etkilerin azalmasına yardımcı olunmaktadır. Ürün izleme teknolojisi kapsamında birçok farklı yaklaşım kullanılmaktadır. Teknoloji ilerledikçe bu yaklaşımlar farklılaşarak evrim geçirecektir.

Günümüzde algılama ve görüntüleme teknolojisi, 2019 yılında 1,5 milyar dolar olarak değerlendirilen ve 2025-2026 yıllarında 3,1 milyar dolara ulaşması beklenen ürün izleme pazarında en büyük paya sahip bulunmaktadır; söz konusu teknolojinin 2020-2025 yılları arasında %14,4'lük bir CAGR (Bileşik Yıllık Büyüme Oranı) ile artış göstermesi öngörülmektedir. Otomasyon ve robotik teknolojileri için ürün izleme pazarı ise 2019 yılında 226 milyon dolar olarak değerlenmiş olup, 2025 yılına kadar 539 milyon dolara ulaşması ve %17,8'lik bir CAGR ile büyümesi beklenmektedir. Algılama ve görüntüleme teknolojisi, bu alandaki hızlı gelişmeler ve tarımda İHA'ların yaygınlaşması sayesinde en büyük pazar payına sahip olmaya devam etmektedir. Değişken oranlı teknolojiler için ürün izleme pazarı ise 2019 yılında 398 milyon dolar olarak değerlendirilmiş olup, 2025 yılına kadar 898 milyon dolara ulaşması ve 2020-2025 döneminde %16,7'lik bir CAGR ile büyümesi öngörülmektedir. (Markets and Markets, 2020). Tüm bu veriler, yakın gelecekte ürün izleme teknolojilerinde farklı yazılım, donanım ve hizmet modellerinin ortaya çıkacağını göstermektedir. Özellikle sensörler ve görüntüleme teknolojileriyle biriken büyük verinin, veri analitiği teknikleriyle anlamlandırılması; bu geri bildirimlerin çiftçilere ya da otonom sistemlere iletilerek ürün izlenebilirliğinin yapay zeka ile entegre edilmesini mümkün kılmaktadır.

Ürün izlenebilirliği ileriki zamanlarda dijital ikize evrilecektir. Tarımda dijital ikiz, fiziksel bir tarım arazisinin veya tarımsal süreçlerin dijital ortamda oluşturulmuş sanal bir kopyasıdır. (Cesco ve ark., 2023) . Bu teknoloji, tarlada olup bitenleri dijital bir model üzerinden takip etmeye, analiz etmeye ve optimize etmeye olanak sağlayacaktır. Dijital ikiz; sensörler, İHA'lar, uydu görüntüleri ve diğer veri toplama araçlarıyla sürekli veri akışı sağlayarak fiziksel ortamda meydana gelen değişiklikleri anında dijital modeline yansıtır. Bu teknoloji, ileride tarımda uygulandığında verimliliği artırmak için çiftçilere büyük avantajlar sunacaktır. Dijital ikiz, ürün sağlığını izlemek, gübreleme ve sulama stratejilerini optimize etmek, zararlıların yayılmasını önceden tahmin etmek gibi karar destek süreçlerinde kullanılabilir. Sonuç olarak, ürün izleme açısından tarımda dijital ikiz teknolojisi, daha verimli ve sürdürülebilir bir üretim sağlamada kritik bir rol oynayacaktır.

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Makale yazarları aralarında herhangi bir çıkar çatışması bulunmamaktadır.

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Yazarlar çalışmaya eşit oranda katkı sağlamıştır.

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Etik Onay

Bu makalede insan veya hayvan deneklerle herhangi bir çalışma bulunmaması nedeniyle etik onaya gerek duyulmamaktadır.

KAYNAKÇA

Aghighi, H., Azadbakht, M., Ashourloo, D., Shahrabi, H. S., ve Radiom, S. (2018). Machine Learning Regression Techniques for the Silage Maize Yield Prediction Using Time-Series Images of Landsat 8 OLI. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *11*(12), 4563-4577. https://doi.org/10.1109/JSTARS.2018.2823361

Ahmed, I., Ahmad, M., Ghazouani, H., Barhoumi, W., ve Jeon, G. (2025). Intelligent Computing for Crop Monitoring in CIoT : Leveraging AI and Big Data Technologies. *Expert Systems*, *42*(2), 1-14. https://doi.org/10.1111/exsy.13786

Ali, A. M., Abouelghar, M., Belal, A. A., Saleh, N., Yones, M., Selim, A. I., Amin, M. E. S., Elwesemy, A., Kucher, D. E., Maginan, S., ve Savin, I. (2022). Crop Yield Prediction Using Multi Sensors Remote Sensing (Review Article). *The Egyptian Journal of Remote Sensing and Space Science*, *25*(3), 711-716. https://doi.org/10.1016/j.ejrs.2022.04.006

Aria, M., ve Cuccurullo, C. (2017). bibliometrix : An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Aydın Eryılmaz, G., ve Kılıç, O. (2018). Türkiye'de Sürdürülebilir Tarım ve İyi Tarım Uygulamaları. *Kahramanmaraş Sütçü İmam Üniversitesi Doğa Bilimleri Dergisi*, *21*(4), 624-631. https://doi.org/10.18016/ksudobil.345137

Barnes, A. P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Vangeyte, J., Fountas, S., van der Wal, T., ve Gómez-Barbero, M. (2019). Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land Use Policy*, (*80)*, 163-174. https://doi.org/10.1016/j.landusepol.2018.10.004

Bendig, J., Bolten, A., Bennertz, S., Broscheit, J., Eichfuss, S., ve Bareth, G. (2014). Estimating Biomass of Barley Using Crop Surface Models (CSMs) Derived from UAV-Based RGB Imaging. *Remote Sensing*, *6*(11), 10395-10412. https://doi.org/10.3390/rs61110395

Birner, R., Daum, T., ve Pray, C. (2021). Who drives the digital revolution in agriculture? A review of supply-side trends, players and challenges. *Applied Economic Perspectives and Policy*, *43*(4), 1260-1285. https://doi.org/10.1002/aepp.13145

Cesco, S., Sambo, P., Borin, M., Basso, B., Orzes, G., ve Mazzetto, F. (2023). Smart agriculture and digital twins: Applications and challenges in a vision of sustainability. *European Journal of Agronomy*, (*146)*, 126809. https://doi.org/10.1016/j.eja.2023.126809

Chergui, N., ve Kechadi, M. T. (2022). Data analytics for crop management: a big data view. *Journal of Big Data*, *9*(1), 123. https://doi.org/10.1186/s40537-022-00668-2

Claverie, M., Ju, J., Masek, J. G., Dungan, J. L., Vermote, E. F., Roger, J.-C., Skakun, S. V., ve Justice, C. (2018). The Harmonized Landsat and Sentinel-2 surface reflectance data set. *Remote Sensing of Environment*, (*219)*, 145-161. https://doi.org/10.1016/j.rse.2018.09.002

Cuaran, J., ve Leon, J. (2021). Crop Monitoring using Unmanned Aerial Vehicles: A Review. *Agricultural Reviews*, *42*(2), 121-132. https://doi.org/10.18805/ag.R-180

Deichmann, U., Goyal, A., ve Mishra, D. (2016). Will digital technologies transform agriculture in developing countries? *Agricultural Economics*, *47*(S1), 21-33. https://doi.org/10.1111/agec.12300

Ennouri, K., Smaoui, S., Gharbi, Y., Cheffi, M., Ben Braiek, O., Ennouri, M., ve Triki, M. A. (2021). Usage of Artificial Intelligence and Remote Sensing as Efficient Devices to Increase Agricultural System Yields. *Journal of Food Quality*, (*2021)*, 1-17. https://doi.org/10.1155/2021/6242288

Fountas, S., Mylonas, N., Malounas, I., Rodias, E., Hellmann Santos, C., ve Pekkeriet, E. (2020). Agricultural Robotics for Field Operations. *Sensors*, *20*(9), 1-27. https://doi.org/10.3390/s20092672

Garcia-Sanchez, A.-J., Garcia-Sanchez, F., ve Garcia-Haro, J. (2011). Wireless sensor network deployment for integrating video-surveillance and data-monitoring in precision agriculture over distributed crops. *Computers and Electronics in Agriculture*, *75*(2), 288-303. https://doi.org/10.1016/j.compag.2010.12.005

Gomiero, T. (2019). Saving Food Production, Supply Chain, Food Waste and Food Consumption İçinde C. M. Galanakis (Ed.) *Soil and crop management to save food and enhance food security* (ss. 33-87). Academic Press. https://doi.org/10.1016/B978-0-12-815357-4.00002-X

Hasan, M., Uddin, K. N. W., Sayeed, A., ve Tasneem, T. (2021). Smart Agriculture Robotic System Based on Internet of Things to Boost Crop Production. *2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST)*, 157-162. https://doi.org/10.1109/ICREST51555.2021.9331091

Javaid, M., Haleem, A., Khan, I. H., ve Suman, R. (2023). Understanding the potential applications of Artificial Intelligence in Agriculture Sector. *Advanced Agrochem*, *2*(1), 15-30. https://doi.org/10.1016/j.aac.2022.10.001

Karmakar, P., Teng, S. W., Murshed, M., Pang, S., Li, Y., ve Lin, H. (2024). Crop monitoring by multimodal remote sensing: A review. *Remote Sensing Applications: Society and Environment*, *33*, 101093. https://doi.org/10.1016/j.rsase.2023.101093

Kum, S., Oh, S., ve Moon, J. (2024). Edge AI Framework for Large Scale Smart Agriculture. *27th Conference on Innovation in Clouds, Internet and Networks (ICIN)*, 143-147. https://doi.org/10.1109/ICIN60470.2024.10494451

Kumar, P., Singh, A., Rajput, V. D., Yadav, A. K. S., Kumar, P., Singh, A. K., ve Minkina, T. (2022). Bioinformatics in Agriculture Next Generation Sequencing Era İçinde P. Sharma, D. Yadav and R. K. Gaur (Ed.), *Role of artificial intelligence, sensor technology, big data in agriculture: next-generation farming* (ss. 625-639). Academic Press. https://doi.org/10.1016/B978-0-323-89778-5.00035-0

Le Mouël, C., ve Forslund, A. (2017). How can we feed the world in 2050? A review of the responses from global scenario studies. *European Review of Agricultural Economics*, *44*(4), 541-591. https://doi.org/10.1093/erae/jbx006

Markets and Markets. (2020). *Crop Monitoring Market with Covid-19 Impact - Global Forecast to 2025*. https://www.marketsandmarkets.com/Market-Reports/crop-monitoring-market-8994590.html Erişim Tarihi: 19.05.2025

Marques, L. S., Ferraz, G. A. e S., Moreira Neto, J., Magalhães, R. R., de Lima, D. A., Tsuchida, J. E., ve Fuzatto, D. C. (2022). Agricultural Machinery Telemetry: A Bibliometric Analysis. *AgriEngineering*, *4*(4), 939-950. https://doi.org/10.3390/agriengineering4040060

Milella, A., Rilling, S., Rana, A., Galati, R., Petitti, A., Hoffmann, M., Stanly, J. L., ve Reina, G. (2024). Robot-as-a-Service as a New Paradigm in Precision Farming. *IEEE Access*, *12*, 47942-47949. https://doi.org/10.1109/ACCESS.2024.3381511

Ndikumana, E., Ho Tong Minh, D., Dang Nguyen, H. T., Baghdadi, N., Courault, D., Hossard, L., ve El Moussawi, I. (2018). Estimation of Rice Height and Biomass Using Multitemporal SAR Sentinel-1 for Camargue, Southern France. *Remote Sensing*, *10*(9), 1394. https://doi.org/10.3390/rs10091394

Olson, D., ve Anderson, J. (2021). Review on unmanned aerial vehicles, remote sensors, imagery processing, and their applications in agriculture. *Agronomy Journal*, *113*(2), 971-992. https://doi.org/10.1002/agj2.20595

O'Sullivan, J. N. (2023). Demographic Delusions: World Population Growth Is Exceeding Most Projections and Jeopardising Scenarios for Sustainable Futures. *World*, *4*(3), 545-568. https://doi.org/10.3390/world4030034

Paul, K., Chatterjee, S. S., Pai, P., Varshney, A., Juikar, S., Prasad, V., Bhadra, B., ve Dasgupta, S. (2022). Viable smart sensors and their application in data driven agriculture. *Computers and Electronics in Agriculture*, *198*, 107096. https://doi.org/10.1016/j.compag.2022.107096

Research And Markets. (2025). *Europe Precision Agriculture Market: Focus on Application, Product, and Country - Analysis and Forecast, 2024-2034*. https://www.researchandmarkets.com/report/europe-precision-agriculture-market Erişim Tarihi: 19.05.2025

Sishodia, R. P., Ray, R. L., ve Singh, S. K. (2020). Applications of Remote Sensing in Precision Agriculture: A Review. *Remote Sensing*, *12*(19), 3136. https://doi.org/10.3390/rs12193136

Story, D., Kacira, M., Kubota, C., Akoglu, A., ve An, L. (2010). Lettuce calcium deficiency detection with machine vision computed plant features in controlled environments. *Computers and Electronics in Agriculture*, *74*(2), 238-243. https://doi.org/10.1016/j.compag.2010.08.010

T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı. (2019). *On Birinci Kalkınma Planı (2019-2023)*. https://www.sbb.gov.tr/wp-content/uploads/2022/07/On_Birinci_Kalkinma_Plani-2019-2023.pdf Erişim Tarihi: 19.05.2025

T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı. (2023). *On İkinci Kalkınma Planı (2024-2028)*. https://www.sbb.gov.tr/wp-content/uploads/2023/12/On-Ikinci-Kalkinma-Plani_2024-2028_11122023.pdf Erişim Tarihi: 19.05.2025

T.C. Kalkınma Bakanlığı. (2013). *Onuncu Kalkınma Planı (2014-2018)*. https://www.sbb.gov.tr/wp-content/uploads/2022/08/Onuncu_Kalkinma_Plani-2014-2018.pdf Erişim Tarihi: 19.05.2025

Torres-Torriti, M., ve Burgos, P. N. (2023). Encyclopedia of Digital Agricultural Technologies İçinde Q. Zhang (Ed.), *Field Machinery Automated Guidance* (ss. 509-526). Springer International Publishing. https://doi.org/10.1007/978-3-031-24861-0_229

van Dinter, R., Tekinerdogan, B., ve Catal, C. (2022). Predictive maintenance using digital twins: A systematic literature review. *Information and Software Technology*, *151*, 107008. https://doi.org/10.1016/j.infsof.2022.107008

Veloso, A., Mermoz, S., Bouvet, A., Le Toan, T., Planells, M., Dejoux, J.-F., ve Ceschia, E. (2017). Understanding the temporal behavior of crops using Sentinel-1 and Sentinel-2-like data for agricultural applications. *Remote Sensing of Environment*, *199*, 415-426. https://doi.org/10.1016/j.rse.2017.07.015

Virlet, N., Sabermanesh, K., Sadeghi-Tehran, P., ve Hawkesford, M. J. (2017). Field Scanalyzer: An automated robotic field phenotyping platform for detailed crop monitoring. *Functional Plant Biology*, *44*(1), 143. https://doi.org/10.1071/FP16163

Wei, Y., Lee, K., ve Lee, K. (2024). Autonomous Field Navigation of Mobile Robots for Data Collection and Monitoring in Agricultural Crop Fields. *21st International Conference on Ubiquitous Robots (UR)*, 707-712. https://doi.org/10.1109/UR61395.2024.10597470

Wu, B., Gommes, R., Zhang, M., Zeng, H., Yan, N., Zou, W., Zheng, Y., Zhang, N., Chang, S., Xing, Q., ve Van Heijden, A. (2015). Global Crop Monitoring: A Satellite-Based Hierarchical Approach. *Remote Sensing*, *7*(4), 3907-3933. https://doi.org/10.3390/rs70403907

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Review Article

Bioactive Properties and Mechanisms of Effect of Phenolic Compounds

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ABSTRACT

The desire of people to live a healthy and long life has encouraged an increase in interest in natural and balanced nutrition. The production of natural food additives from plant, animal and fungal sources is gaining importance day by day to produce food with natural ingredients. Phenolic compounds commonly found in plants are organic compounds that contributes to improve the textural and sensory properties of foods, as well as enriching their nutritional values, and takes an active role in ensuring food safety due to its antimicrobial, antioxidant and antifungal effects. Studies conducted also show that phenolic compounds can be used in the treatment of infection, obesity, diabetes, cardiovascular health problems and aging. In this review study, the mechanisms of antimicrobial, antioxidant, anti-fungal, anti-biofilm, anti-oxidative stress, anti-inflammatory, anti-obesity, anti-diabetic, anti-aging and cardiovascular effects of phenolic compounds were investigated.

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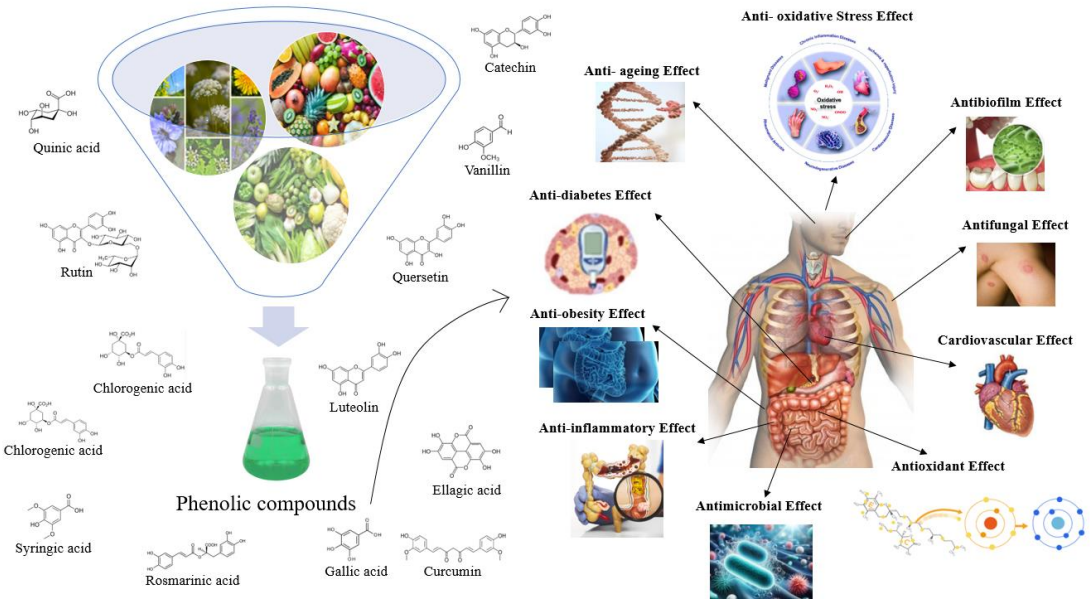

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INTRODUCTION

Phenolic compounds or polyphenols found in various organs of plants (vegetables, fruits, nuts, cereals, legumes, etc.) and described as secondary metabolites are bioactive compounds that play an important role in various physiological phenomena. These bioactive compounds play a role in the formation of organoleptic properties in plants, such as pigmentation, bitterness or astringency. In addition, they act as protective substances in plant defense against UV light, parasites and insects (Alara et al.,2021; Albuquerque et al., 2021).

Phenolic compounds contain a benzene ring (C_6H_6) with one or more hydroxyl groups, also called phenol. As a result of studies to date, phenolic compounds with more than 8000 different molecular structures have been identified (Artık et al., 2016; Cosme et al., 2020; Zhang et al., 2022). Phenolic compounds can be found in free form or in water-soluble or insoluble forms bound with carbohydrates, proteins, organic acids or other biomolecules (Alara et al., 2021; de Araújo et al., 2021). Phenolic compounds are generally classified according to the number of phenolic rings, the substituents attached to the rings and the structural elements that connect these rings. The main classes of polyphenols or phenolic compounds are phenolic acids, flavonoids, chalcones, phenolic alcohols, stilbenes, lignans, coumarins and tannins (Maniglia et al., 2021). However, the main phenolic compounds found in foods are mostly examined in two groups as phenolic acids (hydroxycinnamic acids, hydroxy benzoic acids, hydroxycinnamic acid derivatives) and flavanoids (anthocyanidins, catechins, flavonols, flavones, flavanones, procyanidins, loyco-anthocyanidins and dihydro-chalcones) (Artık et al., 2016; Arfaoui, 2021).

After the discovery of the biological activities of phenolic compounds for various diseases, interest in these compounds has increased day by day. A large number of studies have been carried out in order to improve human health, prevent or treat diseases. When the studies were examined, it was determined that phenolics are agents with beneficial properties in terms of health such as antioxidant, anti-inflammatory, antimicrobial, anti-allergenic, antiviral, anticarcinogenic (Grgić et al., 2020; Zhang et al., 2022), anti-diabetic, anti-biofilm, anti-fungal (Onat et al., 2021) activities, and in preventing diseases such as oxidative stress, obesity, osteoporosis and cardiovascular diseases (de Araújo et al., 2021).

Antimicrobial, antioxidant, antifungal, antibiofilm, anti-oxidative stress, anti-inflammatory, anti-obesity, anti-diabetes, anti-aging and cardiovascular mechanisms of effect were investigated in relation to the bioactivity of phenolic compounds. The explanation of the bioactivity and mechanisms of action of phenolic compounds is of great importance for food scientists and pharmacologists. Food scientists can use them as natural food additives due to the antimicrobial, antibiofilm, antioxidant and antifungal effects of phenolic compounds and the knowledge of their mechanisms of action. Pharmacologists can integrate phenolic compounds into existing treatment methods due to the knowledge of the pathway in which phenolic compounds are effective in the treatment of many diseases, or they can include phenolic compounds in new methods to be developed.

Mechanism of Antimicrobial Effect

Artificial food additives in the food industry have started to be replaced by natural food additives as a result of developing technology. The use of phenolic compounds obtained from plants as natural food additives is increasing day by day due to their antimicrobial effects. It has been confirmed that phenolic compounds have inhibitory effects on many foodborne pathogenic *(Escherichia coli, Salmonella* Typhimurium, *Pseudomonas aeruginosa, Bacillus cereus, Staphylococcus aureus* and *Listeria monocytogenes* etc.) and spoilage causing microorganisms. However, the mechanism of antimicrobial effect of phenolic compounds could not be clearly declared (Martinez-Gonzalez et al., 2017; Pernin et al., 2019).

