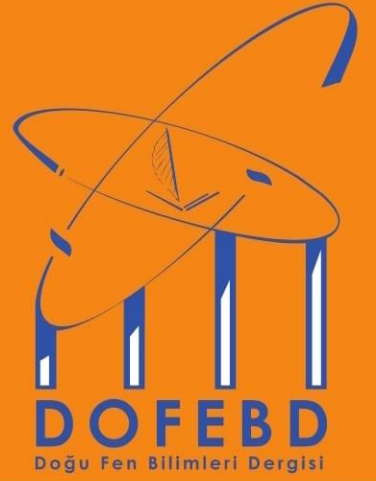




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Statistical Analysis and Optimization of Milling Parameters for Better Surface Roughness with Minimum Cutting Time in Machining of Al7075 Materials

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Abstract

Machining of materials requires high temperature and pressure for chip removal to reproduce the raw surface. Fresh surface after machining determines the quality of the operation and give clues about the accuracy of the parameter selection. Aluminum materials used extensively in prominent sectors i.e. transportation, architecture, industrial areas, aviation, construction industry, electrical and electronics with their properties such as lightness, durability, high corrosion resistance machinability, electrical and thermal conductivity. 7075 materials are an aluminum alloy containing zinc as the primary alloying element. It has superior mechanical properties, exhibiting flexibility, good strength, toughness, and fatigue behavior. Current paper presents Al7075 milling tests were performed under varying cutting conditions (cutting speed, feed rate and cutting tool). During operations, milling times were recorded depending on the cutting parameters considering same cutting length. An average surface roughness (Ra) value was calculated after a series of measurements taken from the machined surfaces. The lowest values (0.23 and 0.44) occurred at a feed rate of 0.15 mm/rev and a cutting speed of 175 m/min for both cutting tools, while the highest values (0.762 and 0.678) occurred at a feed rate of 0.15 mm/rev and a cutting speed of 200 m/min for both tools. Optimal surface quality and cutting time were determined using graphical and statistical analysis. This study aims to provide insights about overcoming the challenges in milling of aluminum alloys in terms of part quality and productivity.

Keywords: Al7075 Alloy, Surface roughness, Variance analysis, Cutting time, Cutting length

Al7075 Malzemelerin İşlenmesinde Minimum Kesme Süresiyle Daha iyi Yüzey Pürüzlülüğü için Frezeleme Parametrelerinin İstatistiksel Analizi ve Optimizasyonu

Özet

Malzemelerin işlenmesi, ham yüzeyi yeniden üretmek için talaş kaldırılması için yüksek sıcaklık ve basınç gerektirir. İşleme sonrası işlenmiş yüzey, işlemin kalitesini belirler ve parametre seçiminin doğruluğu hakkında ipuçları verir. Alüminyum malzemeler, hafiflik, dayanıklılık, yüksek korozyon direnci, işlenebilirlik, elektriksel ve termal iletkenlik gibi özellikleriyle ulaşım, mimari, endüstriyel alanlar, havacılık, inşaat endüstrisi, elektrik ve elektronik gibi önemli sektörlerde yaygın olarak kullanılmaktadır. 7075 malzemeler, birincil alaşım elementi olarak çinko içeren bir alüminyum alaşımıdır. Esneklik, iyi mukavemet, tokluk ve yorulma davranışı gösteren üstün mekanik özelliklere sahiptir. Mevcut makale, değişen kesme koşulları altında (kesme hızı, ilerleme hızı ve kesici takım) gerçekleştirilen Al7075 frezeleme testlerini sunmaktadır. İşlemler sırasında, aynı kesme uzunluğu dikkate alınarak kesme parametrelerine bağlı olarak frezeleme süreleri kaydedilmiştir. İşlenmiş yüzeylerden alınan bir dizi ölçümden sonra ortalama bir yüzey pürüzlülüğü (Ra) değeri hesaplanmıştır. En düşük değerler (0,23 ve 0,44) her iki kesici takımında da 0,15 mm/dev ilerleme miktarı ve 175 m/dak kesme hızında, en yüksek değerler (0,762 ve 0,678) ise yine her iki takımında da 0,15 mm/dev ilerleme ve 200 m/dak kesme hızında oluşmuştur. Grafiksel ve istatistiksel analiz kullanılarak optimum yüzey kalitesi ve kesme süresi belirlenmiştir. Bu çalışmanın amacı, alüminyum alaşımlarının frezeleme sürecinde parça kalitesi ve verimliliği açısından karşılaşılan zorlukların üstesinden gelinmesine yönelik fikirler sunmaktır.

Anahtar Kelimeler: Al7075 alaşımı, Yüzey pürüzlülüğü, Varyans analizi, Kesme süresi, Kesme uzunluğu

Introduction

Milling is defined as the process that enables to cut flat or curved surfaces with a relative movement of an axial feeding of a workpiece and a rotating cutter (Mohanraj, Shankar, Rajasekar, Sakthivel, and Pramanik, 2020). The placement of multiple cutters around the toolholder makes this operation an intermittent process which defines the cutting mechanism again. Because of the continuous cutting in turning creates chips any moment cutting tool never finds time for cooling and temperature gradients show increasing trend. As a result, development of the frictional force causes higher tool wear and reduced surface roughness. However, milling cutter differs from this type of cutting mechanism with pros and cons. Intermittent cutting provides extra time for cutters during rotation in air which cool down the insert into a determined temperature level. On the other hand, repetitive entrance and exit from the workpiece lead to a hammering effect and fatigue-based wear find opportunities to advance on the cutting tool (Pimenov et al., 2022). Worn cutting tools are the primary reason against smooth surfaces.

Main goal in machining is to create smooth, fine surfaces as it defines the quality of the machined part in a way (Duan et al., 2021). However, the surface condition of the material is not the only result since there are many contributors such as inputs and outputs defining the process. Parameter selection necessitates a period of time to find ideal machining operations. This procedure also requires energy consumption and digital tools such as sensor applications, data collection units and machine learning approaches (Daniyan, Tlhabadira, Mpofu, and Adeodu, 2021). Recently, search for sustainable methods for green manufacturing including minimum carbon footprint are increasing due to the government policies (Pimenov et al., 2023; Kuntoğlu et al., 2025). In the perspective of productivity, a machine element should be manufactured with minimum cost and time (Imad, Hopkins, Hosseini, Yussefian, and Kishawy, 2022; Demirpolat et al., 2024). Therefore, machining is a science of multiple goals that contains many aspects need to be balanced (as schematized in Figure 1). Preserving the balance depends on taking attention on developing sustainable, futuristic and productive methods (Khanna et al., 2021). One of the important technological aspects of these groups of variables cutting time and surface roughness which will be the main subject of this paper (Sarıkaya et al., 2021).

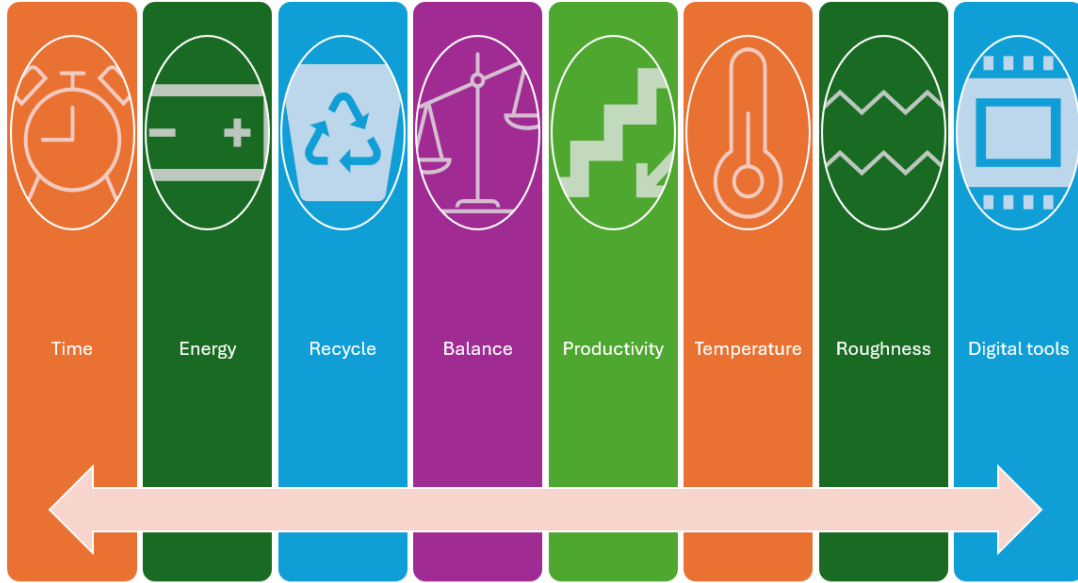


Figure 1. Machining is a science surrounded and affected by many technical and sustainable factors.

There is a wide and yeared literature for machinability of Al7075 alloys. Akdeniz et al. investigated the influences of cutting speed, side depth of cut, tool holder type and feed rate (Akdeniz, Bozdemir, Yılmaz, and Gezer, 2024). Surface roughness and machining accuracy were examined using the Taguchi method. Statistics were performed to understand the effects of machining and the analysis suggested that low cutting speeds should be selected to achieve low surface roughness values. While tool holder types have little effect on surface roughness values, they have a significant effect on machining accuracy. Çaydaş et al. used feed rate and drill point angles as input parameters to evaluate the machinability of AA7075 (Çaydaş and Çelik, 2017). Consequently, they evaluate input and output parameters based on surface roughness, feed force, and tool tip temperature. In this experiment, 8 mm diameter tools with different tip angles were used on milling machine. The results of this experiment showed that the surface roughness of the samples increased with increasing feed rate and drill point angle, but the tool tip temperature decreased. Three different chip types were formed with increasing feed rate: continuous helical chip, short interrupted chip, and tangled band chip. Binali evaluated the machinability of Inconel 718 superalloy, which is widely used in the aviation and space industry, in dry and minimum quantity lubrication environments using machine learning (Binali, 2024). Subramanian et al. (Subramanian, Sakthivel, Sooryaprakash, and Sudhakaran, 2013) created a model based on statistical evaluation using rake angle, tool radii and cutting parameters for end milling. The influence of vibration amplitude was also considered in this work to evaluate the impacts of the input parameters for development of predictive models with higher confidence levels. Lukic et al. (Lukic et al., 2020) realized a series of experiments for thin walled 7075 samples using Taguchi method. The input parameters were selected among wall thickness, tool path and cutting parameters to evaluate dimensional accuracy and surface quality. Optimal conditions for mentioned outputs were determined. Manimaran et al. investigated the machined surface modification and cutting tool wear as a result of milling Nimonic 80A material under hybrid lubrication conditions (Manimaran et al., 2021). Karabuğa et al. selected several cutting conditions as input parameters in their machinability tests (Karabuğa, Karabulut, and Güllü, 2021). Output parameters were surface roughness, tool wear, post-machining material structure, and noise levels during machining. Akgün et al. conducted their

experiments on a lathe (Akgün, Yurtkuran, and Ulas, 2020). 7075 materials were commercially available with a T6 heat treatment, and the effects of aging on machinability were investigated. Furthermore, changes in surface roughness were evaluated in their experiments, taking into account cutting parameters and the cutting tool tip radius. Cutting parameters were optimized using signal to noise response tables, variance analysis, and regression analyses. The results showed that surface roughness decreased with increasing cutting tool tip radius, and that the increase in hardness in the aging-treated material, compared to the base material, improved machinability. Singh et al. focused on the optimal turning parameters for an aerospace alloy (Singh, Gill, and Mahajan, 2024). Different cutting environments were evaluated to improve the machinability of this type of alloy. According to the findings of this work, minimum quantity lubrication decreased the frictional force which affected positively the surface roughness and tool wear. As seen from the literature papers, Al7075 was machined under different conditions and varying parameter combinations with dry and lubricated conditions. However, the studies about this special type of aluminum are still insufficient considering the place and importance of the material.

This paper focuses on the experimental trials of two distinct cutting tool to test the cutting performances in milling under varied cutting speeds and feed rates. Surface roughness and cutting time will be handled as the response parameters. Statistical approach and graphical evaluation will be performed for optimal results.

Material and Method

This section outlines the materials used as cutting tool and workpiece material with usage reasons and also machine tool specifications including experimental details. The response parameters such as cutting time and surface roughness were also explained. Lastly, statistical method used in the study will be detailed.

Al7075 aluminum alloy stands out as an important material in industrial sectors and is widely used especially in fields such as aerospace, automotive and defense industries. Good mechanical properties including elasticity, strength, toughness, and fatigue are the characteristic features of this type of alloys. Cutting tool selection has major impact on the machinability on any material. Therefore, optimal parameter combination and cutting tool type need to be identified for economic and improved machinability. APKT1035PDSR and LOGU0303 type milling cutters were used to measure their performances in producing new surfaces

The experiments were carried out on a CNC milling machine considering the geometry of the material has flat surface. The experiments were done under dry medium. The simplicity and less equipment requirement made this type of machining easy in some way. The parameters used in the milling experiments were: 0.1 mm/tooth, 0.15 mm/tooth and 0.2 mm/tooth values of feed rate and 150 m/min, 175 m/min and 200 m/min values of cutting speed respectively. The depth of cut was kept as same (0.1 mm) in all experiments. As mentioned before two different cutting tool geometries were selected which make total experiment number 18. Full factorial design principle was embraced not to miss any line of the experimental scheme.

Surface roughness was chosen as the response parameter in this work. Average surface roughness defined as Ra was used for the surface roughness criteria in this study. For the calculation of the average value, five measurements were collected from the machined surfaces. After eliminated highest and lowest values, three moderate values

were averaged. Three levels of cutting speed and feed were combined for CNC milling. After adding two types of cutting tool, 18 total experiments were performed for Al7075 material. During each test, cutting time was recorded by a clock. Cutting time is a specific output that gives the actual cutting period. Figure 2 presents the experimental setup as a scheme and the measurement devices also variables used in the physical tests.

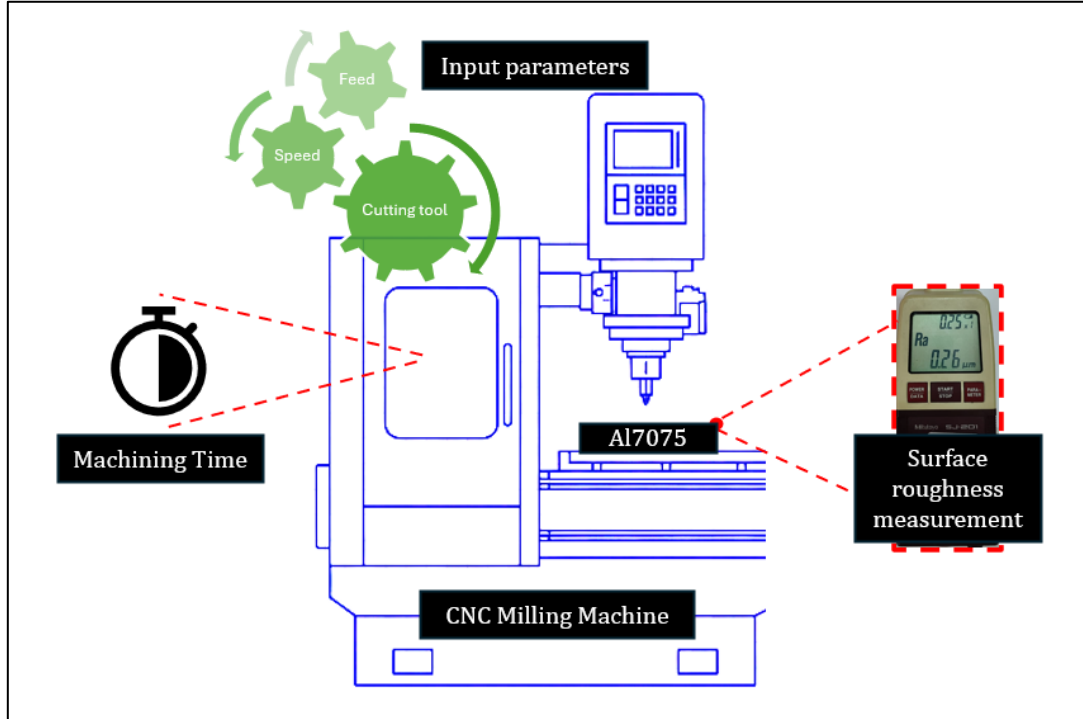


Figure 2. CNC milling machine center and experimental scheme of the study.

Experimental data collected were evaluated by variance analysis. Variance analysis provides to understand which parameter has effectiveness on a response parameter. Also, the optimization technique based on signal to noise ratio provides which level of an input should be chosen for the ideal results. For this aim, Minitab 16 software was utilized. Graphical results of the obtained surface roughness (Ra) and cutting time (s) were also given in the results section.

Results and Discussion

Surface roughness is highly important machining characteristic thanks to its reliability in showing the quality of the machined surface. Therefore, one of the main aims for machining specialists is surface roughness. Surface roughness can be expressed by many criteria. In this work, Ra, one of the most used roughness calculators will be used. Roughness is a negative indicator with increasing, therefore minimum surface roughness is goaled in general. From this point of view Figure 3 shows the surface roughness variation and it's possible to mention that LOGU0303 is better than APKT1035PDSR until a determined material removal rate namely 0.15 mm/tooth and 175 m/min. After that point it is clear to see that LOGU0303 cutting tools is unable to reduce roughness values. 0.15 mm/tooth and 175 m/min cutting parameters belong to feed rate and cutting speed is the best condition for both cutting tools which produce 0.23 μm and 0.44 μm respectively for LOGU0303 and APKT1035PDSR. Pul and Özerkan

reported similar results in the machining of AA6061 alloy (Pul and Özerkan, 2022). Kaya et al. also made similar statements regarding the effects of cutting tool nose radius on machinability output parameters (Kaya et al., 2025).

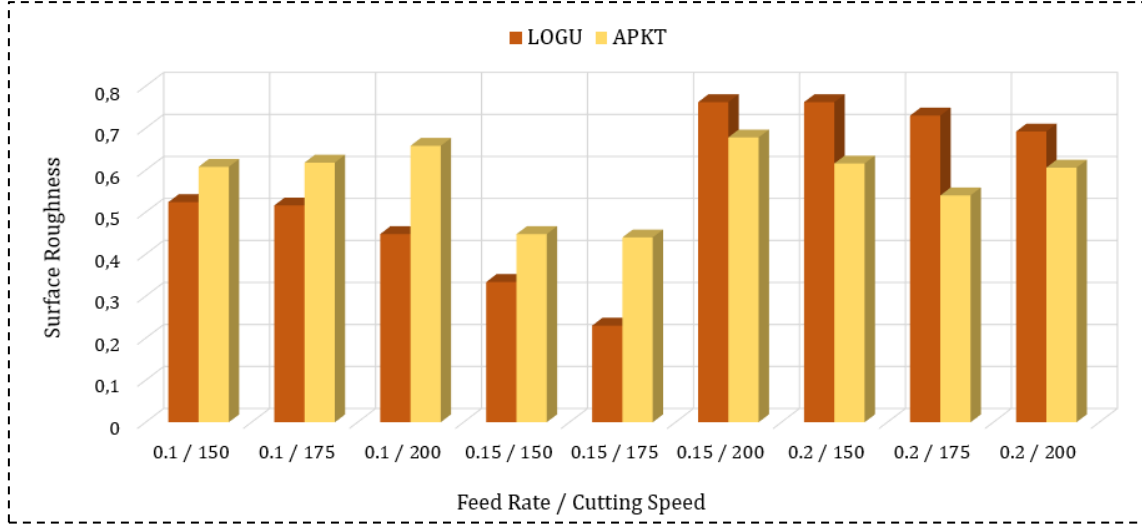


Figure 3. Surface roughness variation based on different cutting tools.

Figure 4 presents the main effects plot for signal to noise ratios for surface roughness including the parameters used in the experiments. These graphs were obtained from the Minitab software. Signal to noise approach gives the best parameter levels for each input parameter which can be observed by maximum values. From this point of view, 0.15 mm/tooth, 175 m/min and LOGU0303 cutting tools should be selected for minimum surface roughness. Figure 5 represents the analysis of variance for surface roughness results. According to this information it can be said that feed rate is the most effective parameter which is followed by cutting speed and cutting tool type respectively. It is expected situation which has been found before numerously. This expected situation was also stated by Binali and his colleagues in their study on S906QL steel (Binali, Yıldız and Neşeli, 2024). This situation has also been referred to in the literature (Yalçın et al., 2024; Kuntoğlu and Sağlam, 2019; Korkmaz and Günay, 2018; Kaya et al., 2025).

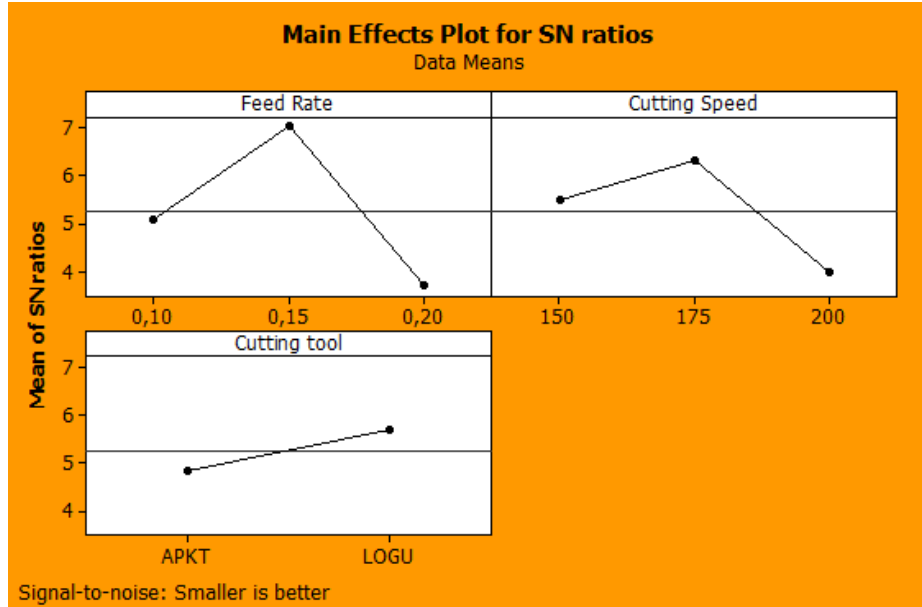


Figure 4. According to main effects plot for signal to noise ratios for surface roughness.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	2	33,416	33,416	16,708	2,94	0,092
Cutting Speed	2	16,859	16,859	8,429	1,48	0,266
Cutting tool	1	3,336	3,336	3,336	0,59	0,459
Residual Error	12	68,275	68,275	5,690		
Total	17	121,886				

Figure 5. Analysis of variance for signal to noise ratios for surface roughness.

Machining time is an important factor due to its direct influence on the machining economy due to decreased cutting time contributes into the cutting tool lifetime and piecework periods. As a result, lower cutting time is expected and accepted as ideal condition. In this regard, Figure 6 gives the minimum times which indicates LOGU0303 is better than APKT1035PDSR without any exception. As expected with the increase of cutting speed and feed rate, cutting time show decreasing trend.

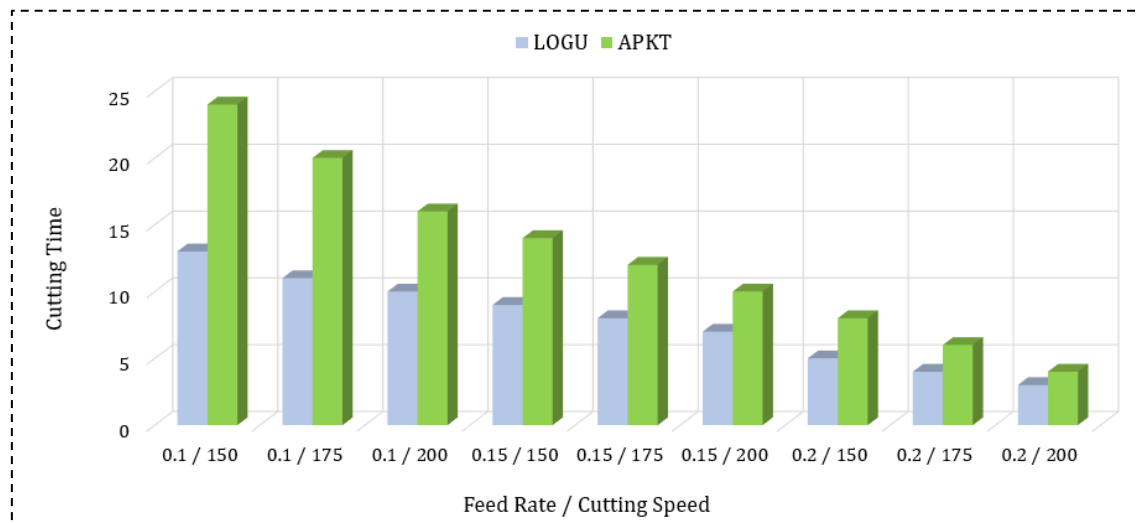


Figure 6. Cutting time variation based on different cutting tools.

Figure 7 represents the main effects plot for signal to noise ratios for cutting time including the parameters used in the experiments. Signal to noise approach provides better and worse parameter levels all parameters which can be seen by maximum values. From this point of view, 0.2 mm/tooth, 200 m/min and LOGU0303 cutting tools should be selected for cutting time. Figure 8 represents the analysis of variance for cutting time results. It can be said that feed rate is the most effective parameter which is followed by cutting tool type and cutting speed respectively. It is expected situation which has been found before numerously. From the general evaluation of the data provides that feed rate optimization is critical for multiple goals in terms of surface roughness and cutting time. This situation has also been noted in the literature (Park, Qi, Dang and Park, 2018; Armillotta, 2021). It is particularly evident in the study by Qehaja et al. on the effect of machining time on roughness (Qehaja et al., 2015).