There are many different theories about the mechanisms of antimicrobial effect of phenolic compounds. The first one of these theories is the hydroxyl groups (OH-) in the structure of phenolic compounds interact with the cell membrane of bacteria, disrupting the membrane structure of the cells and causing cellular components to leak out of the cell. Another theory is; OH- groups in the structure of phenolic compounds cause delocalisation of electrons acting as proton exchangers and decrease the tendency of bacterial cells on the cytoplasmic membrane, causing cell death due to collapse of the proton motive force and decrease in the ATP pool. It is also known that OH- groups can change the enzyme metabolism by easily binding to the active part

of enzymes by changing the cell metabolism of microorganisms. While; low concentrations of phenolic compounds affect enzymes responsible for energy production, high concentrations show antimicrobial effect by increasing the denaturation of proteins. As a result, it is possible to explain the mechanisms of antimicrobial effect of phenolic compounds in the form of damage to the cytoplasmic membrane, collapse of protein movement force, disruption of electron flow and coagulation of cell components caused by decreased active transport, leakage of macromolecules such as ribose and Na glutamate from the cell structure, changes in cell membrane permeability and denaturation of protein structure, changes in protein and nucleic acid synthesis mechanisms and changes in enzyme mechanism (Öncül and Karabıyıklı, 2016; Yücel-Şengün and Öztürk, 2018).

The mechanism of fungal inactivation by the combination of phenolic acids and 405 nm irradiation was associated with the formation of H_2O_2 and hydroxyl radicals following 405 nm irradiation of phenolic acid solutions. It was understood that irradiation of phenolic acids caused a significant increase in the level of intracellular reactive oxygen derivatives and it increased cell inactivation. The increase in the level of intracellular reactive oxygen derivatives could not be associated with changes in membrane permeability and ATP content was significantly reduced. These results show that the first stage in the photofungicidal mechanism is the system of oxidative damage to mitochondria or the cellular catabolism system associated with ATP synthesis because of the photoreaction of phenolic acids absorbed by the fungus (Shirai et al., 2022).

The mechanisms of effect of phenolic acids, such as the decrease of extracellular pH in the presence of phenolic acids directly inhibiting growth against *Listeria monocytogenes*, the inhibitory effect of the undissociated acid form, and the inhibitory effect of the dissociated acid form, were all studied. Firstly, chlorogenic acid and gallic acid have a low antimicrobial activity on bacterial development, mainly by inhibiting the growth of *L. monocytogenes* with their ability to lower extracellular pH. Second, caffeic acid, p-hydroxybenzoic acid, protocatechuic acid and vanillic acid exhibit antimicrobial behaviour mainly through the ability of their undissociated forms to inhibit the growth of *Listeria monocytogenes*. Third, p-coumaric acid and ferulic acid similarly exhibit antimicrobial behaviour through their undissociated forms, but their dissociated forms also show significant antimicrobial activity (Pernin et al., 2019).

Valine and chlorogenic acid can cause bacterial death by destroying the surface membrane and internal structure of cells (Lou et al., 2011; Li et al., 2014; Jiang et al., 2020). Quercatinin causes cell death by cell membrane disruption (membrane hardening), DNA gyrase inhibition, Type 3 secretion inactivation, dehydratase inhibition and protein kinase inhibition mechanisms (Plaper et al., 2003; Zhang et al., 2008; Shakya et al., 2011; Wu et al., 2013; Tsou et al., 2016). Apigenin causes dehydratase inhibition and protein kinase inhibition (Zhang et al., 2008; Shakya et al., 2011).

Mechanism of Antioxidant Effect

Phenolic compounds found in plants are known to be powerful antioxidants that prevent oxidative damage caused by biomolecules. The mechanism of antioxidant effect is mainly based on the scavenging of free radicals, inhibition of lipid peroxidation and activation of the endogenous antioxidant system. The antioxidant potential of phenolic compounds is related to their structure and is affected by hydroxyl groups and glycolisation factor. Since hydroxyl groups are a source of hydrogen and electrons, their number and position are related to the antioxidant effect of phenolic compounds. The presence of substituents in the aromatic ring affects the radical trapping activity due to the stabilisation of the molecule. Glycolysis of compounds is also known to affect antioxidant activity as it interferes with the structure, methylation, and electron displacement of the molecule. It has also been observed that methylation of compounds reduces antioxidant ability (Ferraira et al., 2017; Kumar and Goel, 2019; Vuolo et al., 2019).

Studies have shown that phenolic antioxidants have significant free radical scavenging activity due to their capacity to donate hydrogen atoms or electrons and their ability to bind transition metallic ions (Piechowiak and Balawejder, 2019). The mechanisms of antioxidant effect can be explained by hydrogen atom transfer, single electron transfer, sequential proton loss electron transfer and transition metal chelation. During hydrogen atom transfer, phenolic antioxidant containing H atom reacts with free radicals. While the free radical is stabilised to form a neutral group, the phenolic antioxidant is converted into an antioxidant free radical. The phenolic antioxidant donates one H atom to the free radical substrate, forming a non-radical substrate group

and the antioxidant free radical. The H atom donated by the antioxidant can be explained by its reduction potential (Zeb, 2020).

The mechanism of single electron transfer depends on the proton dissociation energy and ionisation potential of the reactive functional group. During single electron transfer, firstly, electron loss occurs from one molecule of the phenolic antioxidant and a cation radical is formed, while in the second step, proton loss from the phenolic antioxidant occurs. Thus, a non-radical group is formed (Antonijević et al., 2021; Platzer et al., 2021). Sequential proton loss electron transfer takes place in two stages. In the first stage, an anion group is formed as a result of the phenolic antioxidant giving a proton to a free radical. In the second stage, a non-radical group and a free radical are occured as a result of electron transfer (Najafi et al., 2011). During transition metal chelation, it has been determined that transition metals are chelated by polyphenols to form stable products. Transition metals such as copper (Cu), magnesium (Mg), cobalt (Co) can catalyse such reactions. Metal chelation can reduce the formation of reactive hydroxyl-free radicals by directly inhibiting Fe+3 reduction (Zeb, 2020).

Ferulic acid has been proven to provide antioxidant activity by hydrogen-atom transfer reaction (Berton et al., 2020). It is known that phenolic compounds obtained from scallops have antioxidant effects through the mechanisms of chelating metal ions and inhibiting lipoxygenase (Xie et al., 2019). The thermodynamics of the three mechanisms of the primary antioxidant effect of 14 phenolic acids were investigated. Hydrogen atom transfer, single electron transfer-proton transfer and sequential proton loss electron transfer mechanisms were calculated for non-polar media (benzene) and aqueous solution model. The lowest O-H bond dissociation enthalpies and bond dissociation energies for hydrogen atom transfer representing the relevant reaction pathway in both media were found for sinapic acid (Biela et al., 2022).

Mechanism of Antifungal Effect

Phenolic compounds show antifungal effect by disrupting ergosterin biosynthesis and membrane integrity of fungi. Gallic acid has been reported to show antifungal effect by inhibiting enzymes involved in ergosterol synthesis and binding to membrane ergosterol (Carvalhovd., 2018). Gallic acid also reduces ergosterol content in the filamentous fungus *Tricophytum rubrum* by inhibiting sterol 14a-demethylase and squalene epoxidase enzymes (Li et al., 2017). Tannic acid shows antifungal effect against *Penicillium digitatum* by disrupting the integrity of the cell wall and permeability of the membrane (Zhu et al., 2019). Against *Trichophyton rubrum*, quercetin causes the expression of the gene encoding an S-adenosylmethionine-dependent sterol C-24 methyltransferase in the fatty acid synthase and ergosterol biosynthetic pathway to decrease. Thus, quercetin shows antifungal effect by interfering with ergosterol synthesis and causing cell membrane disruption (Bitencourt et al., 2013). Salicylic acid shows antifungal effect against *Penicillium expansum* by damaging the conidial plasma membrane and causing soluble protein leakage (da Rocha Neto et al., 2015).

Tea polyphenols were found to exert antifungal effects by causing disruption of the synthesis of the cell wall, damage to the plasma membrane and fragmentation of hyphae and spore and induction of defence enzyme activities, and directly inhibiting hyphae growth and spore germination of *Rhizopus stolonifer* (Yang and Jiang, 2015). Flavonoids obtained from unripe bitter orange and grapefruit were observed to cause changes in the cell wall of *Aspergillus parasiticus*, retraction of cytoplasm and disruption of nuclear membranes by vesicle formation. It was determined that the flavanoids obtained showed antifungal effect against *Aspergillus parasiticus* due to severe degradation and/or loss of membranes, organelles and other cytoplasmic contents (Pok et al., 2020).

Resveratrol can induce fungal apoptosis involving mitochondrial pathways. Resveratrol, which causes metacaspase activation caused by mitochondrial dysfunction and an increase in cytochrome c release, shows antifungal effect against *Candida albicans* (Lee and Lee, 2015).

Mechanism of Antibiofilm Effect

Phytochemicals are known to have antibiofilm effect. Phytochemicals such as phenols, polyphenols, flavanones, flavonoids, flavonols are known to have quorum sensing (QS) inhibitory activities, which is a key event in the formation and development of bacterial biofilm. QS regulates the production of key virulence

factors in pathogens (Nadaf et al., 2018). QS is a communication system between bacterial cells through the activation of specific signals to facilitate the adaptation of bacteria to adverse environmental conditions, including bacterial population densities. This process involves synthesising, sensing and responding to extracellular chemical signalling molecules called autoinducers (AIs). Gram-negative bacteria communicate using AIs, most commonly acyl-homoserine lactones (AHLs) or other small molecules. Phytochemicals are also involved in the inhibition of binding and deactivation of genes involved in biofilm formation (Nadaf et al., 2018).

Gallic acid and ferulic acid were understood to have antibiofilm effect against biofilms formed by *Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus* and *Listeria monocytogenes*. It has been observed that these phenolic compounds have a higher inhibitory effect on biofilms formed by Gram-negative bacteria (Borges et al., 2012). Epigallocatatin gallate, a polyphenol in green tea, was found to be able to almost completely eliminate the biofilm matrix by directly interfering with the aggregation of curli subunits of the biofilm layer formed by *Escherichia coli* into amyloid fibres and reducing CsgD expression caused by CsgD mRNA targeting by triggering the σ E cell envelope stress response (Serra et al., 2016). Epigallocatatin gallate (EGCG) shows antibiofilm effect by reducing the adhesion of *Fusobacterium nucleatum* to oral epithelial cells and matrix proteins (Lagh et al., 2017).

Ellagic acid (Bakkiyaraj et al., 2013), ginkgolic acid (Lee et al., 2014), rosmarinic acid (Slobodníková et al., 2013), gallic acid, caffeic acid and chlorogenic acid (Luís et al., 2014) were understood to have antibiofilm activity against the biofilm formed by *Staphylococcus aureus*. Gallic acid affected the adhesion property of *Staphylococcus aureus*, while gallic acid and caffeic acid prevented the production of a-haemolysin of the microorganism. It has been observed that caffeic acid interferes with the stability of the cell membrane of *Staphylococcus aureus* and the metabolic activity of its cells (Luis et al., 2014). It was reported that tannic acid from black tea inhibited biofilm formation of *Staphylococcus aureus* without inhibiting bacterial growth through a transglycosylase IsaA-dependent mechanism (Payne et al., 2013). The inhibition of apigenin-7-O-glucoside on biofilm against biofilms formed by *Staphylococcus aureus* and *Escherichia coli* is carried out by inhibiting QS, exopolysaccharides and cell surface hydrophobicity (Pei et al., 2023).

Curcumin, a polyphonic compound obtained from turmeric, has been reported to have QS inhibitory activities against *Pseudomonas aeruginosa* and thus exhibits antibiofilm effect (Prateeksha et al., 2019). It was observed that cinnamic acid effectively inhibited both the production of QS-dependent virulence factors and biofilm formation against *Pseudomonas aeruginosa* PAO1. When the mechanism of antibiofilm action of cinnamic acid was examined, it was understood that it caused a decrease in biofilm development by interfering with the initial attachment of planktonic cells to the substrate (Rajkumari et al., 2018). Salicylic acid and trans-cinnamaldehyde were reported to significantly inhibit biofilm formation at sub-inhibitory levels without any bactericidal effect on the expression of QS regulatory and virulence genes in *Pseudomonas aeruginosa* PAO1 (Ahmed et al., 2019).

Protocatechuic aldehyde reduces the metabolic viability and polysaccharide production of *Vibrio parahaemolyticus*. It also inhibits cell surface flagella-mediated swimming and aggregation phenotypes. Protocatechuic aldehyde was found to have antibiofilm effect by regulating the expression of genes involved in biofilm formation of *Vibrio parahaemolyticus* (Liu and Wang, 2022).

Mechanism of Anti-oxidative Stress Effect

Oxidative stress refers to the imbalance that can damage biological systems between oxidant production and antioxidant defence (Sies et al., 2017). In other words, oxidative stress can be defined as an increase in the production of reactive oxygen species (ROS) and other oxidants that exceeds antioxidant capacity (Nakai and Tsuruta, 2021). ROS, such as free radicals, superoxide radicals, hydrogen peroxide and oxygen, refer to a range of oxygen-containing molecules and radicals produced through oxidative metabolism within mitochondria or in response to external stimuli such as xenobiotics and bacterial invasion (Taylor et al., 2022).

Polyphenols can protect against oxidative damage through various mechanisms and reduce the catalytic activity of enzymes involved in ROS formation. It has been reported that ROS formation increases free metal ions through the reduction of hydrogen peroxidase by the generation of highly reactive hydroxyl radical. Due

to the low redox potentials of polyphenols and their capacity to chelate metal ions and free radicals, they can thermodynamically reduce highly oxidising free radicals (Hussain et al., 2016). It was determined that chlorogenic acid, cryptochlorogenic acid, (+)-catechin, (-)-epicatechin, procyanidin C1, procyanidin A2, rutin, quercetin, quercitrin and ferulic acid in blueberry extract have the ability to chelate Fe 2+ ion (Raudone et al., 2019).

The interaction of polyphenols with nitric oxide (NO) synthase activity may regulate NO production. Xanthine oxidase (KO) is recognised as the main source of free radicals. Some flavonoids such as apigenin, kaempferol, quercetin, silibin and luteolin may act as KO inhibitors involved in oxidative damage in tissues following such ischaemic reperfusion conditions. Flavonoids can also reduce peroxidase activity and inhibit the release of free radicals by neutrophils and the activation of these cells by α 1-antitrypsin (Sandoval-Acuña et al., 2014; Hussain et al., 2016).

The cellular enzymatic redox system (consisting of catalase (CAT), superoxide dismutase (SOD), glutathione peroxidase (GPx), glutathione reductase (GR) and peroxiredoxins (PRX)) is a cellular defense mechanism that maintains the oxidative balance. This mechanism has been shown to be inadequate in cellular environments containing excessive reactive oxygen species (ROS). It has been reported that consumption or supplementation of dietary polyphenols can restore redox homeostasis and prevent systemic or localized inflammation by increasing the activities of antioxidant enzymes SOD, CAT, GPx, and GR.The expressions of these enzymes are modulated by nuclear factor erythroid (Nrf2). Nrf2 is activated and transported by reactive oxygen species; and regulates the antioxidant sensitive element-mediated transcription of genes encoding antioxidant enzymes. Dietary polyphenols can induce Nrf2 or trigger its translocation (via ligand interaction with the cytosolic aryl hydrocarbon receptor (AhR) (Zhang and Tsao, 2016). In a study examining the ability of quercetin, isoquercitrin (quercetin-3- O -glucoside), rutin (quercetin-3- O -rutinoside) and taxifolin (dihydroquercetin) to activate AhR and induce CYP1A1 expression in human hepatoma HepG2 cells, it was observed that quercetin significantly activated AhR and triggered CYP1A1 transcription after 24 hours of exposure (Vrba et al., 2021). In a study examining the ability of quercetin, isoquercitrin (quercetin-3- O -glucoside), rutin and taxifolin (dihydroquercetin) to activate AhR and induce CYP1A1 expression in human hepatoma HepG2 cells, it was observed that quercetin significantly activated AhR and triggered CYP1A1 transcription after 24 hours of exposure (Vrba et al., 2021). In another study, tangeretin 7, 12 - dimethylbenz [a] anthracene (DMBA), one of the citrus flavonoids, was found to reduce oxidative stress caused by DMBA in the liver through Nrf2 / Keap1 and AhR signaling pathways (Arivazhagan and Subramanian, 2015).

Mechanism of Anti-inflammatory Effect

Phenolic compounds could modulate gene expression through regulation of epigenetic mechanisms, including DNA methylation, histone modification or miRNA expression. In general, many phenolic compounds can activate histone deacetylases to stabilise the acetylation of histones. In addition, phenolic compounds can inhibit DNA methyltransferases, activate sirtuin genes and activate or inhibit histone acetyltransferases. Some phenolic compounds have been associated with the regulation of miRNA expression, it was determined inhibit the secretion and production of proinflammatory cytokines and reduce the production of reactive oxygen species (ROS) and nitric oxide (NO) (Číž et al., 2020).

Phenolic compounds tend to act in a complementary manner with non-steroidal anti-inflammatory drugs, but some phenolic compounds can also inhibit the activity of pro-inflammatory mediators or gene expression such as cyclooxygenase (COX). They could up- or down-regulate transcriptional elements involved in antioxidant pathways such as nuclear factor-κB (NF-κB) or nuclear factor-erythroid factor 2 (Nrf-2). Phenolic compounds are thought to suppress the binding of proinflammatory mediators, regulate eicosanoid synthesis, inhibit induced resistant units, or exert anti-inflammatory effects by inhibiting NO synthase and COX-2 activity through inhibitory effects on NF-κB (Rahman et al., 2022).

Chlorogenic acid, caffeic acid, gentisic acid and rutin have been found to exert anti-inflammatory effects by inhibiting NO production and expression of proinflammatory mediators including COX-2, tumour necrosis

factor-alpha (TNF-α) and interleukin 6 (IL-6) (Choi et al., 2017). Flavonoids can reduce neuroinflammation by acting through the regulation of microglial cells. The modulatory effects induced by these compounds are mediated by their effects on important signalling pathways, including mitogen-activated protein kinases (MAPK) and NF-κB (Spagnuolo et al., 2018).

Procyanidins extracted from grape have been found to inhibit inflammatory mediators, resulting in a decrease in NO, prostaglandin E2 and ROS concentrations (Rahman et al., 2022). p -coumaric acid has been found to have a strong anti-inflammatory function by promoting a decrease in the expression of the inflammatory mediator TNF-α and circulating immune complexes (Pragasam et al., 2013).

Procyanidin B2, found in foods such as cocoa, apples, grapes or grape and cider, is a phenolic compound consisting of two flavan-3-ol (-)-epicatechin molecules. Procyanidin B2 has been associated with different anti-inflammatory effects, including modulation of various mediators of inflammation such as eicosanoids, cytokines, and NO production, as well as activation of NF-κB and mitogenesis (Martinez-Micaelo et al., 2015). Prothiandin A2 inhibits the production of cytokines and inflammatory mediators affecting related pathways such as Nrf2 signalling pathway, NF-κB and MAPK pathway (Wang et al., 2020).

It was determined that phenolic compounds in the structure of extra virgin olive oil obtained from Moraiolo olives showed anti-inflammatory effect by causing a decrease in COX-2 isoenzyme and ionised calcium binding adaptor molecule 1 (Iba-1) level. As a result of this study, it is thought that phenolic compounds may be a promising candidate for the prevention of various neuroinflammatory diseases by showing anti-inflammatory activity on brain cells (Taticchi et al., 2019).

It was determined that resveratrol and kaempferolin in the structure of lingonberry (Vaccinium vitis-idaea L.) inhibited proinflammatory M1-type activation by decreasing the expression of IL-6, NO and monocyte chemoattractant protein-1 (MCP-1) in mouse macrophages and TNF-α and IL-6 in human macrophages (Ryyti et al., 2022). Resveratol has been reported to suppress COX-2 expression and show anti-inflammatory effect when activating peroxisome proliferator-activated receptors gamma (Pparγ) and NF-κB (Dull et al., 2019).

Chlorogenic acid, rosmarinic acid and rutin found in the structure of the extract obtained from the curry leaf plant (Elsholtzia ciliata (Thunb.) Hyl.) were found to have anti-inflammatory effects by significantly reducing the secretion level of proinflammatory cytokines TNF-α, IL-6 and prostaglandin E2 induced by lipopolysaccharide treatment in mouse peritoneal macrophage cell culture (Pudziuvelyte et al., 2020).

Mechanism of Anti-obesity Effect

Phenolic compounds exert anti-obesity effects through modulation of proteins, transcriptional factors and genes involved in the digestion, energy expenditure, and metabolism of carbohydrates, increasing lipolysis, decreasing lipogenesis, stimulating B-oxidation of fatty acids, and increasing lipolysis (Oliveira et al., 2022). The phenolic extract from the fruit of Bignay (Antidesma bunius L.) has been found to exhibit a potential anti-obesity effect contributed by inhibitory effects of lipase enzyme and adipogenesis in adipocytes (Krongyut and Sutthanut, 2019).

Catechins have anti-obesity effect by means of fat oxidation, downregulation of the expression of enzymes involved in fat synthesis, upregulation of the mRNA level of fat β-oxidation genes, stimulation of sympathetic nervous system activity and increased expression of adipose tissue mismatched proteins. Many of these effects are carried out through induction of genes or inhibition of transcription factors. Catechins are also able to inhibit fat absorption through suppression of pancreatic lipase and increase the production of small absorbable metabolites that can show anti-obesity effects after absorption in the colon by correcting colonic microbiota (Akhlaghi and Kohanmoo, 2018).

The phenolic extract containing protocathequic, caffeic and ellagic acids is combined with adenosine monophosphate with the downregulation of the expression of adipogenic/lipogenic genes such as PPARy, amplifier ligands/booster binding protein-a (C/EBPa), sterol regulatory element binding protein-1 (SREBP-1), acetyl CoA carboxylase-1 (ACC1), fatty acid synthase and lipoprotein lipase-1 the receptor gamma coactivator 1-alpha activated by increasing the phosphorylation of activated protein kinase (AMPK) and by peroxisome

proliferator, lipolytic genes such as sirtuin-1 (SIRT-1) and carnitine palmitoyltransferase 1-alpha and adipokine adiponectin have been reported to have an anti-obesity effect by upregulation of expression (Lin et al., 2019).

Quinic acid, caffeic acid, chlorogenic acid and 3,4-dicaffeoylquinic acid caused a decrease in serum triglyceride and low-density lipoprotein cholesterol (LDL-cholesterol) levels in obese mice fed a high-fat diet. Studies show that the anti-obesity mechanisms of action of the phenolic extract are down-regulation of C/EBPa, PPARγ and SREBP-1c to suppress adipogenesis, activating the activated protein kinase pathway, increasing ACC phosphorylation and downstream carnitine palmitoyltransferase I expression (Zheng et al., 2021).

Mechanism of Anti-diabetes Effect

Phenolic compounds have anti-diabetic effects by improving pancreatic β-cell function and improving insulin resistance, modulating various molecular targets and cell signaling pathways in hepatocytes, adipocytes and skeletal muscle cells, increasing insulin secretion (Edirisinghe and Burton-Freeman, 2016; de Paulo Farias et al., 2021). In addition, phenolic compounds also provide anti-diabetic effects through mechanisms such as AMPK pathway activation, inhibition of a glucosidase/a amylase, improvement of glucose uptake and insulin sensitivity, and PPAR activation (Deka et al., 2022).

Aldose reductase (AR), α-amylase and α-glycosidase are vital enzymes to prevent diabetic complications. Genistein has been found to have an inhibitory effect against AR and α-glycosidase (Demir et al., 2019). Quercetin, luteolin, luteolin -7 - O -glucoside, kaempferol and apigenin have a lowering effect on the insulin resistance of HepG2 cells by activating ampk (Huang et al., 2015). Curcumin prevents cell death by improving pancreatic β cell functions and thus reduces insulin resistance (Pivari et al., 2019). The anti-diabetic effect of quercetin is materialized by reducing lipid peroxidation, glucose absorption by glucose transporters-2, inhibition of insulin-dependent activation of phosphoinositide 3-kinases, stimulation of glucose uptake in muscle cells and activation of AMPK (Al-Ishaq et al., 2019). Rutin exerts anti-diabetic effects by improving glucose uptake by tissues, activating insulin secretion from pancreatic β cells, reducing carbohydrate absorption from the small intestine, suppressing tissue gluconeogenesis, and protecting islets of Langerhans (Ghorbani, 2017). In damaged pancreatic cells, Luteolin improves insulin secretion in uric acid by decreasing micro-autologous fat transcription, a trans activator of the insulin gene via the NF-κB signalling pathway, in pancreatic β cells (Ding et al., 2014).

Mechanism of Anti-ageing Effect

The biological process in which cellular organelles such as proteins, DNA and mitochondria are damaged is called aging. As a result of biochemical reactions that develop during the aging process, cell proliferation decreases, and cellular wear and tear occurs. Phenolic compounds included in diets show anti-aging effect by taking part in the prevention of cellular destruction caused by the aging process (Pyo et al., 2020).

Equol is a type of isoflavone found in soya beans and many mechanisms of action have been declared in studies to elucidate its anti-aging effect. Equol can show anti-aging effect by reducing ROS production through oxidative stress and stimulation of Nrf2. It is known that excessive ROS production damages DNA. Equol, which causes a decrease in ROS production, is also involved in the protection of DNA and the repair of nerve and tissue cells. Equol is known to inhibit activator protein-1, neoplastic cell growth, metalloproteinases, elastase and proinflammatory transcription factor (NFkappaB). Equol, which stimulates matrix metalloprotease-1, collagen, elastin and antioxidant/detoxifying enzymes, shows anti-aging effect on human skin (Lephart et al., 2016; Gong et al., 2023).

It is known that ellagic acid has a high anti-inflammatory and antioxidant effect capacity and shows anti-aging effect. Studies show that ellagic acid can reduce neuronal defects, increase neuronal vitality, and can be used in the treatment of neurodegenerative diseases such as Parkinson's disease, Alzheimer's disease, and cerebral ischemia (Zhu et al., 2022). It has been understood that quercetin, myricetin, ellagic acid, gallic acid and chlorogenic acid improve the aging process, scavenging free radicals, increasing the amount of antioxidant enzymes catalase and superoxide dismutase, and decreasing the level of malondialdehyde (Wu et al., 2022).

Phenolic-containing extract obtained from two different tragacanth herbs show anti-aging effects by activating the PI3K/Akt signalling pathway, which is an important intracellular signalling pathway in the regulation of oxidative stress balance and cell cycle (Gong et al., 2021).

Mechanism of Cardiovascular Effect

Phenolic compounds are effective in the treatment of cardiovascular diseases. Dietary phenolic compounds have beneficial effects on the cardiovascular system by decreasing platelet activity, suppressing the oxidation of LDL-cholestorol, lowering blood pressure, improving endothelial dysfunction, adjusting the ratio of atherosclerotic plaque and HDL / LDL in the cardiovascular system, reducing inflammatory stress and promoting increased antioxidant effect (Lutz et al., 2019; Behl et al., 2020; Zhao and Yu, 2021). Polyphenols in blueberries and strawberries are involved in the improvement of various cardiovascular risks such as endothelial function, blood pressure, blood lipids and arterial stiffness after acute and short-term consumption (Rodriguez-Mateos et al., 2014).

Atherosclerosis is one of the main factors behind cardiovascular diseases. Phenolic compounds could inhibit important risk factors that contribute to the initiation and development of atherosclerosis, reduce oxidative and inflammatory stress. Hydroxycinnamic acid, flavanols, anthocyanidins and guaiacols exert lipid regulatory action by promoting cholesterol excretion via the small intestine or gallbladder, inhibiting lipid absorption in the small intestine and novo lipid synthesis in the liver. Activation of transcription regulators such as SIRT-1, PPAR and liver X receptor is responsible for lipid regulation (Toma et al., 2020). Caffeic acid, caffeic acid phenethyl ester and synthetic caffeic acid phenethyl amide exhibit vasorelaxant activity by acting on endothelial and vascular smooth muscle cells. Caffeic acid and caffeic acid phenethyl ester, in addition to having a vascular relaxant effect, promote a decrease in heart rate and show blood pressure lowering activity because they can suppress the renin-angiotensin-aldosterone axis (Silva and Lopes, 2020).

CONCLUSION

Phenolic compounds commonly found in plants are very important bioactive substances in terms of the quality of foods and human health. As a result of the rewieved studies, it has been found that phenolic compounds have an antimicrobial effect. When examined from the point of view of food technology, the degradation factor and the antimicrobial effect they both against pathogenic bacteria make phenolic compounds very valuable. In addition, it has been observed that these compounds also have the property of inhibiting biofilm formation, which leads to serious problems for the food industry and human health. Biofilms are polymeric layers produced by bacteria that protect bacteria against adverse environmental conditions, factors such as exposure to UV light. It has been found that the effect of anti-biofilm mechanism of phenolic compounds occurs according to inhibiting the quorum sensing process of bacteria, deactivating the genes responsible for biofilm formation and blocking binding, reducing CsgD expression, affecting the adhesion properties of bacteria, and inhibiting cell surface hydrophobicity. Phenolic compounds have been found to have antifungal activity against fungi by disrupting the biosynthesis of ergosterol and membrane integrity of fungi, damaging the plasma membrane, infiltrating soluble proteins and gene expression. The fact that phenolic compounds have antimicrobial, antifungal and antibiofilm properties allows the availability of these compounds as natural food additives. The use of these compounds as food additives is expected to replace artificial food additives in improving the quality of food, extending the shelf life of food, and ensuring food safety.

The effect of phenolic antioxidants are related to their structure and are based on the scavenging of free radicals, inhibiting of lipid peroxidation and activating of the endogenous antioxidant system. Antioxidants protect human health against various diseases by removing free radicals from the body and contribute to the development of immunity. Polyphenols have been found to have anti-oxidative stress properties against oxidative stress, which occurs because of the imbalance between reactive oxygen species and antioxidant defense and damages human health. In addition, as a result of the rewieved studies, it has been determined that phenolic compounds have a preventive effect against obesity, which has increased in recent years due to unbalanced nutrition, hormone disorder, lack of physical activity, etc.

It has been observed that some phenolic compounds exhibit anti-inflammatory effects against inflammation, which is popularly known as inflammation but includes abscesses as well as inflammation. This effect is thought to be anti-inflammatory by suppressing the binding of proinflammatory mediators by phenolics,

regulating eicosanoid synthesis, inhibiting NO synthase and COX-2 activity by inhibiting stimulated units or inhibitory effects on NF-κB.

Phenolic compounds have anti-diabetic effects by improving pancreatic β-cell function, increasing insulin secretion, and improving insulin resistance. They can show anti-aging effects by reducing the production of reactive oxygen species and oxidative stress, scavenging free radicals, increasing the amount of catalase and superoxide dismutase enzymes, and reducing malondialdehyde levels. In addition, dietary phenolic compounds have been found to have beneficial effects on the cardiovascular system by reducing platelet activity, suppressing the oxidation of LDL-cholesterol, lowering blood pressure, improving endothelial dysfunction, reducing inflammatory stress, and increasing antioxidant effect.

Studies on the bioactivity of phenolic compounds generally show that they have positive properties in the protection of food quality and human health. In recent years, it hass predicted that phenolic compounds as natural additives will replace artificial additives because of their use in foods has been discussed. However, the most important issue in the use of phenolics both as additives in foods and in dietary consumption is the determination of acceptable daily intake amounts. It is seen that the bioactive properties of phenolic compounds depend on their chemical structure. For this reason, the mechanisms of bioactive effect of the phenolic compounds identified need to be fully understood.

Conflict of interest

The authors declared no conflict of interest.

Author contribution

All authors contributed equally.

Ethical Statement

During the writing process of the study titled "**Bioactive Properties and Mechanisms of Effect of Phenolic Compounds**", scientific rules, ethical and citation rules were followed; No falsification has been made on the collected data and this study has not been sent to any other academic media for evaluation. Ethics committee approval is not required.

REFERENCES

Ahmed, S. A., Rudden, M., Smyth, T. J., Dooley, J. S., Marchant, R., & Banat, I. M. (2019). Natural quorum sensing inhibitors effectively downregulate gene expression of Pseudomonas aeruginosa virulence factors. *Applied microbiology and biotechnology*, 103, 3521-3535. https://doi.org/10.1007/s00253-019-09618-0

Akhlaghi, M., & Kohanmoo, A. (2018). Mechanisms of anti-obesity effects of catechins: a review. *International Journal of Nutrition Sciences*, 3(3), 127-132.

Albuquerque, B. R., Heleno, S. A., Oliveira, M. B. P., Barros, L., & Ferreira, I. C. (2021). Phenolic compounds: Current industrial applications, limitations and future challenges. *Food & function*, *12*(1), 14-29. https://doi.org/10.1039/D0FO02324H

Al-Ishaq, R. K., Abotaleb, M., Kubatka, P., Kajo, K., & Büsselberg, D. (2019). Flavonoids and their anti-diabetic effects: Cellular mechanisms and effects to improve blood sugar levels. *Biomolecules*, 9(9), 430. https://doi.org/10.3390/biom9090430

Antonijević, M.R., Simijonović, D.M., Avdović, E.H., Ćirić, A., Petrović Z.D., Dimitrić-Marković, J., Stepanić, V., & Marković, Z.S. (2021). Green One-Pot Synthesis of Coumarin-Hydroxybenzohydrazide Hybrids and Their Antioxidant Potency. *Antioxidants*, 10(7), 1106. https://doi.org/10.3390/antiox10071106

Arfaoui, L. (2021). Dietary plant polyphenols: Effects of food processing on their content and bioavailability. *Molecules*, *26*(10), 2959. https://doi.org/10.3390/molecules26102959

Arivazhagan, L., & Subramanian, S. P. (2015). Tangeretin, a citrus flavonoid attenuates oxidative stress and protects hepatocellular architecture in rats with 7, 12-dimethylbenz (a) anthracene induced experimental mammary carcinoma. *Journal of Functional Foods*, 15, 339-353.

Artık, N., Anlı, E., Konar, N., & Vural, N. (2016). Gıdalarda bulunan fenolik bileşikler. *Bölüm: Fenolik Bileşiklerin Yapıları. Sidas Medya Ltd. Şti.,* İzmir.

Bakkiyaraj, D., Nandhini, J. R., Malathy, B., & Pandian, S. K. (2013). The anti-biofilm potential of pomegranate (Punica granatum L.) extract against human bacterial and fungal pathogens. *Biofouling*, 29(8), 929-937. https://doi.org/10.1080/08927014.2013.820825

Behl, T., Bungau, S., Kumar, K., Zengin, G., Khan, F., Kumar, A., Kaur, R., Venkatachalam, T., Tit, D.,M.,Vesa, C., M., Barsan, G., & Mosteanu, D. E. (2020). Pleotropic effects of polyphenols in cardiovascular system. *Biomedicine & Pharmacotherapy*, 130, 110714. https://doi.org/10.1016/j.biopha.2020.110714

Berton, S.B.R., Cabral, M.R.P., Jesus, G.A.M., Sarragiotto, M.H., Pilau, E.J., Martins, A.F., Bonafé, E.G., & Matsushita, M. (2020). Ultra-high-performance liquid chromatography supports a new reaction mechanism between free radicals and ferulic acid with antimicrobial and antioxidant activities. *Industrial Crops and Products*, 154, 112701. https://doi.org/10.1016/j.indcrop.2020.112701

Biela, M., Kleinová, A., & Klein, E. (2022). Phenolic acids and their carboxylate anions: Thermodynamics of primary antioxidant action. *Phytochemistry*, 200, 113254. https://doi.org/10.1016/j.phytochem.2022.113254

Bitencourt, T. A., Komoto, T. T., Massaroto, B. G., Miranda, C. E. S., Beleboni, R. O., Marins, M., & Fachin, A. L. (2013). Trans-chalcone and quercetin down-regulate fatty acid synthase gene expression and reduce ergosterol content in the human pathogenic dermatophyte Trichophyton rubrum. *BMC complementary and alternative medicine*, 13, 1-6. https://doi.org/10.1186/1472-6882-13-229

Borges, A., Saavedra, M. J., & Simões, M. (2012). The activity of ferulic and gallic acids in biofilm prevention and control of pathogenic bacteria. *Biofouling*, 28(7), 755-767. https://doi.org/10.1080/08927014.2012.706751

Carvalho, R. S., Carollo, C. A., De Magalhães, J. C., Palumbo, J. M. C., Boaretto, A. G., e Sá, I. N., Ferraz, A.C., Lima, W., G.de Siqueira, J.M., & Ferreira, J. M. S. (2018). Antibacterial and antifungal activities of phenolic compound-enriched ethyl acetate fraction from Cochlospermum regium (mart. Et. Schr.) Pilger roots: Mechanisms of action and synergism with tannin and gallic acid. *South African Journal of Botany*, 114, 181-187. https://doi.org/10.1016/j.sajb.2017.11.010

Choi, J. H., Seo, E. J., Sung, J., Choi, K. M., Kim, H., Kim, J. S., Lee, J., Efferth, T., & Hyun, T. K. (2017). Polyphenolic compounds, antioxidant and anti-inflammatory effects of Abeliophyllum distichum Nakai extract. *Journal of Applied Botany & Food Quality*, 90. https://doi.org/10.5073/JABFQ.2017.090.033

Číž, M., Dvořáková, A., Skočková, V., & Kubala, L. (2020). The Role of Dietary Phenolic Compounds in Epigenetic Modulation Involved in Inflammatory Processes. *Antioxidants*, 9(8), 691. https://doi.org/10.3390/antiox9080691

Cosme, P., Rodríguez, A. B., Espino, J., & Garrido, M. (2020). Plant phenolics: Bioavailability as a key determinant of their potential health-promoting applications. *Antioxidants*, *9*(12), 1263. https://doi.org/10.3390/antiox9121263

da Rocha Neto, A. C., Maraschin, M., & Di Piero, R. M. (2015). Antifungal activity of salicylic acid against Penicillium expansum and its possible mechanisms of action. *International journal of food microbiology*, 215, 64-70. https://doi.org/10.1016/j.ijfoodmicro.2015.08.018

de Araújo, F. F., de Paulo Farias, D., Neri-Numa, I. A., & Pastore, G. M. (2021). Polyphenols and their applications: An approach in food chemistry and innovation potential. *Food chemistry*, *338*, 127535. https://doi.org/10.1016/j.foodchem.2020.127535

de Paulo Farias, D., de Araujo, F. F., Neri-Numa, I. A., & Pastore, G. M. (2021). Antidiabetic potential of dietary polyphenols: A mechanistic review. *Food Research International*, 145, 110383. https://doi.org/10.1016/j.foodres.2021.110383

Deka, H., Choudhury, A., & Dey, B. K. (2022). An overview on plant derived phenolic compounds and their role in treatment and management of diabetes. *Journal of pharmacopuncture*, 25(3), 199. https://doi.org/10.3831/KPI.2022.25.3.199

Demir, Y., Durmaz, L., Taslimi, P., & Gulçin, İ. (2019). Antidiabetic properties of dietary phenolic compounds: Inhibition effects on α-amylase, aldose reductase, and α-glycosidase. *Biotechnology and applied biochemistry*, 66(5), 781-786. https://doi.org/10.1002/bab.1781

Ding, Y., Shi, X., Shuai, X., Xu, Y., Liu, Y., Liang, X., Wei, D., & Su, D. (2014). Luteolin prevents uric acid-induced pancreatic β-cell dysfunction. *Journal of biomedical research*, 28(4), 292. https://doi.org/10.7555/JBR.28.20130170

Dull, A. M., Moga, M. A., Dimienescu, O. G., Sechel, G., Burtea, V., & Anastasiu, C. V. (2019). Therapeutic approaches of resveratrol on endometriosis via anti-inflammatory and anti-angiogenic pathways. *Molecules*, 24(4), 667. https://doi.org/10.3390/molecules24040667

Edirisinghe, I., & Burton-Freeman, B. (2016). Anti-diabetic actions of Berry polyphenols–Review on proposed mechanisms of action. *Journal of Berry Research*, 6(2), 237-250. https://doi.org/10.3233/JBR-160137

Ferreira, I.C.F.R., Martins, N., & Barros, L. (2017). Phenolic Compounds and its bioavailability: In vitro bioactive compounds or health promoters?. *Advances in Food and Nutrition Research*, 82, 1-44. https://doi.org/10.1016/bs.afnr.2016.12.004

Ghorbani, A. (2017). Mechanisms of antidiabetic effects of flavonoid rutin. *Biomedicine & Pharmacotherapy*, 96, 305-312. https://doi.org/10.1016/j.biopha.2017.10.001

Gong, P., Wang, D., Cui, D., Yang, Q., Wang, P., Yang, W., & Chen, F. (2021). Anti-aging function and molecular mechanism of Radix Astragali and Radix Astragali preparata via network pharmacology and PI3K/Akt signaling pathway. *Phytomedicine*, 84, 153509. https://doi.org/10.1016/j.phymed.2021.153509

Gong, Y., Lv, J., Pang, X., Zhang, S., Zhang, G., Liu, L., Wang, Y., & Li, C. (2023). Advances in the Metabolic Mechanism and Functional Characteristics of Equol. *Foods*, 12(12), 2334. https://doi.org/10.3390/foods12122334

Grgić, J., Šelo, G., Planinić, M., Tišma, M., & Bucić-Kojić, A. (2020). Role of the encapsulation in bioavailability of phenolic compounds. *Antioxidants*, *9*(10), 923. https://doi.org/10.3390/antiox9100923

Huang, Q., Chen, L., Teng, H., Song, H., Wu, X., & Xu, M. (2015). Phenolic compounds ameliorate the glucose uptake in HepG2 cells' insulin resistance via activating AMPK: anti-diabetic effect of phenolic compounds in HepG2 cells. *Journal of Functional Foods*, 19, 487-494. https://doi.org/10.1016/j.jff.2015.09.020

Hussain, T., Tan, B., Yin, Y., Blachier, F., Tossou, M. C., & Rahu, N. (2016). Oxidative stress and inflammation: what polyphenols can do for us?. *Oxidative medicine and cellular longevity*, 2016. https://doi.org/10.1155/2016/7432797

Jiang, Y., Mei, C., Huang, X., Gu, Q., & Song, D. (2020). Antibacterial Activity and Mechanism of a Bacteriocin Derived from the Valine-Cecropin A(1–8)-Plantaricin ZJ5(1–18) Hybrid Peptide Against *Escherichia coli* O104. *Food Biophysics*, 15, 442-451. https://doi.org/10.1007/s11483-020-09636-w

Krongyut, O., & Sutthanut, K. (2019). Phenolic profile, antioxidant activity, and anti-obesogenic bioactivity of Mao Luang fruits (*Antidesma bunius* L.). *Molecules*, 24(22), 4109. https://doi.org/10.3390/molecules24224109

Kumar. N., & Goel, N. (2019). Phenolic acids: Natural versatile molecules with promising therapeutic applications. *Biotechnology Reports*, 24, e00370. https://doi.org/10.1016/j.btre.2019.e00370

Lagh, A.B., Haas, B., & Grenier, D. (2017). Tea polyphenols inhibit the growth and virulence properties of *Fusobacterium nucleatum*, *Scientific Reports*, 7, 44815.

Lee, J. H., Kim, Y. G., Ryu, S. Y., Cho, M. H., & Lee, J. (2014). Ginkgolic acids and Ginkgo biloba extract inhibit *Escherichia coli* O157: H7 and *Staphylococcus aureus* biofilm formation. *International journal of food microbiology*, 174, 47-55. https://doi.org/10.1016/j.ijfoodmicro.2013.12.030

Lee, J., & Lee, D. G. (2015). Novel antifungal mechanism of resveratrol: apoptosis inducer in *Candida albicans*. *Current microbiology*, 70, 383-389.