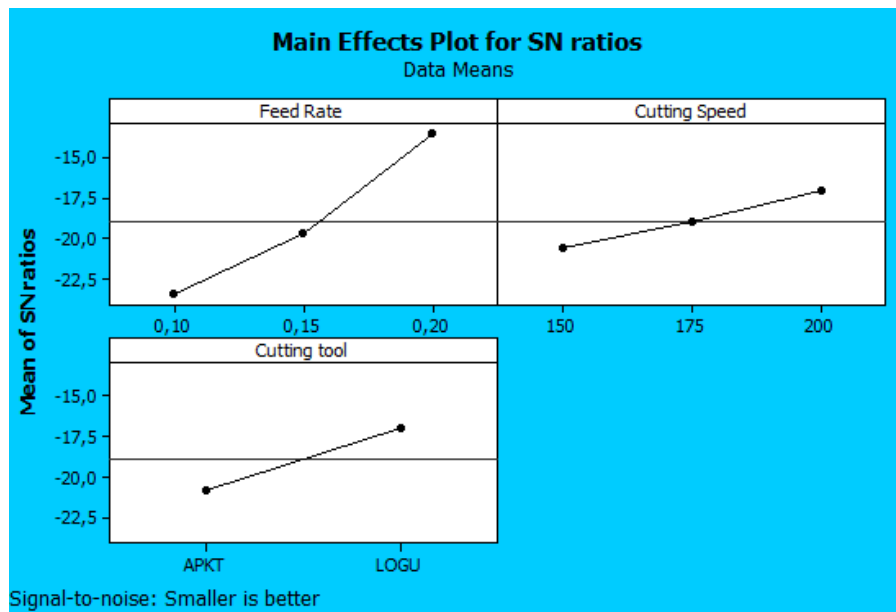


Figure 7. Main effects plot for signal to noise ratios for machining time.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed Rate	2	302,169	302,169	151,084	235,01	0,000
Cutting Speed	2	38,114	38,114	19,057	29,64	0,000
Cutting tool	1	68,683	68,683	68,683	106,84	0,000
Residual Error	12	7,714	7,714	0,643		
Total	17	416,681				

Figure 8. Analysis of variance for signal to noise ratios for machining time.

Conclusion

In this study, the machinability of Al 7075 material by CNC milling under dry cutting conditions was evaluated according to surface roughness and machining time. The outcomes from this study can be summarized as follows.

- ✓ LOGU0303 is better than APKT1035PDSR until a determined material removal rate (0.15 mm/tooth and 175 m/min) however it is clear to see that LOGU0303 cutting tools show worse performance after that point.

- ✓ At specific point of feed rate (0.15 mm/tooth) and cutting speed (175 m/min) is the best condition for both cutting tools which produce 0.23 μm and 0.44 μm respectively for LOGU0303 and APKT1035PDSR.
- ✓ 0.15 mm/tooth, 175 m/min and LOGU0303 cutting tools should be selected for minimum surface roughness according to main effects plot for signal to noise ratios.
- ✓ Feed rate is the most effective parameter which is followed by feed rate and cutting tool type respectively according to analysis of variance.
- ✓ LOGU0303 is better than APKT1035PDSR without any exception in terms of cutting time results. With the increase of cutting speed and feed rate, cutting time show decreasing trend.
- ✓ From the general evaluation of the data provides that feed rate optimization is critical for multiple goals in terms of surface roughness and cutting time.
- ✓ In future studies, comparison of existing tools with machining environments and optimization of different machinability output parameters can be conducted.

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The First Record of Greater Flamingo *Phoenicopterus roseus* (Pallas, 1811) from Diyarbakır Province, Türkiye

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Abstract

The Greater Flamingo *Phoenicopterus roseus* is firstly determined in three different locations in the same period in Diyarbakır province. During the field excursions that conducted in the region between June and October 2025 the observed individual together with available earlier records for the region have been evaluated. Between 1 June and 8 October 2025 period, a total of 99 Greater Flamingo individuals comprising both juveniles and adults were recorded at three distinct locations characterized by dam and pond habitats. These findings underscore the ecological value of freshwater systems in southeastern Anatolia and point to emerging environmental changes in the area. These observations show that flamingos make use of the region during the migration period, specifically from June until the first half of September. Although flamingos generally favour saline wetlands, their occurrence in these freshwater areas indicates they have adapted to using freshwater areas as well during migration. Recent assessments suggest that the migration routes of flamingos in Türkiye are more extensive than previously assumed and are shaped by the presence of diverse wetland ecosystems. Understanding the spatial and temporal distribution of the species is essential and important for effective conservation planning, particularly in light of ongoing threats such as habitat degradation, alterations in water management, climate-induced changes, and increasing human disturbance.

Key words: *Phoenicopterus roseus*, Greater Flamingo, Diyarbakır, Türkiye.

Büyük Flamingo *Phoenicopterus roseus* (Pallas, 1811)'un Türkiye'de Diyarbakır İlinden İlk Kaydı

Özet

Büyük Flamingo *Phoenicopterus roseus*, üç farklı lokasyonda, ilk kez aynı dönemde Diyarbakır ilinde tespit edilmiştir. Haziran-Ekim 2025 tarihleri arasında bölgede gerçekleştirilen arazi çalışmaları sırasında, gözlemlenen bireyler, bölgeye ait daha önceki kayıtlarla birlikte değerlendirilmiştir. 1 Haziran-8 Ekim 2025 tarihleri arasında, baraj ve gölet habitatlarıyla karakterize edilen üç farklı lokasyonda hem genç hem de erişkin bireylerden oluşan toplam 99 Büyük Flamingo bireyi kaydedilmiştir. Söz konusu bulgular, Güneydoğu Anadolu Bölgesindeki tatlı su sistemlerinin ekolojik değerini vurgulamakta ve bölgede ortaya çıkan çevresel değişikliklere işaret etmektedir. Gözlemler, flamingoların göç döneminde, özellikle Haziran ayından Eylül ayının ilk yarısına kadar bölgeyi kullandıklarını göstermektedir. Her ne kadar flamingolar tuzlu sulak alanları tercih etseler de bu tatlı su alanlarındaki varlıkları, göç sırasında tatlı su alanlarını da kullanmaya adapte olduklarını göstermektedir. Son değerlendirmeler, Türkiye'deki flamingoların göç yollarının daha önce tahmin edilenden daha geniş olduğunu ve çeşitli sulak alan ekosistemlerinin varlığından etkilendiğini göstermektedir. Türlerin mekânsal ve zamansal dağılımını anlamak, özellikle yaşam alanı bozulması, su yönetimindeki değişiklikler, iklim kaynaklı değişiklikler ve artan insan kaynaklı rahatsızlıklar gibi devam eden tehditler ışığında, etkili koruma planlaması için elzem ve önemlidir.

Anahtar kelimeler: *Phoenicopterus roseus*, Büyük Flamingo, Diyarbakır, Türkiye.

¹ The field studies of this research were carried out within the scope of master's thesis of one of author Rahmi Aktaş.

Introduction

The Greater Flamingo *Phoenicopterus roseus* (Pallas, 1811) is a widely distributed Palearctic waterbird species that breeds primarily in extensive saline and brackish wetland areas. The species occupies a broad range mainly from the southern Iberian Peninsula and coastal West Africa, spanning to the Mediterranean basin, extending eastward to the Southwest Asia, and extends southward through Sub-Saharan Africa -especially through East Africa- reaching as far as South Africa (Cramp, 1998; BirdLife, 2025). European distribution of the species mainly confined to Mediterranean basin (Tucker and Heath 1994). In addition, related to its wide distribution range and together with an increasing population trend (BirdLife, 2019) in many areas, it is classified as Least Concern (LC) species globally by IUCN (IUCN, 2025).

There are different estimations available that given for the overall population size of the Greater Flamingos globally; such as 550,000 and 680,000 individuals (Wetlands International (2015) or 690,000–910,000 individuals (Salvador et al., 2024). The size of European population of the species was reported approximately about 89,900 to 125,000 individuals (BirdLife, 2018). The breeding population of the species in Türkiye is believed to consist of 9,900 to 37,500 pairs, whereas the European breeding population is estimated at 35,900 to 133,000 pairs (BirdLife, 2021) together with increasing population trend. Likewise, the wintering population across Europe is thought to number between 234,000 and 420,000 individuals, while Türkiye hosts an estimated 58,300 to 146,000 wintering individuals (BirdLife, 2021). However, based on the Mid-Winter Waterbird Counts conducted in Türkiye between 2018 and 2022 periods, the highest number of individuals was recorded in 2021 winter as 79,231 individuals (DKMP, 2022; Karataş et al. 2022).

In Türkiye, formerly, the species is revealed as a resident species, mainly distributed across Inner Anatolia and the Aegean region, with an estimated population size of 14,000 to 18,000 pairs (Kasperek and Bilgin, 1996). Despite of the existence of other breeding sites in the past, for example during the 1970s and 1980s, such as Sultan Marshes, Lake Seyfe, and the Ereğli wetlands, two principal regions have remained the most significant recently; the Gediz Delta and Lake Tuz. These two special areas stand out as critical habitats and hosting a significant portion of Türkiye's flamingo population (Balkız et al., 2007; 2015). Recent evaluations indicate that Great Flamingos mainly showing distribution in the western half of the Türkiye as a resident species while using much larger parts of the country during transition periods. Also, large gatherings of flamingos -about 1,000 individuals- observed around Lake Van, particularly between late-summer and early-autumn, are believed to originate from the breeding population at Lake Urmia in Iran (Kirwan et al., 2008). Juveniles from this Iranian population have been documented to dispersing over vast distances, reaching western and southern part of Europe, northwestern Africa, and even the Arabian Peninsula. Likewise, flamingo chicks that ringed in the Gediz Delta -Türkiye- have been recorded reaching various regions across the eastern and western Mediterranean, as well as Israel and northwestern Africa.

Türkiye hosts a significant portion of the Eastern Mediterranean population of the Great flamingos. Species mainly occupies brackish / saline wetland areas for feeding and breeding aims as colonies of up to a few thousand individuals. Even though some studies have suggested that the Mediterranean population has bred more frequently in Türkiye since the 2000s (Carboneras and Béchet, 2020), the overall trend appears to show a decrease in numbers. Despite a seemingly stable overall population, the species is

classified as endangered in Türkiye, nationally (Kılıç and Eken, 2004). Great flamingo is relatively common in coastal and western regions, but its presence in the inland areas of southeastern Türkiye remains poorly known. Historical records suggest that flamingos were observed in Southeastern Anatolia, including the Diyarbakır area, as early as the 19th century (Kirwan et al., 2008). Although it has been reported that the species was rarely observed in the Southeastern Anatolia Region during migration periods, formerly, there have been no records or details from the past 20–30 years (Kirwan et al., 2008). Nevertheless, the region's warm climate, seasonal wetlands, and extensive river systems may could serve as a migration corridor or temporary habitat, even though evidence for regular breeding remains absent. In this paper, the first verified record of species from Diyarbakır have been presented, supported by direct observation and photographic documentation.

Material and Methods

Methods

During the field excursion that conducted in Devegeçidi Dam (Figure 1) between June and October 2025 the observed individual of Great flamingos together with available earlier records for the region and Diyarbakır province was evaluated. These long-necked and long-legged waterbird species, which prefer shallow wetlands especially for feeding, are very easily identifiable morphologically (Figure 2). Field observations were performed using standardized ornithological equipment, including binoculars (8×40), telescope (20-60×80) and ornithological field guides. All procedures followed established protocols for avian monitoring to ensure consistency and reliability in data collection (Bibby et al. 1998; Mullarney et al. 1999).



Figure 1. Locations of the where Greater flamingo determined in Diyarbakır province



Figure 2. Three juveniles that observed Devegeçidi Dam, Diyarbakır province

Study Area

All of the records have been obtained from man-made wetland areas that known as pond and dam. One of the sites Devegeçidi Dam where observed records were collected is designated as an Important Bird Area's -IBA's- (No. TR176), while the other two - Bozçalı and Yayık Village- exhibit the ecological features of a pond and a dam, respectively (Kılıç and Eken, 2004). The distance between Devegeçidi and Yayık village (near Batman Dam) is approximately 97 km, while the distance between Devegeçidi and Bozçalı village is about 46 km as the crow flies. All of the individuals observed in shallow freshwater areas and altitude range is about 660-748 m. In general, water depth decreases due to high summer temperatures and the use of water for irrigation purposes all of the region including mentioned location. Moreover, all of these locations are characterized by terrestrial and freshwater ecosystems.

Results

Totally 99 individuals recorded including young and adult individuals between 1 June 2025 to 8 October 2025 periods without the number for the group given in the news. The recorded individual during field excursions and other records during 2025 year has given in table (Table 1). The records were obtained from three different locations; Bozçalı Village, Yayık Village (near Batman dam) and Devegeçidi Dam areas. The first record of the species is based on a news source stating that individuals were found in Bozçalı village of Çınar district of Diyarbakır province on June 1, 2025 (News, 2025). The second record was obtained based on vocalizations detected for the first time in the Devegeçidi Dam area on 21 August 2025, without any visual confirmation of the species. During the observation on 31 August 2025, three individuals were observed on the shore of the dam lake. These individuals were observed for approximately 30 minutes while they were feeding in the shallow area. On the next observation, 07 September 2025, a total of four individuals were observed while they feeding near the pond. Three of these individuals

were observed in a group, while another was feeding alone approximately 15 meters away. During this observation, it was also observed that the individual feeding alone was occasionally disturbed by the Eurasian Coot *Fulica atra*. In the observation on 15 September 2025, 30 individuals were seen in flight. These individuals were flying from the direction of north to south-west. Their flight formation does not have a "V" formation like that of geese. During the observation on 23 September 2025, no flamingo individuals were observed in the area. The other hand, during the field excursion on 8 October 2025, 25 individuals observed while they flying to the direction of north to south-west. During subsequent observations, no flamingo individuals were observed in the study area.

Table 1. All records of Greater flamingo in the region during 2025 year.

Location	GPS	Latitude	Dates	Number	Observer / Resource
Diyarbakır (Bozçalı Village)	37S 619064 / 4178709 N	670 m	01.06.2025	A group	News
Batman Dam (Yayık Village)	37S 683841 / 4235420 N	660 m	15.07.2025	37	M. YILMAZ
Devegeçidi Dam	37S 586284 / 4212582 N	748 m	31.08.2025	3	R. AKTAŞ & R. KARAKAŞ
Devegeçidi Dam	37S 586284 / 4212582 N	748 m	07.09.2025	4	R. AKTAŞ & R. KARAKAŞ
Devegeçidi Dam	37S 586284 / 4212582 N	748 m	15.09.2025	30	R. AKTAŞ & R. KARAKAŞ
Devegeçidi Dam	37S 586284 / 4212582 N	748 m	08.10.2025	25	R. AKTAŞ & R. KARAKAŞ

These records suggest that flamingos pass through Diyarbakır during migration, or possibly when wetland conditions are favourable. The current habitats including locations where the species was reported during this study that support these sightings include ponds, small wetlands, and minor dam lakes. These water bodies often experience reduced water levels and become shallower, especially during the migration period, and may be used by the species as stopover sites or feeding grounds. Furthermore, the observations show that flamingos make use of the area during the migration period, specifically from June until the first half of September. Considering that the incubation period of flamingos in Türkiye lasts from early April to mid-June, and that they reach sexual maturity at approximately 3–4 years of age (Kirwan et al., 2008; Karataş et al., 2022), with most individuals observed in the region being immature, it can be inferred that younger flamingos initiate migratory activity earlier than breeding adults. After the breeding season, the species demonstrates different distinct dispersal behaviours, and also, often returning to previously occupied habitats that phenomena known as philopatry. Although species prefers shallow and salty or alkaline wetlands mainly during breeding season, inland marshes and lakes are utilized by the species in outside of the breeding season, as reported in multiple studies (Shirihai, 1996; Kirwan et al., 2008; Salvador et al., 2024). These records from Diyarbakır indicate that species using small or large wetlands such as less depth ponds together with dams during spring migration season.

Although the species is not currently threatened, the conservation and monitoring of wetlands which serve as critical habitats as feeding and breeding areas together with stopover sites during migration are essential for its long-term survival. The importance of shallow wetlands, especially those suitable for the ecology of the species, is even more prominent, as in the example of the shallow ponds next to the Devegeçidi Dam. In

addition, this study has once again shown that flamingos may use freshwater wetlands as stopover sites during the migration period.

Hence, Türkiye functions as an ecological bridge between the flamingo populations inhabiting the western Mediterranean and those of southwestern Asia. Understanding the spatial and temporal distribution of the species is essential and important for effective conservation planning, particularly in light of ongoing threats such as habitat degradation, alterations in water management, climate-induced changes, and increasing human disturbance. Due to these wetlands play for numerous bird species including flamingos -both during migration and breeding periods-, developing protective measures and raising awareness for the protection of these special areas is critical importance for preserving natural values and biodiversity. Recent assessments suggest that the migration routes of flamingos in Türkiye are more extensive than previously assumed and are shaped by the presence of diverse wetland ecosystems. Consequently, wetlands play a crucial role in maintaining the breeding, feeding, and resting cycles of these birds. Safeguarding such habitats is therefore essential for sustaining the migration of flamingos as well as other waterbird species.

Discussion

The flamingo population inhabiting the Mediterranean basin within the Western Palearctic region functions as a metapopulation, interconnected with groups in Northwest Africa and Western Asia (Balkız, 2006). This structure is presumably shaped by gene flow, driven by the dispersal of juvenile individuals across regions. This species typically inhabits shallow wetlands with fluctuating water levels, which influence their foraging behaviour and often necessitate relocation between feeding sites (Johnson and Cézilly, 2007; Delany and Scott, 2006). Movements of individuals across population boundaries serve as a key process linking different populations into a larger biological network. This movement fosters genetic exchange, counteracts isolation, and shapes the hierarchical structure typical of metapopulations (Nager et al., 1996; Balkız et al., 2015).

In Türkiye, Greater flamingos exhibit a combination of short-range movements - such as natal dispersal and post fledging wandering- and long-distance migrations that connect Anatolian colonies with sites across the Mediterranean and Africa. Ring recoveries have revealed individuals originating from breeding grounds in Türkiye reached regions as distant as the western Mediterranean, Israel, and parts of West Africa (Amat et al., 2005; Balkız et al., 2007; Boucheker et al., 2011; Balkız et al., 2015). And also observed individuals in Diyarbakır may have been originated from the breeding population at Lake Urmia in Iran due to juveniles from Iranian population have been recorded from Africa and Arabian Peninsula (Kirwan et al., 2008).

Türkiye serves as a vital migratory bridge between Europe and Africa; East and Mediterranean population of flamingos occasionally arriving both for breeding and foraging (Balkız, 2015) or use the region for transit passing purposes. Although flamingos generally favour saline environments and shallow lakes, they may temporarily utilize freshwater habitats along their migration routes. Despite having beaks that are anatomically specialized for filtering nutrients from water, flamingos are believed to adapt their feeding strategies to access various food sources in different habitats particularly in freshwater ecosystems. This behavioural flexibility enhances their ability to respond to environmental changes and plays a key role in their ecological success. In this context, the wetland ecosystems in or near Diyarbakır such as dams or ponds play a strategically important role. Observations of flamingos in this region, though infrequent,

underscore its ecological significance and its capacity to support migratory bird species. Due to these wetlands play for numerous bird species including flamingos -both during migration and breeding periods-, developing protective measures and raising awareness for the protection of these special areas is critical importance for preserving natural values and biodiversity.

Although some bird distribution maps have included the Southeastern Anatolia Region and Diyarbakır Province within the species' distribution range (Furtun et al., 2021), there are no documented observation according to published scientific literature or ornithological fieldwork conducted in the area during last two-three decades (Biricik, 1996; Karakaş, 2010; 2017; Kılıç, 2013). This evaluation represents the first confirmed records of species for the region at least over the last 20-30 years. These records suggest that flamingos used the region and Diyarbakır during migration, or at least perhaps when wetland conditions are favourable (Aktaş, 2025). Also, this study indicates that both flamingos' migration range may expanding and the use of such artificial wetlands as alternative habitats during migration is important for preserving biodiversity in the region. Although no specific analysis of climatic parameters has been conducted, the occurrence of the species in Diyarbakır may be associated with global warming or ongoing ecological changes in the region. Furthermore, assessing the potential impact of climate change on the migratory behaviour and routes of this species constitutes the focus of a distinct research effort.

Conclusions

As a conclusion, it could be stated that the Greater flamingo *Phoenicopterus roseus* exhibits a well-defined distribution across Türkiye, with Lake Tuz and the Gediz Delta functioning as core breeding sites. Occasional nesting occurs in other wetlands, and numerous stopover locations are utilized during migratory movements. While recent population trends appear promising, the species remains vulnerable to a range of threats that could compromise these advances. Sustained conservation efforts will require ongoing population monitoring, the preservation of key hydrological systems, protection of essential habitats, and adaptive strategies to confront emerging challenges such as climate change and intensified competition for water resources. Due to its unique geographical position and geological history, Türkiye hosts an extraordinary array of ecosystems and wildlife components including birds. Over time, however, this natural heritage has come under increasing pressure from human activities such as urbanization, intensive farming, unsustainable forestry and fishing, and pollution. Consequently, many rare ecosystems and the species that rely on them have experienced significant declines. So, the conservation of these critical habitats and the species that rely on them should be considered a responsibility toward future generations, and the necessary measures must be taken.

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Sıçan Derisinde Vimentin, Desmin ve Laminin'in Dağılımı

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Özet

Deri, çok katmanlı yapısı ve kıl örtüsü ile organizmayı dış etmenlerden koruyan bir yapıdır. Vücut yüzeyinden dışarı çıkan deri uzantısı olan saç, tüy, pul, tırnak, pençe gibi oluşumlar organizmayı kururken, vücutta yayılan deri uzantıları yağ bezi, ter bezi, meme bezi gibi oluşumlar organizmayı, çevresel adaptasyon gibi özel fizyolojik işlevler kazandırır. Vimentin, desmin ve laminin gibi İntermediyer filamanlar organizmanın oluşum ve gelişiminde önemli rollere sahiptirler. Bu IF'ler aynı zamanda birçok çalışmada tümöral oluşumlarda marker olarak kullanılabilecekleri yönünde bildirilmişlerdir. IF'lerin hücrelerin oluşum ve gelişimindeki rolleri ve tümörlerde marker olarak kullanılabilecek olmaları durumundan yola çıkarak çalışmamızda, erişkin sıçanların deri dokusunda, intermedier filamentlerden vimentin ve desmin ile bağdoku komponentlerinden laminin'in ekspresyonlarını ortaya koyduk. Bulgularımız, sıçan derisinde bu komponentlerin kılın medulla katmanında, bazı bağ doku hücrelerinde, derinin kas katmanında, kılın retraktor kaslarında, kılın medullasında, bazı kan damarlarında ve kılın dış epitel hücrelerinde çeşitli güçlükte reaksiyonlar verdiğini ortaya koydu. Diğer memelilerde olduğu gibi, sıçan derisinde de vimentin, desmin ve lamininin bazı hücre gruplarından eksprese olması, deride bu faktörlerin hücre iskeletine ve doku bütünlüğüne katkı sunduğunu göstermiştir.

Anahtar Kelimeler: Deri, Kıl, Laminin, Desmin, Vimentin

Distribution of Vimentin, Desmin, and Laminin in Rat Skin

Abstract

The skin is a structure that protects the organism from external factors with its multi-layered structure and hair covering. Structures such as hair, feathers, scales, nails, and claws, which are skin extensions protruding from the body surface, contribute to the organism's structure, while skin extensions such as sebaceous glands, sweat glands, and mammary glands, which are distributed throughout the body, confer special physiological functions such as environmental adaptation. Intermediate filaments such as vimentin, desmin, and laminin play important roles in the formation and development of the organism. These IFs have also been reported in many studies as potential markers in tumor formation. Based on the roles of IFs in cell formation and development and their potential use as markers in tumors, in our study, we investigated the expression of vimentin and desmin, which are intermediate filaments, and laminin, which is a connective tissue component, in the skin tissue of adult rats. Our findings showed that these components reacted with varying degrees of intensity in the medulla layer of the hair, some connective tissue cells, the muscle layer of the skin, the retractor muscles of the hair, the medulla of the hair, some blood vessels, and the outer epithelial cells of the hair. As in other mammals, the expression of vimentin, desmin, and laminin in certain cell groups in rat skin indicates that these factors contribute to the cellular skeleton and tissue integrity in the skin.

Keywords: Skin, Hair, Laminin, Desmin, Vimentin

Giriş

Deri, vücudun en büyük organıdır ve tüm dış yüzeyini kaplar. Farklı anatomik yapı ve işlevlere sahip olan deri tabakalı bir yapıdan meydana gelir. Derinin yapısı, iç ortam ile dış dünya arasında koruyucu bir arayüz görevi görür. Termoregülasyon, immunojenik savunma, duyuşsal algılama, su kaybının önlenmesi ve patojenlerin girişinin engellenmesinde kritik roller oynar. Histolojik olarak, deri koruyucu bir bariyer görevi gören çok katlı yassı keratinize epitel olan epidermis; vasküler, nöral ve apendiks yapıları destekleyen bağ dokusu tabakası olan dermis ile yalıtım ve enerji depolama görevi gören, esas olarak yağ dokusundan oluşan hipodermisten oluşur. Her tabaka, derinin bütünlüğünü ve işlevini korumak için gerekli olan belirli hücre tiplerini ve hücre dışı bileşenleri içerir. Bundan dolayı da, derinin hücresel yapılarında (epitel, stromal, melanosit hücreleri v.s.) lokalize olan moleküler faktörlerin (intermediyer flamanlar gibi) varlığının ya da dağılımının doğru bir şekilde ortaya konulması, tıp eğitimi, dermatolojik durumların klinik tanısı ve yara iyileşmesi, rejeneratif tıp ve kozmetik dermatoloji gibi alanlardaki ilerlemelere katkı sunabilir (Widelitz ve ark., 1997; Prost-Squarcioni, 2006).

IF proteinleri arasında yer alan sitokeratinler (CK'ler) çoğunlukla epitel hücrelerinde lokalize olur. Büyük ölçüde organ veya dokuya özgü olarak ekspresse edilirler. Bir epitel hücresi tarafından ekspresse edilen sitokeratin esas olarak epitel hücresinin türüne, terminal farklılaşma sürecindeki durumuna ve gelişim aşamasına bağlıdır. Buna göre, spesifik sitokeratin ekspresyonları epitel hücrelerinin tanımlanmasını sağlar (Grim, 2006; Jaiswal ve ark., 2018; Sun ve ark., 2010). Asidik tip I sitokeratinler (CK9-CK20) ve bazik ya da nötral tip II sitokeratinler (CK1-CK8) olmak üzere iki tip sitokeratin mevcuttur.

Vimentin, tip III IF protein ailesinin en yaygın şekilde ekspresse edilen, 57 kDa'lık bir proteindir. Normalde mezenkimal hücreler tarafından ekspresse edilir (Raymond ve Leong 1989), ancak insanlarda ve diğer memelilerde meme bezinde de varlığı gösterilmiştir (Guelstein ve ark., 1988; Hellmén ve Lindgren 1989; Warburton ve ark. 1985). Ayrıca, vimentin'in, pankreasın öncü hücreleri, sertoli, sinir, trofoblast dev, fibroblastlar, endotel, renal tübüler ve stromal hücreleri ile makrofajlar, nötrofiller ve lökositlerden de ekspresse olduğu bildirilmiştir (Fuchs ve Weber, 1994; Herrmann ve Harris, 1998; Herrmann ve ark., 1992; Hesse ve ark., 2001; Loh ve ark., 2000; Madekurozwa, 2013; Prasad ve ark., 1998).