Lephart, E. D. (2016). Skin aging and oxidative stress: Equol's anti-aging effects via biochemical and molecular mechanisms. *Ageing research reviews*, 31, 36-54. https://doi.org/10.1016/j.arr.2016.08.001

Li, G., Wang, X., Xu, Y., Zhang, B., & Xia, X. (2014). Antimicrobial effect and mode of action of chlorogenic acid on *Staphylococcus aureus*. *European Food Research and Technology*, 238, 589–596. https://doi.org/10.1016/j.micpath.2022.105748

Li, Z.J., Liu, M., Dawuti, G., Dou, Q., Ma, Y., Liu, H. G., & Aibai, S. (2017). Antifungal activity of gallic acid in vitro and in vivo. *Phytotherapy research*, 31(7), 1039-1045. https://doi.org/10.1002/ptr.5823

Lin, S., Wang, Z., Lin, Y., Ge, S., Hamzah, S. S., & Hu, J. (2019). Bound phenolics from fresh lotus seeds exert anti-obesity effects in 3T3-L1 adipocytes and high-fat diet-fed mice by activation of AMPK. *Journal of functional foods*, 58, 74-84. https://doi.org/10.1016/j.jff.2019.04.054

Liu, Y., & Wang, L. (2022). Antibiofilm effect and mechanism of protocatechuic aldehyde against *Vibrio parahaemolyticus*. *Frontiers in Microbiology*, 16. https://doi.org/10.3389/fmicb.2022.1060506

Lou, Z., Wang, H., Zhu, S., Ma, C., & Wang, Z. (2011). Antibacterial activity and mechanism of action of chlorogenic acid. *Journal of Food Science*, 76, M398–M403. https://doi.org/10.1111/j.1750-3841.2011.02213.x

Luís, Â., Silva, F., Sousa, S., Duarte, A. P., & Domingues, F. (2014). Antistaphylococcal and biofilm inhibitory activities of gallic, caffeic, and chlorogenic acids. *Biofouling*, 30(1), 69-79. https://doi.org/10.1080/08927014.2013.845878

Lutz, M., Fuentes, E., Ávila, F., Alarcón, M., & Palomo, I. (2019). Roles of phenolic compounds in the reduction of risk factors of cardiovascular diseases. *Molecules*, 24(2), 366. https://doi.org/10.3390/molecules24020366

Maniglia, B. C., Rebelatto, E. A., Andrade, K. S., Zielinski, A., & de Andrade, C. J. (2021). Polyphenols. *Food Bioactives and Health*, 1-39. https://doi.org/10.1007/978-3-030-57469-7

Martinez-Gonzalez, A.I., Díaz-Sánchez, Á.G., De La Rosa, L.A., Vargas-Requena, C.L., Bustos-Jaimes, I., & Alvarez-Parrilla, E. (2017). Polyphenolic compounds and digestive enzymes: In vitro non-covalent interactions, *Molecules*, 22 (4), 1-24. https://doi.org/10.3390/molecules22040669

Martinez-Micaelo, N., González-Abuín, N., Pinent, M., Ardévol, A., & Blay, M. (2015). Procyanidin B2 inhibits inflammasome-mediated IL-1β production in lipopolysaccharide-stimulated macrophages. *Molecular nutrition & food research*, 59(2), 262-269. https://doi.org/10.1002/mnfr.201400370

Nadaf, N.H., Parulekar, R.S., Patil, R.S., Gade, T.K., Momin, A.A., Waghmare, S.R., Dhanavade, M.J., Arvindekar, A.U., & Sonawane, K.D. (2018). Biofilm inhibition mechanism from extract of *Hymenocallis littoralis* leaves. *Journal of Ethnopharmacology*, 222, 121-132. https://doi.org/10.1016/j.jep.2018.04.031

Najafi, M., Mood, K.H., Zahedi, M., & Klein, E. (2011). DFT/B3LYP study of the substituent effect on the reaction enthalpies of the individual steps of single electron transfer–proton transfer and sequential proton loss electron transfer mechanisms of chroman derivatives antioxidant action, *Computational and Theoretical Chemistry*, 969(1–3), 1-12. https://doi.org/10.1016/j.comptc.2011.05.006

Nakai, K., & Tsuruta, D. (2021). What are reactive oxygen species, free radicals, and oxidative stress in skin diseases?. *International journal of molecular sciences*, 22(19), 10799.

Oliveira, A. K. D. S., de Oliveira e Silva, A. M., Pereira, R. O., Santos, A. S., Barbosa Junior, E. V., Bezerra, M. T., Barreto, R.,S.,S., Quintans-Junior, L., J., & Quintans, J. S. (2022). Anti-obesity properties and mechanism of action of flavonoids: A review. *Critical Reviews in Food Science and Nutrition*, 62(28), 7827-7848. https://doi.org/10.1080/10408398.2021.1919051

Onat, K. A., Sezer, M., & Çöl, B. (2021). Fenolik bileşiklerden Sinnamik Asit, Kafeik Asit ve p-kumarik Asit'in bazı biyolojik aktiviteleri. *Journal of the Institute of Science and Technology*, *11*(4), 2587-2598. https://doi.org/10.21597/jist.885898

Öncül. N., & Karabıyıklı, Ş. (2016). Mechanism of antibacterial effect of plant based antimicrobials, *Ukrainian Food Journal*, 5(3), 541-549.

Payne, D. E., Martin, N. R., Parzych, K. R., & Rickard, A. H., Underwood, A., Boles, B. R. (2013). Tannic acid inhibits *Staphylococcus aureus* surface colonization in an IsaA-dependent manner. *Infection and immunity*, 81(2), 496-504. https://doi.org/10.1128/iai.00877-12

Pei, Z. J., Li,C., Dai, W., Lou, Z., Sun, X., Wang, H., Khan, A.A., & Wan, C. (2023). The Anti-Biofilm Activity and Mechanism of Apigenin-7-O-Glucoside Against *Staphylococcus aureus* and *Escherichia coli*. *Infection and Drug Resistance*, 16.

Pernin, A., Guillier, L., & Dubois-Brissonnet, F. (2019). Inhibitory activity of phenolic acids against *Listeria monocytogenes*: Deciphering the mechanisms of action using three different models. *Food Microbiology*, 80, 18-24. https://doi.org/10.1016/j.fm.2018.12.010

Piechowiak, T., & Balawejder, M. (2019). Onion skin extract as a protective agent against oxidative stress in *Saccharomyces cerevisiae* induced by cadmium, *Food Biochem*, 43(7), e12872. https://doi.org/10.1111/jfbc.12872

Pivari, F., Mingione, A., Brasacchio, C., & Soldati, L. (2019). Curcumin and type 2 diabetes mellitus: prevention and treatment. *Nutrients*, 11(8), 1837. https://doi.org/10.3390/nu11081837

Plaper, A., Golob, M., Hafner, I., Oblak, M., Šolmajer, T., & Jerala, R. (2003). Characterization of quercetin binding site on DNA gyrase. *Biochemical and Biophysical Research Communications*, 306, 530–536. https://doi.org/10.1016/s0006-291x(03)01006-4

Platzer, M., Kiese, S., Herfellner, T., Schweiggert-Weisz, U., Miesbauer, O., & Eisner, P. (2021). Common Trends and Differences in Antioxidant Activity Analysis of Phenolic Substances Using Single Electron Transfer Based Assays**,** *Molecules*, 26(5), 1244 https://doi.org/10.3390/molecules26051244

Pok, P. S., Londoño, V. A. G., Vicente, S., Romero, S. M., Pacín, A., Tolaba, M., Alzamora, S., M., & Resnik, S. L. (2020). Evaluation of citrus flavonoids against Aspergillus parasiticus in maize: Aflatoxins reduction and ultrastructure alterations. Food chemistry, 318, 126414. https://doi.org/10.1016/j.foodchem.2020.126414

Pragasam, S. J., Venkatesan, V., & Rasool, M. (2013). Immunomodulatory and anti-inflammatory effect of p-coumaric acid, a common dietary polyphenol on experimental inflammation in rats. *Inflammation*, 36, 169-176

Prateeksha, Rao, C. V., Das, A. K., Barik, S. K., & Singh, B. N. (2019). ZnO/curcumin nanocomposites for enhanced inhibition of *Pseudomonas aeruginosa* virulence via LasR-RhlR quorum sensing systems. *Molecular pharmaceutics*, 16(8), 3399-3413. https://doi.org/10.1021/acs.molpharmaceut.9b00179

Pudziuvelyte, L., Liaudanskas, M., Jekabsone, A., Sadauskiene, I., & Bernatoniene, J. (2020). *Elsholtzia ciliata* (Thunb.) Hyl. extracts from different plant parts: Phenolic composition, antioxidant, and anti-inflammatory activities. *Molecules*, 25(5), 1153. https://doi.org/10.3390/molecules25051153

Pyo, I. S., Yun, S., Yoon, Y. E., Choi, J. W., & Lee, S. J. (2020). Mechanisms of aging and the preventive effects of resveratrol on age-related diseases. *Molecules*, 25(20), 4649. https://doi.org/10.3390/molecules25204649

Rahman, M. M., Rahaman, M. S., Islam, M. R., Rahman, F., Mithi, F. M., Alqahtani, T., Almikhlafi, M.,A., Alghamdi,S.,O., Alruwaili, A.,S., Hossain, M., S., Ahmed, M., Das, R., Emran, T., B., & Uddin, M. S. (2022). Role of phenolic compounds in human disease: current knowledge and future prospects. *Molecules*, 27(1), 233. https://doi.org/10.3390/molecules27010233

Rajkumari, J., Borkotoky, S., Murali, A., Suchiang, K., Mohanty, S. K., & Busi, S. (2018). Cinnamic acid attenuates quorum sensing associated virulence factors and biofilm formation in *Pseudomonas aeruginosa* PAO1. *Biotechnology letters*, 40, 1087-1100. https://doi.org/10.1007/s10529-018-2557-9

Raudone, L., Vilkickyte, G., Pitkauskaite, L., Raudonis, R., Vainoriene, R., & Motiekaityte, V. (2019). Antioxidant activities of *Vaccinium vitis-idaea* L. leaves within cultivars and their phenolic compounds. *Molecules*, 24(5), 844. https://doi.org/10.3390/molecules24050844

Rodriguez-Mateos, A., Heiss, C., Borges, G., & Crozier, A. (2014). Berry (poly) phenols and cardiovascular health. *Journal of agricultural and food chemistry*, 62(18), 3842-3851. https://doi.org/10.1021/jf403757g

Ryyti, R., Hämäläinen, M., Leppänen, T., Peltola, R., & Moilanen, E. (2022). Phenolic compounds known to be present in lingonberry (*Vaccinium Vitis-Idaea* L.) enhance macrophage polarization towards the anti-inflammatory M2 phenotype. *Biomedicines*, 10(12), 3045. https://doi.org/10.3390/biomedicines10123045

Sandoval-Acuña, C., Ferreira, J., & Speisky, H. (2014). Polyphenols and mitochondria: An update on their increasingly emerging ROS-scavenging independent actions. *Archives of Biochemistry and Biophysics*, 559, 75-90. https://doi.org/10.1016/j.abb.2014.05.017

Serra, D.O., Mika, F., Richter, A.M., & Hengge, R. (2016). Yeşil çay polifenolü EGCG, amiloid kıvrımlı lif düzeneğini bozarak ve σE'ye bağımlı sRNA RybB yoluyla biyofilm düzenleyici CsgD'yi aşağı doğru düzenleyerek E. coli biyofilm oluşumunu engeller. *Molecular Biology*, 101 (1), 136-151. https://doi.org/10.1111/mmi.13379

Shakya, T., Stogios, P.J., Waglechner, N., Evdokimova, E., Ejim, L., & Blanchard, J.E. (2011). A small molecule discrimination map of the antibiotic resistance kinome. *Chemistry & Biology*, 18, 1591–1601. https://doi.org/10.1016/j.chembiol.2011.10.018

Shehata, M. G., Awad, T. S., Asker, D., El Sohaimy, S. A., Abd El-Aziz, N. M., & Youssef, M. M. (2021). Antioxidant and antimicrobial activities and UPLC-ESI-MS/MS polyphenolic profile of sweet orange peel extracts. *Current research in food science*, 4, 326-335. https://doi.org/10.1016/j.crfs.2021.05.001

Shirai, A., Kawasaka, K., & Tsuchiya, K. (2022). Antimicrobial action of phenolic acids combined with violet 405-nm light for disinfecting pathogenic and spoilage fungi. *Journal of Photochemistry and Photobiology B: Biology*, 229, 112411. https://doi.org/10.1016/j.jphotobiol.2022.112411

Sies, H., Berndt, C., & Jones, D. P. (2017). Oxidative stress. *Annual review of biochemistry*, 86, 715-748. https://doi.org/10.1146/annurev-biochem-061516-045037

Silva, H., & Lopes, N. M. F. (2020). Cardiovascular effects of caffeic acid and its derivatives: a comprehensive review. *Frontiers in physiology*, 11, 595516. https://doi.org/10.3389/fphys.2020.595516

Slobodníková, L., Fialová, S., Hupková, H., & Grančai, D. (2013). Rosmarinic acid interaction with planktonic and biofilm *Staphylococcus aureus*. *Natural product communications*, 8(12), 1934578X1300801223. https://doi.org/10.1177/1934578X1300801223

Spagnuolo, C., Moccia, S., & Russo, G. L., (2018). Anti-inflammatory effects of flavonoids in neurodegenerative disorders. *European Journal of Medicinal Chemistry*, 153, 105-115. https://doi.org/10.1016/j.ejmech.2017.09.001

Sun, S., Huang, S., Shi, Y., Shao, Y., Qiu, J., Sedjoah, R. C. A. A., Yan,Z., Ding, L., Zou, D.,& Xin, Z. (2021). Extraction, isolation, characterization and antimicrobial activities of non-extractable polyphenols from pomegranate peel. *Food Chemistry*, *351*, 129232. https://doi.org/10.1016/j.foodchem.2021.129232

Sun, W., & Shahrajabian, M. H. (2023). Therapeutic potential of phenolic compounds in medicinal plants—Natural health products for human health. *Molecules*, *28*(4), 1845. https://doi.org/10.3390/molecules28041845

Taticchi, A., Urbani, S., Albi, E., Servili, M., Codini, M., Traina, G., Balloni, S., Patria, F., F., Perioli, L., Beccari, T., & Conte, C. (2019). In vitro anti-inflammatory effects of phenolic compounds from Moraiolo virgin olive oil (MVOO) in brain cells via regulating the TLR4/NLRP3 axis. *Molecules*, 24(24), 4523. https://doi.org/10.3390/molecules24244523

Taylor, E., Kim, Y., & Zhang, K., Chau, L., Nguyen, B. C., Rayalam, S., Wang, X. (2022). Antiaging Mechanism of natural compounds: Effects on autophagy and oxidative stress. *Molecules*, 27(14), 4396. https://doi.org/10.3390/molecules27144396

Toma, L., Sanda, G. M., Niculescu, L. S., Deleanu, M., Sima, A. V., & Stancu, C. S. (2020). Phenolic compounds exerting lipid-regulatory, anti-inflammatory and epigenetic effects as complementary treatments in cardiovascular diseases. *Biomolecules*, 10(4), 641. https://doi.org/10.3390/biom10040641

Tsou, L. K., Lara-Tejero, M., Rosefigura, J., Zhang, Z. J., Wang, Y.C., & Yount, J. S. (2016). Antibacterial flavonoids from medicinal plants covalently inactivate type III protein secretion substrates. *Journal of the American Chemical Society*, 138, 2209–2218. https://doi.org/10.1021/jacs.5b11575

Vrba, J., Kren, V., Vacek, J., Papouskova, B., & Ulrichova, J. (2012). Quercetin, quercetin glycosides and taxifolin differ in their ability to induce AhR activation and CYP1A1 expression in HepG2 cells. Phytotherapy research, 26(11), 1746-1752. https://doi.org/10.1002/ptr.4637

Vuolo, M. M., Lima, V.S., & Maróstica Junior, M. R. (2019). Phenolic Compounds: Structure, Classification, and Antioxidant Power. *In Bioactive Compounds*, 33-50. https://doi.org/10.1016/B978-0-12-814774-0.00002-5

Wang, Q. Q., Gao, H., Yuan, R., Han, S., Li, X. X., Tang, M., ng, B.,Li,J.,Zhao, L.,Feng, J., & Yang, S. (2020). Procyanidin A2, a polyphenolic compound, exerts anti-inflammatory and anti-oxidative activity in lipopolysaccharide-stimulated. *PLoS One*, 15(8), e0237017. https://doi.org/10.1371/journal.pone.0237017

Wu, M., Cai, J., Fang, Z., Li, S., Huang, Z., Tang, Z., Luo, Q., & Chen, H. (2022). The composition and anti-aging activities of polyphenol extract from *Phyllanthus emblica* L. fruit. *Nutrients*, 14(4), 857. https://doi.org/10.3390/nu14040857

Wu, T., Zang, X., He, M., Pan, S., & Xu, X. (2013). Structure-activity relationship of flavonoids on their anti-Escherichia coli activity and inhibition of DNA gyrase. *Journal of Agricultural and Food Chemistry*. 61, 8185–8190. https://doi.org/10.1021/jf402222v

Xie, H.K., Zhou, D.Y., Yin, F.W., Rakariyatham, K., Zhao, M.T., Liu, Z.Y., Li. D.Y., Zhao, Q., Liu, Y.X., Shahidi, F., & Zhu, B.W. (2019). Mechanism of antioxidant action of natural phenolics on scallop (*Argopecten irradians*) adductor muscle during drying process. *Food Chemistry*, 281. 251-260. https://doi.org/10.1016/j.foodchem.2018.12.108

Yahfoufi, N., Alsadi, N., Jambi, M., & Matar, C. (2018). The immunomodulatory and anti-inflammatory role of polyphenols. *Nutrients*, 10(11), 1618. https://doi.org/10.3390/nu10111618

Yang, X., & Jiang, X. (2015). Antifungal activity and mechanism of tea polyphenols against Rhizopus stolonifer. *Biotechnology Letters*, 37, 1463-1472.

Yücel-Şengün, İ., & Öztürk, B. (2018). Bitkisel Kaynaklı Bazı Doğal Antimikrobiyaller. *Anadolu Üniversitesi Bilim ve Teknoloji Dergisi C- Yaşam Bilimleri ve Teknoloji*, 7(2), 256-276. https://doi.org/10.18036/aubtdc.407806

Zeb, A. (2020). Concept, mechanism, and applications of phenolic antioxidants in foods. *Journal of Food Biochemistry*, 44(9), e13394. https://doi.org/10.1111/jfbc.13394

Zhang, H., & Tsao, R. (2016). Dietary polyphenols, oxidative stress and antioxidant and anti-inflammatory effects. *Current Opinion in Food Science*, 8, 33-42.

Zhang, L., Kong, Y., Wu, D., Zhang, H., Wu, J., & Chen, J. (2008). Three flavonoids targeting the β-hydroxyacyl-acyl carrier protein dehydratase from *Helicobacter pylori*: crystal structure characterization with enzymatic inhibition assay. *Protein Science*, 17, 1971–1978. https://doi.org/10.1110/ps.036186.108

Zhang, Y., Cai, P., Cheng, G., & Zhang, Y. (2022). A brief review of phenolic compounds identified from plants: Their extraction, analysis, and biological activity. *Natural Product Communications*, *17*(1), 1934578X211069721. https://doi.org/10.1177/1934578X211069721

Zhao, H., & Xu, C. (2021). Natural phenolic compounds as anti-obesity and anti-cardiovascular disease agent. In Dietary Phytochemicals: A Source of Novel Bioactive Compounds for the Treatment of Obesity, Cancer and Diabetes (pp. 205-221). Cham: Springer International Publishing.

Zheng, Y., Choi, Y. H., Lee, J. H., Lee, S. Y., & Kang, I. J. (2021). Anti-obesity effect of *Erigeron annuus* (L.) Pers. extract containing phenolic acids. *Foods*, 10(6), 1266. https://doi.org/10.3390/foods10061266

Zhou, L., Zheng, H., Tang, Y., Yu, W., & Gong, Q. (2013). Eugenol inhibits quorum sensing at sub-inhibitory concentrations. *Biotechnology letters*, 35, 631-637. https://doi.org/10.1007/s10529-012-1126-x

Zhu, C., Lei, M., Andargie, M., Zeng, J., &Li, J. (2019). Antifungal activity and mechanism of action of tannic acid against *Penicillium digitatum*. *Physiological and Molecular Plant Pathology*, 107, 46-50. https://doi.org/10.1016/j.pmpp.2019.04.009

Zhu, H., Yan, Y., Jiang, Y., & Meng, X. (2022). Ellagic acid and its anti-aging effects on central nervous system. *International journal of molecular sciences*, 23(18), 10937. https://doi.org/10.3390/ijms231810937

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Derleme

Türkiye'nin Yerel Irklarından Ankara ve Van Kedilerinin Irk Özellikleri

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ÖZET

Bu derleme, dünya genelinde tanınan yerli kedi ırklarımızdan Ankara ve Van kedilerinin sıklıkla karıştırılmasını önlemek amacıyla, genetik yapıları, fizyolojik özellikleri ve davranışsal farklılıklarını incelemekte ve bu ırkların doğru bir şekilde tanıtılmasına katkı sağlamayı amaçlamaktadır. Ankara ve Van kedileri, Türkiye'ye özgü iki önemli kedi ırkıdır ve her biri kendine özgü fizyolojik ve davranışsal özelliklere sahiptir. Ankara ve Van kedileri, genellikle beyaz tüy rengi ve benzer göz renkleri nedeniyle sıkça karıştırılmaktadır. Ancak, bu iki kedi ırkı arasında bazı belirgin morfolojik farklar bulunmaktadır. Van kedisinin yüz yapısı yuvarlak iken, Ankara kedisinin yüzü daha sivri bir şekle sahiptir. Ankara kedisinin gözleri yuvarlak iken, Van kedisinin gözleri badem şeklindedir. Her iki ırk da genellikle beyaz tüy rengine sahip olmakla birlikte, Van kedisinin baş ve kuyruğunda sarımsı lekeler gözlemlenebilmektedir. Van kedisinin tüy uzunluğu, genellikle Ankara kedisinin tüylerinden daha kısa olup, bu da her iki ırkın ayırt edilmesine yardımcı olan önemli bir başka farktır. Bu morfolojik farklılıklar, her iki ırkın birbirinden ayırt edilmesine olanak tanımaktadır. Ayrıca Ankara kedisi, sağırlıkla ilişkilendirilen W genini taşıyan nadir kedi ırkları arasında yer alırken, Van kedisi ise, suyu sevme özellikleriyle ünlüdür ve bu davranışları onları diğer kedi ırklarından ayırmaktadır.

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Breed Characteristics of Ankara and Van Cats, Local Breeds of Türkiye

ABSTRACT

This review aims to examine the genetic structure, physiological characteristics and behavioral differences of Ankara and Van cats, which are two of our globally recognized domestic cat breeds, in order to prevent frequent confusion and to contribute to the correct introduction of these breeds. Ankara and Van cats are two significant indigenous cat breeds from Türkiye, each distinguished by their unique physiological and behavioral traits. Although both breeds share a common white fur color and similar eye shades, they can be differentiated by several morphological characteristics. The Van cat has a round face, while the Ankara cat has a more pointed face. The Ankara cat's eyes are round, in contrast to the almond-shaped eyes of the Van cat. While both breeds are primarily white, the Van cat often exhibits yellowish spots on its head and tail. Additionally, the fur of the Van cat is generally shorter than that of the Ankara cat, which is another distinguishing feature. The Ankara cat carries the W gene, linked to deafness, whereas the Van cat is particularly known for its affinity for water, setting it apart from other breeds. These differences contribute to the clear distinction between the two Turkish cat breeds.