Desmin, miyojenik kökenli hücrelerin karakteristik ara filament proteindir ve tek bir gen tarafından kodlanır (Rangdaeng ve Truong 1991). Kalp, iskelet ve düz kaslardan ekspresse edilen ana ara filament (IF) proteindir. Kontraktil aparat ile hücrenin diğer yapısal unsurları arasında uzamsal bir ilişki sağlayan sürekli bir hücre iskeleti ağı oluşturmak için diğer proteinlerle etkileşime girer ve böylece hücresel bütünlüğün, kuvvet iletiminin ve mekano-kimyasal sinyalin korunmasını sağlar. Özellikle desmin, kalp kasında iskelet kasındakinden çok daha fazla bulunur ve kalbin koordineli bir şekilde kasılmasını sağlayan özelleşmiş miyokardiyal iletim sistemi olan Purkinje liflerinin önemli bir bileşenini oluşturur (Goldfarb ve Dalakas, 2009). Aynı zamanda desminin yara iyileşmesindeki fibrotik dokuda ve tümör stromasındaki bazı hücrelerden de ekspresse edildiği bildirilmiştir.

Laminin, bazal membranın önemli bir bileşenidir ve çapraz şekilli yapıya sahip glikoprotein ailesini içerir (Streuli ve ark., 1995). Günümüzde, on sekiz laminin izoformu tanımlanmış olsa da bazılarının in vivo varlığının hala doğrulanması gerekmektedir (Timpl ve Brown, 1994). Lamininler, dokuya özgü ve teporal olarak kontrollü bir şekilde

ekspresse edilen α , β ve γ alt birimlerinden oluşan heterotrimerlerdir (Ahmed ve Ffrench-Constant, 2016).

Sıçan derisinde vimentin, desmin ve laminin'in immünohistokimyasal dağılımının belirlenmesi, dermal ve epidermal yapıların fizyolojik bütünlüğü ile yara iyileşmesi süreçlerinin anlaşılmasında önemli rol oynar. Vimentin, fibroblast ve endotelial hücrelerde ara filament proteini olarak görev yapar ve yara iyileşmesinde fibroblast göçü ile matriksin yeniden şekillendirilmesinde artış gösterir (Raymond ve Leong, 1989; Guelstein ve ark., 1988; Warburton ve ark., 1985; Fuchs ve Weber, 1994). Desmin, arrector pili kası ve vasküler düz kas hücrelerinde iskelet stabilitesini sağlayarak dermal kas yapılarının bütünlüğünü korur ve vasküler yeniden yapılanmada rol oynar (Rangdaeng ve Truong, 1991; Goldfarb ve Dalakas, 2009). Laminin ise epidermis–dermis bağlantı noktasında bazal membranın ana bileşeni olup, hücre adezyonu ve doku morfogenezini için gereklidir. Ayrıca, bazal membranın hasar görmesi durumunda, onarımında rol oynadığı da gösterilmiştir (Streuli ve ark., 1995; Timpl ve Brown, 1994; Ahmed ve Ffrench-Constant, 2016). Yaptığımız çalışmada, sıçan derisinde vimentin, desmin ve lamininin bölgesel ve hücresel lokalizasyonları immünohistokimyasal olarak ortaya konulmuştur. Bu proteinlerin hücresel lokalizasyonlarının gösterilmesi, deri homeostazını, rejeneratif süreçleri ve patolojik değişimleri anlamada bizlere güvenilir bir model sunacaktır. Ayrıca insan dermatolojik hastalıklarının mekanizmalarının aydınlatılmasında bir köprü işlevi görebileceği düşünülmektedir.

Materyal ve Yöntem

Hayvanların etik beyanı ve deney koşulları

Çalışmada Dicle Üniversitesi Prof. Dr. Sabahattin PAYZIN Sağlık Bilimleri Araştırma ve Uygulama Merkezi (DÜSAM) Müdürlüğü'nden temin edilen 35 adet erişkin, 220-250 g ağırlığında Sprague-Dawley ırkı dişi sıçan kullanıldı. Hayvanlar, deney süresince 12 saat aydınlık ve 12 saat karanlık ışık periyodunda barındırıldı. Pelet yem ve su ihtiyaçları ad libitum olarak karşılandı. Hayvanlar her grupta 7 hayvan olacak şekilde rastgele 5 gruba ayrıldı. Bu çalışma Dicle Üniversitesi Deney Hayvanları Yerel Etik Kurulu (DÜHADEK) tarafından onaylanmıştır (karar sayısı 2008-02).

Doku örneklerinin toplanması ve işlenmesi

Ketalar (Ketamin HCl-Phizer) (90mg/kg) anestezisi altında; abdominal bölgedeki deriden kesitler alındı. Deney hayvanları postoperatif bakıma alındı. Bütün gruplardan alınan deri dokuları %10 nötral formalin solüsyonunda 24 saat tespit edildi. Daha sonra bir gün süreyle akarsu altında dokular yıkandı. Yıkama işlemini takiben dokular dereceli alkoller, metil benzoat ve benzol serilerinden geçirilerek parafasta bloklandı. Hazırlanan parafin bloklarından, 5 mikrometre kalınlığında seri kesitler alındı. Bu kesitler vimentin, desmin ve laminini immünohistokimyasal olarak belirlemek için 3-aminopropyl-triethoxysilane (APES) ile kaplanmış lamlara alındı.

İmmünohistokimya (IHC)

Vimentin, desmin ve laminin proteinleri standart bir streptavidin-biotin immünoperoksidaz tekniği uygulanarak gösterildi (Bayram ve ark., 2023). Kesitler

endojen peroksidaz aktivitesini engellemek için 15 dakika boyunca metanolde %3 hidrojen peroksit (H₂O₂) ile muamele edildi. Daha sonra, PBS'de yıkanan kesitler Tris-EDTA tamponuna (pH 9,0) yerleştirildi, antijen geri kazanımı için 30 dakika boyunca 90 °C'de su banyosunda ısıtıldı ve 20 dakika boyunca soğutuldu. Daha sonra, kesitler PBS'de yıkandı ve immünoglobulinlerin nonspesifik bağlanmasını önlemek için 5 dakika boyunca bloklayıcı solüsyonu (Ultra V Block, Thermo Fisher Scientific, LabVision Corporation, Fremont, CA, ABD) ile muamele edildi. Daha sonra kesitler, Vimentin (fare monoklonal, Thermo Scientific, MS-129-R7, 1/200 seyreltme), Desmin (fare monoklonal, Thermo Scientific, MS-376-S1, 1/200 seyreltme) ve Anti-Laminin (tavşan poliklonal, Abcam, ab11575, 1/200 seyreltme) primer antikoları ile +4 °C'de bir gece inkübe edildi. Ertesi gün, kesitler PBS ile yıkandı ve biyotinlenmiş sekonder anti-tavşan veya anti-fare antikoları (Thermo Fisher Scientific Lab Vision Corporation, Kullanıma Hazır) ile oda sıcaklığında 20 dakika inkübe edildi. PBS'de yıkamadan sonra, kesitler streptavidin peroksidaz (Thermo Fisher Scientific Lab Vision Corporation, Fremont, CA, Kullanıma Hazır) ile 20 dakika inkübe edildi ve ardından PBS ile yıkandı. Kesitler 5 dakika boyunca 3,3-diaminobenzidin tetrahidroklorür (DAB, TA-125-HD, Thermo Fisher Scientific Lab Vision Corporation, Fremont, CA, ABD) ile inkübe edildi. Daha sonra, kesitler 3 dakika boyunca Gill hematoksin ile zıt boyandı, akar su altında yıkandı, alkollerde geçirildi, ksilende parlatıldı ve Entellan ile kapatıldı.

İmmünohistokimyasal boyama özgüllüğü negatif kontrol kesitleri kullanılarak test edildi. Negatif kontrol reaksiyonları, vimentin, desmin ve laminine karşı birincil tavşan antikolarının benzer konsantrasyonlarda bağışık olmayan tavşan (Santa Cruz Biotechnology, sc-2027) fare (Santa Cruz Biotechnology, sc-2025) serumlarıyla değiştirilmesiyle, protokolden birincil antikor adımının çıkarılmasıyla yapıldı. Negatif kontroller, tüm antikorlar için immün boyama göstermedi.

Doku kesitleri geleneksel ışık mikroskobu (Nikon-Eclipse 400) ile incelendi ve vimentin, desmin ve laminin immünoreaktivitesi açısından değerlendirildi. Kesitler, NIS Elements Imaging Software-version 3.10 özellikli dijital kamera (Nikon DSLR) ile fotoğraflandı.

IHC boyama sonuçlarının değerlendirilmesi

Vimentin, desmin ve lamininin sıçan deri dokusundaki ekspresyonu, DS-RI1 video kamera (DS-U3, Nikon, Tokyo, Japonya) ile donatılmış bir ışık mikroskobu (E-400; Nikon, Tokyo, Japonya) kullanılarak 4X, 10X ve 40X büyütmede incelendi. Her kesitteki en az 100 hücre içeren farklı alanlar, görüntü analizi ile dijitalleştirildi ve NIS Elements D Görüntüleme Yazılımı (Microvision, Evry, Fransa) kullanılarak monitorize edildi. İmmünohistokimyasal yoğunluk yarı kantitatif olarak değerlendirildi. Bu amaçla, vimentin, desmin ve laminin için immünoreaktivite yoğunluğu negatif (-), zayıf (+), orta (++) veya güçlü (+++) pozitif olarak puanlandı (Sağsöz ve ark., 2017). Hücrelerdeki immünohistokimyasal reaksiyonların yoğunluk skorları araştırmacı tarafından yapıldı. Sıçan derisinde, luminal ve bez epitel hücreleri, stroma, kas hücreleri ve kıl folikülleri ile miyoepitelyal hücreleri boyanma yoğunluğu açısından değerlendirildi (Tablo 1).

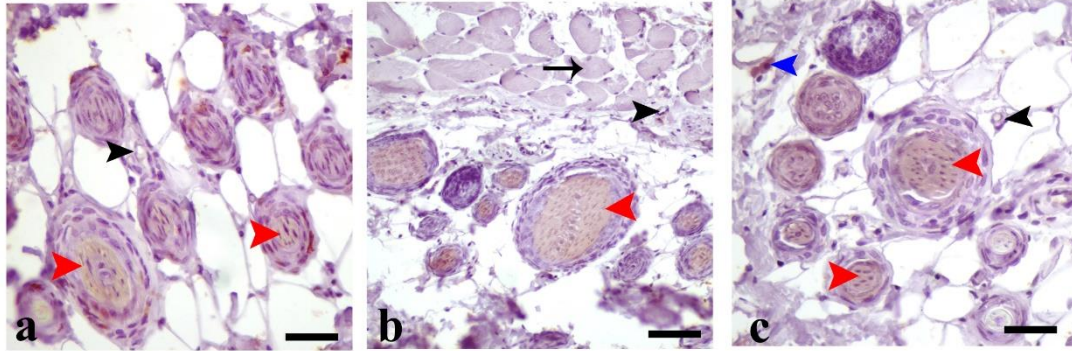
Tablo 1. Luminal ve bez epitel hücreleri, stroma, kas hücreleri ve kıl folikülleri ile miyoepitelyal hücreleri boyanma yoğunluğu (Hocam Tablo yeni eklendi)

<i>Doku/Hücre</i>	<i>Vimentin</i>	<i>Desmin</i>	<i>Laminin</i>
<i>Kıl Medullası</i>	Zayıf	Zayıf	Zayıf
<i>Kıl korteksi</i>	Negatif	Negatif	Negatif
<i>Kıl dış epitel hücreleri</i>	Negatif	Negatif	Güçlü
<i>Kıl iç epitel hücreleri</i>	Negatif	Negatif	Negatif
<i>Kılın retraktör kası</i>	Negatif	Güçlü	Negatif
<i>Derinin kas tabakası</i>	Negatif	Güçlü	Orta
<i>Bağ doku hücreleri</i>	Orta	Negatif	Güçlü
<i>Kan damarı</i>	Negatif	Orta	Zayıf

Bulgular

Vimentin

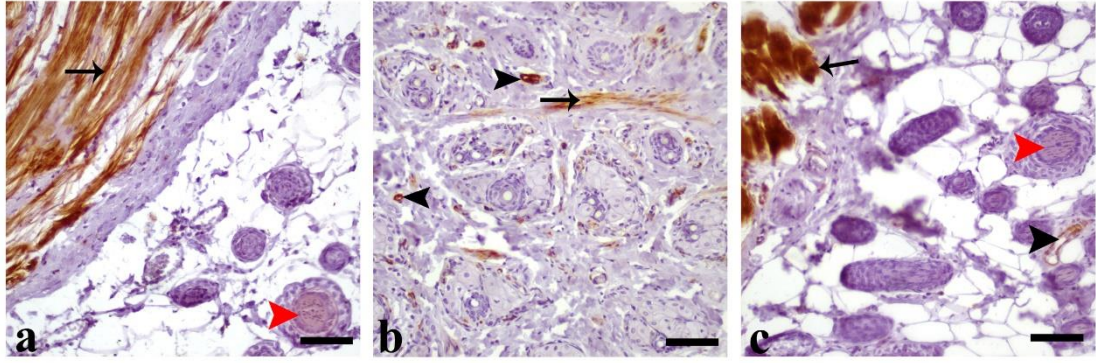
Deri ve kıl kökleri vimentin açısından incelendiğinde, kılın medulla katmanının bazı kesitlerde zayıf boyandığı, diğer kesitlerde ise boyanmanın olmadığı görüldü. Bağ doku hücrelerinin de buna benzer şekilde bazı kesitlerde orta güçlükte boyanmalar gösterdiği ancak diğer kesitlerde zayıf veya negatif reaksiyon verdiği görüldü. Kılın retraktör kası, epitel hücreleri, korteks ve medullası gibi bölümlerde boyanmalara rastlanmadı (Şekil 1).



Şekil 1. Sıçan derisinin epitel hücreleri ile düz kas hücrelerinde vimentin için güçlü lokalizasyonların görünümü. Siyah ok başı Kan damarı, kırmızı ok başı kıl folikülü, mavi ok başı bağ dokusu, siyah ok Kas dokusu. Barlar a,b,c: 50µm.

Desmin

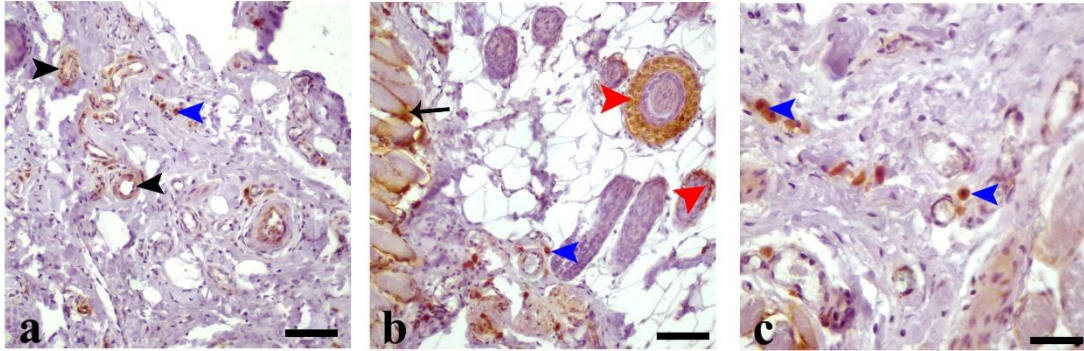
Deri ve kılın histolojik yapısı desmin bakımından incelendiğinde, derinin kas katmanının ve kılın retraktör kaslarının güçlü reaksiyonlar verdiği, bazı kan damarlarında orta güçlükte reaksiyonlar, kılın medullasında ise zayıf reaksiyon verdiği görüldü. Dokular desmin açısından incelendiğinde, kılın epitel hücreleri ve medullası gibi bölümünde boyanmaya rastlanmadı (Şekil 2).



Şekil 2. Sıçan derisinin epitel hücreleri ile düz kas hücrelerinde desmin için güçlü lokalizasyonların görünümü. Siyah ok başı Kan damarı, kırmızı ok başı kıl folikülü, mavi ok başı bağ dokusu hücresi, siyah ok Kas dokusu. Barlar a,b,c 50μm.

Laminin

Lamininin derinin kas tabakasında orta güçlükte reaksiyonlar verdiği, bazı bağ doku hücrelerinin güçlü reaksiyonlar verdiği, kılın dış epitel hücrelerinin güçlü reaksiyonlar verirken iç epitelial hücrelerinin reaksiyon vermediği, kılın medullasının ise zayıf reaksiyon verdiği görüldü. Kılın retraktör kasında herhangi bir reaksiyona rastlanmadı (Şekil 3).



Şekil 3. Sıçan derisinin epitel hücreleri ile düz kas hücrelerinde laminin için güçlü lokalizasyonların görünümü. Siyah ok başı Kan damarı, kırmızı ok başı kıl folikülü, mavi ok başı bağ dokusu hücresi, siyah ok Kas dokusu. Barlar a 25 μm, b,c 50μm.

Tartışma

Deri çok katmanlı keratinize yapısıyla organizmayı koruyan bir örtü görevi görür. Deri dış epidermis, dermis ve hipodermisten oluşan, sinirleri, kan damarlarını, bezleri ve saç köklerini içeren kompleks bir yapıdır (Prost-Squarcioni, 2006). Vücut yüzeyinden dışarı çıkan deri uzantısı olan saç, tüy, pul, tırnak, pençe gibi oluşumlar organizmayı korurken, vücuda yayılan deri uzantıları yağ bezi, ter bezi, meme bezi gibi oluşumlar organizmaya, çevresel adaptasyon gibi özel fizyolojik işlevler kazandırır (Widelitz ve ark. 1997). Derinin bütünlüğü ve sağlıklı bir yapıda olması, organizmanın dış etmenlerden korunması, çeşitli hastalık etmenlerinin organizmaya girişini engeller ve/veya zorlaştırır.

Bu çalışmada, erişkin sıçanların deri dokusunda, intermedier filamentlerden vimentin ve desmin ile bağdoku komponentlerinden laminin'in ekspresyonlarını ortaya

koyduk. Bulgularımızda, sıçan derisinde bu komponentlerin kılın medulla katmanında, bazı bağ doku hücrelerinde, derinin kas katmanında, kılın retraktor kaslarında, kılın medullasında, bazı kan damarlarında ve kılın dış epitel hücrelerinde çeşitli güçlükte reaksiyonlar verdiği görüldü. Diğer memelilerde olduğu gibi, sıçan derisinde de vimentin, desmin ve lamininin bazı hücre gruplarından eksprese olması, deride bu faktörlerin hücre iskeletine ve doku bütünlüğüne katkı sunduğunu göstermiştir.

Köpeklerde kulağın sağlıklı deri dokusu ve deri tümörleri ile yapılan bir çalışmada, tümör örneklerinin desmin ve vimentin açısından pozitif reaksiyon gösterdiği bildirilmiştir. Aynı çalışmada, epidermal melanositlerde ve dendritik epidermal ve matris hücrelerinde (Langerhans hücreleri) vimentin boyaması olduğu ifade edilmiştir. Vimentin reaktivitesinin epitelyal olmayan dermal ve perimatriks dokularda (fibroblastlar, kan hücreleri, vasküler endotel ve makrofajlar) daha belirgin olduğu gösterilmiştir (Broekaert ve ark. 1988). Vimentinin derideki yara iyileşmesi üzerine yapılan bir çalışmada, Vimentin kaybının, fibroblast büyümesinde ciddi bir eksikliğe yol açtığı, buna bağlı olarak, keratinosit aktivasyonunda kayıp, sınırlı keratinizasyon ve yavaş yeniden epitelizasyon görüldüğü bildirilmiştir. Bu çalışmada, vimentinin fibroblast proliferasyonunu, TGF- β 1-Slug sinyali, kollajen birikimini ve EMT işlemeyi kontrol ederek iyileşmeyi düzenlediğini ve bunların hepsinin gerekli keratinosit aktivasyonunu yönettiği belirtilmiştir (Cheng ve ark., 2016). Lensin epitel katmanı üzerine yapılan bir çalışmada, yara kenarındaki onarım hücrelerinde vimentin filamentleri olduğu bildirilmiştir. Mikrotübüllerin, onarım hücrelerinde vimentin filamentlerinin uzatılmasında, vimentin açısından zengin çıkıntıların oluşturulmasında ve yaranın kapanmasında rol oynadığı ortaya konulmuştur (Menko ve ark., 2014). Sığırların vasküler endotel hücreleri üzerinde yapılan bir çalışmada, vimentinden zayıf dokuların iyileşme güçlerinin zayıf olduğu, vimentinden güçlü olan dokuların güçlü bir endotelial iyileşme gücüne sahip olduğu bildirilmiştir (Helmke ve ark., 2000). Bizim çalışmamızda, yukarıdaki çalışmaların aksine vimentin varlığı güçlü ekspresyonlar göstermemiştir. Vimentinin kılın medullasında zayıf ekspresyonlar gösterdiği ortaya konulmuştur. Bağ doku hücrelerinin bazılarında ise Helmke ve ark.'larının (2000) çalışmalarına benzer şekilde güçlü reaksiyonların olduğunu ancak bu reaksiyonların bazı bağdoku hücreleri ile sınırlı olduğu belirlenmiştir.

Kirfel ve ark.'ları (2002) tarafından farelerin bazal epidermisleri üzerinde yapılan bir çalışmada, desmin, hücrelerdeki hücre iskeleti mimarisi ve tasarımında merkezi olduğu fikrini desteklediği bildirilmiştir. Desmin ile yapılan bir çalışmada, incelenen doku örneklerin güçlü desmin ekspresyonları olduğu bildirilmiştir (Bruecks ve Trotter, 2002). Normal insan derisinde, desminin önemli ölçüde ekspresyon gösterdiği bildirilmiştir (Walter ve ark., 1998). Farklı deri hastalıkları taşıyan köpeklerde desminin orta güçlükte reaksiyonlar verdiği ancak bu reaksiyonların güvenilir olmadığı ifade edilmiştir (Andreasen ve ark., 1988). Desminin daha çok kas dokularında ve kassel yapılarda varlığı bildirilmiştir, ayrıca neoplastik dokularda ekspresyonunun önemli ölçüde arttığı belirlenmiştir (Andreasen ve ark., 1988; Bruecks ve Trotter, 2002; Kirfel ve ark., 2002; Walter ve ark., 1998). Broekaert ve ark. köpek kulağında desminin dermisteki bazı vasküler düz kas hücreleriyle sınırlı olduğunu ortaya koymuşlardır (Broekaert ve ark., 1988). Bizim çalışmamızda, desmin kılın retraktor kası, damar düz kas hücreleri ve derinin lamina muskularisinde güçlü, kılın medulla kısmında ise zayıf ekspresyonlar gösterdiği saptanmıştır.

İnsanlarda yeni doğan derisinde immüno Floresan boyama ile yapılan bir çalışmada, keratinosit göçüne endojen laminin birikiminin eşlik ettiği ortaya konulmuştur (Zhang ve

Kramer, 1996). İnsan derisinde lamininin, epidermisin bazal tabakası, kıl folikülleri ve kan damarı duvarlarında güçlü reaksiyonlar verdiği bildirilmiştir. Dolayısıyla matris bileşenleri ve bunların reseptörlerinin, insan derisinin büyüme, gelişme ve organizasyonunun düzenlenmesinde lamininin etkili olduğu ileri sürülmüştür (Peltonen ve ark., 1989). Derideki basal hücre karsinomları (BCC) üzerine immunohistokimyasal ve histopatolojik olarak yapılan bir çalışmada, laminin BCC'nin düzensiz bir sitoplazmik dağılım gösterdiği belirlenmiştir. Basal membran (BM) dağılımının düzensiz olduğu kalın laminal alanlarda daha güçlü ekspresyonların olduğu, ince alanlarda zayıf ekspresyonların olduğu ifade edilmiştir (Mostafa ve ark., 2010). Li ve ark., (2003) insan kıl foliküllerinde, laminin ekspresyonunun güçlü olduğunu bildirmiştir. Aynı çalışmada, laminin varlığının kıl oluşumunda önemli olduğu yokluğunda kıl oluşum ve gelişiminde aksaklıklar oluştuğu gösterilmiştir. Sunulan çalışmamıza benzer şekilde, sıçan derisinin kas tabakasının orta güçlükte reaksiyonlar verdiği, bazı bağ doku hücrelerinin güçlü reaksiyonlar verdiği, kılın dış epitel hücrelerinin güçlü reaksiyonlar verirken iç epitelial hücrelerinin reaksiyon vermediği, kılın medullasının ise zayıf reaksiyon verdiği belirlendi. Li ve ark. (2003) tarafından belirtildiği üzere, kılın dış hücrelerinde gözlenen reaksiyonların, kıl gelişimi üzerinde etkili olabileceği yönündeki düşünceleri sıçanlarda da desteklediği görülmüştür.

Sonuç

Sonuç olarak, sıçan derisindeki çeşitli doku ve hücre gruplarından vimentin, desmin ve lamininin eksprese olduğu ortaya konulmuştur. Bu sonuçlar; vimentinin deri ve kıl oluşumu ile ilgili güçlü bir belirteç olmadığını, desminin derinin kassel oluşumlarında güçlü bir belirteç olduğu ancak kıl kökü için zayıf bir belirteç olabileceğini, lamininin ise epitel hücrelerindeki güçlü ekspresyonlarının bu hücrelerde önemli fonksiyonları yerine getirebileceğini düşündürmüştür. Ayrıca lamininin epitel hücrelerdeki güçlü varlığı, kılın oluşumu ve gelişimi için önemli rollere sahip olduğu düşüncesini geliştirmiştir.