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GİRİŞ

Kediler, dünya genelinde yetiştirilen en popüler evcil hayvanlardan biri olup, zoolojik sistemde Felidae ailesi, *Felis* cinsi, *Felis silvestris* türü ve *F. silvestris catus* alt türünde yer almaktadır (Driscoll ve ark., 2007). Kedilerin evcilleştirilmesiyle ilgili kesin tarihi bilgiler mevcut olmamakla birlikte, çeşitli arkeolojik ve genetik çalışmaların sonuçları doğrultusunda bazı öngörülerde bulunulmuştur. Kedi ve insan arasındaki ilişkiye dair en erken arkeolojik bulguların yaklaşık 9500 yıl öncesine ait olduğu ve Kıbrıs'ta bulunduğu bildirilmektedir (Serpell, 2000; Vigne ve ark., 2004; Driscoll ve ark., 2007). Evcilleştirme sürecine ilişkin başka bir çalışmada da, evcilleştirme tarihlerinin, bulunan en erken arkeolojik bulgularla uyumlu olduğu kabul edilmektedir. Bu bulgular, kedilerin evcilleştirilmesinin, yerleşik tarım toplumlarının ortaya çıkışıyla paralel bir gelişim gösterdiğini desteklemektedir (Hart ve ark., 2013).

Esas olarak etçil bir diyetle beslenen kediler, güçlü avcılık yetenekleri, keskin duyuları ve esnek vücut yapılarıyla tanınmaktadır (Serpell, 2000). Kediler, farklı coğrafyalardaki değişken iklim koşullarına uyum sağlama yetenekleri sayesinde geniş bir dağılım alanına sahiptir (Lipinski ve ark., 2008). Bugün farklı fiziksel özellikleri, tüy yapıları ve davranış özellikleri ile karakterize edilen birçok kedi genotipi bulunmaktadır (Serpell, 2000; Driscoll ve ark., 2007; Kurushima ve ark., 2013; Salonen ve ark., 2019). Dünya genelinde kedilerin sayısına ilişkin kesin bir istatistiki bilgi bulunmamakla birlikte, Amerika Birleşik Devletleri en fazla kedi popülasyonuna sahip ülke olarak kabul edilmekte olup hanelerin yaklaşık üçte birinde kedi bulunduğu ve dünya genelinde 600 milyonun üzerinde kedinin insanlar ile birlikte yaşadığı bildirilmektedir (Menotti-Raymond ve ark., 2008; Driscoll ve ark., 2009; Montague ve ark., 2014).

Dünya genelinde kedi ırklarının tanıtımı, ırksal özelliklerinin belirlenmesi ve ırklar arası standardizasyonun sağlanması uluslararası düzeyde faaliyet gösteren çeşitli kuruluşlar tarafından gerçekleştirilmektedir. Bu kuruluşlar arasında Canadian Cat Association (CCA-AFC), The International Cat Association (TICA), American Cat Fanciers Association (ACFA) ve Cat Fanciers Association (CFA) gibi önemli kuruluşlar yer almaktadır. Bu kuruluşlar, kedi ırklarının fiziksel, genetik ve davranışsal özelliklerini tanımlayarak, her bir ırk için belirli standartlar oluşturmaktadır. Kedi ırklarının korunması, geliştirilmesi ve popülasyonlarının sürdürülebilirliğinin sağlanmasında bu kuruluşlar önemli bir rol üstlenmektedir. Ayrıca bu kuruluşlar yalnızca ırk kayıtlarını tutmakla kalmayıp genetik çeşitliliğin korunması, ırk standartlarının belirlenmesi ve uluslararası düzeyde tanıtılması gibi alanlarda da önemli faaliyetler yürütmektedirler (TICA, CCA-AFC, CFA, 2024).

Bu kurumlardan, The International Cat Association (TICA) tarafından toplamda 73 kedi ırkı tanımlanmış ve bu ırkların karakteristik özellikleri belirlenmiştir (TICA, 2024). 1960 yılında kurulan Canadian Cat Association (CCA-AFC)'da ise farklı coğrafyalarda tanımlanan çeşitli ırklara ait 190.000'den fazla kedi kaydı bulunmaktadır (CCA-AFC, 2024). Dünya çapında en eski kuruluşlardan biri kabul edilen Cat Fanciers Association (CFA) ise 45 kedi ırkını resmi olarak tanımakta (CFA, 2024) iken, 1955 yılında kurulan American Cat Fanciers Association (ACFA) tarafından ise 69 kedi ırkı resmi olarak kabul edilmektedir (ACFA, 2024). Bu kurumlar kedi ırklarının yalnızca uluslararası düzeyde tanıtılmasına katkı sağlamakla kalmamakta, aynı zamanda bu ırkların genetik mirasının korunmasına da olanak tanımaktadır. Bu uluslararası kuruluşların kedi ırklarını tanımlama ve sınıflandırma çalışmalarında, Türkiye'ye özgü Ankara Kedisi (Türk Angora) ve Van Kedisi (Türk Van) de yer almaktadır. Her iki ırk da, TICA, CFA, ACFA ve CCA-AFC gibi uluslararası kedi kuruluşlarında resmi olarak yer almakta ve ırk standartları tanımlanmaktadır (TICA, CCA-AFC, CFA, 2024).

ANKARA VE VAN KEDİLERİNİN IRK ÖZELLİKLERİ VE TÜRKİYE'DE YETİŞTİRİCİLİĞİ

Ankara Kedisi

Ankara kedisi, Türkiye'nin başkenti Ankara'dan adını alan zeki, sevimli ve meraklı evcil bir kedi ırkıdır. Bu ırk, genellikle orta uzunlukta ipeksi beyaz tüyleriyle tanınır ancak siyah, mavi, kırmızı, duman ve tarçın gibi toplamda yirmiden fazla renk çeşitliliği bulunmaktadır (Çak, 2017; Sfetcu, 2021). Ankara kedisinin göz renkleri, mavi tonlarından gök mavisi ve safir, yeşil tonlarından Bektaşi üzüm yeşili ve zümrüt, ayrıca kehribar tonlarında olabilmektedir. Bir gözü mavi, diğer gözü yeşil, yeşil-altın veya kehribar renginde olan

heterokromi durumuna sahip kediler de görülmektedir. Ankara kedisinin gözleri yuvarlak bir yapıya sahiptir (Çak, 2017).

Ankara kedisinin vücudu, ipeksi, uzun ve parlak tüylerle kaplıdır; özellikle boyun ve kuyruk bölgesindeki tüyler daha uzundur. Baş, üçgen şeklinde olup vücuda oranla daha küçüktür. Kulaklar orta büyüklükte, uçları sivri ve tüylü olup, kulaklar arasındaki mesafe geniştir. Vücut, uzun ve gelişmiş bir kas yapısına sahiptir ve arka bacaklar ön bacaklara göre biraz daha uzundur. Kuyruk, uzun ve yoğun tüylerle kaplıdır; genellikle sırta paralel pozisyonda tutulmaktadır (Çak, 2017; Sfetcu, 2021). Erkek ve dişi Ankara kedilerinin morfolojik özellikleri sırasıyla; cidago yüksekliği 23 cm ve 22 cm, vücut uzunluğu 27 cm ve 24 cm, kuyruk uzunluğu 30 cm ve 29,5 cm, göğüs çevresi 39 cm ve 34,6 cm, canlı ağırlık ise 3792 g ve 3559 g olarak belirlenmiştir (Çak, 2017; Erat, 2023). Ankara kedisinin ortalama gebelik süresi 62,33 gün (60-64 gün aralığında) olarak belirlenmiş olup, ortalama yavru sayısı 3,33 (3-4) olarak bildirilmektedir (Macun ve ark., 2011).

Beyaz tüylü ve mavi gözlü kedilerde doğuştan sağırlığın yaygın olduğu ve genellikle sağırlığın mavi gözün bulunduğu tarafta ortaya çıktığı yaygın bilinmektedir. Kedilerde sağırlık genellikle genetik bir bozukluğa bağlı olarak ortaya çıkmakta olup, bu durum Ankara, Van ve diğer beyaz kedi ırklarında sıklıkla gözlemlenmektedir. Sağırlığın, beyaz tüy oluşumundan sorumlu White (W) geni ile ilişkili olduğu belirlenmiştir. Beyaz renk, White (W) ve White spotting (S) olmak üzere iki baskın gen tarafından kontrol edilmektedir. W geni taşıyan kediler tamamen beyaz renkte olmakla birlikte, beyaz kedi popülasyonlarında sağırlık prevalansının yüksek olduğu belirlenmiştir (Strain, 2011; Almaç ve Kaya, 2023). Bu durumda, Ankara kedileri W genini taşırken, Van kedilerinin bu geni taşımadığı (Sfetcu, 2021), ayrıca Van kedilerinde tek taraflı sağırlık oranının, diğer beyaz renkli kedi ırklarına göre çok daha düşük olduğu bildirilmektedir (Almaç ve Kaya, 2023).

CFA 1973'te, Ankara kedisini güzelliği ve ırk özellikleri nedeniyle şampiyon kedi olarak kabul etmiş ve 1978 yılında yalnızca saf beyaz renkli olan Ankara kedilerinin kaydı yapılmıştır (Sfetcu, 2021; CFA, 2024). Ankara Kedisi, dünya genelinde tanınan ve uluslararası kuruluşlar tarafından tescillenen yerli bir kedi ırkıdır. Ankara kedilerini korumak ve nesillerinin devamı için 1900'lerin başında Türkiye Cumhuriyeti ve Ankara Hayvanat Bahçesi ile birlikte titiz bir yetiştirme programı başlatılmış (Sfetcu, 2021), ırkın korunması ve tanıtılması amacıyla, 2018 yılında Ankara'nın Pursaklar ilçesinde 'Ankara Kedisi Üretme, Koruma, Yaşatma ve Tanıtma Merkezi' kurulmuştur. Merkez, iki kedi evi, ameliyathane, veteriner hekim odası ve idari personel ofisinin yanı sıra, 240 m²'lik bir kedi tanıtım evi, doğumhane, karantina ve müşahede odası gibi kapsamlı bir altyapıya sahiptir. Bu tesisin temel amacı, Ankara Kedisi'nin popülasyonunu artırmak, uluslararası yarışmalar yoluyla ırkın dünya genelinde tanınırlığını ve popülerliğini sürdürmek ve ırkın genetik devamlılığını sağlamaktır. Ayrıca, merkezde yürütülen koruma ve üretim faaliyetleri, hem ulusal hem de uluslararası düzeyde ırkın korunmasına katkı sağlamaktadır (purbelltd.com/kedievi, 2024).

Van Kedisi

Van kedisi, adını Türkiye'nin Doğu Anadolu Bölgesi'nde yer alan Van ilinden almakta ve bu bölgeye has endemik bir tür olarak kabul edilmektedir (Zeder, 2008; Altunok ve ark., 2011; Erat, 2023). Van kedileri genellikle beyaz tüy rengi ile bilinmekle birlikte alacalık ve beneklilikten sorumlu Piebald genine sahip kedilerde çeşitli renk varyasyonları da gözlemlenebilmektedir. Suya karşı gösterdikleri ilgi ile dikkat çeken Van Kedileri sahip oldukları kaşmir ya da tavşan kürküne benzer tüy yapısı sayesinde ıslandıklarında hızla kuruyabilmektedirler. Bu ırkın suya olan ilgisi, kediler arasında nadir görülen bir davranıştır ve Van kedilerine özgü karakteristik bir özellik olarak tanımlanmaktadır. Bu nedenle "Yüzen Kediler" (Swimming Cats) olarak da bilinmektedirler (Erat ve Arikan, 2012; Çak, 2017; Sfetcu, 2021).

Van kedilerinin karakteristik özelliklerinden olan göz renkleri; her iki gözü mavi, her iki gözü kehribar veya bir gözü mavi bir gözü kehribar olmak üzere üç gruba ayrılmakta (Altunok ve ark., 2011; Çak, 2017), bir gözü mavi, diğer gözü kehribar renginde olan kedilerin yetiştiriciliği daha yaygın yapılmaktadır (Erat ve Arikan, 2012). Van kedisinin gözleri badem şeklinde bir yapıdadır. Van kedilerinin tüy uzunluğu da uzun, orta ve kısa olmak üzere üç gruba ayrılmaktadır (Çak, 2017). Tüy rengi genellikle tekir veya beyaz olmakla birlikte, baş, sırt, kulaklar, bacaklar ve kuyruğundaki renkler kırmızı, krem, siyah, mavi, kırmızı tekir, krem tekir, kahverengi tekir, mavi tekir, kaplumbağa kabuğu (Tortoiseshell), açık kaplumbağa (Dilute tortoise), kahverengi yamalı tekir, mavi yamalı tekir ve Siyam ya da Himalayan gibi noktalı (pointed) renk varyasyonlarına sahip olabilmektedir (Çak, 2017; Sfetcu, 2021).

Van kedilerinde baş, kısa ve belirgin yuvarlak hatlara sahiptir. Kulaklar, uzun ve dik olup yüzle uyumludur. Gövde, orta uzunlukta ve derin bir göğüs yapısına sahiptir. Kuyruk, kalınlığı uca doğru incelen bir yapıdadır ve genellikle beyaz renkte olmakla birlikte kırmızı-sarı lekeler de görülebilir; ayrıca kısa veya uzun tüylü olabilir (Çak, 2017). Erkek ve dişi Van kedilerinin bazı morfolojik özellikleri sırasıyla şöyle bildirilmektedir: cidago yüksekliği 31 cm ve 27 cm, vücut uzunluğu 38 cm ve 36 cm, kuyruk uzunluğu 27 cm ve 25,5 cm, göğüs çevresi 30 cm ve 30,5 cm, canlı ağırlıkları ise 3392 g ve 3132 g'dır (Çak, 2017). Van kedilerinde ortalama gebelik süresi 64 gün (61-66 gün aralığında) olarak belirlenmiş, ortalama yavru sayısı ise 4,25 (4-5) olarak bildirilmiştir (Macun ve ark., 2011). Van kedisi, Ankara kedisine göre daha büyük bir vücut yapısına sahiptir ve olgunlaşma süresi de daha uzundur (Çak, 2017). Van kedilerinin büyüme ve gelişimlerinin 3 ila 5 yıl sürebildiği bildirilmektedir (Sfetcu, 2021).

Van kedileri ilk olarak 1982 yılında Amerika Birleşik Devletleri'ne getirilmiş ve 1994 yılında Cat Fanciers Association (CFA) tarafından şampiyon kedi gösterileri için kabul edilmiştir (Sfetcu, 2021). Van Kedisi, Türkiye'nin yerli ve endemik kedi ırklarından biri olup, özellikle beyaz tüyleri, farklı renkteki gözleri ve sosyal yapısıyla ulusal ve uluslararası düzeyde tanınmaktadır. Bu değerli ırkın korunması ve sürdürülebilirliğinin sağlanması amacıyla, Van Yüzüncü Yıl Üniversitesi bünyesinde 'Van Kedisi Evi' kurulmuştur. Bu merkez, Van Kedisi'nin popülasyonunu artırmayı, ırkın genetik bütünlüğünü korumayı ve gelecek nesillere aktarılmasını sağlamayı hedefleyen bilimsel ve koruyucu bir misyon üstlenmiştir. Merkezde, kedi sağlığını ve refahını sağlamak amacıyla modern altyapı ve olanaklar sunulmaktadır. Doğumhane, müşahede ve karantina odaları gibi bölümler, ırkın üreme süreçlerini kontrol altında tutmak ve genetik çeşitliliği korumak için tasarlanmıştır. Ayrıca, veteriner hekimlerin gözetiminde gerçekleştirilen düzenli sağlık taramaları, genetik deformasyonların ve kalıtsal hastalıkların önlenmesine katkı sağlamaktadır. Van Kedisi Evi'nin bir diğer önemli işlevi ise, bu nadir ırkın tanıtımına ve farkındalığın artırılmasına yönelik faaliyetler yürütmektir. Ulusal ve uluslararası düzeyde düzenlenen tanıtım programları, bilimsel etkinlikler ve yarışmalar aracılığıyla, Van Kedisi'nin dünya genelinde bilinirliği artırılmaktadır. Bu faaliyetler, sadece genetik mirasın korunmasına değil, aynı zamanda bölgenin kültürel ve turistik değerlerinin tanıtılmasına da katkı sağlamaktadır. Böylece Van Yüzüncü Yıl Üniversitesi bünyesindeki Van Kedisi Evi, yalnızca bir koruma merkezi değil, aynı zamanda bilimsel araştırmaların ve toplum bilincinin gelişimine hizmet eden çok yönlü bir kurum olarak işlev görmektedir (kulturportali.gov.tr/turkiye/van/gezilecekyer/van-kedisi-evi, 2024).

Ankara ve Van kedilerinin birbirlerine benzerlikleri nedeniyle akraba oldukları konusu tartışmalara yol açmıştır. Van kedisinin Ankara kedisinin bir varyasyonu olabileceğini öne süren görüşlerin yanı sıra, Ankara kedisinin Van kedisinin bir varyasyonu olduğuna dair görüşler de bulunmaktadır. Ancak bu konuda bilimsel bir çalışma bulunmamaktadır (Güre, 1993; Odabaşıoğlu ve Ateş, 2000; Arikan ve ark., 2003; Erat ve Arikan, 2012). Ankara ve Van kedileri üzerine yapılan kan grubu çalışması sonucunda, her iki ırkta da B tipi kanın yüksek prevalansa sahip olduğu ve bu iki ırkın kökeninin benzer olabileceği bildirilmektedir (Arikan ve ark., 2003). Ankara ve Van kedi ırklarının genetik ilişkilerini inceleyen araştırma bulguları, bu iki yerli ırkın Rus Mavisi (Russian Blue), British Shorthair/Scottish Fold ve Sphynx/Devon Rex gibi uluslararası kedi ırklarıyla genetik etkileşim içerisinde olabileceğini bildirmektedir (Menotti-Raymond ve ark., 2008; Çak, 2017).

Ankara ve Van kedileri, hem genetik hem de morfolojik özellikleri bakımından özgün ve önemli yerli ırklar olarak öne çıkmaktadır. Her iki ırk da genellikle beyaz tüylü ve benzer göz renklerine sahip olsa da, morfolojik açıdan belirgin farklılıklara sahiptirler. Ayrıca Van kedisinin suya olan ilgisi ve Ankara kedisinin sağırlıkla ilişkilendirilen W genini taşıması, bu kedileri diğer kedi ırklarından ayıran belirgin özelliklerdir. Bu kedilerin taşıdığı genetik özellikler ve davranışsal farklılıklar biyolojik çeşitlilik açısından önemlerini artırmaktadır (Eroğlu ve Altunok, 2007; Çak, 2017). Bu nedenle her iki ırkın daha ayrıntılı biyolojik ve genetik incelemelerinin yapılması yerli ırkların korunması, tanıtılması ve genetik çeşitliliğin sürdürülmesi açısından büyük önem taşımaktadır.

SONUÇ

Türkiye'nin yerli kedi ırkları arasında yer alan ve genetik özellikleriyle uluslararası düzeyde tanınan Ankara ve Van kedileri, aynı zamanda kültürel mirasın önemli temsilcilerindendir. Bu iki kedi ırkı yalnızca estetik ve kültürel değerlerini sürdürmekle kalmayıp, aynı zamanda dünya genelinde kedi genetik çeşitliliğinin korunması açısından da büyük önem taşımaktadır. Yerli kedi ırklarının genetik bütünlüğünün korunması büyük öneme sahiptir. Ancak, bilinçsiz melezlemeler ve sorumsuz sahiplenme gibi faktörler, bu ırkların

genetik yapısının bozulmasına yol açmaktadır. Özellikle bilinçsiz veya kısa süreli sahiplenme sonucunda kedilerin sokağa terk edilmesi karşılaşılan önemli sorunlar arasındadır. Kedilerin sokağa bırakılması, yalnızca bu ırkların genetik çeşitliliğini bozmakla kalmaz, aynı zamanda toplumda istenmeyen kedi popülasyonunun artmasına da yol açar. Bu durum, sağlık problemleri, aşırı kedi popülasyonu ve genetik hastalıkların yayılmasına zemin hazırlar.

Ankara ve Van kedileri başta olmak üzere diğer kedi ırklarından birini sahiplenen bireylerin sorumlu bir şekilde davranması ve kedilerinin uygun şekilde bakımını sağlayarak korumaları büyük önem taşımaktadır. Bu konuda farkındalık yaratmak ve bilinçli sahiplenmeyi teşvik etmek, Ankara ve Van Kedileri gibi yerel kedi ırklarının korunması ve sağlıklı nesillerin yetişmesi adına son derece önemli bir adımdır. Ankara ve Van illerindeki ilgili kurumlara sağlanacak devlet desteğinin artırılması ve üniversitelerin veteriner fakültelerinin ilgili akademik birimlerince düzenlenecek eğitim programları yerel kedi ırklarının genetik çeşitliliğini koruma sürecinde büyük bir öneme sahiptir. Devletin bu ırkların korunmasına yönelik politikalar geliştirmesi, biyolojik çeşitliliğin sürdürülebilirliğini sağlarken, eğitim çalışmalarının yaygınlaştırılması da toplumda hayvan refahı bilincini artıracaktır. Bu girişimler, yerli ırk kedilerin gelecek nesillere aktarılmasını sağlamanın yanı sıra Türkiye'nin biyolojik çeşitliliğinin ve kültürel zenginliğinin korunmasına da önemli katkı sağlayacaktır.

ÇIKAR ÇATIŞMASI

Yazarın herhangi bir çıkar çatışması yoktur.

YAZAR KATKISI

Derleme yazar tarafından titizlikle araştırılmış ve yazılmıştır.

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'Türkiye'nin Yerel Irklarından Ankara ve Van Kedilerinin Irk Özellikleri' başlıklı bu derleme çalışmasında bilimsel ve etik kurallara uyulmuştur. Çalışma, daha önce herhangi bir akademik yayın ortamına değerlendirilmek üzere gönderilmemiştir. Güncel literatür taramasına dayanan bir derleme olması nedeniyle etik kurul onayı gerekmemektedir.

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Bu derleme herhangi bir kurum ya da kişi tarafından desteklenmemiştir.

Veri Erişimi

Bu derleme makalesinde orijinal veri kullanılmamış olup, tüm bilgiler açık erişimli kaynaklardan derlenmiştir.

Yayın İçin Onay

Yazar, bu makalenin yayımlanmasına onay vermekte olup, herhangi bir üçüncü taraf izni gerekmemektedir.

KAYNAKÇALAR

ACFA (2024). https://en.wikipedia.org/wiki/American_Cat_Fanciers_Association (Erişim tarihi: 04.12.2024).

Almaç, Ç., F., Kaya, A. (2023). Investigations on the incidence of deafness in Van cats and its distribution by eye color. Ankara Universitesi Veteriner Fakultesi Dergisi, 70(2). https://doi.org/10.33988/auvfd.975163

Altunok, V., Yüksek, N., Berkman, C. C., Ağaoğlu, Z. T., & Togan, I. (2011). Genetic structure and variation of Van cats. Biochemical genetics, 49, 511-522. https://doi.org/10.1007/s10528-011-9426-8

Arikan, S., Duru, S. Y., Gurkan, M., Agaoglu, Z. T., & Giger, U. (2003). Blood type A and B frequencies in Turkish Van and Angora cats in Turkey. Journal of Veterinary Medicine Series A, 50(6), 303-306. https://doi.org/10.1046/j.1439-0442.2003.00536.x

CCA-AFC (2024). https://www.cca-afc.com/About/ (Erişim tarihi: 04.12.2024).