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LC-MS/MS Content Analysis of Ethanol Extracts from Some Naturally Occurring Plants and Their Biological Activity Against Certain Plant Pathogenic Microorganisms Under *In Vitro* Conditions

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Abstract

There is a significant need for environmentally friendly organic pesticides. This study was conducted to analyze the content of ethanol extracts from some naturally occurring plant parts in Elazığ, Türkiye, using LC-MS/MS and to determine their activity against certain plant pathogenic bacteria and microfungi. The study was carried out under *in vitro* conditions using a Randomized Complete Block Design with four replications. Antibacterial activity was assessed using the Agar Well Diffusion Method in Mueller-Hinton medium, while antifungal activity was determined using the Poisoned Food Method in Malt Extract Agar medium. The statistical analysis of the obtained data sets was performed using the Kruskal-Wallis H test. As a result, among the 33 standard compounds investigated in the extracts, none were found in *Asphodelus aestivus* L. and *Melissa officinalis*; three compounds (vanillin, gentisic acid, chlorogenic acid) were identified in *Tanacetum parthenium*; and four compounds (vanillin, trans-cinnamic acid, p-coumaric acid, hydroxybenzaldehyde) were identified in *Rosa canina* L. *Rosa canina* L. extract showed no activity against the pathogenic test microfungi, while the activity of *Tanacetum parthenium* extract increased with higher concentrations. It was observed that the extracts of *Asphodelus aestivus* L. and *Melissa officinalis* completely inhibited the growth of microfungi at concentrations of 15% and above (v/v). It is believed that the ethanol extracts exhibiting activity have the potential for use as food preservatives and biopesticides.

Keywords: Antimicrobial activity, Bioactive compounds, Biopesticide, *Fusarium oxysporum*, *Verticillium dahliae*

Doğal Yayılış Gösteren Bazı Bitkilerin Etanol Ekstraktlarının LC-MS/MS İçerik Analizi, *In Vitro* Şartlarında Bazı Bitki Patojeni Mikroorganizmalar Üzerindeki Biyolojik Aktivitesi

Özet

Çevre dostu organik pestisitlere ciddi derecede gereksinim duyulmaktadır. Bu çalışma, Elazığ'da (Türkiye) doğal yayılış gösteren bazı bitki kısımlarının etanol ekstraktlarının LC-MS/MS ile içerik analizi, bitki patojeni bazı bakteri ve mikrofungalara karşı aktivitesini belirleme amacıyla yapılmıştır. Çalışma, *in vitro* şartlarında Tesadüf Parselleri Deneme Deseninde ve dört tekerrürlü olarak yürütülmüştür. Antibakteriyel aktivite, Agar Well Diffüzyon Yöntemiyle Mueller-Hinton ortamında; antifungal aktivite, Zehirli Plak Yöntemi kullanılarak Malt Ekstrat Agar ortamında belirlenmiştir. Elde edilen veri setlerinin istatistiksel analizinde Kruskal Wallis H testi kullanılmıştır. Sonuç olarak: Ekstraktlarda araştırılan 33 standart bileşikten *Asphodelus aestivus* L. ve *Melissa officinalis*'te rastlanılmadığı; *Tanacetum parthenium*'da üç (sırasıyla vanillin, gentisic acid, chlorogenic acid); *Rosa canina* L.'da dört (sırasıyla vanillin, trans-cinnamic acid, p-coumaric acid, ydroxybenzaldehyde) bileşik belirlenmiştir. Patojen test mikrofungusları üzerine *Rosa canina* L. ekstraktının aktivite göstermediği; *Tanacetum parthenium*

ekstraktının artan konsantrasyonlarla birlikte aktivitesinin arttığı; *Asphodelus aestivus* L. ve *Melissa officinalis* ekstraktlarının %15 ve üzeri oranlarda (v/v) mikrofungusların çoğalmasını tamamen engellediği görülmüştür. Aktivite gösteren etanol ekstraktlarının gıda koruyucu ve biyopestisit amaçlı kullanıma potansiyelinin olduğu düşünülmektedir.

Anahtar Kelimeler: Antimikrobiyal aktivite, Biyoaktif bileşikler, Biyopestisit, *Fusarium oxysporum*, *Verticillium dahliae*

Introduction

Plant pathogenic bacteria and fungi cause damage to crops, particularly in agriculture, and pose significant threats to agricultural sustainability and global food security, leading to considerable economic losses (Strange and Scott 2005; Nelson et al. 2018; Martins et al. 2018; Holtappels et al. 2021; Sharma et al. 2022; Anand and Rajeshkumar 2022; Koščak et al. 2023). Important bacterial plant pathogens include *Ralstonia solanacearum*, *Erwinia amylovora*, *Xylella fastidiosa*, *Agrobacterium tumefaciens*, *Xanthomonas oryzae* pv. *oryzae*, *Xanthomonas campestris* pathovars, *Pseudomonas syringae* pathovars, *Dickeya* (*dadantii* and *solani*), *Pectobacterium carotovorum* (and *Pectobacterium atrosepticum*), *Xanthomonas axonopodis* pathovars, and (Mansfield et al. 2012). Pathogenic fungi of the *Fusarium* and *Verticillium* genera are among the pathogens that cause serious damage to plants worldwide (Klosterman et al. 2009; Ferrigo et al. 2016). With the increase in human population, it is essential to reduce crop losses caused by pathogens to meet the rising food demands (Buttimer et al. 2017). Synthetic pesticides are commonly preferred in combating these agents (Sharma et al. 2022; Khan et al. 2023; Koščak et al. 2023). Despite some benefits, numerous studies have identified undesirable effects of synthetic pesticides on non-target organisms and the environment (Arora and Sahni 2016; Buttimer et al. 2017; Kowalska 2021; Tudi et al. 2021; Sharma et al. 2022; Lyubenova et al. 2023; Khan et al. 2023; Koščak et al. 2023). Biopesticides should be developed to manage both pathogens and the undesirable effects of chemical pesticides (Tudi et al. 2021; Koščak, 2023). Natural-based biopesticides are considered alternatives to conventional pesticides. Active compounds from certain plant species, along with beneficial microorganisms, can serve as sources of biopesticides. Among the promising biopesticide sources are plants like *Tanacetum parthenium* (*T. parthenium*) (Lyubenova et al. 2023). The *Tanacetum* genus belongs to the Asteraceae or Compositae family and has been used as a medicinal agent in traditional medicine worldwide since ancient times. A literature review has identified the presence of numerous chemical compounds in different *Tanacetum* species. More than 200 compounds have been identified in the essential oils obtained from these species. Traditionally, they are used in the production of cosmetics, insecticides, pharmaceuticals, dyes, balms, preservatives, and herbal medicines (Kumar and Tyagi 2013; Ghavam 2021; Michalak et al. 2024; Bandi et al. 2025). Ghavam (2021) reported that the essential oil of *T. parthenium* exhibited activity against *Aspergillus brasiliensis*. Among the plants used in traditional medicine are those from the *Asphodelus* genus found in the Mediterranean region of Southeast Asia and North Africa. These plants have been used by indigenous peoples for various pathologies, including burns, nephrolithiasis, psoriasis, acne, toothache, alopecia areata, and local inflammation (Malmir et al. 2018; Dioguardi et al. 2019). *Asphodelus aestivus* Brot. (*A. aestivus* Brot.) is recognized as an important wild medicinal plant (Farid et al. 2021; El-Elmat et al. 2024; Zöngür, 2024). It has been observed that different concentrations of *A. aestivus* Brot. essential oils are effective

against all tested fungi (Zöngür, 2024). An important plant family is Lamiaceae, which includes 236 genera and 250 species. *Melissa officinalis* (*M. officinalis*) is the most common species in this family (Hassan et al. 2019). *M. officinalis* L. is a perennial plant with various ethnomedical, therapeutic, and culinary applications. Traditionally, it has been used in the treatment of infectious bites, ulcers, herpes, wounds, and parasitic disorders (Abdel-Naime et al. 2019). Another significant plant family is Rosaceae, which consists of approximately 200 species, mostly shrubs (Fayaz et al. 2024). *Rosa canina* L. (Dog rose) (*R. canina* L.) is a plant species that naturally grows in Europe, temperate Eurasia, Western Asia, North Africa, and the northern hemisphere of North and South America (Köroğlu, 2023). The *Rosa* species exhibit various pharmacological activities, including anti-diabetic, hepatoprotective, antimicrobial, anti-inflammatory, anti-arthritic, anti-proliferative/anti-cancer, neurological, and anti-obesity effects (Öğüt, 2022; Fayaz et al. 2024). *R. canina* contains a large amount of pharmacologically active components (flavonols, carotenoids, tannins, and organic acids) (Öğüt, 2022). Due to the negative effects of chemical pesticides, the search for alternative biopesticides is ongoing. Literature searches indicate that the substances present in plants are effective in various fields, from health to food preservation. Due to their natural distribution and the active compounds they contain, medicinally significant plants play an important role in the search for biopesticides. Undoubtedly, the use of plant-based biopesticides will contribute to the restoration of disrupted ecosystems. Literature searches have shown that parameters such as the location where the plants grow, the substances and methods used in extraction, and the microorganisms used in activity tests significantly affect the results (Abdellatif et al. 2014; Ehsani et al. 2017; Mabrouki et al. 2018; Alizadeh Behbahani and Shahidi 2019; Abdel-Naime et al. 2019). This research was carried out to determine the content analysis of ethanol extracts of some plants (*Asphodelus aestivus* L., *Melissa officinalis*, *Rosa canina* L., *Tanacetum parthenium*) that grow naturally in Elazığ province and to determine their activities against some plant pathogenic microorganisms under *in vitro* conditions.

Materials and Methods

Plants

In this study, the leaves of *Asphodelus aestivus* L. (*A. aestivus* L., Asphodelaceae), the leaves of *Melissa officinalis* (*M. officinalis*, Lamiaceae), the fruits of *Rosa canina* L. (*R. canina* L., Rosaceae), and the flowers of *Tanacetum parthenium* (*T. parthenium*, Asteraceae or Compositae) were used, all of which are naturally occurring and utilized by the local population in Elazığ, Türkiye.

Extraction Process

The plants collected from the natural habitat and identified were dried in the shade. Subsequently, an extraction process was carried out using a 1:1 ethanol/water mixture at a temperature of 60 °C for 10 hours, with a plant/solvent ratio of 1:20 (g/mL). The obtained extracts were stored at -20 °C until used in the experimental study.

Test Microorganisms

The plant pathogenic bacterial isolates *Erwinia amylovora*, *Pseudomonas syringae* pv. *syringae*, *Xanthomonas euvesicatoria*, *Clavibacter michiganensis* subsp. *michiganensis*, and *Verticillium dahliae*, *Fusarium oxysporum* fungal isolates, were

obtained from the Van Yüzüncü Yıl University, Faculty of Agriculture, Department of Plant Protection.

Content Analysis by LC-MS/MS

For the chemical analyses of the extracts, 50 mg samples of each extract were taken into 2 mL Eppendorf tubes. To each sample, 1 mL of a mixed solvent (acetonitrile-methanol-water in a 1:1:1 ratio) was added for dissolution. The samples were vortexed until dissolved, and any undissolved material was treated in an ultrasonic bath. Subsequently, 0.8 mL of hexane was added to perform the extraction process. The samples were centrifuged at 7000 rpm for 5 minutes. The lower phase was then collected and diluted at a ratio of 1:4. Finally, the samples were filtered through a 0.25 µm filter before LC-MS/MS analysis was conducted (Atalar et al. 2021). Additional information regarding the analysis procedure is summarized in Table 1.

Table 1. LC-MS/MS conditions

	Time (min)	A (%)	B (%)	Features
1	0	85	15	System: Agilent 6460 Agilent 6460 Triple Quad LCMS Column: Poroshell 120 EC-C18 (50 mm 4.6 mm I.D., 2.7 µm) Injection volume: 4.00 µl Flow: 0.400 mL/min Temperature: 30.00 °C Method time: 40.00 min A: Water 0.1% Formic acid, 5mM ammonium formate B: Acetonitrile 0.1% Formic acid
2	5	75	25	
3	15	25	75	
4	16	0	100	
5	20	0	100	
6	22	85	15	
7	40	85	15	

Determination of Antimicrobial Activity

Antibacterial Activity Studies

The antibacterial activity of the plant extracts was determined using the Agar Well Diffusion Method (Balouiri et al. 2016). In this study, the turbidity of the 24-hour cultures of the pathogenic bacterial strains used was adjusted according to the 0.5 McFarland standard (Anonymous, 2019). A volume of 100 µL from the cultures with standard turbidity was spread onto the surface of Mueller-Hinton Agar (MERCK) using a sterile glass rod. Subsequently, wells of 10 mm diameter were created using a Cork Borer. To these wells, 50 µL of solutions diluted with distilled water at concentrations of 5%, 10%, 15%, 20%, and 25% (v/v) were applied. Chloramphenicol (30 µg) and Ciprofloxacin (5 µg) standard disks were used as control antibiotics. After incubating the Petri plates at 35°C for 24 hours, the zones of inhibition around the wells and disks were evaluated as positive results.

Antifungal Activity Studies

The antifungal activities of the plant extracts were determined using the Poisoned Food Method reported by Balouiri et al. (2016). For this purpose, the final concentrations of the extracts were prepared by adding them to Malt Extract Agar (MERCK) at concentrations of 5%, 10%, 15%, 20%, and 25% (v/v) in Petri plates. Ten millimeter diameter sections from cultures of *Verticillium dahliae* (*V. dahliae*) and *Fusarium oxysporum* (*F. oxysporum*) fungal isolates were transferred to the extract-containing Petri plates. For positive control, 50 µL of Cycloheximide (prepared by dissolving at a concentration of 35 mg/mL in ethanol) was added to Malt Extract Agar plates, and sections of 10 mm diameter from both microfungus cultures were aseptically transferred

to the negative control Malt Extract Agar plates. After inoculation, the Petri plates were incubated at 27°C for 7 days. The study was conducted using a Randomized Complete Block Design with four replications. After incubation, the microfungi in the Petri dishes were checked, and the colony diameters were measured and recorded. The percentage of mycelium growth inhibition was calculated using the following formula (Yahyazadeh et al. 2008).

$$\text{MGI (\%)} = [(C - T)/C] \times 100$$

MGI (%) is the percent mycelial growth inhibition, C the colony radius of the pathogen when growing (negative control); T the colony radius of the pathogen for each extract concentration.

Statistical Analysis

The normality of the obtained data was assessed using the Shapiro-Wilk Goodness of Fit Test and the Kolmogorov-Smirnov Test. It was determined that the data did not conform to a normal distribution. Accordingly, the colony diameters were compared using the Kruskal-Wallis H test. The statistical significance level was considered to be $p < 0.05$. The analyses were performed using the SPSS (Statistical Package for the Social Sciences, SPSS Inc., Chicago, IL) version 21 software.

Results

Content Analysis

The content analysis of the extracts was investigated for 33 standard compounds using LC-MS/MS. No such compounds were detected in the extracts of *A. aestivus* L. and *M. officinalis*. In the extract of *R. canina* L., four compounds were identified (namely vanillin, trans-cinnamic acid, p-coumaric acid, and hydroxybenzaldehyde), while three compounds (namely vanillin, gentisic acid, and chlorogenic acid) were identified in the extract of *T. parthenium* (Table 2).

Table 2. LC-MS/MS analysis (µg/L)

No	Standards	*R.T. (min)	<i>R. canina</i> L.	<i>A. aestivus</i> L.	<i>M. officinalis</i>	<i>T. parthenium</i>
1	Gallic acid	2.227	*N.D.	N.D.	N.D.	N.D.
2	Epigallocatechin	2.576	N.D.	N.D.	N.D.	N.D.
3	Chlorogenic acid	2.572	N.D.	N.D.	N.D.	43.07
4	Catechin	2.826	N.D.	N.D.	N.D.	N.D.
5	Gentisic acid	3.082	N.D.	N.D.	N.D.	125.19
6	Caffeic Acid	3.321	N.D.	N.D.	N.D.	N.D.
7	Syringic acid	3.495	N.D.	N.D.	N.D.	N.D.
8	Vanillic acid	3.628	N.D.	N.D.	N.D.	N.D.
9	Rutin	2.885	N.D.	N.D.	N.D.	N.D.
10	Isoquercitrin	4.486	N.D.	N.D.	N.D.	N.D.
11	Polydatin	4.601	N.D.	N.D.	N.D.	N.D.
12	Hydroxybenzaldehyde	4.802	8.77	N.D.	N.D.	N.D.
13	p-coumaric acid	4.737	75.09	N.D.	N.D.	N.D.
14	Sinapic acid	5.406	N.D.	N.D.	N.D.	N.D.
15	Vanillin	5.375	481.23	N.D.	N.D.	271.10
16	trans-ferulic acid	5.635	N.D.	N.D.	N.D.	N.D.
17	Taxifolin	5.930	N.D.	N.D.	N.D.	N.D.
18	Salicylic Acid	7.589	N.D.	N.D.	N.D.	N.D.
19	o-coumaric acid	7.824	N.D.	N.D.	N.D.	N.D.
20	Baicalin	8.079	N.D.	N.D.	N.D.	N.D.
21	Protocatechuic ethyl ester	8.353	N.D.	N.D.	N.D.	N.D.

Table 2. LC-MS/MS analysis (µg/L) (Continued)

22	Protocatechuic acid	8.529	N.D.	N.D.	N.D.	N.D.
23	Kaempferol	9.975	N.D.	N.D.	N.D.	N.D.
24	Trans-cinnamic acid	10.995	125.55	N.D.	N.D.	N.D.
25	Naringenin	11.735	N.D.	N.D.	N.D.	N.D.
26	Morin	12.077	N.D.	N.D.	N.D.	N.D.
27	Quercetin	11.839	N.D.	N.D.	N.D.	N.D.
28	7-Hydroxyflavone	12.113	N.D.	N.D.	N.D.	N.D.
29	Chrysin	13.619	N.D.	N.D.	N.D.	N.D.
30	Luteolin	14.042	N.D.	N.D.	N.D.	N.D.
31	Biochanin A	13.719	N.D.	N.D.	N.D.	N.D.
32	5-Hydroxyflavone	15.762	N.D.	N.D.	N.D.	N.D.
33	Diosgenin	20.976	N.D.	N.D.	N.D.	N.D.

*R.T.: Retention Time, *N.D.: Not detected

Antimicrobial Activity

Antibacterial Activity

It was determined that the plant extracts did not exhibit any activity against the tested bacteria.

Antifungal Activity

The extract of *R. canina* L. showed no activity against the tested microfungi (*F. oxysporum* and *V. dahliae*); however, the activity of the *T. parthenium* extract increased with higher concentrations. The extracts of *M. officinalis* and *A. aestivus* L. completely inhibited the tested microfungi at concentrations of 15% and above (v/v) (Table 3, Figures 1-7).

Upon examining Table 3, it is observed that there is a statistically significant difference in the colony diameters of *F. oxysporum* and *V. dahliae* microfungi among the plant extracts, except for *R. canina* L. ($p<0.001$).

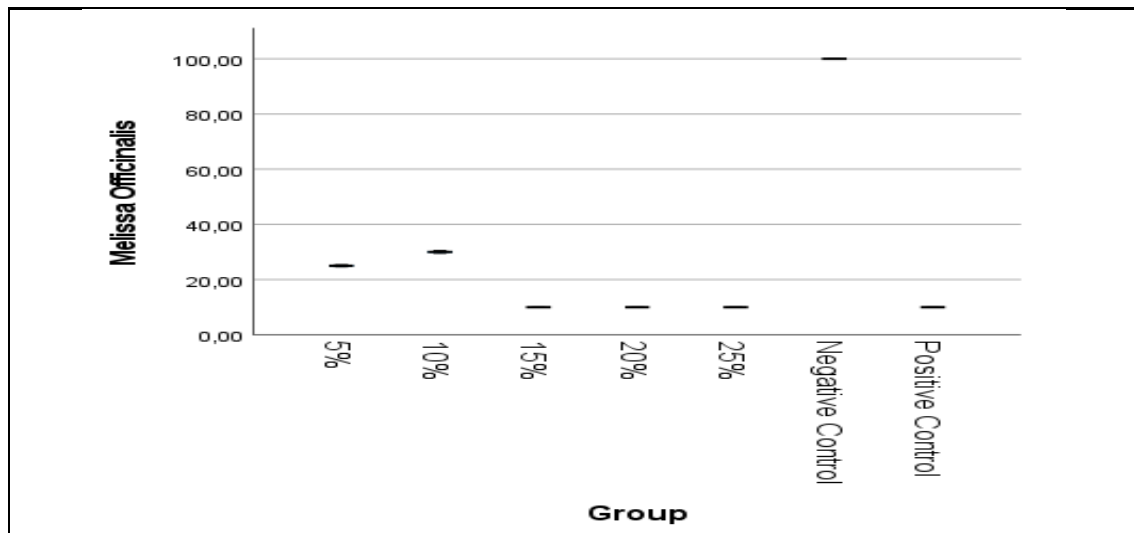


Figure 1. Comparison of the antifungal activity of *M. officinalis* extract against the *F. oxysporum* microfungus in terms of colony diameters.

Upon examining Figure 1, it is observed that the colony diameters of the *F. oxysporum* microfungus in the positive control group, as well as in the *M. officinalis*

extract groups at 15%, 20%, and 25%, are significantly lower than that of the negative control group ($p<0.05$). This indicates that the positive control and the 15%, 20%, and 25% (v/v) applications are significantly more effective compared to the negative control group (Figure 1).

Table 3. Comparison of colony diameters of extracts using the Kruskal-Wallis Test

Test microorganisms	Extracts	Applications (v/v)	N	$\bar{X} \pm SD$	Median	Average inhibition rate (mm)	P value
<i>F. oxysporum</i>	<i>M. officinalis</i>	5%	4	25.00±0.33	25.00	75	<0.001
		10%	4	30.00±0.41	30.00	70	
		15%	4	10.00±0.00	10.00	90	
		20%	4	10.00±0.00	10.00	90	
		25%	4	10.00±0.00	10.00	90	
		Control (Positive)	4	10.00±0.00	10.00	90	
		Control (Negative)	4	100.00±0.00	100.00	0	
	<i>T. parthenium</i>	5%	4	60.00±1.42	60.40	40	<0.001
		10%	4	25.00±0.24	25.00	75	
		15%	4	20.13±0.35	20.15	79.88	
		20%	4	12.00±0.71	12.20	88	
		25%	4	11.75±0.33	11.85	88.02	
		Control (Positive)	4	10.00±0.00	10.00	90	
		Control (Negative)	4	99.75±0.50	100.00	0.25	
	<i>A. aestivus</i> L.	5%	4	55.50±0.56	55.35	44.50	<0.001
		10%	4	19.50±0.41	19.50	80.50	
		15%	4	10.00±0.00	10.00	90	
		20%	4	10.00±0.00	10.00	90	
		25%	4	10.00±0.00	10.00	90	
		Control (Positive)	4	10.00±0.00	10.00	90	
		Control (Negative)	4	100.00±0.00	100.00	0	
<i>V. dahliae</i>	<i>M. officinalis</i>	5%	4	30.00±0.71	29.80	70	<0.001
		10%	4	24.82±0.40	24.80	74.92	
		15%	4	10.00±0.00	10.00	90	
		20%	4	10.00±0.00	10.00	90	
		25%	4	10.00±0.00	10.00	90	
		Control (Positive)	4	10.00±0.00	10.00	90	
		Control (Negative)	4	100.00±0.00	100.00	0	
	<i>T. parthenium</i>	5%	4	55.00±0.71	55.25	45	<0.001
		10%	4	25.00±0.57	25.00	75	
		15%	4	20.00±0.33	20.00	80	
		20%	4	11.03±0.31	11.10	88.97	
		25%	4	11.00±0.71	11.20	89	
		Control (Positive)	4	10.00±0.00	10.00	90	
		Control (Negative)	4	100.00±0.00	100.00	0	
	<i>A. aestivus</i> L.	5%	4	45.00±0.41	45.00	55	<0.001
		10%	4	20.00±0.71	19.80	80	
		15%	4	10.00±0.00	10.00	90	
		20%	4	10.00±0.00	10.00	90	
		25%	4	10.00±0.00	10.00	90	
		Control (Positive)	4	10.00±0.00	10.00	90	
		Control (Negative)	4	100.00±0.00	100.00	0	

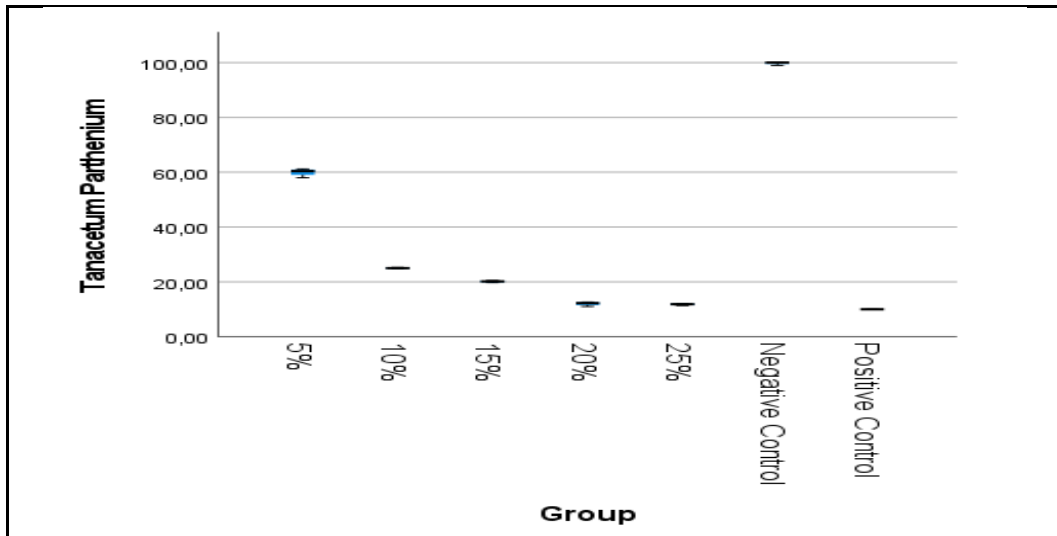


Figure 2. Comparison of the antifungal activity of *T. parthenium* extract against the *F. oxysporum* microfungus in terms of colony diameters

Upon examining Figure 2, it is observed that the colony diameters of the *F. oxysporum* microfungus in the positive control, as well as in the *T. parthenium* extract groups at 20% and 25%, are significantly lower than that of the negative control group ($p<0.05$). This indicates that the positive control and the 20% and 25% (v/v) groups are significantly more effective compared to the negative control group. Additionally, in the *T. parthenium* extract, the colony diameter of the positive control group is significantly lower than that of the 5% group ($p<0.05$). Thus, the positive control group is significantly more effective compared to the 5% group.

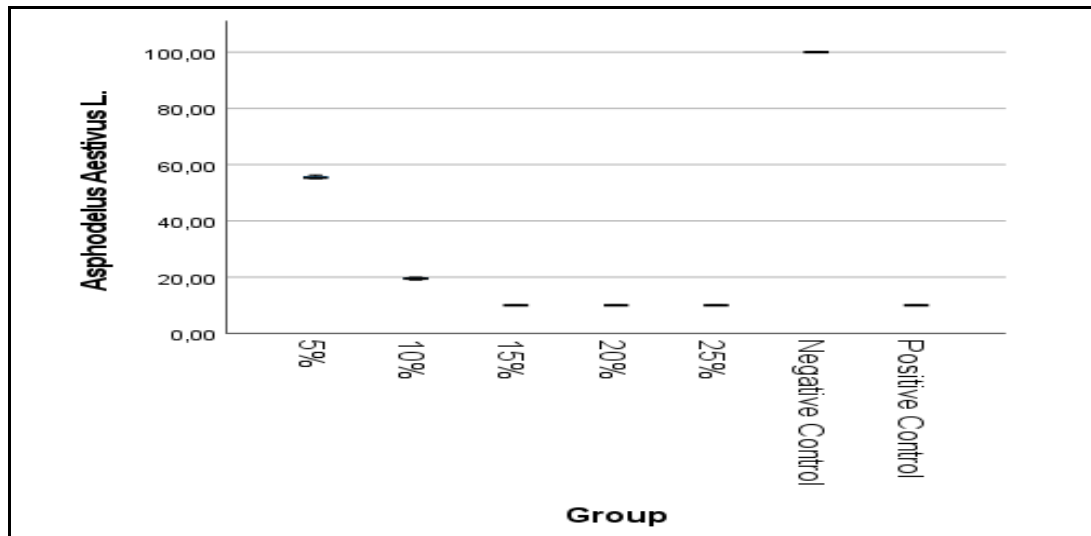


Figure 3. Comparison of the antifungal activity of *A. aestivus* L. extract against the *F. oxysporum* microfungus in terms of colony diameters

Upon examining Figure 3, it is observed that the colony diameters of the *F. oxysporum* microfungus in the positive control, as well as in the *A. aestivus* L. extract groups at 15%, 20%, and 25%, are significantly lower than that of the negative control

group ($p<0.05$). This indicates that the positive control and the 15%, 20%, and 25% (v/v) groups are significantly more effective compared to the negative control group.

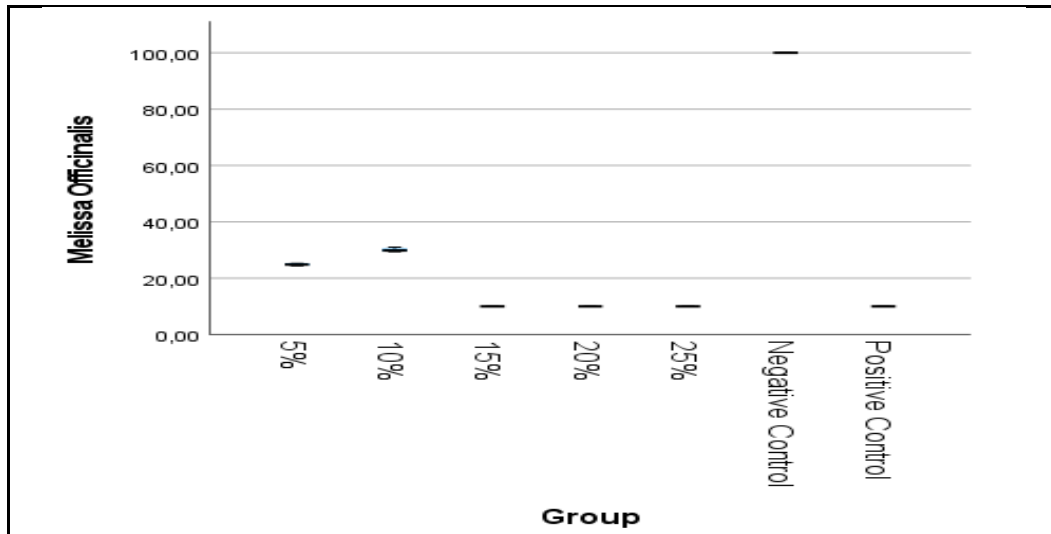


Figure 4. Comparison of the antifungal activity of *M. officinalis* extract against the *V. dahliae* microfungus in terms of colony diameters

Upon examining Figure 4, it is observed that the colony diameters of the *V. dahliae* microfungus in the positive control, as well as in the *M. officinalis* extract groups at 20% and 25%, are significantly lower than that of the negative control group ($p<0.05$). This indicates that the positive control and the 15%, 20%, and 25% (v/v) groups are significantly more effective compared to the negative control group.

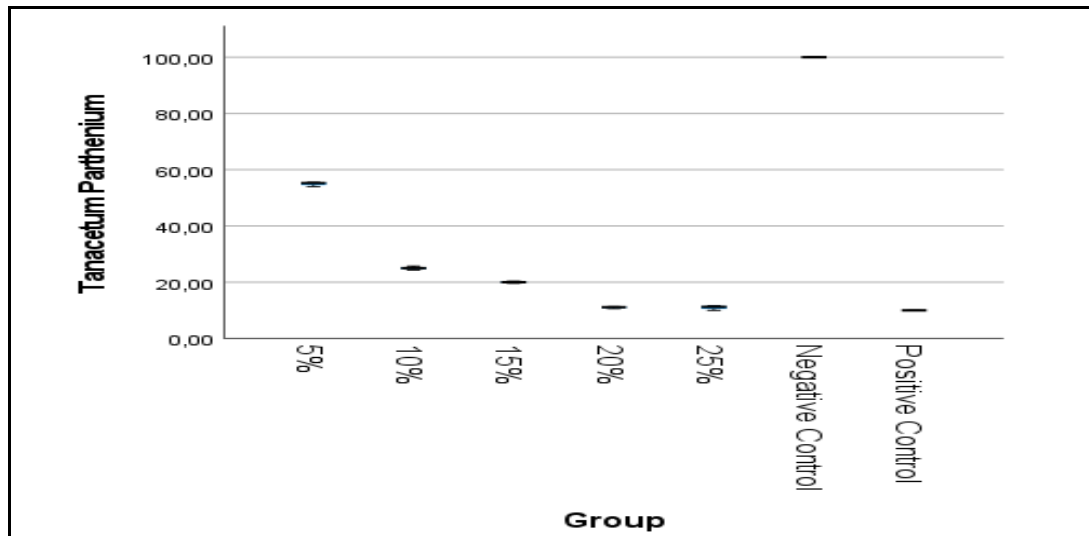


Figure 5. Comparison of the antifungal activity of *T. parthenium* extract against the *V. dahliae* microfungus in terms of colony diameters

Upon examining Figure 5, it is observed that the colony diameters of the *V. dahliae* microfungus in the positive control, as well as in the *T. parthenium* extract groups at 20% and 25%, are significantly lower than that of the negative control group ($p<0.05$).

This indicates that the positive control and the 20% and 25% dosage groups are significantly more effective compared to the negative control group. Additionally, the colony diameter of the positive control group is significantly lower than that of the 5% group in the *T. parthenium* extract ($p<0.05$). Thus, the positive control group is significantly more effective compared to the 5% group.

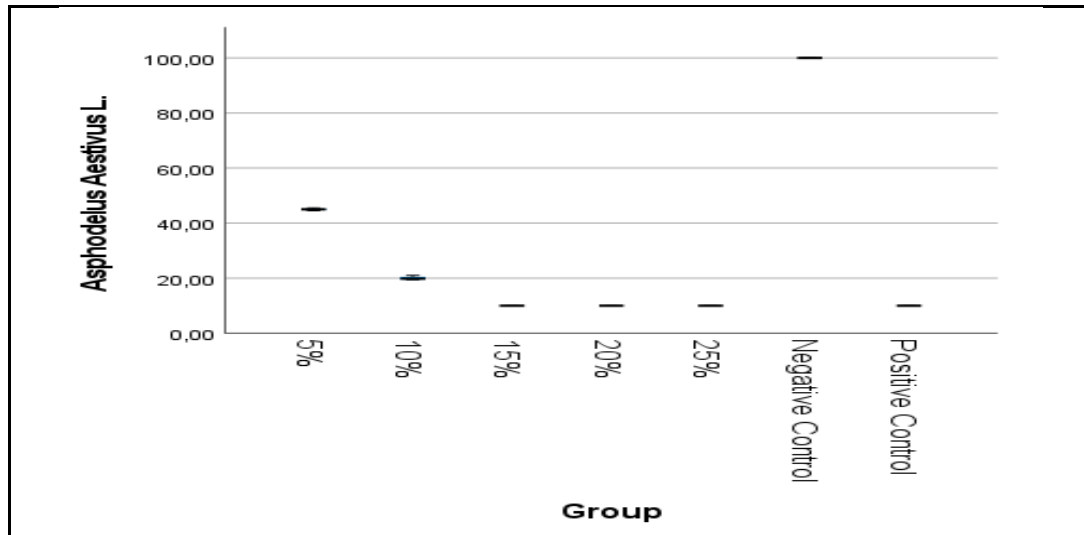


Figure 6. Comparison of the antifungal activity of *A. aestivus* L. extract against the *V. dahliae* microfungus in terms of colony diameters

Upon examining Figure 6, it is observed that the colony diameters of the *V. dahliae* microfungus in the positive control, as well as in the *A. aestivus* L. extract groups at 15%, 20%, and 25%, are significantly lower than that of the negative control group ($p<0.05$). This indicates that the positive control and the 15%, 20%, and 25% (v/v) groups are significantly more effective compared to the negative control group.

Applications (v/v)	<i>M. officinalis</i>	<i>T. parthenium</i>	<i>A. aestivus</i> L.
5%			
10%			

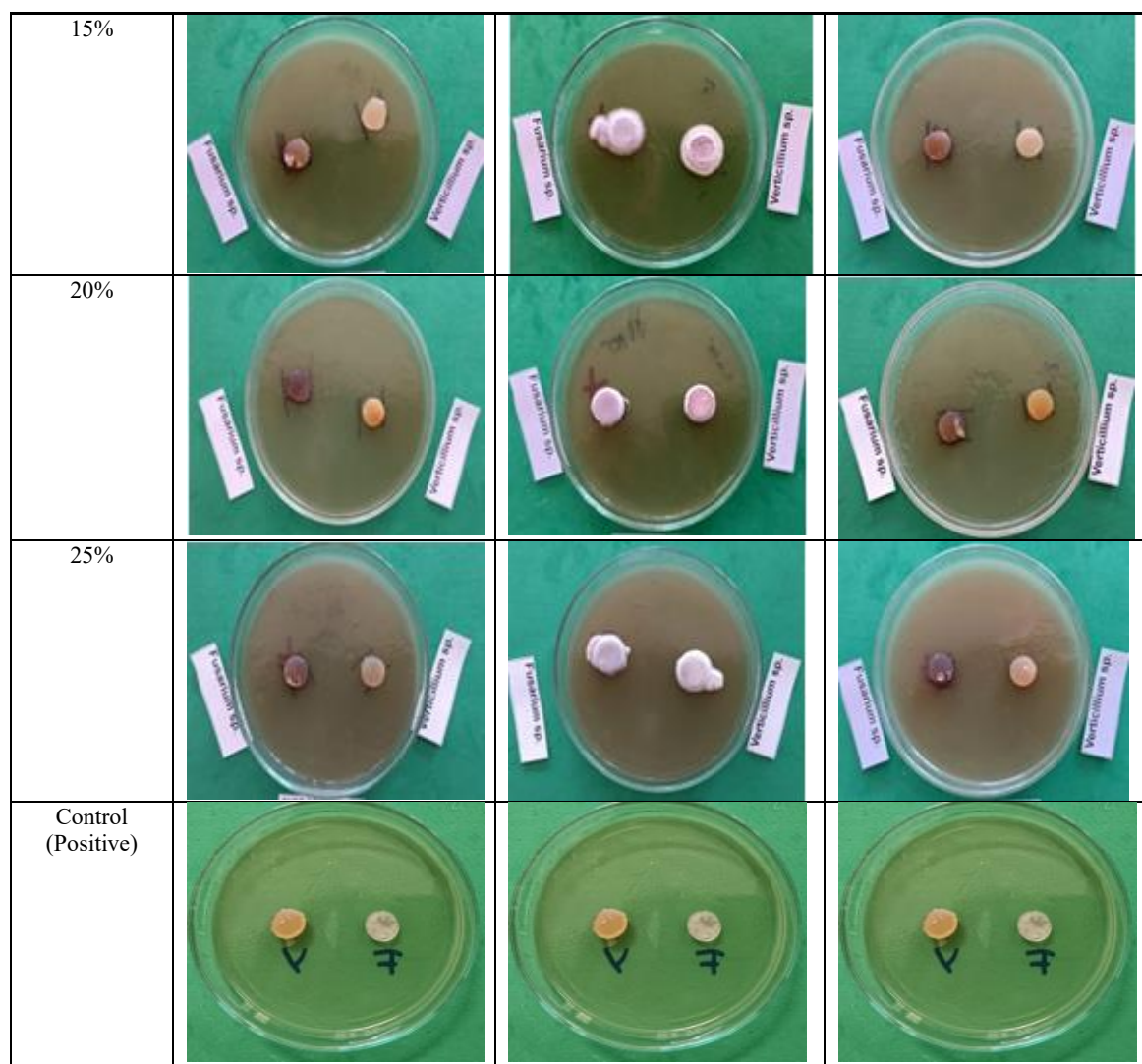


Figure 7. Sample images related to the antifungal activity of plant extracts at different concentrations and positive control (50 µl cycloheximide) applications (Continued).

Discussion

In the current study conducted by us, the ethanol extracts of different parts (such as leaves, fruits, and flowers) of four plant species were evaluated for 33 standard compounds investigated by LC-MS/MS. It was found that some of the analyzed compounds were not present in certain extracts (*M. officinalis* and *A. aestivus* L.); four compounds (namely vanillin, p-coumaric acid, trans-cinnamic acid, and hydroxybenzaldehyde) were detected in *R. canina* L., while three compounds (vanillin, gentisic acid, and chlorogenic acid) were identified in *T. parthenium*. In a similar study conducted in Jordan, seven compounds were identified in the LC-MS analysis of *A. aestivus* Brot. The authors of this study attributed this result to the presence of a wide variety of chemical compounds in the plant and different chemical variations influenced by regional environmental factors (El-Elimat et al. 2024). Due to the lack of sufficient studies in the literature regarding the content analysis of the studied plant extracts using LC-MS/MS, studies conducted with various methods such as GC/MS were evaluated. For example, 22 different components were identified in the extract produced from *A. aestivus*

Brot. using hydrodistillation (GC/MS) (Zöngür, 2024). In a study regarding the extract content produced from the hydrodistillation of *M. officinalis* L. leaves grown in Algeria (GC/MS and GC-FID), 63 compounds were detected (Abdellatif et al. 2014). In a study aimed at characterizing the polyphenolic profile and bioactive properties of the boiled, infused, and hydroalcoholic extracts of *M. officinalis* L., the main phenolic compound identified was rosmarinic acid (Silva et al. 2023). Alizadeh Behbahani and Shahidi (2019) reported that geranyl acetate, citral, z-citral, citronellal, and citronellol were the main components in the GC-MS analysis of *M. officinalis* essential oil. Ehsani et al. (2017) identified components such as citronellal, thymol, citral, and β -caryophyllene in their analyses of *M. officinalis* essential oil (GC-MS). Differences were observed between the findings of our study and the comparative studies. It is estimated that these differences arise from parameters such as the location where the plants are grown, the parts used, the extraction method, and the devices and methods used in content analyses. In the current study conducted by us, it was found that the extracts did not show activity against the plant pathogens *Xanthomonas euvesicatoria*, *Clavibacter michiganensis* subsp. *michiganensis*, *Erwinia amylovora*, and *Pseudomonas syringae* pv. *syringae*; however, different results were obtained regarding their activities against the microfungi *F. oxysporum* and *V. dahliae*. Among these, the extracts of *M. officinalis* and *A. aestivus* L. completely inhibited the test microfungi at concentrations of 15% and above; the activity of *T. parthenium* extract increased with increasing concentrations, while *R. canina* L. extract showed no activity at all. Literature searches revealed that some studies had been conducted on the antimicrobial activities of the plant species used by us. However, there are some differences between these studies and the study we conducted regarding the extraction method, the location where the plants were grown, and the parts used. For instance, Zöngür (2024) reported that the extract produced from *A. aestivus* Brot. was effective against all test species (*Aspergillus flavus*, *Rhizopus oryzae*, *Fusarium oxysporum*, *Alternaria solani*, *Penicillium expansum*, and *Aspergillus parasiticus*) at different concentrations of volatile oils. Zöngür and Buzpinar (2023) stated that the inhibition rates of *A. aestivus* leaf extracts against *Aspergillus flavus* and *Aspergillus parasiticus* ranged from 3.13% to 89.94%. It appears that the results obtained in terms of antifungal activity of *A. aestivus* leaf extracts overlap with the findings of both studies. Rabbani et al. (2016) reported that the hydroalcoholic extract of *M. officinalis* showed the highest antibacterial activity against *Staphylococcus aureus* among various test bacteria. Mabrouki et al. (2018) stated that the ethanol extract produced from *M. officinalis* L. using various solvents exhibited a strong inhibitory effect against *Staphylococcus aureus*. Ehsani et al. (2017) determined that *Staphylococcus aureus* was the most sensitive bacterial species in their activity determination tests conducted on *M. officinalis* essential oil against four foodborne bacteria. In a study by Abdel-Naime et al. (2019), it was reported that *M. officinalis* L. has significant antimicrobial potential, especially against gram-positive bacteria and yeasts. Abdellatif et al. (2014) indicated that the extract produced from the hydrodistillation of *M. officinalis* L. leaves showed high antimicrobial activity against five human pathogenic bacteria, one yeast, and two phytopathogenic fungi. Alizadeh Behbahani and Shahidi (2019) reported that *M. officinalis* has greater inhibitory effects on commercial bacterial strains that cause infections compared to clinical bacterial strains, with the greatest effect occurring against gram-positive bacteria. Yu et al. (2022) reported that the essential oil of *M. officinalis* L. (MOEO) exhibited antimicrobial activity against *Vibrio parahaemolyticus*, attributing this effect to the damage caused by MOEO to the morphology of the cell membrane. Additionally, they

suggested that MOEO has potential as a natural food preservative. It was determined that the studies provided regarding the antimicrobial activity of *M. officinalis* overlap with the antifungal activity of the study conducted by us. In our study, differences were detected between the LC-MS/MS content and antimicrobial activity results. For instance, it was found that *R. canina* L. and *T. parthenium*, which contain the highest phenolic compounds, showed no activity; however, *A. aestivus* L. and *M. officinalis* extracts, which did not have phenolic compounds detected by LC-MS/MS, showed activity only against microfungi. This situation indicates the presence of compounds exhibiting antifungal activity that could not be detected by LC-MS/MS standards. Furthermore, the antimicrobial effects of the compounds identified by LC-MS/MS may vary depending on their concentrations, the type of microorganisms, and many other factors.

Conclusion

In this study, out of 33 standard compounds investigated by LC-MS/MS, four compounds were determined in *R. canina* L. extract (vanillin, trans-cinnamic acid, p-coumaric acid and hydroxybenzaldehyde, respectively) and three compounds were determined in *T. parthenium* extract (vanillin, gentisic acid and chlorogenic acid, respectively). Among the tested pathogenic microfungi, the best activity on *F. oxysporum* and *V. dahliae* was determined to be from *M. officinalis* and *A. aestivus* L. plant species extracts. In particular, it is reported that ethanol extracts of *M. officinalis* and *A. aestivus* L. plant species at 15% and above can be evaluated in terms of antifungal activity. Additionally, it is anticipated that the ethanol extracts exhibiting activity may contribute economically, with potential applications in biotechnology, food preservation, biopesticide development, and the pharmaceutical industry.

Conflict of Interest

The authors declare that they have no conflict of interest

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Comprehensive Investigation of Electrical and Photodiode Characteristics of Au/MgO/n-Si/Al Schottky Barrier Diode for High-Performance Light Detection Applications

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Abstract

In this study, the electrical and optoelectronic properties of the Au/MgO/p-Si/Al metal-insulator-semiconductor (MIS) structure were comprehensively investigated under different light intensities at room temperature (300 K). The structural, morphological, optical and electrical properties of the device were systematically investigated using X-ray diffraction (XRD), atomic force microscopy (AFM), scanning electron microscopy (SEM), UV-Vis spectroscopy and current-voltage (I-V) measurements taken under different illumination conditions. Current-voltage (I-V) characteristics revealed that the structure exhibited a photosensitive diode behavior, and a significant increase in the reverse bias current occurred as the light intensity increased. The dependence of key electrical parameters such as ideality factor (n), saturation current (I_0), and barrier height (Φ_b) on light intensity was analyzed; I_0 and n values increased with light, while Φ_b value decreased. In addition, important photodetector parameters of the device such as photosensitivity, photocurrent, and detection were calculated as a function of light intensity and presented graphically. All these parameters showed an increasing trend, with the detection value especially reaching the Jones level of 3×10^9 under 100 mW/cm^2 light. The findings show that the Au/MgO/p-Si/Al MIS structure is a promising candidate for photodetector applications with high sensitivity and efficient light detection ability.

Key Words: MIS, Photodiode, I-V, Photosensitivity, Detectivity, Magnesium Oxide

Yüksek Performanslı Işık Algılama Uygulamaları için Au/MgO/n-Si/Al Schottky Bariyer Diyotunun Elektriksel ve Fotodiyot Özelliklerinin Kapsamlı Araştırması

Özet

Bu çalışmada, Au/MgO/p-Si/Al metal-yalıtkan-yarıiletken (MIS) yapısının oda sıcaklığında (300 K) farklı ışık şiddetleri altında elektriksel ve optoelektronik özellikleri kapsamlı bir şekilde incelenmiştir. Cihazın yapısal, morfolojik, optik ve elektriksel özellikleri; X-ışını kırınımı (XRD), atomik kuvvet mikroskobu (AFM), taramalı elektron mikroskobu (SEM), UV-Vis spektroskopisi ve farklı aydınlatma koşulları altında alınan akım-voltaj (I-V) ölçümleri kullanılarak sistematik olarak incelenmiştir. Akım-voltaj (I-V) karakteristikleri, yapının ışığa duyarlı bir diyot davranışı sergilediğini ve ışık şiddeti arttıkça ters besleme akımında önemli bir artış olduğunu ortaya koymuştur. İdeallik faktörü (n), doyma akımı (I_0) ve engel yüksekliği (Φ_b) gibi temel elektriksel parametrelerin ışık şiddetine bağımlılığı analiz edilmiştir; I_0 ve n değerleri ışıkla artarken, Φ_b değeri azalmıştır. Ayrıca, cihazın fotoduyarlılık, fotoakım ve dedektiflik gibi önemli fotodedektör parametreleri ışık şiddetine bağlı olarak hesaplanmış ve grafiksel olarak sunulmuştur. Tüm bu parametreler, bir artış eğilimi göstermiş, özellikle dedektiflik değeri 100 mW/cm^2 ışık altında 3×10^9 Jones seviyesine ulaşmıştır. Elde edilen bulgular, Au/MgO/p-Si/Al MIS yapısının yüksek duyarlılığa ve etkin ışık algılama yeteneğine sahip, fotodedektör uygulamaları için umut vadeden bir aday olduğunu göstermektedir.

Anahtar Kelimeler: MIS, Fotodiyot, I-V, Fotoduyarlılık, Dedektiflik, Magnezyum Oksit

Introduction

The rapid development of modern electronic and optoelectronic devices has increased the demand for high-performance, stable, and scalable materials. In this context, metal oxides have assumed a central role in semiconductor technology due to their unique electrical, optical, and chemical properties. As wide-bandgap insulators, metal oxides are used in critical applications, particularly in metal-insulator-semiconductor (MIS) structures and high-k dielectrics. When used as interface layers in conventional Schottky barrier diodes (SBDs), these materials can significantly improve the device's key electrical parameters (barrier height, ideality factor, and dark current) by passivating the semiconductor surface and reducing the Fermi level pinning effect (Dalapati et. al., 2024; Deniz, 2023).

In this study, magnesium oxide (MgO) was selected as the primary interface material for the MIS structure. MgO occupies a superior position among metal oxides and possesses distinctive properties that justify this choice. MgO has an exceptionally wide energy band gap of approximately 7.8 eV (Hwang and Chang, 2022). This makes it a nearly transparent insulator and also enables it to withstand high electric fields in high-voltage applications. Its high dielectric constant helps control device capacitance, while its excellent thermal and chemical stability ensures device longevity and reliability. A critical function of MgO is its ability to effectively passivate trapping surface states on the p-type silicon (p-Si) surface. This passivation reduces the reverse polarization dark current (I_0), which is crucial for photodetection applications, and reduces device noise (Kumar, et. al., 2022).

Schottky barrier photodiodes are devices that operate by converting light energy into electrical signals and are ideal for optical communication systems requiring high-speed detection. The Au/MgO/p-Si/Al structure proposed in this study is designed to offer significant advantages over conventional p-Si-based photodiodes. The use of high-work function gold (Au) metal and the application of a thin layer of MgO insulator allow for optimization of the barrier height (Φ_b) and, thus, more efficient collection of carriers generated under light exposure. Surface passivation induced by MgO reduces the probability of photorecombination of electron-hole pairs. This increases the device's light sensitivity (responsiveness) while helping to maintain critical photodiode properties such as fast response time (Taşer, 2025). The potential of MgO in MIS structures has been widely explored in the literature. Various metal-oxide interface layers have been shown to improve the performance of silicon and gallium arsenide (GaAs)-based photodetectors. For example, studies using p-type semiconductors such as NiO or wide-bandgap insulators such as AlO_3 have demonstrated the significant positive effects of interface modification on electrical ideality and photosensing performance. However, detailed and systematic characterization of the electrical and photoelectric mechanisms of the Au/MgO/p-Si/Al structure fabricated using MgO thin films on p-type silicon remains a gap in the literature, particularly in light of the unique effects of the fabrication method. This paper presents the successful fabrication of an Au/MgO/p-Si/Al MIS Schottky barrier photodiode and its electrical and optical properties under various light conditions (Li, et. al., 2016).

The main contribution of our work is to quantify the unique performance improvement provided by the MgO interface in p-Si-based photodetectors. The findings include detailed analysis of the device using Thermionic Emission (TE) theory and series resistance models, demonstrating the reduction in dark current and improvement in ideality factor, and most importantly, demonstrating the device's high light sensitivity and

fast response performance. This work directly contributes to optoelectronic technology by providing a promising roadmap for developing high-performance, low-cost, and reliable photodetectors using existing silicon-based technology infrastructure through MgO integration. This study's originality lies in providing a detailed and systematic characterization of the electrical and photoelectric mechanisms of the Au/MgO/p-Si/Al structure, addressing a specific gap in the literature concerning the unique performance of MgO thin films fabricated on p-type silicon.