CFA (2024). https://cfa.org/breeds/ (Erişim tarihi: 04.12.2024).

Çak, B. (2017). Turkish Van cat and Turkish Angora cat: a review. J Agric Sci Technol A, 7(3), 151-159. https://doi.org/10.17265/2161-6256/2017.03.002

Driscoll, C. A., Menotti-Raymond, M., Roca, A. L., Hupe, K., Johnson, W. E., Geffen, E., Macdonald, D. W. (2007). The Near Eastern origin of cat domestication. Science, 317(5837), 519-523. https://doi.org/10.1126/science.1139518

Driscoll, C. A., Clutton-Brock, J., Kitchener, A. C., & O'Brien, S. J. (2009). The taming of the cat. Scientific American, 300(6), 68.

Erat, S. (2023). Kedi ve köpek ırkları. İçinde E. Yarsan (Ed.), *Kedi ve köpek hekimliği* (Güncellenmiş 3. baskı, ss. 1-25). Güneş Tıp Kitabevleri. ISBN 9789752779464.

Erat, S., Arikan, Ş. (2012). The hair characteristics of Turkish Angora and Van cats. Turkish Journal of Veterinary & Animal Sciences, 36(3), 215-221. https://doi.org/10.3906/vet-0804-21

Eroğlu, T.; Altunok, V. (2007). Türkiyedeki bazı kedi ırklarının genetik yapılarının mikrosatellitlerle incelenmesi. Selçuk Üniversitesi Saglık Bilimleri Enstitüsü Biyokimya (Vet) Anabilim Dalı, Yüksek Lisans Tezi, Konya.

Güre, A. (1993). Van kedisi. İçinde A. Abdulkadiroğlu (Ed.), Van Kütüğü (No. 8, ss. 722-726). Yüzüncü Yıl Üniversitesi.

Hart, B. L., Hart, L. A., Lyons, L. A. (2013). 11 Breed and gender behaviour differences: relation to the ancient history and origin of the domestic cat. The Domestic Cat: The Biology of its Behaviour, 155.

Kulturportali.gov.tr/turkiye/van/gezilecekyer/van-kedisi-evi: https://www.kulturportali.gov.tr/turkiye/van/gezilecekyer/van-kedisi-evi, Erişim tarihi: 02.12.2024.

Kurushima, J. D., Lipinski, M. J., Gandolfi, B., Froenicke, L., Grahn, J. C., Grahn, R. A., & Lyons, L. A. (2013). Variation of cats under domestication: genetic assignment of domestic cats to breeds and worldwide random - bred populations. Animal genetics, 44(3), 311-324. https://doi.org/10.1111/age.12008

Lipinski, M. J., Froenicke, L., Baysac, K. C., Billings, N. C., Leutenegger, C. M., Levy, A. M., ... & Lyons, L. A. (2008). The ascent of cat breeds: genetic evaluations of breeds and worldwide random-bred populations. Genomics, 91(1), 12-21. https://doi.org/10.1016/j.ygeno.2007.10.009

Macun, H. C., Erat, S., & Arıkan, S. (2011). Comparison of prenatal development of Turkish Angora and Van cats. Veterinarski arhiv, 81(5), 671-682.

Menotti-Raymond, M., David, V. A., Pflueger, S. M., Lindblad-Toh, K., Wade, C. M., O'Brien, S. J., & Johnson, W. E. (2008). Patterns of molecular genetic variation among cat breeds. Genomics, 91(1), 1-11. https://doi.org/10.1016/j.ygeno.2007.08.008

Montague, M. J., Li, G., Gandolfi, B., Khan, R., Aken, B. L., Searle, S. M., ... & Warren, W. C. (2014). Comparative analysis of the domestic cat genome reveals genetic signatures underlying feline biology and domestication. Proceedings of the National Academy of Sciences, 111(48), 17230-17235. https://doi.org/10.1073/pnas.1410083111

Odabaşıoğlu, F., Ateş, C.T. (2000). Van Kedisi. Selçuk Üniversitesi, Konya.

Purbelltd.com/kedievi : https://purbelltd.com/kedievi, Erişim tarihi: 02.12.2024.

Salonen, M., Vapalahti, K., Tiira, K., Mäki-Tanila, A., & Lohi, H. (2019). Breed differences of heritable behaviour traits in cats. Scientific reports, 9(1), 7949.

Serpell, J. A. (2000). Domestication and history of the cat. The domestic cat: The biology of its behaviour, 2, 180-192.

Sfetcu, N. (2021). About Cats. Published by Nicolae Sfetcu.

Strain GM (2011): Deafness in dog and cats. CPI Group, Wallingford.

TICA (2024). https://tica.org/ticas-breeds/browse-all-breeds/ (Erişim tarihi: 04.12.2024).

Vigne, J. D., Guilaine, J., Debue, K., Haye, L., & Gérard, P. (2004). Early taming of the cat in Cyprus. Science, 304(5668), 259-259. https://doi.org/10.1126/science.1095335

Zeder, M. A. (2008). Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. Proceedings of the national Academy of Sciences, 105(33), 11597-11604. https://doi.org/10.1073/pnas.0801317105

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Derleme

Türkiye'de Göçebe Hayvancılık Faaliyetlerinin Sosyo-Ekonomik Durumu ve Sorunları

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ÖZET

MAKALE BİLGİSİ

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Göçebe hayvancılık faaliyeti, insanlık tarihi boyunca avcı-toplayıcı dönemden bu yana göçebe toplulukların geçim ekonomisinin temelini oluşturmaktadır. Göçebe toplulukların sosyal yapısı, geniş aile yapısı ve kan bağıyla sıkı bir bağa dayanır. Göçebelerin hayvanlarıyla gerçekleştirdiği bu faaliyet farklı coğrafi alanlarda değişen mevsimsel koşullara bağımlı bir şekilde gerçekleşmektedir. Günümüzde Afrika ve Asya Kıtaları bu faaliyetin yoğun bir şekilde gerçekleştiği yerler arasındadır. Yaşanan bu göç hareketi ile göçebe topluluklar kaynağa doğru hareket ederek geçim ekonomilerinin temelini oluşturan hayvanlarına uygun otlak alanları değerlendirmektedir. Ekonomik anlamda otlak alanlardaki çayırlar protein içeriği yüksek hayvansal ürünlere dönüşmekte ve değer kazanmaktadır. İnsan, hayvan ve doğa ekseninde gerçekleşen bu üretken model fosil yakıtlara bağımlı olmadan tabiat ile iç içe geçmiş sürdürülebilir bir yapıdadır. Bu faaliyetin gerçekleştiği alanlarda mevcut olan göçebe hayvan varlığı ve üretilen hayvansal ürünler Türkiye ekonomisine katkı sağlamaktadır. Bu bağlamda göçebe hayvancılık faaliyetinin fonksiyonları arasında damızlık hayvanların muhafazası, kırsal alanlarda istihdam sağlama, kırsaldan kente göçü önleme, ekstansif üretim yapısı ile gıda güvencesini sağlama gibi fonksiyonları vardır. Ancak, göçebe topluluklar günümüzde çeşitli sorunlar ve belirsizlikler ile karşı karşıya kalmakta ve kendi imkânları ölçüsünde bu sorunlarına karşı çözüm stratejileri geliştirmektedir.

Anahtar kelimeler: *ekonomi, göçebeler, hayvan göçü, kırsal nüfus.*

Socio-Economic Situation and Problems of Nomadic Animal Husbandry Activities in Türkiye

ABSTRACT

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Nomadic animal husbandry activity has been the basis of the livelihood economy of communities since the hunter-gatherer period throughout human history. The social structure of nomadic communities is based on a tight connection with extended family structure and blood ties. This activity carried out by nomads with their animals is dependent on changing seasonal conditions in different geographical areas. Today, the continents of Africa and Asia are among the places where this activity takes place intensively. With this migration movement, nomadic communities move towards the source and utilise the grazing areas suitable for their animals, which form the basis of their livelihood economy. In economic terms, the meadows in grazing areas turn into animal products with high protein content and gain value. This productive model, which takes place on the axis of human, animal and nature, has a sustainable structure intertwined with nature without being dependent on fossil fuels. Nomadic livestock and animal products produced in the areas where this activity takes place contribute to the Türkiye economy. In this context, the functions of nomadic animal husbandry activity include the preservation of breeding animals, providing employment in rural areas, preventing migration from rural to urban areas, and ensuring food security with its extensive production structure. However, nomadic communities today face various problems and uncertainties and develop solution strategies against these problems within their possibilities.

Keywords: *animal migration, economics, nomads, rural population.*

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GİRİŞ

Göçebelik kavramı insanlık tarihi kadar eski olup, binlerce yıldır yeryüzünde insanların gerçekleştirdiği göç eylemi ekonomik, politik, sosyal ve kültürel nedenler başta olmak üzere birçok nedenden dolayı gerçekleşmektedir. İnsanlık, avcı-toplayıcı dönemden günümüze kadar göçebe olarak yaşamış olup, bu yaşam tarzı belirli bir bölgeye bağlı kalmak yerine, değişen doğa koşullarına ve kaynakların mevcudiyetine göre hareket etmeyi gerektirmektedir.

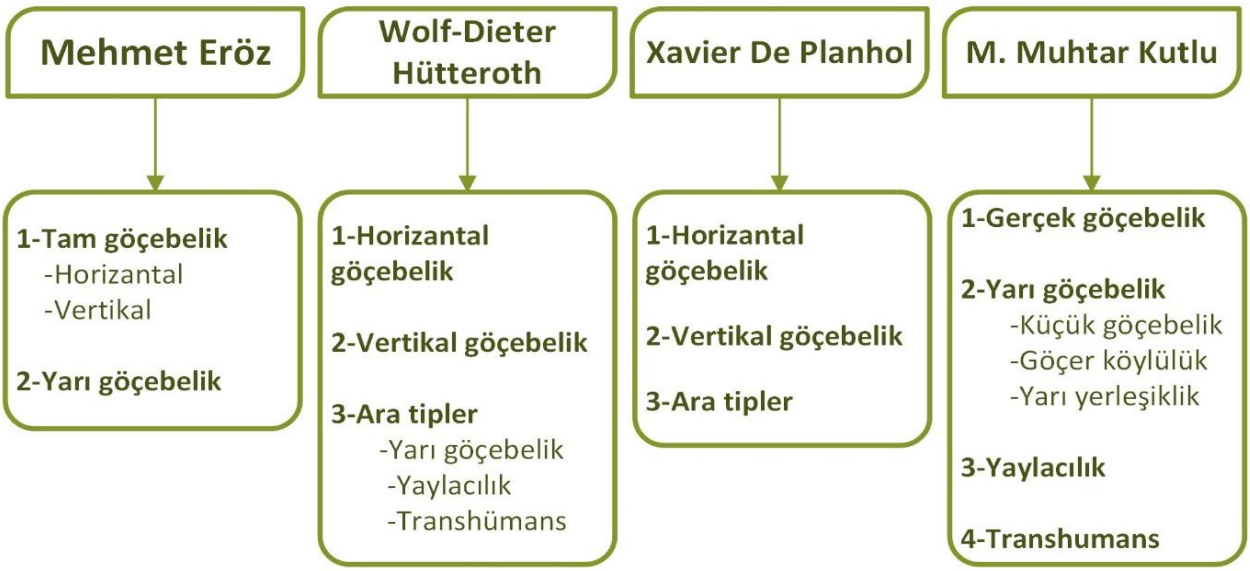
Göçebe hayvancılığın, hayvancılığa bağımlı olduğu ve bu bağımlılığın mekânsal hareketlilikle aynı anda var olması gerektiği ifade edilmiştir (Dyson-Hudson ve Dyson-Hudson, 1980). Göçebe kelimesinin İngilizce karşılığı olan *'nomad'* kelimesinin kavramsal olarak kökeni ise Yunanca *'davar sürmek, otlatmak'* anlamını ifade eden *'némō, nom'* fiilinden türetilmiştir (Seymour-Smith, 1986).

Göçebeliğin tarihini incelediğimizde ise Orta Asya bozkırlarında yaşayan göçebe Türk topluluklarının göçebe hayvancılık ile geçimlerini sağladıkları ve sürülerine otlak alanlar bulmak amacıyla farklı bölgelere göç ettikleri görülmüştür. Osmanlı Devleti döneminde incelenen ve göçebeler ile ilgili sağlıklı kayıtların bulunduğu *Tahrir Defteri* adı verilen defterler de o dönemde yaşayan yerleşik topluluklar ile göçebe toplulukların eşit bir statüde ele alındığı gözlemlenmiştir (Bulut, 2021; Ögel, 2000; Soysal, 2010).

Anadolu'daki göçebe toplulukların sayısı modernleşme ve kentleşme süreçleriyle birlikte önemli ölçüde azalmakla birlikte günümüzde Anadolu'daki göçebe yaşamı, genellikle folklorik ve turistik etkinliklerle yaşatılmakta olup, halen günümüzde ülke genelinde belirli bir topluluk göçebe hayat tarzını sürdürmekte ve geçimini sağlamaktadır. Bu çalışma ile günümüzde göçebe hayvancılık faaliyeti ile geçimini sağlayan göçebe toplulukların bu üretim düzeni incelenmiştir.

Göçebelik faaliyetleri, yapıldığı bölgenin koşullarına bağlı olarak değişiklik gösterebilmektedir. Araştırmacılar göçebeliği belirli koşullara bağlı olarak sınıflandırmıştır. Aşağıdaki tabloda göçebeliğin araştırmacılar tarafından sınıflandırılması yer almaktadır.

Tablo 1. *Araştırmacıların Göçebeliği Tasnifi (Denker, 1960; Ekiz, 2022; Eröz, 1991; Kutlu, 1987; Planhol, 1958).*



Tabloyu incelediğimizde araştırmacıların bakış açısına göre göçebeliğin sınıflandırılmasında bazı farklılıklar olsa da genel olarak tanımını yapacağımız göçebe yaşam tarzları şunlardır:

Sahra Göçebeliği (Horizontal Göçebelik): Geniş mesafeler arasında yatay doğrultuda gerçekleşen göç hareketidir.

Dağ Göçebeliği (Vertikal Göçebelik): Düz alanlardan dağlık bölgelere veya dağlık bölgelerden düz alanlara yapılan göçlerdir.

Gerçek Göçebelik (Göçebe Çobanlık): Bu yaşam biçiminde bireyler sabit bir yerleşim alanına sahip olmadan tamamen çadır hayatı sürdürür. Soy bağlantıları güçlüdür ve temel geçim kaynakları hayvancılıktır.

Yarı Göçebelik: Göçebe yaşam ile yerleşik yaşam arasında bir geçiş modelidir. Bu yaşam tarzı, yerleşik hayata geçişin bir aşaması olarak görülebileceği gibi, kendi başına ekonomik sistem de olabilir (Beuermann, 1967).

Yaylacılık (Practice Transhumance): Hem tarımla hem de hayvancılıkla uğraşan yerleşik köylülerin, yaz aylarında hayvanlarını daha iyi besleyebilmek ve daha kaliteli hayvansal ürünler elde edebilmek için 1,5 – 2 ay boyunca yaylalara göç etmesini ifade eder.

Göçebe Yaylacılık (Nomadic Transhumance): Mevsimsel şartlara bağlı olarak otlakların değerlendirilmesi amacıyla sürülerin uzun mesafeler boyunca göç ettirilmesini kapsar. Bu tür göçte, yalnızca hayvanlar hareket ederken, sürü sahipleri genellikle sabit bir yerleşimde kalır. Sürülerin yönetimi, ücretli çobanlar tarafından sağlanır.

Türkiye'de Göçebe Hayvancılığın Sosyal ve Kültürel Boyutu

Göçebe toplulukların sosyo-kültürel durumları, geçmişten günümüze kadar farklılık göstermiş olup genellikle belirli ortak temele dayandıkları söylenebilir. Göçebe yaşam tarzı, ailelerin sosyal yapılarını, ekonomik faaliyetlerini ve kültürel pratiklerini şekillendirmiştir.

Göçebe topluluklar genellikle tabiata derin bir saygıyla yaklaşırlar ve tabiat ile uyum içinde yaşama stratejileri geliştirmişlerdir. Bu davranışın temelinde ekonomik anlamda hayvancılığa dayalı bir geçim modeli söz konusu olduğundan, tabiatın sunduğu imkânlar doğrultusunda bireylerin yaşamının sürdürebilirliği de tabiata bağlı olup simbiyotik bir ilişki söz konusudur. Aşağıda yer alan görselde, göçebelerin ilkbahar-yaz aylarını geçirdiği yayla ve mera alanları yer almaktadır.

Şekil 1. *Göçebelerin yayla ve mera alanındaki yaşamı (Savaş, 2019).*

Şekilde de görüleceği üzere, yayla ve mera alanında göçebe toplulukların sosyal hayata ilişkin etkileşimi bir nizam içinde gerçekleşmekte, yayla ve mera alanlarında geçirilen zaman diliminde göçebe çadırı, göçebe yaşamın bir temsili halini almakta ve toplumsal yaşam anlayışında gündelik yaşam bu çadır etrafında şekillenmektedir (Ayan, 2022).

Türkiye'de göçebe hayvancılık faaliyetlerini sürdüren topluluklar arasında yer alan ve derin tarihî ve kültürel geçmişe sahip göçebe *Sarıkeçili Yörük* topluluğu, yıl boyunca iki farklı otlak alanı arasında göç ederek

geleneksel göçebe hayvancılık faaliyetlerini halen sürdürmektedir. Kış mevsimini ılıman iklim koşullarına sahip Mersin ve Antalya'nın alçak dağlık bölgelerinde geçiren *Sarıkeçili Yörükleri*, baharın gelmesi ve hava sıcaklıklarının artması ile hayvanların ısı stresine maruz kalmaması için sürüleri ile birlikte serin hava koşulları, taze su kaynakları ve zengin bitki örtüsüne sahip Toros Dağları'nın daha yüksek rakımlı alanlarında bulunan yayla ve meralara doğru göç etmektedirler (Bazin, 1989; Özçatalbaş, 2016).

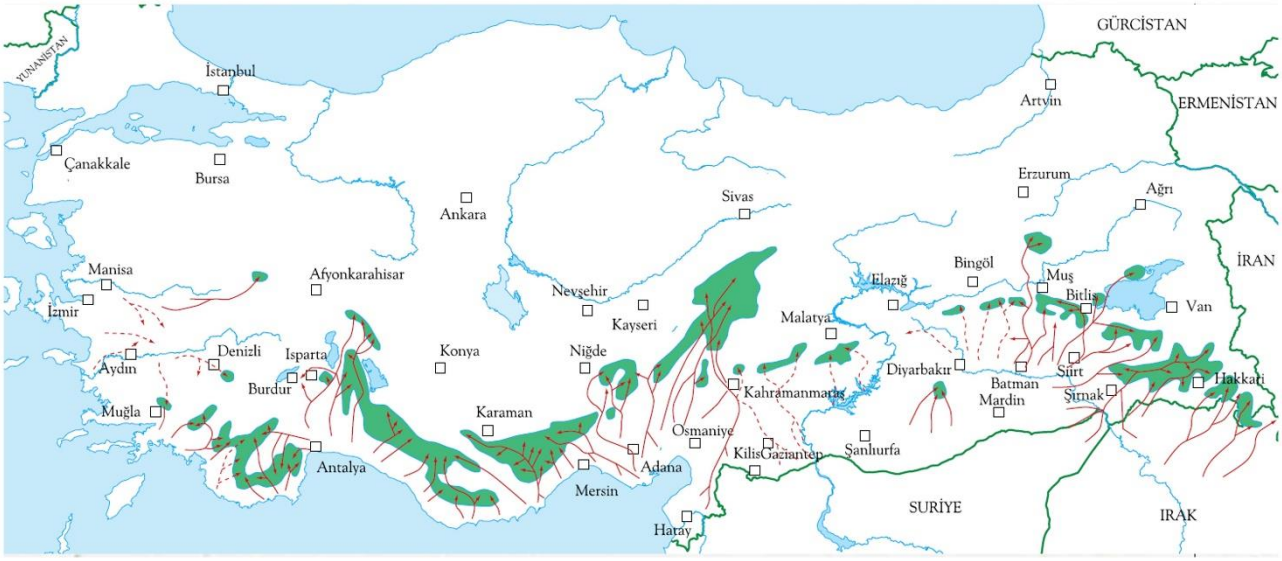
Evlilik kurumuna önem veren göçebe toplulukların, çocuklarını öncelikle kendi toplulukları ya da komşu göçebe topluluklardan biriyle evlendirmeyi tercih etmektedirler. Konu ile ilgili yapılan bir araştırmada, göçebe toplulukların %97'sinin göçebe biriyle evlilik yaptığı görülmüştür. Göçebelerin aile düzeninde ise erkek–kadın ayrımının çoğu noktada olmadığı, kadınların topluluk yaşamında katılımcı ve karar verici konumda olması göçebe toplulukların bir diğer önemli özelliğidir. Fakat göçebe toplumun aile yaşamında kadınlara önem verildiği gözlemlense de genellikle erkek egemen bir aile reisinin karar mekanizmasında daha etkili olduğu belirtilmiştir (Andrews, 1994; Soylu, 1997; Yalgın, 1993).

Türkiye'de Göçebe Hayvancılığın Döngüsü ve Göçebe Hayvancılığın Sürdürülmesine Etki Eden Faktörler

Göçebe Hayvancılığın Coğrafi İlişkisi

Anadolu coğrafyası verimli toprakları sebebiyle, eski çağlardan günümüze kadar çeşitli ekonomik faaliyetlerin gerçekleştirildiği yer olmuştur. Bitkisel ve hayvansal üretim bu ekonomik faaliyetlerin önemli alanları olmuştur. Dağlık coğrafi alanlara sahip olan Anadolu coğrafyasında kısa menzilli alanlarda oluşan rakım farkı bitki türlerinin çeşitliliği ve vejetasyon sürelerinin farklılaşmasıyla beraber farklı alanların oluşmasına ortam hazırlamıştır. Göçebe hayvancılık ile geçimini sürdüren topluluklar açısından bahsi edilen bu koşullar, hayvancılık açısından da farklı alanların oluşmasını sağlamaktadır (Kılıç, 2014).