Materials and Methods

The Au/MgO/p-Si/Al Schottky Barrier Photodiode was fabricated using low-cost and scalable fabrication methods. P-type silicon (p-Si) substrates with a resistivity range of 1–10 $\Omega\cdot\text{cm}$ were used as starting materials. To remove surface contaminants and native oxide layers that could negatively affect device performance, the p-Si substrates were subjected to a rigorous chemical cleaning process based on the industry-standard RCA (Radio Corporation of America) method (Çaldıran, et. al., 2021). The Si substrates were immersed in RCA-1 solution consisting of a mixture of NH_4OH , H_2O_2 , and deionized water (DIH_2O) (1:1:5) and heated to approximately 80 °C for 10 minutes. This step removed organic residues and metallic ions from the surface. To remove the thin native oxide layer formed on the surface, the substrates were immersed in a dilute HF solution for 1 minute. Finally, the substrates were immersed in the RCA-2 solution, which consisted of a mixture of HCl , H_2O_2 , and $\text{DI H}_2\text{O}$ (1:1:6) and heated at approximately 80°C for 10 minutes. This final step ensured the removal of any remaining ionic contaminants. After each cleaning step, the substrates were thoroughly rinsed with abundant $\text{DI H}_2\text{O}$ and dried under a N_2 gas stream to prepare for the next step (Deniz, 2022).

A thin MgO film was deposited as an insulating interface layer on the cleaned p-Si substrate by spin coating. First, a MgO precursor solution prepared in a suitable solvent was dropped onto the p-Si surface. The substrate was spun briefly (30 seconds) at a controlled speed (typically 3000 rpm) to ensure uniform spread of the solution across the surface. Following coating, the sample was thermally treated (annealed) at an appropriate temperature (450 °C) to ensure crystallization and formation of the MgO phase. The metal contacts required to complete the diode structure were deposited using a high-vacuum thermal evaporation system. To create a low-resistance ohmic contact with p-Si, aluminum (Al) metal was evaporated onto the back surface of the p-Si substrate coated with MgO. To ensure the low-resistance Al/p-Si ohmic contact, the samples were subjected to an additional annealing process under Argon atmosphere after evaporation. Au metal was evaporated onto the front surface above the MgO layer in the form of circular point contacts (≈ 1 mm in diameter) with a thin thickness (≈ 7 nm) to allow light penetration. By completing these steps, the fabrication of the Au/MgO/p-Si/Al Schottky barrier photodiode structure was successfully achieved.

Fig. 1 shows a cross-sectional view of a MIS Schottky barrier photodiode with an Au/MgO/p-Si/Al structure and its connection to an electrical measurement setup. The figure visually explains the device's layered architecture and the role of each component. Al, located in the bottom layer of the device, forms a low-resistance ohmic contact with p-type silicon (p-Si), providing a stable electrical connection. This layer is also connected to the cathode terminal. The p-Si above the Al contact forms the active semiconductor region of the device. Incoming light ($h\nu$) creates electron-hole pairs in this layer,

generating photocurrent. A thin MgO insulator film, a critical component of the device, sits on top of the p-Si. This layer passivates the p-Si surface, reducing surface states, which improves barrier height control and lowers the dark current, improving the overall performance of the photodiode. The topmost, semi-transparent Au layer functions as a Schottky contact on the MgO insulator. Its translucency allows incident light ($h\nu$) to penetrate into the p-Si active region. This layer is connected to the anode terminal. The schematic shows the device connected to a SMU (Source Measure Unit). This connection allows the diode's current-voltage (I-V) characteristics to be measured under different voltages, both in the dark and under different light intensities. These measurements are essential for determining the diode's fundamental electrical and photoelectric parameters, such as the ideality factor, barrier height, series resistance, and, most importantly, the photodiode's sensitivity and response time.

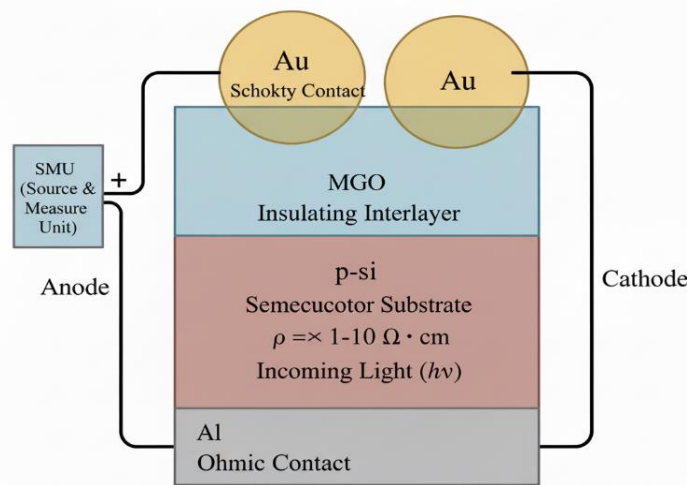


Figure 1. Au/MgO/p-Si/Al Schottky Bariyer Fotodiyotu Şeması.

Results and Discussion

Morphological analysis of MgO thin film

Fig. 2 shows the typical X-ray diffraction (XRD) pattern of a polycrystalline MgO thin film. This pattern provides important information about the film's crystal structure and preferred orientation. Three distinct diffraction peaks are observed in the graph. These peaks correspond to the characteristic crystal planes of MgO in the cubic (rock salt) structure. The first peak belongs to the MgO (111) plane, observed around 30.5° (2θ). The second and most intense peak belongs to the MgO (200) plane, observed around 39.5° (2θ). The third peak belongs to the MgO (220) plane, observed around 58.5° (2θ). These peak positions are consistent with standard MgO XRD data in the literature (JCPDS/ICDD charts) and confirm successful MgO film formation (Aksay, 2019). It is noteworthy that the MgO (200) peak has a much higher intensity compared to the other peaks (especially MgO (111)). This indicates the presence of a strong preferred crystal orientation (or texture) along the (200) plane in the synthesized MgO thin film. In many film growth techniques, the growth of specific crystal planes parallel to the substrate is

observed to minimize surface energy or stress. The presence of the other peaks (MgO (111) and MgO (220)) indicates that the film is not completely single crystalline, but has a polycrystalline structure, with the (200) orientation predominating. In conclusion, this XRD pattern clearly demonstrates that the MgO thin film used in Au/MgO/p-Si/Al diode fabrication was successfully synthesized, has a cubic crystal structure, and is a highly crystalline film with a strong preferred orientation, especially along the (200) plane. This high crystallinity and preferential orientation can contribute positively to the electrical and photoelectric performance of the device (Toprak, et. al., 2024).

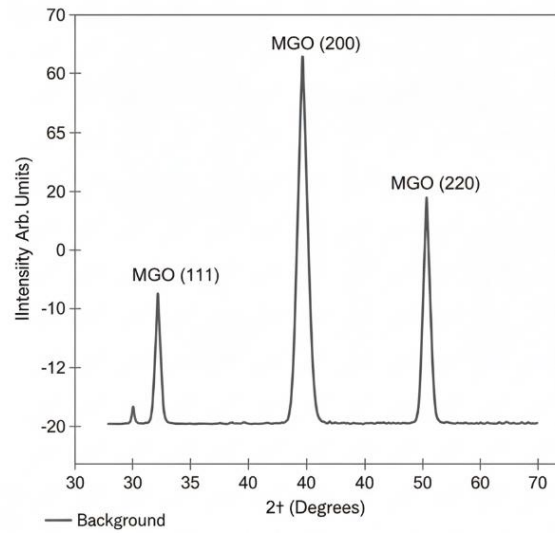


Figure 2. XRD pattern of MgO thin film.

Fig 3 presents a representative surface topography image of the synthesized MgO thin film obtained by Atomic Force Microscopy (AFM). This image highlights the film's microstructural features, particularly its surface morphology and roughness. The image clearly shows that the film surface has a structure composed of distinct, tightly interconnected nano-sized grains. These grains suggest that the film has dense and homogeneous coverage (Giner, et. al., 2015). The grains are generally nearly round in shape and exhibit a regular distribution. This homogeneous grain growth indicates that the film formation conditions were optimized and that no large agglomerations or voids formed on the surface. The RMS Roughness (Root Mean Square Roughness) value indicated below the image is ≈ 1.2 nm. This value indicates a very low roughness level for the MgO interface layer. Low surface roughness is critical for device performance. A smooth surface ensures better and more uniform contact between the surface metal (Au) and the MgO interface. This contributes to a smoother and more stable Schottky barrier. Rough surfaces can cause localized electric field concentrations, which in turn can increase leakage currents (dark currents) in reverse polarization. Low roughness minimizes such leakage paths, improving the signal-to-noise ratio and sensitivity of the photodiode. Smooth surfaces reduce carrier scattering at the interface, which can contribute to more efficient collection of photogenerated carriers. The grayscale scale on the right of the image represents surface height differences. Lighter tones indicate high

regions, while darker tones indicate low regions. Low roughness confirms that the transitions between these tones are smooth and limited. In conclusion, this AFM image demonstrates the successful synthesis of the MgO thin film used in the Au/MgO/p-Si/Al diode, demonstrating a nanocrystalline structure, dense and homogeneous structure, and particularly low surface roughness. These microstructural features support that the MgO layer can significantly improve the electrical and photoelectric performance of the device by providing effective passivation on the p-Si surface and forming a stable interface with the Au metal.

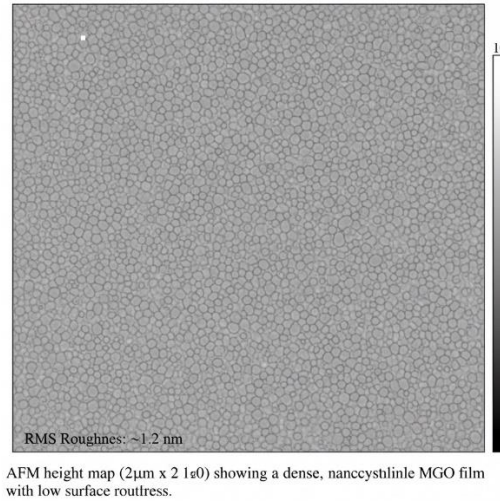


Figure 3. The AFM image of MgO thin film

The SEM image in Fig. 4 shows the surface morphology, grain structure, and homogeneity of the synthesized MgO thin film. The image reveals the film's characteristics at the microscopic scale. The image clearly reveals that the MgO thin film consists of nano-sized grains spread across the surface. These grains indicate that the film has a polycrystalline structure, with individual crystals aggregating to form the film. The grain sizes are generally small; compared to the 500 nm scale bar in the bottom right corner of the image, most grains are estimated to be below 100 nm, even around 50 nm in some areas. A uniform size distribution is a sign of controlled growth conditions. The grains are round or oval in shape, and in some areas, they appear to merge into larger clusters (agglomerations). Such aggregations are typical of spin-coating and subsequent annealing. The film appears to have uniformly coated a large area of the substrate. No obvious voids, pinholes, or uncoated areas are observed in the imaged area. This indicates that the film has good coverage and density (Sim, et. al., 2024). A dense film is critical for insulating properties and reduces unwanted leakage paths in the device. While SEM provides a three-dimensional perspective of the surface, it does not directly provide a quantitative measure of surface roughness (not as much as AFM). However, looking at the overall texture of the image, it can be said that the film surface has a certain roughness due to nanoscale grains, but there are no large-scale, sharp elevation differences. Gaps or elevated regions between grains can have an impact on electrical properties. In conclusion, this SEM micrograph confirms that the MgO thin film used in the Au/MgO/p-Si/Al diode has a nanocrystalline structure, that the surface is composed of nanoscale

grains, and that it exhibits an overall homogeneous and well-covering morphology. These microstructural features support the expected performance of the device by providing effective passivation of the MgO layer on the p-Si surface and creating a stable interface with the top metal electrode.

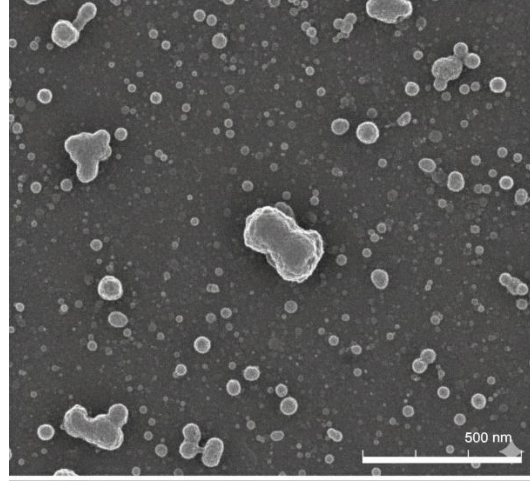


Figure 4. The SEM image of MgO thin film

Fig. 5 shows the UV-Vis spectrum of MgO. MgO is a wide-bandgap insulator. The sharp absorption edge observed in the UV-Vis spectrum (around 200 nm) is related to the band gap energy of MgO. From this wavelength, where absorption begins, the band gap energy ($E_g = hc/\lambda$) can be calculated (Berger, et. al., 2004). The energy value corresponding to around 200 nm (around 6.2 eV) is quite close to the known wide band gap of MgO. This means that electrons in the valence band require this amount of energy to transition to the conduction band. The very low absorbance in the visible region (around 400-700 nm) means that MgO readily transmits light at these wavelengths. This confirms that MgO is an optically transparent material and demonstrates its usefulness in applications such as optical windows, coatings, or insulating layers with high refractive index. Strong absorbance in the UV region indicates that MgO has the ability to block or filter UV rays. This UV-Vis spectrum clearly demonstrates that MgO is a wide band gap material. It exhibits strong absorption in the UV region and high transmittance in the visible and near-infrared regions. These properties make MgO a valuable material for optical and electronic applications.

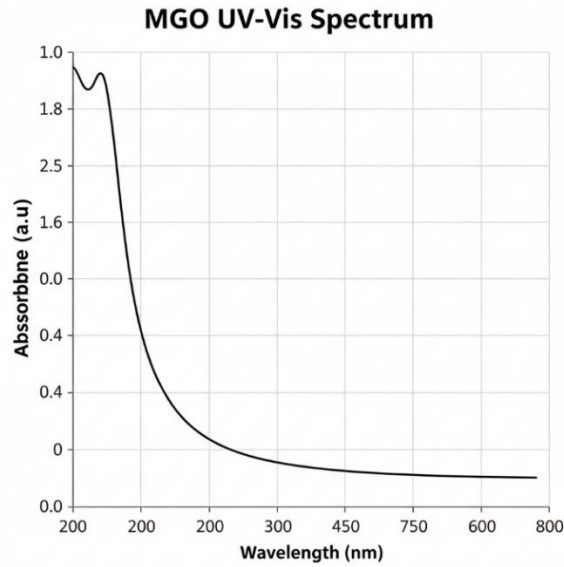


Figure 5. UV-Vis spectra of MgO material

Electrical and optical analysis of Au/p-Si/Al photodiode

To characterize the electrical and optical performance of this photodiode, a fundamental method is to examine the device's I-V characteristics as a function of illumination power. In our study, I-V measurements of the photodiode were performed under varying light intensities in the range of 0 to 100 mW/cm², in 20 mW/cm² steps. This range (20-100 mW/cm²) was chosen to systematically test the device's performance from moderate to strong illumination conditions. In particular, the upper limit of 100 mW/cm² is close to the standard "1 Sun" (AM 1.5) condition widely used in photodetector and solar cell characterization, providing an important reference point for evaluating the device's potential performance in real-world applications. Measurements in 20 mW/cm² steps allowed us to clearly demonstrate the dependence of key parameters such as photocurrent, sensitivity, and detection ability on the incident optical power and the dynamic response of the device. These systematic measurements reveal the device's photoresponse and dark current behavior and allow the calculation of critical parameters such as the ideality factor (n), which determines the device's quality, and the barrier height (Φ_b), which defines its electrical properties. In Schottky diodes with MIS structures, the current carrying mechanism is generally explained by thermal emission theory. Under ideal conditions, the diode current (I) under an applied forward voltage (V) in the dark is expressed by the following formula (Çaldıran, et. al., 2021):

$$I = I_0 [\exp (eV/nkT) - 1] \quad (1)$$

In this equation, I_0 is the reverse saturation current and is given by the formula:

$$I_0 = A A^* T^2 \exp (-q\Phi_b/kT) \quad (2)$$

q is the electron charge, k is the Boltzmann constant, T is the absolute temperature, A is the active device area, and A^* is the effective Richardson constant. The n indicates the extent to which the diode deviates from ideal behavior and indicates the extent to which the charge transport mechanism is affected by non-ideal processes such as tunneling,

recombination, or skin effects. For an ideal diode, $n = 1$, while in practical diodes, $n > 1$ is usually sufficient. The value of n is given by the following equation:

$$n = e/kT dV/d(\ln I) \quad (3)$$

The Φ_b represents the height of the potential barrier at the metal-semiconductor interface and directly affects the electrical performance of the diode. To calculate the I_0 value from the Richardson-Dushman equation, the reverse saturation current is first obtained from the intersection of the $\ln(I)$ vs. V plot at $V=0$. The Φ_b value is given by the following equation (Kim, 2024):

$$e\Phi_b = kT \ln(AA^* T^2/I_0) \quad (4)$$

In this study, the changes in the I_0 values and n and Φ_b parameters obtained from the I-V measurements of the Au/MgO/p-Si/Al photodiode under light intensity using the above formulas were investigated in detail depending on the illumination power.

Fig. 5 shows the I-V characteristics of the Au/MgO/p-Si/Al structure measured at 300 K, under dark conditions, and different light intensities (20, 40, 60, 80, 100 mW/cm²). The current axis, plotted on a logarithmic scale, clearly reveals the wide range of variation in current. A general look at the graph reveals that all curves exhibit the typical behavior of a conventional diode. In the forward-bias region (positive voltages), the current increases exponentially after a certain threshold voltage. In the reverse-bias region (negative voltages), the current remains significantly lower than in the forward-bias region (Yavru, et. al., 2022). The I-V curve under dark conditions (in the absence of light) exhibits a low leakage current of around 1×10^{-7} A at approximately -2 V in the reverse-bias region. This dark current can be explained as a combination of thermally generated carriers in the semiconductor and recombination-generation currents originating from defects at the interface (Priya, et. al., 2023). A low dark current is a desirable property for photodiodes, improving the signal-to-noise ratio and sensitivity of the device. The most important characteristic of a photodiode is its response to light. As can be seen in Figure 1, a dramatic increase in current is observed as the light intensity increases, particularly in the reverse-bias region. For example, while the dark current at -2 V is approximately 1×10^{-7} A, under a 100 mW/cm² light intensity, the current increases to approximately 3×10^{-5} A. This represents the "photocurrent," which occurs when incident photons create electron-hole pairs in the semiconductor's band gap and are separated by the internal electric field under reverse bias. The fact that the photocurrent increases in direct proportion to the light intensity clearly demonstrates the light-sensing capability of the device (Fidan, et. al., 2021). The MgO insulating layer serves as an interface between the Au metal and the p-Si semiconductor. This thin insulating film can influence both the dark current and photocurrent efficiency of the device by affecting the electric field distribution, the interface state density, and thus carrier recombination (Kamruzzaman and Zapien, 2017). As a wide-bandgap material, MgO, thanks to its optical transparency, allows light to reach the active p-Si region while reducing unwanted reactions and interface defects between the metal and semiconductor, helping to optimize device performance.

Table 1 summarizes the important electrical parameters of the Au/MgO/p-Si/Al structure obtained under different light intensities. In the dark, the saturation current is as low as 2.17×10^{-9} A. As the light intensity increases, the saturation current increases significantly. At 100 mW/cm^2 , this value increases to 1.75×10^{-7} A. This increase is consistent with our previous interpretation of the I-V plot and directly reflects the increase in the number of carriers (electron-hole pairs) generated by light. More light produces more carriers, which increases the effective saturation current. This indicates that the device is photosensitive as a photodiode. In the dark, $n = 1.44$. This indicates some deviation from the ideal diode ($n = 1$), suggesting the presence of mechanisms such as recombination or tunneling at the metal-semiconductor interface (Demirezen, et. al., 2023). The MgO insulator layer may also influence this deviation. The ideality factor (n) increases continuously with depending on the increasing illumination power. At 100 mW/cm^2 , the value of n increased to 4.34. The increase in n with light indicates that the device deviates further from ideal diode behavior. This may be an indication of recombination processes of carriers generated under light or an increase in the density of interface states. High ideality factors can generally indicate defects at the interface, tunneling currents, or voltage-dependent barrier heights (Haider, et. al., 2015). Furthermore, these values indicate that carrier dynamics under light differ from those in the dark (Mazzillo, et. al., 2014).

The barrier height in the dark is 0.82 eV. As the light intensity increases, the Φ_b decreases continuously. It decreased to 0.51 eV at 100 mW/cm^2 . This decrease in the barrier height by light indicates a phenomenon known as "photoreduction" or "photoband bending". Light generates carriers at the semiconductor surface, and these carriers reduce the effective barrier height by affecting the surface states or band bending. A lower barrier height makes it easier for carriers to overcome the barrier, which supports increased photocurrent (Öztürk, et. al., 2023). The rectification ratio in the dark is as high as 246.0. This indicates that the device behaves like a good diode in the absence of light, passing high forward current while largely blocking reverse current. As the light intensity increases, the rectification ratio decreases continuously. At 100 mW/cm^2 , this ratio dropped to 39.6. The decrease in rectification ratio with light is due to the significant increase in reverse current due to photocurrent. As we saw earlier in the I-V graph, current increases exponentially with light in a reverse bias. This is a consequence of the device's ability to detect light as a photodiode, but it also demonstrates that its efficiency as a conventional rectifier decreases under light (Somvanshi, et. al., 2013).

Table 1. Electrical parameters of Au/MgO/p-Si/Al structure under different light intensities

Light Power (mW/cm ²)	Saturation Current (A)	n	Φ_b (eV)	Rectification ration ($\pm 2V$)
In Dark	2.17×10^{-9}	1.44	0.82	246.0
20	5.43×10^{-8}	1.93	0.74	173.2
40	8.22×10^{-8}	2.56	0.69	124.5
60	3.43×10^{-7}	3.15	0.64	98.6
80	7.80×10^{-7}	4.01	0.59	72.4
100	1.75×10^{-7}	4.34	0.51	39.6

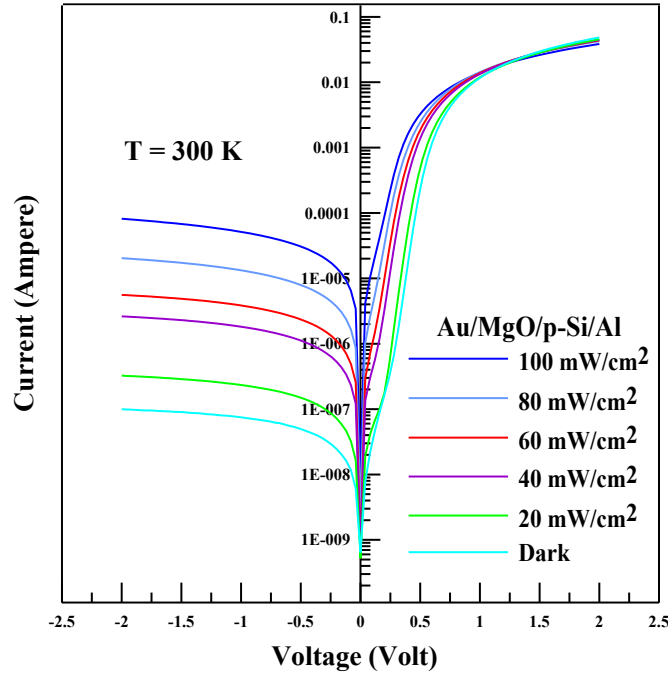


Figure 6. I-V characteristics of the Au/MgO/p-Si/Al structure under different light intensities (at T=300 K)

Fig. 6 shows how the generated photocurrent (I_{ph}) depends on the light intensity at a fixed reverse bias voltage ($V = -2$ V) for the Au/MgO/p-Si/Al structure. The most striking feature of the graph is the continuous and strong increase in photocurrent as the light intensity increases. This demonstrates that the device is highly sensitive to light and operates effectively as a photodetector. The increase in photocurrent is not entirely linear; the rate of increase accelerates, particularly at higher light intensities (60 mW/cm² and above). This suggests that the photocurrent exhibits a power-law relationship with light intensity. In semiconductor photodetectors, such nonlinear responses are generally the result of complex physical mechanisms such as carrier generation, recombination rates, and the charging and depletion of trap centers (Ocaya, et. al., 2023). At low light intensities (20-40 mW/cm²), the photocurrent increase is slower. At higher light intensities (80-100 mW/cm²), the photocurrent increases much more sharply. For example, when switching from 80 mW/cm² to 100 mW/cm², the photocurrent increases from approximately 7.5×10^{-6} A to 3×10^{-5} A (approximately fourfold). A high photocurrent value of 3×10^{-5} A at 100 mW/cm² indicates that the device can generate a significant current and has a good signal output. This confirms that the device is attractive for optical sensing applications.

Fig. 7 shows the change in photosensitivity of the Au/MgO/p-Si/Al structure with light intensity. The most striking feature of the graph is the continuous and significant increase in photosensitivity as light intensity increases. This demonstrates that the Au/MgO/p-Si/Al structure exhibits a strong response to light and functions effectively as a photodetector. The increase in photosensitivity is not entirely linear; the rate of increase accelerates at higher light intensities (Koçyiğit, et. al., 2023). In particular, a sharp increase in photosensitivity is observed from 80 mW/cm² to 100 mW/cm² (approximately 1×10^{-7} to 3×10^{-7}). This exponential or power-law-like increase is common in

semiconductors and may result from complex interactions between carrier generation, recombination, and trap states. A photosensitivity value of around 3×10^{-7} at a relatively high light intensity of 100 mW/cm^2 indicates that the device has significant sensitivity. This suggests that it may also have potential for detecting low-light signals, but this graph expresses photosensitivity as a change in conductivity rather than a change in current or voltage (Bengi, 2023). This photosensitivity graph provides strong evidence for the light-sensing ability of the Au/MgO/p-Si/Al structure. The exponential increase in the device's sensitivity with at higher illumination levels makes it a potential candidate for photodetectors or other optoelectronic applications. The nonlinear and accelerating increase in the graph may be indicative of complex physical mechanisms in the semiconductor's response to light, such as carrier generation, recombination, and surface/interface effects (Kara, et. al., 2025).