Göçebe hayvanların bakımı ve beslenmesi açısından uygun alanlar olan yayla ve meralar, hayvanların temiz ve serin dağ havası alması, taze ve çeşitli otlarla beslenmesi, temiz su içmesi ile birlikte bunlara bağlı olarak verimini artırabilmesi açısından gerekli özellikleri bünyesinde barındırmaktadır. Hayvanların bakımı ve beslenmesi için uygun olan yayla ve meraların Türkiye coğrafyasında kapladığı toplam alan 1935 yılında 44,3 milyon hektar iken, 2001 yılı tarım sayımı verilerine göre 14,6 milyon hektara kadar azalmıştır. Bu süreçte yayla ve meraların sürülerek tarım arazilerine dönüştürülmesi ve işlenmesi, ekstansif bir üretim düzeninde hayvancılık yapan işletme sayısının azalmasına sebep olmuştur. Gelinen bu noktada, mera alanlarının artırılamaması gerçeği, otlatma baskısını azaltmak adına mevcut alanlarda verimliliğin artırılmasını ve bu doğrultuda mera ıslah çalışmalarına ağırlık verilmesini gerekli kılmaktadır (Aral, 2020; Kara, 2009; Kutlu, 1987; Satar, 2021). Aşağıda yer alan harita üzerinde Türkiye coğrafyasında göçebe hayvancılığın faaliyet alanları gösterilmiştir (Kutlu, 1987).



Şekil 2. *Türkiye'de Göçebelerin Faaliyet Alanı (Eken, 2015).*

Yukarıda yer alan haritayı incelediğimizde, Türkiye'de göçebe hayvancılık faaliyetinin yapıldığı başlıca alanların Batı, Orta, Güneydoğu Toros sıradağları olmak üzere Süphan dağı, Bingöl dağları ile Şanlıurfa ilinde

bulunan Karacadağ bölgesinin olduğu anlaşılmaktadır (Alagöz, 1993; Bazin, 1994; Gökalp, 1992). Anadolu coğrafyasında yapılan göçebe hayvancılığı Kutlu (1992) ise şöyle açıklamaktadır: Göçebe topluluklar faaliyetlerini Doğu Anadolu'nun rakımı yüksek yayla ve mera alanları, Akdeniz Bölgesi'nde yer alan Toros Dağları ve Ege Bölgesi ile kısmen Karadeniz Bölgesi'nde özellikle Rize ve çevresinde ilkbaharda yaylalara hayvanlar ile çıkılıp (yükselme), yaz sonu tekrar kışı geçirmek üzere kışlak alanlara (alçalma) göç edilmektedir.

Göçebe Hayvancılığın İklim İlişkisi

Göçebe hayvancılık ile tabiat arasında sıkı bir ilişki söz konusu olduğu için göç esnasında oluşabilecek iklimsel şartların göçü etkileme ihtimali göçebe toplumlar için iklimsel şartları önemli kılmıştır. Bu ilişki göç eylemine karar verme, otlatma alanlarının seçimi ve su kaynaklarına erişim gibi sebeplerden dolayı iklimsel değişikliklere karşı başa çıkma stratejileri açısından önemlidir.

Yağış rejimi, sıcaklık ve nem gibi iklim unsurları, hayvanların göç rotaları ile otlatma alanlarını belirlerken göz önünde bulundurulması gereken önemli etkenlerdir. Yağış rejimi, yayla ve mera alanlarındaki otlak alanların kalitesi ve verimi açısından önem arz etmektedir. Yüksek sıcaklık ve nem değerleri ise hayvanların su kaynaklarına erişimini zorlaştırabilir ve hayvanların ısı stresine maruz kalmasına neden olabilmektedir.

Yerleşik ve yarı göçebe hayvancılık işletmelerinin incelendiği bir araştırmada, sürüdeki hayvanların çevresel sıcaklık ve nem düzeylerine karşı verdikleri fizyolojik tepkileri ölçmek için kullanılan *Sıcaklık Nem İndeksi (SNİ)* verileri analiz edilmiştir. Elde edilen bulgular, yerleşik üretim düzeninde hayvanların orta seviyede ısı stresine maruz kaldığını, buna karşılık yarı göçebe üretim düzeninde ise hayvanların çevresel olumsuzluklara karşı görece daha iyi korunduğu ortaya koyulmuştur. Araştırmada göçebe toplulukların hayvanları ile birlikte yüksek rakımlı serin hava koşullarına sahip yayla ve meralara gerçekleştirdikleri göçlerin, hayvanların ısı stresinden korunmasında ve verimliliklerinin artırılmasında önemli bir rol oynadığı ifade edilmiştir (Çevikkol, 2024).

Yukarıda bahsi geçen bütün coğrafi ve iklimsel unsurların etkisi ile oluşan bu ortamda hayvanların otlak alanları için iki farklı alan meydana gelmektedir. Birincisi kış mevsiminin şiddetini göstermediği ve göçebelerin ***'kışlak'*** olarak adlandırdığı ılıman alanlar, ikincisi ise bahar aylarının gelmesiyle kış mevsiminin etkisini ilkbahar ve yaz mevsimlerine bıraktığı yüksek rakımlı bölgelerde yer alan ***'yazlık'*** olarak adlandırılan yayla ve meralardır. Göçebe hayvancılığın ***göç döngüsü*** ise bu iki farklı alan arasında geçmektedir (Tunçdilek, 1967).

Göçebe Hayvancılıkta Göç Döngüsü

Göçebe topluluklar açısından farklı mevsim dönemlerinde yapılan göçlerde sürüde yer alan hayvanların kaliteli ve sürekli beslenebilmesi nedeniyle otlak alanlar bulma ihtiyacı azami önemlidir. Kışlak ve yazlık alanlar arasında otlak bulmak amacıyla göçebelerin hayvanları ile yaptığı bu göçler bir döngü halinde gerçekleşmekte olup bu göç döngüsü ilkbahar ve yaz mevsiminde yüksek rakımlı yaylalara doğru yapılan ***yükselme göçü*** ve sonbahar ve kış aylarında düşük rakımlı ılıman alanlara doğru yapılan ***alçalma göçü*** olmak üzere iki temel aşamadan oluşmaktadır (Kılıç, 2014).

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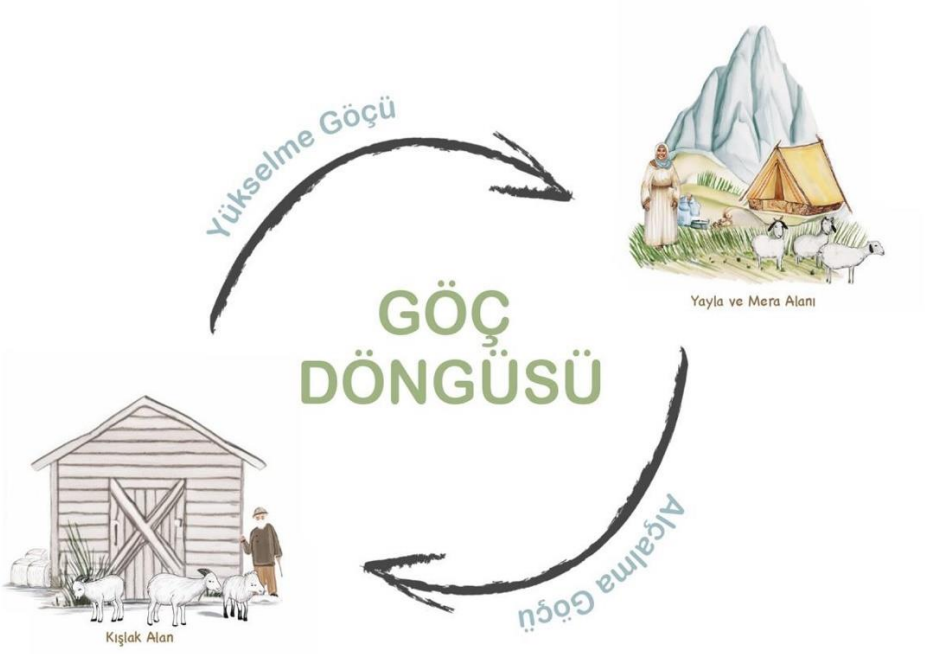


Şekil 3. *Kışlak ve yazlık alanlar arasında gerçekleşen göç döngüsü.*

Yükselme göçünün başladığı Nisan-Mayıs aylarında yayla ve mera alanlarına göç hareketi öncesinde haneden birkaç kişi alana giderek bir önceki yıl göçerek terk edilen çadır alanını düzenlemektedir. Genellikle yapılan bu düzenlemeler ile göçebe topluluklar her yıl aynı çadır alanını kullanmaktadır. Göç hareketi için gerekli hazırlıklar yapılıp eksik olan materyaller temin edilip, oğlak ve kuzular için yemler alındıktan sonra göç hareketi başlamaktadır. Yükselme göçüyle yayla ve meralarda otlatılan göçebe hayvanlar, sonbahar mevsiminin etkisinin hissedilmeye başlamasıyla birlikte kışın sert koşullarından etkilenmemek için kışlak alanlara doğru alçalma göçü gerçekleştirmektedir. Oluşan bu göç döngüsünde göçebe *Sarıkeçili Yörük* topluluğu yayla ve meralar ile kışlak alanlarda göç ederek yerleştiği alanları *"Yazlık Yurt''* veya *"Oturak Yurdu"* şeklinde tanımlarken, yükselme ve alçalma göçü esnasında göç güzergâhı üzerinde 3 ile 10 gün arasında kısa süre konaklanan yerlere ise "*Konalga*" adını vermektedirler (Armağan, 2018; Yel, 2018).

Yapılan bu göç hareketi sırasında göçebe topluluklar belirli aralıklar ile dinlenmek ve hayvanlarını otlatmak zorunda kalmaktadırlar. Bu sebeple kesintisiz göç eylemini sürdürememektedirler. Bir gün boyunca yapılan göç eylemi süre itibarıyla 4-5 saati geçmemektedir. Toros Dağları'nda göçebelerin göç güzergâhı mevcut olmakla birlikte eskiden gelen tecrübe ve kültürel miras ile bu güzergâhlar belirlenmiştir. Ayrıca bazı göçebe hayvancılık işletmeleri, göç esnasında sürü sahiplerinin yaşlı olmaları nedeniyle uzun mesafeleri kat edememesi, ailedeki sonraki nesillerin bu eyleme katılmak istememesi ve göç güzergâhında yerleşik arazi sahipleri ile yaşanan problemler nedeniyle sürülerini kamyon, kamyonet ve tır vasıtası ile göç edilecek mera ve yaylalara götürmektedir (Tolunay ve ark., 2018).

Türkiye'de Göçebe Hayvancılığın Ekonomik Durumu

Göçebe Hayvancılığın Ekonomisi

Khazanov (1984) göçebe hayvancılığın Dünya'nın en eski ekonomik faaliyeti olduğunu ifade etmiştir. Türkiye'de göçebe hayvancılık uzun bir geçmişe sahip olmakla birlikte ülke ekonomisinin bir parçasını oluşturmaktadır. Özellikle kırsal bölgelerde, göçebelerin hayvanlarıyla birlikte yaptıkları göçler, kırsal ekonominin önemli bir bileşeni haline gelmiştir.

Günümüzde yaygın olan entansif üretim yapısının aksine ekstansif üretim yapısına sahip olan göçebe hayvancılık işletmeleri ekonomik açıdan önemi olmayan alanlarda girdisi az ve verimi yüksek şekilde tüketicilere uygun hayvansal ürünleri üretme açısından önemli role sahiptir. Göçebe hayvanlar otlak alanlarda

doğal yetişen bitkileri protein açısından zengin gıdaya dönüştürebilmektedir. Ayrıca göçebe yaşamın bu üretim düzeni, iklim değişikliği nedeniyle Dünya çapında fosil yakıtlara olan bağımlılığın azalması ve sürdürülebilir gıda üretimi açısından daha da değerli hale gelebilir (Waters ve Wario, 2022).

Göçebelerin dağlık ve kırsal bölgelerdeki mera ve yaylalara yaptıkları göçler, hayvanların doğal otlanma alanlarını kullanmasını sağlayıp, kaynak kullanımında etkinliği sağlamaktadır. Küçükbaş yoğun göçebe hayvancılık işletmeleri bu faaliyetleri ile Türkiye'nin et ve süt gibi hayvansal ürünler ile damızlık materyal anlamında kendi kendine yeterliliğini muhafaza etmekte ve kırsal alanlarda istihdamı sağlamaktadır. Ayrıca göçebelerin göç ettiği bölgelerde yerel ekonomilere canlılık getirdiği ve yerel pazarları da hareketlendirdiği gözlemlenmektedir.

Kırsal alanlarda yaşamını sürdüren topluluklar açısından, kırsal alanlarda gelir olanaklarının çeşitlenmemesi ve istihdamın yetersiz olması, kırsal alanlardaki bitkisel ve hayvansal üretim faaliyetlerini önemli kılmaktadır. Göçebe toplulukların, yaşanan tüm zorluklara rağmen kültürel miraslarına sahip çıkarak göçebe hayvancılığı sürdürme çabaları göz önüne alındığında, kırsalda sürdürülebilir bir işgücünün sağlanabilmesi açısından göçebe hayvancılık faaliyetinin önemi göz ardı edilmemelidir (Aşkın ve ark., 2013; Gümüş ve ark., 2012; Yılmaz ve ark., 2014).

Kayseri ilinde yapılan bir çalışmada, göçebe hayvancılık faaliyetinin yoğun bir şekilde gerçekleştiği Akkışla/Gömürgen köyünde yaşayan göçebe hanelerin, bu faaliyet ile herhangi bir uğraşısı olmayan diğer bölgelere göre ekonomik kalkınma ve sosyal refah açısından daha iyi bir konumda olduğu belirtilmiştir (Koca, 2021).

Türkiye'nin farklı coğrafyalarını göçebe hayvan yetiştiriciliği açısından incelediğimizde ise Doğu Anadolu ve Güneydoğu Anadolu bölgesindeki koyun varlığının %60'ını göçebe hayvancılık faaliyetinde bulunan işletmelerin oluşturduğunu, Konya ve Mersin illerinde göçebe hayvancılık ile geçimini sağlayan göçebe *Sarıkeçili Yörük* topluluğuna ait toplamda 54.540 adet keçi ile bölgede damızlık materyal açısından ciddi bir hayvan varlığı oluşturduğu, Bitlis ilindeki yayla ve meralara 2002 -2005 yılları arasında bir sezonda gelen göçebe hayvanların toplamda 150.000 adet küçükbaş olduğu ifade edilmiştir (Sevinç, 1981; Sezgin, 2006; Tolunay ve ark., 2018).

Göçebe Hayvancılık İşletmelerinin Gelir-Gider Unsurları

Göçebe hayvancılık işletmelerinde gelir ve gider unsurları belirli salt başlıklar olup, göçebe hayvancılık işletmelerinin iktisadi olarak devamlılığı açısından gelir ve gider dengesinin işletme sahipleri tarafından analiz edilmesi işletmenin sürdürebilirliği açısından önemlidir. İktisadi olarak her işletmenin en temel amacı kârını en üst düzeye çıkarma çabasıdır.

Göçebe ve yerleşik hayvancılık işletmelerinin incelendiği bir araştırmada, göçebe hayvancılık işletmelerinde canlı ağırlık artışının ve verimliliğin yerleşik hayvancılık işletmelerine göre daha yüksek olduğu ayrıca yayla ve meralara dayalı ekstansif bir üretim düzeni sayesinde göçebe hayvancılık işletmelerinin, yerleşik hayvancılık işletmelerine kıyasla daha kârlı bir üretim yapısına sahip oldukları belirtilmiştir (Aydınlı, 2019).

Göçebe hayvancılığın gelir kalemlerinin, miktar açısından gelirdeki önem sırası hakkında, en önemi gelirin sırasıyla; başta canlı hayvan satışı olmak üzere süt, peynir, yoğurt, tereyağı ve yapağı yünden sağlandığı yapılan araştırma ile tespit edilmiştir. Bu gelir kalemi içinde en fazla gelir getirici kalem canlı hayvan satışında genellikle erkek hayvanlar satılmakta olup dişi hayvanlar ise damızlık olarak sürüde tutulmaktadır. Göçebe hayvancılık faaliyetinde bulunan hanelerin kendi sürüsü ile birlikte çobanlık yaptığı diğer sürünün ücretini alması ve göçe katılmayıp farklı işlerde çalışması ayrıca gelir sağlamaktadır. Gider unsurları ise otlatma alanlarının kirası, veterinerlik hizmetleri, çoban parası ve yem giderleri olduğu gözlemlenmiştir (Akgün, 2022; Koca, 2021; Tuztaş, 2005).

Canlı hayvan satış geliri, gelir kalemleri arasında miktarsal olarak önemli bir yere sahiptir. Bu satış sürecinde tüccarlar etkin bir rol oynamaktadır. Göçebe işletme sahibi ile tüccar arasında, etin piyasadaki satış fiyatına bağlı olarak oğlak ve kuzular için bir fiyat belirlenmektedir. Belirlenen bu fiyat peşin ya da vadeli ödeme şekline göre farklılık göstermektedir. Ayrıca geçmiş yıllarda göçebe *Sarıkeçili* topluluğunun canlı hayvan

satışının iç pazarın yanı sıra besilik materyal için Doğu Avrupa'ya, Kurban Bayramı için Orta Doğu'ya dışsatım yaptığı yazar tarafından belirtilmiştir (Akgün, 2022; Bazin, 1994).

Hayvansal Ürünlerin Üretimi ve Pazarlanması

Göçebe hayvancılığın gelir kaynaklarından biri olan hayvansal ürünlerin üretimi, çeşitli ürünlerin elde edilmesini sağlamaktadır. Özellikle süt ve süt ürünleri bu üretimin önemli bir bileşenidir. Göçebe haneler için temel bir besin kaynağı oluşturan bu ürünler, aynı zamanda ihtiyaç fazlasının satılmasıyla gelir elde edilmesine de katkıda bulunmaktadır. Marx (2006), göçebelerin belirli bir dereceye kadar pazar odaklı üretim yaptıklarını, bu nedenle kent nüfusuna bağımlı olduklarını ifade etmiştir. Marx'a göre bu üretim modeli kendi kendine yeterli bir ekonomik sistem olarak değerlendirilemez ve geçime dayalı bir ekonomi olarak ele alınamaz.

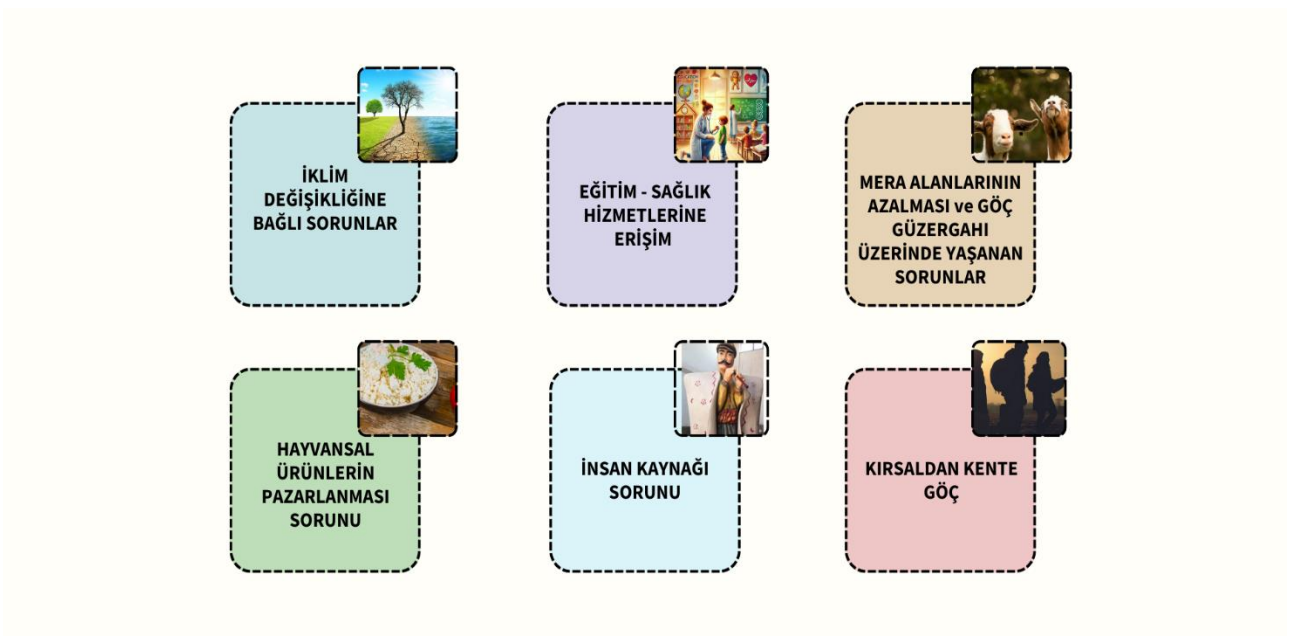
Yukarıda bahsi geçen tespitleri de göz önüne aldığımızda Şanlıurfa ve Erzurum illeri arasında göçebe hayvancılık yapan Beritan topluluğunda yapılan araştırma ve gözlemlerde, küçükbaş hayvanların süt sağımının Mayıs ile Eylül ayları arasında gerçekleştiği, yaz mevsiminin ortasından itibaren süt veriminin giderek azaldığı, Eylül-Ekim aylarında ise koç katımını takiben koyunların gebe kalması nedeniyle sağım işleminin durduğu gözlemlenmiştir. Göçebe hanelerin, bu üretim döngüsünde sağılan sütleri peynir yaparak sattığı tespit edilmiştir. Ürünlerin pazarlanması sürecinde ise yayla ve meralardaki üreticilerden mandıracıların süt ve süt ürünlerini toplayarak tüketiciye ulaştırdığı ifade edilmiştir (Akgün, 2022; Tuztaş, 2005; Yetim, 2016).

Hayvansal ürünlerin pazara arzı ile ilgili küçükbaş hayvancılık işletmelerinin incelendiği bir araştırmada, işletmeler hayvan sayısına göre üç farklı ölçekte (1-100, 101-200, 200+) gruplandırılmış, hayvanlardan elde edilen hayvansal ürünlerin pazarlanması hususunda işletme ölçeği büyüdükçe süt ve süt ürünlerinin pazarlama oranı da artmaktadır. Hayvanlardan elde edilen sütün, %52,51'i peynir, %27,39'u yoğurt, %10,23'ü içme sütü ve %9,87'si tereyağı olacak şekilde pazara sunulmaktadır (Dellal ve ark., 2002; Paksoy, 2007).

Hayvansal ürünlerden yün, kıl ve keçeden geçmişte gelir elde edilirken, günümüzde bu ürünlerin fazla kazanç sağlamadığı belirtilmektedir. Bu durumun başlıca sebebi ise endüstriyel ürünlerin yaygınlaşmasıyla birlikte yün satışlarının azalması olarak görülmektedir. Öte yandan son yıllarda hayvansal gübrelerin satışının gelir kaynağı haline geldiği belirtilmektedir (Meydan, 2016).