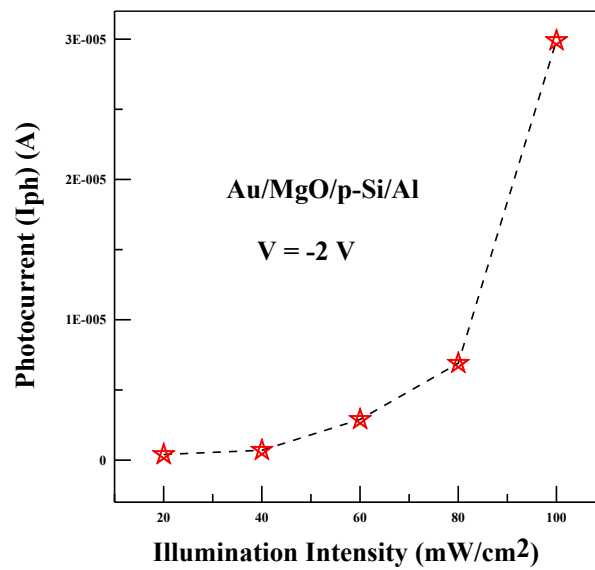


Figure 7. The I_{ph} plots of Au/MgO/p-Si/Al photodiode depends on the light intensity

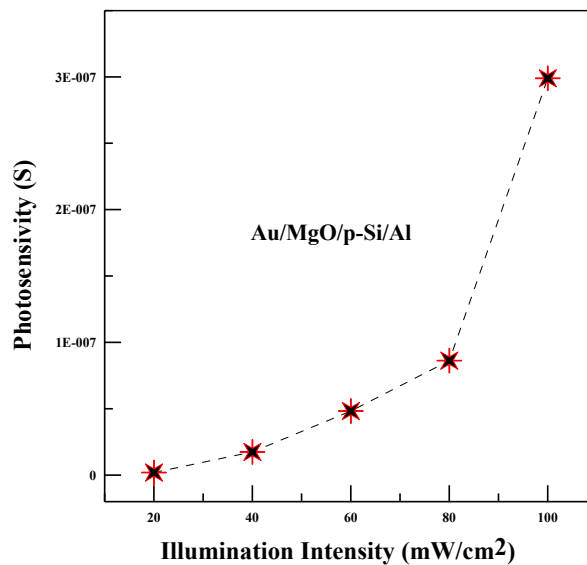


Figure 8. The photosensitivity plots of Au/MgO/p-Si/Al photodiode depends on the light intensity

Detectivity (D^*) is a measure of a photodetector's ability to detect weak light signals. Fig. 8 shows the variation of the detection values with light intensity. The most striking feature of the graph is the continuous and strong increase in the detection value as the applied light intensity increases. This indicates that the Au/MgO/p-Si/Al structure is not only sensitive to light but also has a better signal-to-noise ratio at higher light levels, thus increasing its ability to detect weak signals (Farbod, et. al., 2021). The increase in detection is nonlinear; the rate of increase accelerates at higher light intensities. A sharp jump in detection is observed, particularly from 80 mW/cm² to 100 mW/cm². This is consistent with the similar nonlinearity in the previous photocurrent and photosensitivity graphs. This behavior suggests that the carrier generation and recombination mechanisms within the detector vary with light intensity, and that performance improves significantly above a certain light level. At a light intensity of 100 mW/cm², the detection efficiency is around 3×10^9 Jones. This is quite good for many optoelectronic applications. A high detection efficiency indicates a high detector's ability to detect weak optical signals and distinguish them from noise (Jezeh, et. al., 2021). This detection efficiency plot clearly demonstrates that the Au/MgO/p-Si/Al photodiode structure is a high-performance photodetector that improves significantly as the light intensity increases under a fixed reverse bias of -2 V (Fig. 9).

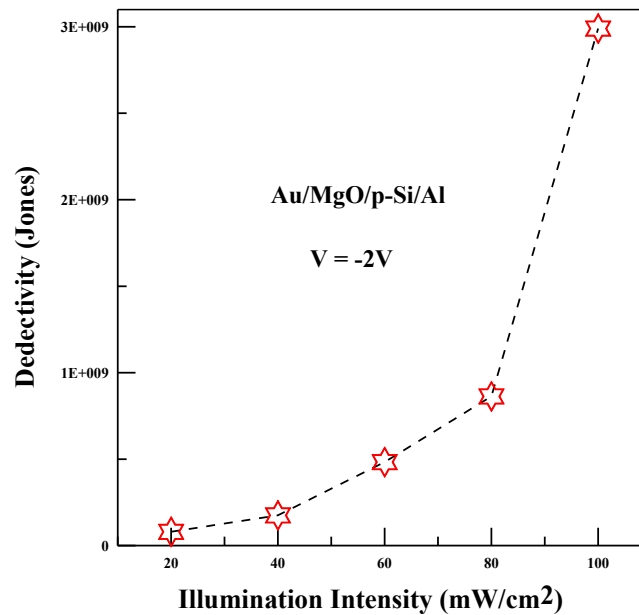


Figure 8. The D^* values of Au/MgO/p-Si/Al photodiode depending on the illumination intensity

Conclusions

This study presents a detailed analysis of the electrical and optoelectronic performance of the Au/MgO/p-Si/Al MIS photodiode structure. The I-V characteristics of the structure clearly demonstrated a distinct diode behavior both in the dark and under different light intensities at room temperature (300 K). The device exhibited a significant increase in

photocurrent under light, especially at the reverse bias voltage (-2 V). This increase is directly related to the applied light intensity, proving that the structure functions as an effective photodetector. The parameter analyses in Table 1 show that the saturation current and ideality factor increase with light intensity, while the barrier height decreases. The increase in the n factor indicates the complexity of carrier recombination mechanisms and interface effects under light, while the decrease in Φ_b is consistent with photoreduction effects and facilitates carrier injection. The investigated photosensitivity, photocurrent, and detection plots indicated significant improvements in the optoelectronic performance of the device. Photocurrent and photosensitivity increased nonlinearly and rapidly as the light intensity increased. The most striking result is the high detection value, reaching 3×10^9 Jones at -2 V at 100 mW/cm² light intensity. This value demonstrates the high ability of the Au/MgO/p-Si/Al structure to detect weak optical signals and effectively distinguish them from noise. In summary, this study highlights the high performance potential of the Au/MgO/p-Si/Al MIS structure as a photodetector. The presence of the MgO insulating layer plays an important role in modulating the electrical and optoelectronic properties of the device. The high detection values obtained indicate that this structure is a promising candidate for a wide range of applications in areas such as optical sensing, optical communication, and imaging.

Acknowledgments

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Flora of Kaz Lake and Its Surroundings (Zara/Sivas)

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Abstract

In this study, the flora of Kaz Lake and its surroundings was investigated. As a result of field studies conducted in Kaz Lake and its vicinity between 2021 and 2022, approximately 520 plant specimens were collected. Based on the identification of these specimens, 218 taxa belonging to 44 families and 157 genera were determined. Among the identified taxa, 1 belongs to the Pteridophyta and 217 to the Spermatophyta divisions. All members of Spermatophyta fall under the Angiospermae subdivision. Of the Angiosperms, 27 taxa (11.44%) belong to the class Monocotyledoneae, while 190 taxa (87.1%) belong to the class Dicotyledoneae. 20 taxa (9.21%) of the collected specimens were found to be endemic, and one was identified as rare. The conservation status of the endemic and rare taxa in the area was assessed. According to this assessment, 18 species were categorized as Least Concern (LC), one species as Endangered (EN), and one species as Vulnerable (VU). The species evaluated as rare was also categorized as Vulnerable (VU). Similarly, the five families with the highest number of taxa identified in the area were reported as Asteraceae (40 taxa), Fabaceae (27 taxa), Lamiaceae (17 taxa), Brassicaceae (14 taxa), and Caryophyllaceae (10 taxa). The phytogeographical distribution of the taxa identified in the study area was determined as follows: Irano-Turanian elements with 68 taxa (31.34%), Euro-Siberian elements with 23 taxa (10.6%), and Mediterranean elements with 8 taxa (3.71%). A total of 119 taxa (54.37%) were classified as multi-regional or of unknown phytogeographical origin. Kaz Lake comprises two primary habitat types aquatic and terrestrial. The aquatic areas, dominated by the *Phragmites australis*-*Typha latifolia* association, feature dense stands of *Phragmites australis* with occasional occurrences of *Typha angustifolia* and *Schoenoplectus lacustris* subsp. *lacustris*, while the surrounding terrestrial zone is largely characterized by steppe vegetation.

Keywords: Kaz Lake, Kaz Lake Flora, Sivas Flora, Flora.

Kaz Gölü ve Çevresinin Florası (Zara/Sivas)

Özet

Bu çalışma ile Kaz Gölü ve çevresinin florası araştırılmıştır. 2021-2022 yılları arasında Kaz Gölü ve çevresinde gerçekleştirilen araştırmalar sonucunda yaklaşık 520 bitki örneği toplanmıştır. Bu bitkilerin teşhisleri sonucunda, 44 familya ve 157 cinse ait 218 takson belirlenmiştir. Belirlenen taksonlardan 1'i Pteridophyta ve 217'si Spermatophyta bölümlerine aittir. Spermatophyta üyelerin tamamı Angiospermae alt bölümü üyesidir. Angiosperma'ların 27 taksonu (% 11.44) Monocotyledonea ve 190 taksonu (% 87.1) Dicotyledonea sınıfında yer almaktadır. Sahada toplanan örneklerden 20 (% 9.21)'si endemik ve 1 nadir olarak belirlenmiştir. Alandaki endemik ve nadir taksonlara ilişkin tehlike kategorilerinin tespiti yapılmıştır. bu tespit neticesinde 18 türün düşük riskli "LC"; 1 tür Tehlikede "EN" ve 1 tür Zarar görebilir "VU" olduğu görülmüştür. Nadir olarak değerlendirilen türün ise Zarar görebilir "VU" kategorisinde yer aldığı tespit edilmiştir. Benzer şekilde alanda tespit edilen taksonlara ilişkin en fazla taksona sahip ilk 5 familyanın sırasıyla; Asteraceae (40 takson), Fabaceae (27 takson), Lamiaceae (17 takson), Brassicaceae (14 takson) ve Caryophyllaceae (10 takson) olduğu rapor edilmiştir. Araştırma alanından tespit edilen taksonların fitocoğrafik bölgelere dağılımı ve oranları ise İran-Turan elementleri 68 (% 31.34), Avrupa-Sibirya elementleri 23 (% 10.6), Akdeniz elementleri 8 (% 3.71) türle temsil edilmektedir. Çok bölgeli veya fitocoğrafik bölgesi bilinmeyenler ise 119 takson (% 54.37) olduğu belirlenmiştir. Kaz Gölü, sucul ve karasal olmak üzere iki temel habitat tipinden oluşmaktadır. Sucul alanlar, *Phragmites australis*-*Typha*

latifolia birliğinin hâkim olduğu, yoğun *Phragmites australis* örtüsü ile yer yer *Typha angustifolia* ve *Schoenoplectus lacustris* subsp. *lacustris*'in görüldüğü bölgelerden oluşurken, gölü çevreleyen karasal ekosistem büyük ölçüde step bitki örtüsü ile karakterizedir.

Anahtar Kelimeler: Kaz Gölü, Kaz Gölü Florası, Sivas Florası, Flora.

Introduction

Wetlands are crucial habitats that support a wide range of organisms, host high levels of biological diversity, and exert direct influence on adjacent terrestrial ecosystems. These ecosystems harbor a rich variety of species, including fish, birds, plankton, and aquatic plants. The terrestrial areas surrounding wetlands are also ecologically valuable due to the presence of endemic species and overall species richness. While all plants require water to survive, certain species have adapted to live permanently in aquatic environments. Wetlands are ecosystems where water is present at or near the surface either permanently or seasonally. Turkey is among the leading countries in the world in terms of floristic diversity, and one of the primary reasons for this richness is the presence of extensive wetlands characterized by diverse climatic and topographic conditions. In the past, wetlands were often regarded as unproductive areas suitable for conversion into agricultural land. However, their critical importance in terms of ecosystem services and biological richness is now widely recognized (Eken et al., 2006; Kadioğlu et al., 2006).

Numerous studies have been conducted to reveal the floristic richness and vegetation of Turkey, a country that hosts a rich and remarkable flora by global standards. Similar research efforts continue across various regions. The earliest studies on the flora of Turkey date back to the 1700s, initiated by the French botanist Tournefort. However, the first significant contribution was made by the Swiss botanist Boissier, who published his findings in the seminal work *Flora Orientalis*. Building upon the efforts of both foreign and Turkish researchers, the monumental nine-volume series *Flora of Turkey and the East Aegean Islands* (1965–1985), edited by Davis, was produced, followed by Supplement I (Davis et al., 1988) and Supplement II (Güner et al., 2000). According to these 11 volumes, the total number of plant species recorded in the Turkish flora was 9,222, with a total of 12,006 taxa. Among these, 2,981 species are endemic, and the total number of endemic taxa is 3,778, corresponding to an endemism rate of 28% (Erik & Tarıkahya, 2004). Türkiye is renowned for its exceptional vegetation diversity and remarkable floristic richness. Recent studies indicate that, on average, a new taxon has been added to the Turkish flora every 4 days and 20 hours. To date, the flora of Turkey comprises 10,460 species, 2,066 subspecies, 888 varieties, and 287 hybrids. Current data show that the rate of endemism has reached 32%. In total, 4,319 endemic native vascular plant taxa have been documented across the country (Özhatay et al., 2022).

Situated at the intersection of the Mediterranean, Irano-Turanian, and Euro-Siberian phytogeographical regions, Turkey functions as a significant biogeographical bridge between Southwest Asia and Europe. Owing to this unique geographical and ecological position, the country serves as a center of origin and genetic diversification for numerous plant genera and species. Furthermore, the territory of Turkey is recognized as the center of origin or domestication for a variety of economically important cultivated plant species.

The present study was conducted to investigate the floristic composition and general vegetation structure of Kaz Lake, a wetland area located within the Zara district of Sivas Province, Turkey.

Materials and Methods

The research material consists of approximately 520 plant specimens collected during field studies conducted in Kaz Lake and its surroundings between 2021-2022. During the fieldwork, plant specimens were collected from both aquatic and terrestrial habitats. Each specimen was recorded along with its locality and other relevant ecological and geographical data. A unique collector number was assigned to every specimen for accurate documentation and reference. The collected samples were preserved following standard herbarium procedures, including pressing and drying under appropriate conditions to maintain morphological integrity.

In periods when fieldwork could not be conducted, identification and classification of previously collected and dried specimens were carried out using appropriate floristic and taxonomic references.

All specimens were documented in a field notebook, including their collector numbers, locality information, and GPS coordinates. They were then preserved using standard herbarium methods. The primary source for plant identification was Flora of Turkey and the East Aegean Islands (Davis, 1965–1985; Davis et al., 1988; Güner et al., 2000). When this source was insufficient, additional regional floras were used, including Flora Iranica (Rechinger, 1965–1977), Flora Europaea (Tutin & Heywood, 1964–1981), Flora of Iraq (Townsend & Guest, 1966–1985), and Flora Palaestina (Zohary, 1966–1986).

In order to ensure the accurate and up-to-date scientific identification of plant specimens, several authoritative databases were consulted, including Türkiye Bitkileri Listesi (Güner et al., 2012), the World Checklist of Selected Plant Families (Govaerts, 2016), Plants of the World Online (POWO, 2025), the International Plant Name Index (IPNI, 2021), and The Plant List (2021).

The families, genera, and species included in the floristic list are presented in alphabetical order (Table 1). Threat categories for endemic and rare taxa are presented. The conservation status of these taxa was evaluated using criteria from Ekim et al. (2000), as well as from IUCN (2001, 2016), Özhatay et al. (2005), and Akçakaya (2005). The abbreviations and their meanings used in the IUCN Red List of Threatened Species categories are as follows: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Lower Risk/conservation dependent (LR/cd), Least Concern (LC), Extinct (EX), Extinct in the Wild (EW), and Data Deficient (DD).

The vegetation of the study area was investigated according to the Braun-Blanquet (1932) method. Sample plots representing plant communities were selected from homogeneous areas during periods of peak vegetation development. The size of the sample plots was determined using the minimal area method. Plant communities or associations were classified and described following the Braun-Blanquet approach.

Geographical location of the study area

Kaz Lake is located within the borders of Ütük village, Zara district of Sivas province (Türkiye). The area within the registration border of Kaz Lake Wetland is 315 ha. From the edge of the registered wetland boundary, Kaz Lake is located 1.92 km (as the crow flies) from the center of Eymir Village, 3 km from Ütük Village, 3.22 km from Yapak Village, 9.5 km from the Zara district center, and 58.5 km from the Sivas provincial center (Figure 1). Kaz Lake is generally fed by water coming from seasonal rainfall and

groundwater. The lake, located south of the Zara-Bahçecik road, has an altitude of 1,430 m and is surrounded by agricultural lands. The lake area was fragmented during road construction. The part to the north of the road has lost its wetland character. It is mostly used as pasture by the local people (Figure 2).



Figure 1. Map showing the location of Kaz Lake in the region.



Figure 2. Kaz Lake wetland.

Results and Discussion

The habitats supporting aquatic vegetation in Anatolia exhibit significant ecological differences. Kaz Lake is poorly fed, remains stagnant, and is located in close proximity to residential areas. There are no stream beds that feed the lake; it relies solely on precipitation and snowmelt. The meadow areas are highly variable due to fluctuations in groundwater levels and drainage activities carried out by locals for hay harvesting.

Wetlands, reed beds, meadows, pastures, and rocky areas constitute the predominant landscape of Kaz Lake and its surroundings. Forested areas are absent, while agricultural lands are primarily located around the study area and in the vicinity of residential settlements (Figure 3).



Figure 3. Kaz Lake and its surroundings.

Comprehensive floristic surveys were conducted between 2021 and 2022 to document the plant diversity of Kaz Lake and its adjacent habitats. After the collected specimens were prepared as herbarium material, various floristic works such as Flora of Turkey, Flora Iranica, Flora Europaea, Flora of Iraq, and Flora Palaestina were consulted for identification purposes. In addition, to ensure the accurate and up-to-date determination of scientific names, sources such as the List of Turkish Plants (Güner et al., 2012), World Checklist of Selected Plant Families (Govaerts, 2016), International Plant Name Index (IPNI, 2021), and The Plant List (2021) were utilized. In the floristic list, families, genera, and species are presented in alphabetical order (Table 1). Accordingly,

the family name, species name, habitat, endemism status, phytogeographical region, and threat categories of endemic and rare species are provided in sequence.

As a result of all the research conducted in and around Kaz Lake, approximately 520 plant specimens were collected. Based on their identification, a total of 218 taxa belonging to 44 families and 157 genera were recorded. Among these, 1 taxon belongs to the division Pteridophyta, while the remaining 217 belong to the division Spermatophyta. All members of Spermatophyta identified in the study are classified under the subclass Angiospermae. Within the angiosperms, 27 taxa (11.44%) are classified under the class Monocotyledoneae and 190 taxa (87.1%) under the class Dicotyledoneae. Of the specimens collected from the field, 20 taxa (9.21%) are endemic, and 1 taxon is considered rare (Figure 4).

The collected specimens were pressed and dried in accordance with herbarium standards. All samples were recorded in the field notebook along with collector numbers, locality information, and GPS coordinates, and were stored under appropriate conditions in the Hakkari University Biodiversity Research Herbarium.

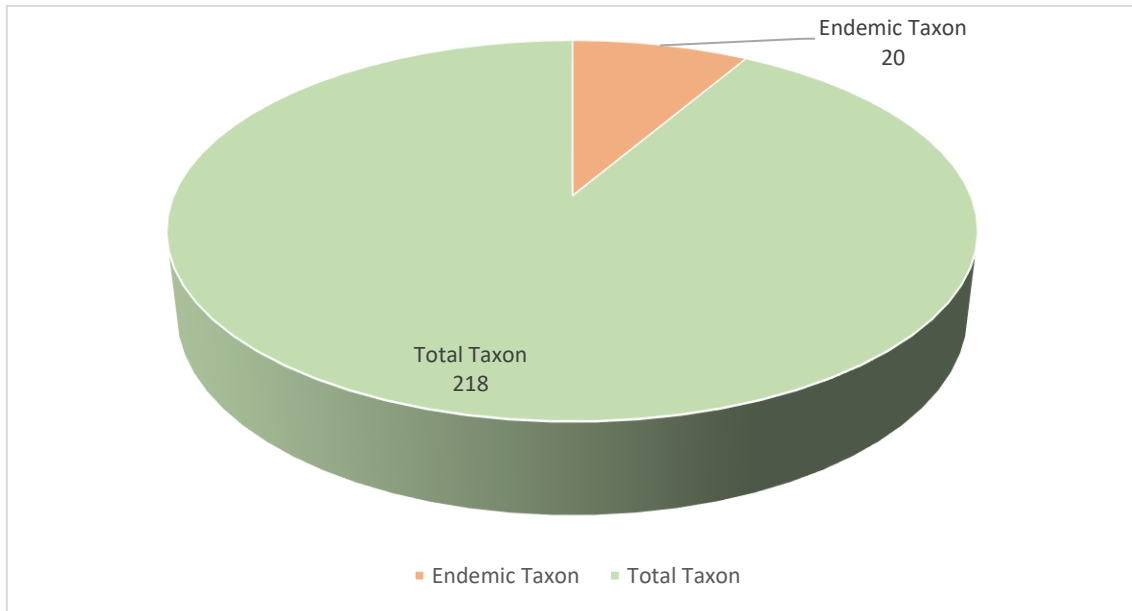


Figure 4. Endemic taxon graph.

Around Kaz Lake, 20 endemic and 1 rare taxon were recorded. The threat categories of these endemic and rare species were assigned according to the *Red Data Book of Turkish Plants* and the 2001 IUCN categories. The distribution of species across threat categories (Ekim et al., 2000) is as follows: 18 taxa are classified as Least Concern (LC), 1 taxon as Endangered (EN), and 1 taxon as Vulnerable (VU). The rare taxon is also classified under the Vulnerable (VU) category.

The first 10 families with the highest number of taxa are; Asteraceae 40, Fabaceae 27, Lamiaceae 17, Brassicaceae 14, Caryophyllaceae 10, Poaceae 10, Apiaceae 8, Ranunculaceae 7, Boraginaceae 6 and Plantaginaceae 6, respectively (Figure 5).

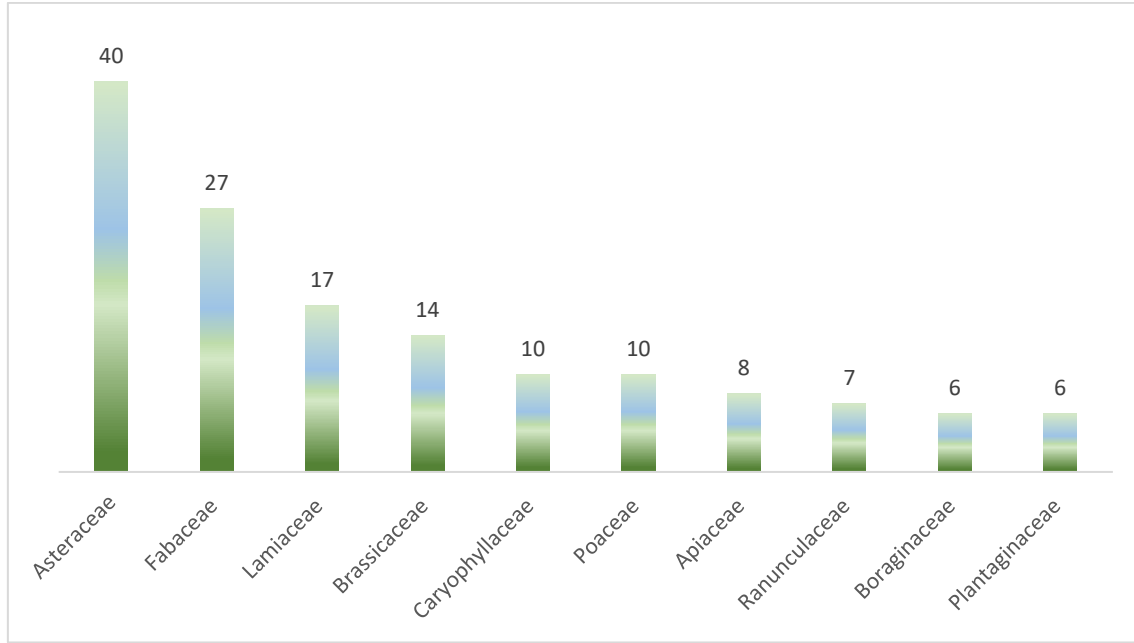


Figure 5. Distribution graph of plant taxa according to families

The phytogeographical distribution of the taxa identified in the study area is as follows: 68 taxa (31.34%) belong to the Irano-Turanian region, 23 taxa (10.6%) to the Euro-Siberian region, and 8 taxa (3.71%) to the Mediterranean region. A total of 119 taxa (54.37%) are either widespread across multiple regions or have an unknown phytogeographical origin.