Göçebe Hayvancılığın Sorunları

Göçebe hayvancılık faaliyeti derin tarihi mirası ile birlikte değişen koşullara uyum sağlayarak günümüze kadar varlığını sürdürmüş, toplulukların geçimini sağlamıştır. Bütün boyutlarını ele alarak incelemeye çalıştığımız göçebeliğin günümüzde yaşadığı sorunlara değinecek olursak bu geleneksel yaşam modeli iklim değişikliği, eğitim ve sağlık hizmetlerine erişim zorlukları, mera alanlarının azalması ve göç güzergâhında yaşanan problemler, hayvansal ürünlerin pazarlanması ve kırsaldan kente göçler ile oluşan insan kaynağı sorunu gibi tehditler ve kısıtlar ile karşı karşıyadır. Tespit edilen bu sorunlar göçebe hayvancılığın sürdürülebilirliğini zorlaştırmaktadır.



Şekil 4. *Göçebe hayvancılığın sorunları*.

Göçebe toplulukların göç döngüsünde ilkbahar zamanı kışlaktan mera ve yaylalara ve sonbahar zamanında yazlık alanlardan kışlaklara göçe başlamada karar verme açısından kilit rol oynayan mevsimsel hava şartlarının belirsizliği önemli bir sorun teşkil etmektedir. İklim değişikliğine bağlı mevsimsel değişimlerin beklenen süre zarfında gerçekleşmeyip, aşırı sıcak ve aşırı soğuk hava olaylarının olması, yağış rejiminin düzenini kaybetmesi çözülmesi zor sorunların başında gelmekte olup bu değişiklikler yayla ve mera alanlarında botanik varlığı tehdit etmekte ve su kaynaklarını açısından kısıt oluşturmaktadır.

Eğitim ve sağlık hizmetleri açısından göçebe hanelerin sorunlarını ele aldığımızda Nisan ayını takiben yaylalara çıkan göçebe hanelerin, Kasım ayının sonlarına kadar yaylalarda kalması ve çocukların en fazla 4-5 ay eğitim görmesi yayla ve mera alanlarında çocukların eğitiminin aksadığı ifade edilmektedir. Göçebelerin genellikle uzak ve erişilmesi zor bölgelerde izole bir şekilde yaşaması sağlık hizmetlerine erişimi zorlaştırmakta, acil durumlarda tıbbi yardımlar zamanında sağlanamamaktadır. Ayrıca göçebe haneler üzerine yapılan bir araştırmada göçebe toplulukların eğitim hizmetlerine erişim açısından %55 oranında memnun olduğu, sağlık hizmetlerine erişimde ise %80 oranında memnun oldukları bildirilmiştir (Kılıç, 2014; Yücel, 2022).

Geçmiş yıllarda başlayan ve devamında artan tarımsal mekanizasyon ile yayla ve mera alanları sürülerek tarım arazisine dönüştürülmüş, hayvanların doğal otlak alanı olan yayla ve mera alanları önemli ölçüde azalmakla birlikte, ekstansif bir şekilde faaliyet gösteren göçebe hayvancılık işletmelerinin göç güzergâhı üzerinde yer alan yayla ve mera alanlarının özel veya tüzel kullanıma tahsis edilmesi, bununla birlikte mülkiyet hakkı elde eden yerleşik toplulukların göçebe topluluklara baskı uygulaması ile birlikte ormanlık alanlar için alınan tedbirler, göçebe hayvancılığın temelini oluşturan göç döngüsüne engel teşkil etmektedir (Sakarya, 2020).

Göç edilen yayla ve meraların yerleşim yerlerinden izole olması tedarik zinciri açısından pazarlamayı olumsuz etkilemektedir. Mevcuttaki pazarlama kanalı ile oluşan yapıda özellikle aracıların kâr marjında üreticiyi ürünün piyasa şartlarında hak ettiği değerde almaması ve satarken de tüketici aleyhinde bir fiyatlama ile iki tarafı da mağdur edebilmektedir.

Günümüz koşullarında göçebe yaşam, geniş aileler ve her yaş grubundan bireylerle sürdürülmeye devam edilse de bu yaşam modeli daha çok yaşlı nüfus tarafından teşvik edilmektedir. Ayrıca, göçebe toplulukların giderek yaşlanması nedeniyle, 15-20 yıl içinde yayla ve mera alanlarında bu faaliyetin tamamen yok olma tehlikesiyle karşı karşıya kalabileceği ifade edilmiştir. Doğu Anadolu Bölgesi'nde yapılan bir araştırmada ise, yetiştiricilerin küçükbaş hayvancılığı bırakma nedenleri arasında işgücü bulma konusunda yaşanan zorlukların yanı sıra, yayla ve mera alanlarına dayalı hayvancılığın yaygın olduğu bu bölgede, gençlerin kırsal yaşamı

cazip görmemesi ve kent hayatının cazibesine kapılması nedeniyle bu faaliyeti sürdürmek istemedikleri gözlemlenmiştir (Aksoy ve Yavuz, 2012; Gökdai, 2019; Hadimli ve ark., 2010).

Yerleşik yaşamın daha cazip fırsatlar sunması ve göçebe yaşamın zorlukları neticesinde, hayvancılıkla uğraşan göçebe haneler, genellikle sanayi ve hizmetler sektöründe çalışmak üzere kırsal alanlardan kentlere doğru göç etmektedir. Kırsaldaki çözülmesi zor altyapı eksiklikleri bu göç sürecini engelleyememektedir. Bu durum, göçebe işletmelerde insan kaynağı açısından işgücü arzının sürdürülebilirliğini tehdit etmektedir.

SONUÇ VE ÖNERİLER

Göçebe toplulukların hayvanları ile gerçekleştirdiği bu faaliyet, tabiatın sunduğu kaynakları etkin bir şekilde kullanarak günümüze kadar ulaşmıştır. Ancak günümüzde, göçebelerin karşılaştıkları sorunları çözmek için yalnızca göçebe toplulukların değil, diğer paydaşların da katkısı gerekmektedir. İfade edilen yaklaşımın temel amacı göçebe yaşamın sürdürülebilirliğini sağlamak için çok boyutlu bir çözüm önerisi sunmaktır. Bu faaliyetin ekonomik ve sosyal anlamda desteklenmesi gerektiğini ifade etmemiz gereklidir.

Hayvanların yayla ve mera alanlarında otlatılması kontrollü ve denetimli bir şekilde yönetilmeli ve göçebe hayvan sürülerinin göç güzergâhında yaşadığı sorunların çözümünde göç güzergâhı, işletme sahiplerinin beyanı ile varış noktasına (yurt) kadar kesin bir şekilde belirtilmelidir. Bu güzergâh üzerinde yer alan toplulukların özel alanlarına girmeden göç eyleminin devam edebilmesi için göç koridoru oluşturulmalı ve belirlenen koridor üzerinde bulunan topluluklar yerel yönetimler tarafından bilinçlendirilip, yaşanabilecek sorunların çözümünde, yerel yönetimler arabuluculuk anlamında yetkilendirilmeli ve bu konuda ilgili bütün paydaşlara farkındalık kazandırılmalıdır.

Yayla ve mera alanlarında üretilen süt ve süt ürünlerini satarken tüccarların insafına kaldığından dolayı şikâyetçi olan göçebe topluluklar; devlet destekli bir kooperatifin kurulması ve ürettikleri ürünlerin coğrafi işaret ile pazara sunulmasının ekonomik anlamda işletmeleri için daha yararlı olacağını düşünmektedirler. Ayrıca göçebe aileler, çocuklarının eğitim sorunlarının çözüme kavuşması için sürekli konakladığı yayla ve meralarda yaz okulu açılmasını talep etmektedir. Yayla ve meralarda yaşayan göçebe topluluklar, okul çağında çocuklarının olduğunu ifade etmiş olup, gönüllü veya görevlendirilecek öğretmenler vesilesiyle veya taşımalı olarak bu sorunun çözüme kavuşacağına inanmaktadır (Kılıç, 2014).

Göçebe hayvancılıkla uğraşan hanelere yönelik ekonomik destek programları ve uygun politikalar ile bu sorunlara çözüm bulunabilir ve göçebe hayvancılıkla uğraşan toplulukların gelir düzeyini artırarak yaşam kalitesini de iyileştirebilir. Ayrıca göçebe toplulukların sorunlarının çözümünde sadece insan odaklı değil, hayvan ve doğa faktörlerini de kapsayacak şekilde geniş bir bakış açısı ile konunun ele alınması sürdürebilir bir kalkınma için önemlidir. Bu çözüm ve öneriler hem bireylerin hem de toplumun genel refahını artırarak, daha adil ve sürdürülebilir bir kalkınma sağlayabilir.

ÇIKAR ÇATIŞMASI

Yazarlar herhangi bir çıkar çatışması olmadığını tasdik ederler.

YAZAR KATKISI

Tüm yazarlar eşit katkı sağlamıştır.

ETİK BEYAN

‘’Türkiye’de Göçebe Hayvancılık Faaliyetlerinin Sosyo-Ekonomik Durumu ve Sorunları’’ başlıklı çalışmanın yazım sürecinde bilimsel kurallara, etik ve alıntı kurallarına uyulmuş, toplanan veriler üzerinde herhangi bir tahrifat yapılmamış ve bu çalışma herhangi başka bir akademik yayın ortamına değerlendirme için gönderilmemiştir. Bu araştırma doküman analizi ve betimsel incelemeye dayalı olarak yapıldığından etik kurul kararı zorunluluğu bulunmamaktadır.

KAYNAKLAR

Akgün, Ö., (2022). Göçebe aşiretlerde hayvancılık ve doğa-kültür ilişkisi: Alikan, Duderan ve Soran Aşiretleri örneğinde halkbilim açısından karşılaştırmalı bir inceleme. Doktora Tezi, Ardahan Üniversitesi Lisansüstü Eğitim Enstitüsü, Türk Dili ve Edebiyatı Ana Bilim Dalı Türk Halk Edebiyatı Bilim Dalı, Ardahan, Türkiye.

Aksoy, A., Yavuz, F., (2012). Çiftçilerin Küçükbaş Hayvan Yetiştiriciliğini Bırakma Nedenlerinin Analizi: Doğu Anadolu Bölgesi Örneği. Anadolu Tarım Bilimleri Dergisi, 27(2): 76-79

Alagöz, CA., (1993). Türkiye'de yaylacılık araştırmaları. Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Türkiye Coğrafyası Dergisi, 2, 1-51. Ankara, Türkiye.

Andrews, PA., (1994). Türkiye'de etnik gruplar. (Çeviren: M. Köpüşoğlu). İstanbul: ANT Tüm Zamanlar Yayınları.

Aral, S., Cevger, Y., (2000). Türkiye Hayvancılık Kongresi, ATO (38-56). Ankara, Türkiye.

Armağan, M., (2018). Göçebe topluluklarda iskân ve terk stratejisinin etnoarkeolojik açıdan incelenmesi: Sarıkeçililer örneği. Yüksek Lisans Tezi, Trakya Üniversitesi Sosyal Bilimler Enstitüsü, Arkeoloji Anabilim Dalı, Edirne.

Aşkın, EÖ., Yayar, R., ve Oktay, Z., (2013). Kırsal Göçün Ekonometrik Analiz: Yeşilyurt İlçesi Örneği. Cumhuriyet Üniversitesi İktisadi İdari Bilimler Dergisi, 14(2): 231-252.

Ayan, S., (2022). Diyarbakır ili göçer hayvancılık işletmelerinin yapısal, sosyal ve ekonomik özellikleri üzerine bir araştırma. Yüksek Lisans Tezi, Siirt Üniversitesi, Fen Bilimleri Enstitüsü, Siirt, Türkiye.

Aydınlı, S., (2019). Karya koyunlarda yerleşik ve göçer koyunculuğun bazı özelliklerinin karşılaştırılması. Yüksek Lisans Tezi, Uşak Üniversitesi, Fen Bilimleri Enstitüsü, Zootekni Anabilim Dalı, Uşak, Türkiye.

Bazin, M., (1989). Orta Toros Yörüklerinden Sarıkeçili Aşiret. Çeviren Hamdi Kara. Production Pastorale et Société, S. 20, Fransa.

Bazin, M., (1994). Orta Toros yörüklerinden Sarıkeçili aşireti. Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Dergisi, 3, 323-350. Ankara, Türkiye.

Beuermann, A., (1967). Fernweidewirtschaft in Südosteuropa. Braunschweig.

Bulut, S., (2021). Göç, göçebe, göçer, göçer evli/evlü, göçer oba, göçgün(cü) / göçkün(cü), göçmen / göçmel ve konargöçer/göçerkonar sözcükleri üzerine bazı notlar. Kahramanmaraş Sütçü İmam Üniversitesi Sosyal Bilimler Dergisi, 18(3), s. 1671-1720.

Çevikkol, E., (2024). Koyun yetiştiriciliğinde yerleşik ve yarı göçer üretim sisteminin hayvan refahı ve verim özellikleri üzerine etkileri. Yüksek Lisans Tezi , Ondokuz Mayıs Üniversitesi Lisansüstü Eğitim Enstitüsü Zootekni Ana Bilim Dalı, Samsun, Türkiye.

Dellal, İ., Keskin, G., ve Dellal, G., (2002). GAP bölgesinde küçükbaş hayvan yetiştiren işletmelerin ekonomik analizi ve hayvansal ürünlerin pazara arzı. TEAE, Yayın No:83, Ankara, Türkiye.

Denker, B., (1960). Güney Doğu Toroslarda Göçebelik Dr. Wolf-Dieter Hütteroth"a Göre. Türk Coğrafya Dergisi, 20, 136-142.

Dyson-Hudson, R., Dyson-Hudson, N., (1980). Nomadic Pastoralism. Annual review anthropol, 9, 15-61.

Eken, G., (2015). Sonsuz Göç, Sarıkeçililer. Magma Dergisi, Ağustos, 69-87.

Ekiz, E., (2022). Kültürel Coğrafya Açısından Bir Araştırma: Burdur İli Yörükleri. Doktora Tezi. Afyon Kocatepe Üniversitesi, Sosyal Bilimler Enstitüsü Coğrafya Anabilim Dalı. Afyon, Türkiye.

Eröz, M., (1991). Yörükler. İstanbul: Türk Dünyası Araştırmaları Vakfı Yayını.

Gökalp, Z., (1992). Kürt aşiretleri hakkında sosyolojik tetkikler (Haz. Şevket Beysanoğlu). Sosyal Yayınlar, İstanbul.

Gökdai, A., (2019). Çanakkale İli Saanen Keçi İşletmelerinin Teknik ve Ekonomik Analizi. Doktora Tezi, Ankara Üniversitesi, Sağlık Bilimleri Enstitüsü, Hayvan Sağlığı Ekonomisi ve İşletmeciliği Anabilim Dalı, Ankara, Türkiye.

Gümüş, SG., Olgun, FA. ve Adanacıoğlu, H., (2012). Türkiye'de Kırsal Alanda Yoksulluğu Azaltma ve Gelir Çeşitliliği Yaratma Olanakları. Ege Ünverstesi Ziraat Fakültesi Dergisi, 49(3): 275-286.

Hadimli, H., Karakuzulu, Z., Birinci, S., (2010). Akseki ilçesindeki göçebe hareketler. Uluslararası Sosyal Araştırmalar Dergisi, 3(10), 348-359.

Kara, A., (2009). Meraya Dayalı Hayvancılık Yapan İşletmelerin Sosyoekonomik analizi ve mera kalitesinin işletme başarısına etkisi : Erzurum İli Örneği. Doktora Tezi, Atatürk Üniversitesi, Fen Bilimleri Enstitüsü, Tarım Ekonomisi Anabilim Dalı, Erzurum, Türkiye.

Khazanov, AM., (1984). Nomads and the outside World, trans. Julia Crookenden, foreword by Ernest Gellner. The University of Wisconsin Press, Madison.

Kılıç, T., (2014). Karacadağ'da göçebe hayvancılık ve göçerler. Fırat Üniversitesi Sosyal Bilimler Dergisi, 24(2), 1-12, Elâzığ.

Koca, R., (2021). Yarı göçebe hayvancılık faaliyetlerinin kırsal sistemlerin sürdürülebilirliği ve gıda güvencesi bakımından önemi: Gömürgen köyü (Kayseri) örneği. Doktora Tezi, Ankara Üniversitesi, Sosyal Bilimler Enstitüsü, Coğrafya Anabilim Dalı, Ankara, Türkiye.

Kutlu, M., (1992). Yaşayan bir alt-kültür geleneği: Anadolu göçer kültürü. 4. Milletlerarası Türk Halk Kültürü Kongresi Bildirileri, Cilt: 1, Genel Konular. Kültür Bakanlığı Halk Kültürlerini Araştırma ve Geliştirme Genel Müdürlüğü Yayınları, 164, 59-66.

Kutlu, M., (1987). Şavaklı Türkmenlerde göçer hayvancılık, gelenek-görenek ve inançlar. Kültür ve Turizm Bakanlığı Milli Folklor Araştırma Dairesi Yayınları, 84, Ankara.

Marx, E., (2006). The political economy of Middle Eastern and North African pastoral nomads. In D.Chatty (eds.), Nomadic societies in the Middle East and North Africa entering the 21st century, Brill, Leiden, pp. 78-97.

Meydan, A., (2016). Dünden Bugüne Sebil Yörükleri. Pegem Akademi Yayınları, Ankara.

Ögel, B., (2000). Türk Kültür Tarihine Giriş, Cilt: 1. Kültür Bakanlığı Yayınları.

Özçatalbaş, O, (2016). Yörük Türkmen topluluğunun mevcut durumu ve konumunun geliştirilmesi üzerine bir araştırma. Türkiye 1.Yörük Türkmen Çalıştayı ve Arama Konferansı Bildiri Kitabı ve Sonuç Raporu, 210-232, 26-28 Şubat 2016. Antalya.

Paksoy, M, (2007). Kahramanmaraş İlinde Süt Üretimine Yönelik Keçi Yetiştiriciliğine yer veren tarım işletmelerinin ekonomik analizi. Doktora Tezi, Ankara Üniversitesi, Fen Bilimleri Enstitüsü, Tarım Ekonomisi Ana Bilimdalı, Ankara, Türkiye.

Planhol, X., (1958). De la Plaine Pamphylienne Aux Lacs Pisidiens – Nomadisme et vie Paysanne. Paris: Librairie Adrien-Maisonneuve.

Sakarya, E., (2020). Hayvancılık sektörüne ekonomik bakış. Önsöz, İksad Yayıncılık, Ankara, ISBN: 978-625-7687-16-4.

Satar, M., (2021). Kırsal Kalkınma Kapsamında, Genç Çiftci Projesi İle Desteklenen Küçükbaş Hayvancılık İşletmelerinin Sosyo-Ekonomik Analizi. Doktora Tezi, , Ankara Üniversitesi, Sağlık Bilimleri Enstitüsü, Hayvan Sağlığı Ekonomisi ve İşletmeciliği Anabilim Dalı, Ankara, Türkiye.

Savaş, İ., (2019). Iğdır İlinde Göçer Hayvancılık. Yüksek Lisans Tezi, Iğdır Üniversitesi, Fen Bilimleri Enstitüsü, Zootekni Anabilim Dalı, Iğdır, Türkiye.

Sevinç, A., (1981). Türkiye'de hayvansal üretimin yapısı, potansiyeli, geliştirme olanakları ve önlemleri. Ankara Üniversitesi Veteriner Fakültesi Yayınları, No: 367, Ankara.

Sezgin, Y., (2006). Bitlis ilinde göçer ailelerin küçükbaş hayvancılık faaliyetleri. Yüksek Lisans Tezi, Yüzüncü Yıl Üniversitesi, Fen Bilimleri Enstitüsü, Zootekni Anabilim Dalı, Van, Türkiye.

Seymour-Smith, C., (1986). Macmillan dictionary of anthropology, Macmillan, London.

Soylu, S., (1997). Göçebe yörük kültürüyle ilgili bazı gözlemler. İçel Kültürü Dergisi, 46(61), 7-9.

Soysal, I., (2010). Antalya'daki yörüklerin yerel siyasetteki yeri ve önemi. Yüksek Lisans Tezi, Akdeniz Üniversitesi, Sosyal Bilimler Enstitüsü, Kamu Yönetimi Ana Bilim Dalı, Antalya, Türkiye.

Tolunay, A., Türkoğlu, T., Özmış, M., (2018). Batı Akdeniz bölgesinde hayvancılıkla uğraşan konargöçer toplulukların göç yollarının CBS kullanılarak belirlenmesi ve haritalaması. 1. International Symposium on Silvopastoral Systems and Nomadic Societies in Mediterranean Countries. s.249-255.

Tunçdilek, N., (1967). Türkiye iskân coğrafyası. İstanbul Üniversitesi Edebiyat Fakültesi Yayını 1283, Coğrafya Enstitüsü Yayınları. No.49, 1967, s.20, İstanbul.

Tuztaş, HA., (2005). Günümüzde Isparta'da yaşayan yörüklerin siyasi ve kültür tarihleri. Yüksek Lisans Tezi, İstanbul Üniversitesi, Sosyal Bilimler Enstitüsü, Tarih Anabilim Dalı, İstanbul, Türkiye.

Yalgın, AR., (1993). Cenup'ta Türkmen oymakları. Kültür Bakanlığı Yayınları, Ankara.

Yel, M., (2018). Silifke (Mersin) ilçesinde göçebe hayvancılık ve yaylacılık faaliyetleri: Kavra Dağı örneği. Yüksek Lisans Tezi, Uşak Üniversitesi, Sosyal Bilimler Enstitüsü, Coğrafya Anabilim Dalı, Uşak, Türkiye.

Yetim, N., (2016). Beritan Aşiretinin Konar-Göçer Yaylacılık Faaliyetleri. Yüksek Lisans Tezi, Harran Üniversitesi, Sosyal Bilimler Enstitüsü, Coğrafya Anabilim Dalı, Şanlıurfa, Türkiye.

Yılmaz, O., Karaca, O., İnce, D., Cemal, İ., Yaralı, E., Varol, M., Sevim, S., (2014). Batı Anadolu göçer koyunculuğu ve ıslah planlamalarındaki rolü. Namık Kemal Üniversitesi Ziraat Fakültesi Dergisi, s.89-97, Tekirdağ.

Yücel, İ., (2022). Göçer karya koyunu yetiştiriciliğinin sürdürülebilirlik değerlendirmesi. Yüksek Lisans Tezi , Adnan Menderes Üniversitesi Fen Bilimleri Enstitüsü, Aydın.

Waters, BA., Wario, HT., (2022). Pastoralism and large-scale renewable energy and green hydrogen projects potential and threats. Brot für die Welt and Heinrich Böll Foundation.