Table 1. List of terrestrial and aquatic plant species identified in the study area

No	Family and Taxon Name	Habitat	Endemism	Phytogeographic Region	Threat Category (IUCN)
<u>PTERIDOPHYTA</u>					
<u>EQUISETACEAE</u>					
1.	<i>Equisetum arvense</i> L.	Wetlands	Not Endemic	Unknown	-
<u>SPERMATOPHYTA</u>					
<u>ACANTHACEAE</u>					
2.	<i>Acanthus hirsutus</i> Boiss.	Steppe	Not Endemic	Ir.-Tur.	-
<u>ALISMATACEAE</u>					
3.	<i>Alisma plantago-aquatica</i> L.	Grassland	Not Endemic	Euro.-Sib.	-
<u>AMARANTHACEAE</u>					
4.	<i>Amaranthus albus</i> L.	Field	Not Endemic	Unknown	-
5.	<i>Noaea mucronata</i> (Forssk.) Asch. & Schweinf.	Steppe	Not Endemic	Unknown	-
<u>AMARYLLIDACEAE</u>					
6.	<i>Allium atrovioleaceum</i> Boiss.	Steppe	Not Endemic	Unknown	-
7.	<i>Allium vineale</i> L.	Grassland	Not Endemic	Unknown	-
<u>APIACEAE</u>					
8.	<i>Anthriscus nemorosus</i> (M.Bieb.) Spreng.	Grassland	Not Endemic	Unknown	-
9.	<i>Bupleurum croceum</i> Fenzl	Field	Not Endemic	Ir.-Tur.	-

10.	<i>Eryngium campestre</i> L.	Steppe	Not Endemic	Unknown	-
11.	<i>Heracleum incanum</i> Boiss. & A.Huet	Grassland	Endemic	Unknown	LC
12.	<i>Ferulago platycarpa</i> Boiss. & Balansa	Steppe	Endemic	Unknown	LC
13.	<i>Oenanthe pimpinelloides</i> L.	Grassland	Not Endemic	Unknown	-
14.	<i>Turgenia latifolia</i> (L.) Hoffm.	Step	Not Endemic	Unknown	-
15.	<i>Zosima absinthiifolia</i> (Vent.) Link	Grassland	Not Endemic	Unknown	-
ASPARAGACEAE					
16.	<i>Bellevallia speciosa</i> Woronow ex Grossh.	Field	Not Endemic	Unknown	-
17.	<i>Muscari neglectum</i> Guss. ex Ten.	Grassland	Not Endemic	Unknown	-
18.	<i>Ornithogalum narbonense</i> L.	Field	Not Endemic	Medit.	-
ASTERACEAE					
19.	<i>Achillea arabica</i> Kotschy	Field	Not Endemic	Ir.-Tur.	-
20.	<i>Achillea millefolium</i> L. subsp. <i>millefolium</i>	Steppe	Not Endemic	Euro.-Sib.	-
21.	<i>Artemisia absinthium</i> L.	Steppe	Not Endemic	Unknown	-
22.	<i>Bidens tripartita</i> L.	Wetlands	Not Endemic	Unknown	-
23.	<i>Centaurea carduiformis</i> DC. subsp. <i>carduiformis</i> var. <i>carduiformis</i>	Steppe	Not Endemic	Unknown	-
24.	<i>Centaurea glastifolia</i> L.	Steppe	Not Endemic	Ir.-Tur.	-
25.	<i>Centaurea iberica</i> Trev. ex Sprengel	Grassland	Not Endemic	Unknown	-
26.	<i>Centaurea polypodiifolia</i> Boiss. var. <i>szovitsiana</i> (Boiss.) Wagenitz	Steppe	Not Endemic	Ir.-Tur.	-
27.	<i>Centaurea pterocaula</i> Trautv.	Steppe	Not Endemic	Ir.-Tur.	-
28.	<i>Centaurea solstitialis</i> L. subsp. <i>solstitialis</i>	Steppe	Not Endemic	Unknown	-
29.	<i>Cichorium intybus</i> L.	Grassland	Not Endemic	Unknown	-
30.	<i>Cirsium arvense</i> (L.) Scop.	Grassland	Not Endemic	Unknown	-
31.	<i>Cirsium subinerme</i> . Fisch. & C.A.Mey.	Grassland	Not Endemic	Ir.-Tur.	-
32.	<i>Cota altissima</i> (L.) J.Gay	Grassland	Not Endemic	Unknown	-
33.	<i>Cota coelopoda</i> (Boiss.) Boiss. var. <i>bourgaei</i> (Boiss.) U.Özbek & Vural	Field	Not Endemic	Unknown	-
34.	<i>Cota tinctoria</i> (L.) J.Gay ex Guss. var. <i>tinctoria</i>	Steppe	Not Endemic	widespread	-
35.	<i>Crepis foetida</i> L. subsp. <i>rhoeadifolia</i> (M.Bieb.) Čelak.	Steppe	Not Endemic	widespread	-
36.	<i>Cyanus depressus</i> (M.Bieb.) Soják	Steppe	Not Endemic	widespread	-
37.	<i>Cyanus triumfettii</i> (All.) Dostál ex Á.Löve & D.Löve subsp. <i>triumfetti</i>	Steppe	Not Endemic	widespread	-
38.	<i>Echinops pungens</i> . Trautv. var. <i>pungens</i>	Steppe	Not Endemic	Ir.-Tur.	-
39.	<i>Erigeron acris</i> L. subsp. <i>pycnotrichus</i> (Vierh.) Grierson	Grassland	Not Endemic	Euro.-Sib.	-
40.	<i>Gundelia tournefortii</i> L. var. <i>tournefortii</i>	Steppe	Not Endemic	Ir.-Tur.	-
41.	<i>Helichrysum aucheri</i> Boiss.	Steppe	Endemic	Ir.-Tur.	LC
42.	<i>Inula britannica</i> L.	Grassland	Not Endemic	Euro.-Sib.	-
43.	<i>Inula oculus-christi</i> L.	Grassland	Not Endemic	Euro.-Sib.	-
44.	<i>Jurinea aucherana</i> DC.	Steppe	Not Endemic	Ir.-Tur.	-
45.	<i>Jurinea consanguinea</i> DC.	Steppe	Not Endemic	Unknown	-
46.	<i>Lactuca serriola</i> L.	Steppe	Not Endemic	Euro.-Sib.	-
47.	<i>Picnomon acarna</i> (L.) Cass.	Steppe	Not Endemic	Unknown	-

48.	<i>Pilosella hoppeana</i> (Schult.) F.W.Schultz & Sch.Bip. subsp. <i>testimonials</i> (Naegli ex Peter) P.D.Sell & C.West	Steppe	Not Endemic	Euro.-Sib.	-
49.	<i>Onopordum turcicum</i> Danin	Steppe	Not Endemic	Ir.-Tur.	-
50.	<i>Scorzonera incisa</i> DC.	Steppe	Not Endemic	Ir.-Tur.	-
51.	<i>Scorzonera parviflora</i> Jacq.	Steppe	Not Endemic	Unknown	-
52.	<i>Scorzonera tomentosa</i> L.	Steppe	Endemic	Ir.-Tur.	LC
53.	<i>Senecio vernalis</i> Waldst. & Kit.	Steppe	Not Endemic	Unknown	-
54.	<i>Taraxacum revertitans</i> Greuter	Grassland	Endemic	Ir.-Tur.	LC
55.	<i>Tragopogon bupthalmoides</i> (DC.) Boiss.	Field	Not Endemic	Ir.-Tur.	-
56.	<i>Tripleurospermum parviflorum</i> (Willd.) Pobed.	Steppe	Not Endemic	Unknown	-
57.	<i>Tripleurospermum oreades</i> (Boiss.) Rech.f. var. <i>oreades</i>	Steppe	Not Endemic	Unknown	-
58.	<i>Xeranthemum annuum</i> L.	Steppe	Not Endemic	widespread	-
BERBERIDACEAE					-
59.	<i>Berberis crataegina</i> DC.	Steppe	Not Endemic	Ir.-Tur.	-
BORAGINACEAE					-
60.	<i>Alkanna orientalis</i> (L.) Boiss. var. <i>orientalis</i>	Field	Not Endemic	Ir.-Tur.	-
61.	<i>Anchusa azurea</i> Mill. var. <i>azurea</i>	Field	Not Endemic	Unknown	-
62.	<i>Anchusa leptophylla</i> Roem. & Schult. subsp. <i>leptophylla</i>	Field	Not Endemic	Unknown	-
63.	<i>Cerinthe minor</i> L. subsp. <i>auriculata</i> (Ten.) Domac	Steppe	Not Endemic	Unknown	-
64.	<i>Echium italicum</i> L.	Steppe	Not Endemic	Medit.	-
65.	<i>Nonea stenosen</i> Boiss. & Balansa	Field	Endemic	Ir.-Tur.	LC
BRASSICACEAE					-
66.	<i>Alyssum desertorum</i> Stapf.	Steppe	Not Endemic	Unknown	-
67.	<i>Alyssum hirsutum</i> M.Bieb.	Steppe	Not Endemic	Unknown	-
68.	<i>Alyssum simplex</i> Rudolph	Steppe	Not Endemic	Unknown	-
69.	<i>Barbarea brachycarpa</i> Boiss.	Grassland	Not Endemic	Unknown	-
70.	<i>Capsella bursa-pastoris</i> (L.) Medik.	Field	Not Endemic	Unknown	-
71.	<i>Conringia orientalis</i> (L.) Dumort.	Field	Not Endemic	Unknown	-
72.	<i>Erysimum crassipes</i> Fisch. & C.A.Mey.	Steppe	Not Endemic	Unknown	-
73.	<i>Erysimum smyrnaeum</i> Boiss. & Balansa	Field	Not Endemic	Unknown	-
74.	<i>Isatis glauca</i> Aucher ex Boiss. subsp. <i>iconia</i> (Boiss. & Heldr.) P.H.Davis	Steppe	Endemic	Ir.-Tur.	LC
75.	<i>Lepidium chalepense</i> L.	Field	Not Endemic	Ir.-Tur.	-
76.	<i>Lepidium latifolium</i> L.	Field	Not Endemic	Unknown	-
77.	<i>Neslia paniculata</i> (L.) Desv.,	Field	Not Endemic	Unknown	-
78.	<i>Sisymbrium loeselii</i> L.	Field	Not Endemic	Unknown	-
79.	<i>Thlaspi ceratocarpon</i> Murray	Grassland	Not Endemic	Unknown	-
BUTOMACEAE					-
80.	<i>Butomus umbellatus</i> L.	Wetlands	Not Endemic	Unknown	-
CAMPANULACEAE					-
81.	<i>Asyneuma limonifolium</i> (L.) Janehen subsp. <i>limonifolium</i>	Steppe	Not Endemic	Unknown	-

CAPRIFOLIACEAE					
82.	<i>Dipsacus laciniatus</i> L.	Field	Not Endemic	Unknown	-
83.	<i>Cephalaria dipsacoides</i> Boiss. & Balansa	Steppe	Not Endemic	Medit.	-
84.	<i>Cephalaria syriaca</i> (L.) Schrad.	Steppe	Not Endemic	Medit.	-
85.	<i>Morina persica</i> L. var. <i>decussatifolia</i> Erik & Demirkuş	Steppe	Endemic	Ir.-Tur.	EN
86.	<i>Scabiosa argentea</i> L.	Steppe	Not Endemic	Unknown	-
CARYOPHYLLACEAE					
87.	<i>Acanthophyllum mucronatum</i> C.A.Mey.	Steppe	Not Endemic	Ir.-Tur.	-
88.	<i>Agrostemma githago</i> L.	Field	Not Endemic	Unknown	-
89.	<i>Dianthus zederbaueri</i> Vierh.	Steppe	Endemic	Ir.-Tur.	LC
90.	<i>Holosteum marginatum</i> C.A.Mey.	Grassland	Not Endemic	Unknown	-
91.	<i>Holosteum umbellatum</i> L.	Grassland	Not Endemic	Unknown	-
92.	<i>Minuartia corymbulosa</i> (Boiss. & Balansa) McNeill var. <i>corymbulosa</i>	Steppe	Endemic	Ir.-Tur.	LC
93.	<i>Silene bupleuroides</i> L.	Steppe	Not Endemic	Unknown	-
94.	<i>Silene spergulifolia</i> (Desf.) M.Bieb.	Steppe	Not Endemic	Ir.-Tur.	-
95.	<i>Vaccaria hispanica</i> (Mill.) Rauschert	Field	Not Endemic	Unknown	-
96.	<i>Velezia rigida</i> L.	Steppe	Not Endemic	Unknown	-
COLCHICACEAE					
97.	<i>Colchicum kotschy</i>	Grassland	Not Endemic	Ir.-Tur.	-
CONVOLVULACEAE					
98.	<i>Convolvulus arvensis</i> L.	Field	Not Endemic	Unknown	-
99.	<i>Convolvulus galaticus</i> Rost. ex Choisy	Steppe	Not Endemic	Ir.-Tur.	-
100.	<i>Cuscuta palaestina</i> Boiss.	On Medicago falcata	Not Endemic	Unknown	-
CUCURBITACEAE					
101.	<i>Bryonia aspera</i> Stev. ex Ledeb.	Steppe	Not Endemic	Unknown	-
CYPERACEAE					
102.	<i>Bolboschoenus maritimus</i> (L.) Palla	Wetlands	Not Endemic	Unknown	-
103.	<i>Blysmus compressus</i> (L.) Panz. ex Link subsp. <i>compressus</i>	Wetlands	Not Endemic	Unknown	-
104.	<i>Carex distans</i> L. subsp. <i>distans</i>	Wetlands	Not Endemic	Euro.-Sib.	-
105.	<i>Cyperus longus</i> L.	Wetlands	Not Endemic	Unknown	-
106.	<i>Schoenoplectus lacustris</i> (L.) Palla subsp. <i>lacustris</i>	Wetlands	Not Endemic	Unknown	-
EUPHORBIACEAE					
107.	<i>Euphorbia denticulata</i> Lam.	Steppe	Not Endemic	Ir.-Tur.	-
108.	<i>Euphorbia macroclada</i> Boiss.	Field	Not Endemic	Ir.-Tur.	-
FABACEAE /LEGUMINOSAE					
109.	<i>Astragalus aucheri</i> Boiss.	Steppe	Not Endemic	Ir.-Tur.	-
110.	<i>Astragalus deinacanthus</i> Boiss.	Steppe	Rare	Ir.-Tur.	VU
111.	<i>Astragalus kurdicus</i> Boiss.	Steppe	Not Endemic	Ir.-Tur.	-
112.	<i>Astragalus lagopoides</i> Lam.	Steppe	Not Endemic	Ir.-Tur.	-
113.	<i>Astragalus melanophrurius</i> Boiss.	Steppe	Endemic	Ir.-Tur.	LC
114.	<i>Astragalus pendulus</i> DC.	Steppe	Not Endemic	Ir.-Tur.	-
115.	<i>Astragalus pennatulus</i> Hub.-Mor. & D.F.Chamb.	Steppe	Endemic	Ir.-Tur.	LC

116.	<i>Astragalus micropterus</i> Fisch.	Steppe	Endemic	Ir.-Tur.	LC
117.	<i>Ebenus laguroides</i> Boiss.	Steppe	Endemic	Ir.-Tur.	LC
118.	<i>Hedysarum pestalozzae</i> Boiss.	Steppe	Endemic	Ir.-Tur.	LC
119.	<i>Lathyrus hirsutus</i> L.	Grassland	Not Endemic	Geniş	-
120.	<i>Lens culinaris</i> Medik. subsp. <i>culinaris</i>	Grassland	Not Endemic	Unknown	-
121.	<i>Lotus corniculatus</i> L. var. <i>corniculatus</i>	Grassland	Not Endemic	Unknown	-
122.	<i>Medicago</i> (L.) Huds. <i>arabica</i>	Steppe	Not Endemic	widespread	-
123.	<i>Medicago falcata</i> L.	Steppe	Not Endemic	widespread	-
124.	<i>Medicago sativa</i> L. subsp. <i>sativa</i>	Field	Not Endemic	Unknown	-
125.	<i>Melilotus officinalis</i> (L.) Desr.	Field	Not Endemic	Unknown	-
126.	<i>Onobrychis oxyodonta</i> Boiss. var. <i>oxyodonta</i>	Steppe	Not Endemic	Euro-Sib.	-
127.	<i>Onobrychis radiata</i> (Desf.) M.Bieb.	Grassland	Not Endemic	Unknown	-
128.	<i>Onobrychis stenostachya</i> Freyn subsp. <i>krausei</i> (Širj.) Hedge	Steppe	Endemic	Ir.-Tur.	VU
129.	<i>Ononis spinosa</i> L.	Grassland	Not Endemic	Unknown	-
130.	<i>Securigera varia</i> (L.) Lassen	Grassland	Not Endemic	Unknown	-
131.	<i>Trifolium campestre</i> Schreb.	Grassland	Not Endemic	Unknown	-
132.	<i>Trifolium repens</i> L. var. <i>repens</i>	Grassland	Not Endemic	Unknown	-
133.	<i>Vicia balansae</i> Boiss.	Grassland	Not Endemic	Euro-Sib.	-
134.	<i>Vicia cracca</i> L. subsp. <i>cracca</i>	Grassland	Not Endemic	Euro-Sib.	-
135.	<i>Vicia hybrida</i> L.	Grassland	Not Endemic	Medit.	-
GERANIACEAE					
136.	<i>Erodium cicutarium</i> (L.) L'Hér subsp. <i>cutarium</i>	Steppe	Not Endemic	Unknown	-
HYPERICACEAE					
137.	<i>Hypericum lydiu</i> m Boiss.	Grassland	Not Endemic	Ir.-Tur.	-
138.	<i>Hypericum scabrum</i> L.	Steppe	Not Endemic	Ir.-Tur.	-
JUNCACEAE					
139.	<i>Juncus articulatus</i> L. subsp. <i>articulatus</i>	Wetlands	Not Endemic	Euro-Sib.	-
140.	<i>Juncus bufonius</i> L.	Wetlands	Not Endemic	Unknown	-
141.	<i>Juncus gerardi</i> Loisel. subsp. <i>gerardi</i>	Wetlands	Not Endemic	Euro-Sib.	-
LAMIACEAE					
142.	<i>Ajuga chamaepitys</i> (L.) Schreb. subsp. <i>chia</i> (Schreb.) Arcang.	Steppe	Not Endemic	Unknown	-
143.	<i>Lamium purpureum</i> L. var. <i>purpureum</i>	Steppe	Not Endemic	Euro-Sib.	-
144.	<i>Marrubium parviflorum</i> Fisch. & C.A.Mey. subsp. <i>parviflorum</i>	Steppe	Not Endemic	Ir.-Tur.	-
145.	<i>Mentha aquatica</i> L.	Grassland	Not Endemic	Unknown	-
146.	<i>Mentha longifolia</i> (L.) L. subsp. <i>longifolia</i>	Wetlands	Not Endemic	Euro-Sib.	-
147.	<i>Phlomis pungens</i> Willd. var. <i>hirta</i> Velen.	Steppe	Not Endemic	Unknown	-
148.	<i>Salvia candidissima</i> Vahl subsp. <i>candidissima</i>	Steppe	Not Endemic	Ir.-Tur.	-
149.	<i>Salvia cyanescens</i> Boiss. & Balansa	Steppe	Endemic	Ir.-Tur.	LC
150.	<i>Salvia multicaulis</i> Vahl	Steppe	Not Endemic	Ir.-Tur.	-
151.	<i>Salvia virgata</i> Jacq.	Steppe	Not Endemic	Unknown	-
152.	<i>Stachys iberica</i> M.Bieb. subsp. <i>iberica</i>	Steppe	Endemic	Ir.-Tur.	LC
153.	<i>Stachys lavandulifolia</i> Vahl var. <i>lavandulifolia</i>	Steppe	Not Endemic	Unknown	-

154.	<i>Teucrium polium</i> L.	Steppe	Not Endemic	Unknown	-
155.	<i>Teucrium orientale</i> L. var. <i>orientale</i>	Steppe	Not Endemic	Ir.-Tur.	-
156.	<i>Teucrium scordium</i> L. subsp. <i>scordium</i>	Grassland	Not Endemic	Euro-Sib.	-
157.	<i>Thymus pectinatus</i> Fisch. & C.A.Mey.	Steppe	Endemic	Ir.-Tur.	LC
158.	<i>Ziziphora capitata</i> L.	Steppe	Not Endemic	Ir.-Tur.	-
LILIACEAE					
159.	<i>Gagea villosa</i> (M.Bieb.) Sweet var. <i>hermonis</i> Dafni & Heyn	Grassland	Not Endemic	Ir.-Tur.	-
160.	<i>Gagea villosa</i> (M.Bieb.) Sweet var. <i>villosa</i>	Grassland	Not Endemic	Medit.	-
MALVACEAE					
161.	<i>Alcea apterocarpa</i> (Fenzl) Boiss.	Steppe	Not Endemic	Ir.-Tur.	-
162.	<i>Malva neglecta</i> Wallr.	Grassland	Not Endemic	Unknown	-
163.	<i>Malva sylvestris</i> L.	Field	Not Endemic	Unknown	-
ONAGRACEAE					
164.	<i>Epilobium minutiflorum</i> Hausskn.	Wetlands	Not Endemic	Ir.-Tur.	-
OROBANCHACEAE					
165.	<i>Bornmuelleranthus aucheri</i> (Boiss.) Rothm.	Steppe	Not Endemic	Ir.-Tur.	-
166.	<i>Melampyrum arvense</i> L. var. <i>arvense</i>	Grassland	Not Endemic	Euro-Sib.	-
167.	<i>Pedicularis comosa</i> L. var. <i>sibthorpii</i> (Boiss.) Boiss.	Grassland	Not Endemic	Unknown	-
PAPAVERACEAE					
168.	<i>Glaucium grandiflorum</i> Boiss. & A.Huet var. <i>grandiflorum</i>	Steppe	Not Endemic	Ir.-Tur.	-
169.	<i>Fumaria asepalae</i> Boiss.	Field	Not Endemic	Unknown	-
170.	<i>Papaver rhoeas</i> L.	Steppe	Not Endemic	Unknown	-
PLANTAGINACEAE					
171.	<i>Hippuris vulgaris</i> L.	Wetlands	Not Endemic	Unknown	-
172.	<i>Globularia trichosantha</i> Fisch. & C.A.Mey.	Steppe	Not Endemic	Unknown	-
173.	<i>Linaria corifolia</i> Desf.	Steppe	Endemic	Ir.-Tur.	LC
174.	<i>Linaria kurdica</i> Boiss. & Hohen. subsp. <i>kurdica</i>	Steppe	Not Endemic	Ir.-Tur.	-
175.	<i>Plantago lanceolata</i> L.	Grassland	Not Endemic	Unknown	-
176.	<i>Plantago major</i> L.	Grassland	Not Endemic	Unknown	-
177.	<i>Plantago maritima</i> L.	Steppe	Not Endemic	Unknown	-
178.	<i>Veronica anagallis-aquatica</i> L.	Wetlands	Not Endemic	Ir.-Tur.	-
PLUMBAGINACEAE					
179.	<i>Plumbago europaea</i> L.	Steppe	Not Endemic	Euro-Sib.	-
POACEAE					
180.	<i>Aeluropus littoralis</i> (Gouan) Parl.	Grassland	Not Endemic	Unknown	-
181.	<i>Alopecurus myosuroides</i> Huds. var. <i>myosuroides</i>	Field	Not Endemic	Euro-Sib.	-
182.	<i>Arrhenatherum kotschy</i> Boiss.	Steppe	Not Endemic	Ir.-Tur.	-
183.	<i>Bromus danthoniae</i> Trin.	Grassland	Not Endemic	Unknown	-
184.	<i>Bromus tomentellus</i> Boiss.	Grassland	Not Endemic	Ir.-Tur.	-
185.	<i>Elymus hispidus</i> (Opiz) Melderis subsp. <i>barbulatus</i> (Schur) Melderis	Steppe	Not Endemic	Unknown	-
186.	<i>Hordeum bulbosum</i> L.	Steppe	Not Endemic	Unknown	-
187.	<i>Poa bulbosa</i> L.	Grassland	Not Endemic	Unknown	-
188.	<i>Poa timoleontis</i> Heldr. ex Boiss.	Grassland	Not Endemic	Medit.	-

189.	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Wetlands	Not Endemic	Euro-Sib.	-
POLYGALACEAE					
190.	<i>Polygala anatolica</i> Boiss. & Heldr.	Grassland	Not Endemic	Bilinmiyor	-
POLYGONACEAE					
191.	<i>Atraphaxis billardieri</i> Jaub. & Spach var. <i>billardieri</i>	Steppe	Not Endemic	Ir.-Tur.	-
192.	<i>Polygonum setosum</i> Jacq.	Steppe	Not Endemic	Ir.-Tur.	-
193.	<i>Rumex angustifolius</i> Campd. subsp. <i>angustifolius</i>	Steppe	Not Endemic	Unknown	-
194.	<i>Rumex scutatus</i> L.	Steppe	Not Endemic	Unknown	-
PRIMULACEAE					
195.	<i>Androsace maxima</i> L.	Steppe	Not Endemic	Unknown	-
RANUNCULACEAE					
196.	<i>Adonis aestivalis</i> L. subsp. <i>aestivalis</i>	Field	Not Endemic	Unknown	-
197.	<i>Ceratocephala falcata</i> (L.) Pers.	Field	Not Endemic	Unknown	-
198.	<i>Consolida orientalis</i> (J.Gay) Schrödinger	Field	Not Endemic	Ir.-Tur.	-
199.	<i>Nigella latisepta</i> P.H.Davis	Steppe	Not Endemic	Ir.-Tur.	-
200.	<i>Ranunculus arvensis</i> L.	Grassland	Not Endemic	Unknown	-
201.	<i>Ranunculus cuneatus</i> Boiss.	Grassland	Not Endemic	Unknown	-
202.	<i>Ranunculus trichophyllus</i> Chaix ex Vill.	Wetlands	Not Endemic	Unknown	-
RESEDACEAE					
203.	<i>Reseda lutea</i> L. var. <i>lutea</i>	Steppe	Not Endemic	Unknown	-
ROSACEAE					
204.	<i>Agrimonia eupatoria</i> L.	Wetlands	Not Endemic	Unknown	-
205.	<i>Potentilla geranioides</i> Willd.	Grassland	Not Endemic	Ir.-Tur.	-
206.	<i>Pyrus elaeagnifolia</i> Pall. subsp. <i>kotschyana</i> (Boiss.) Browicz	Steppe	Not Endemic	Unknown	-
207.	<i>Rosa canina</i> L.	Steppe	Not Endemic	Unknown	-
208.	<i>Sanguisorba minor</i> L. subsp. <i>minor</i>	Grassland	Not Endemic	Unknown	-
RUBIACEAE					
209.	<i>Asperula arvensis</i> L.	Field	Not Endemic	Medit.	-
210.	<i>Cruciata taurica</i> (Pall. ex Willd.) Ehrend.	Steppe	Not Endemic	Ir.-Tur.	-
211.	<i>Galium verum</i> L. subsp. <i>verum</i>	Steppe	Not Endemic	Euro-Sib.	-
212.	<i>Galium incanum</i> Sm. subsp. <i>elatius</i> (Boiss.) Ehrend.	Steppe	Not Endemic	Ir.-Tur.	-
SALICACEAE					
213.	<i>Populus nigra</i> L. subsp. <i>nigra</i>	Field	Not Endemic	Unknown	-
214.	<i>Salix alba</i> L.	Field	Not Endemic	Euro-Sib.	-
SCROPHULARIACEAE					
215.	<i>Verbascum cheiranthifolium</i> Boiss. var. <i>asperulum</i> (Boiss.) Murb.	Steppe	Not Endemic	Unknown	-
216.	<i>Verbascum phlomoides</i> L.	Grassland	Not Endemic	Euro-Sib.	-
SOLANACEAE					
217.	<i>Hyoscyamus niger</i> L.	Field	Not Endemic	Unknown	-
TYPHACEAE					
218.	<i>Typha angustifolia</i> L.	Wetlands	Not Endemic	Unknown	-

Ir.-Tur.: Irano-Turanian, Euro-Sib.: Euro-Siberian, Medit.: Mediterranean, LC: Least Concern, EN: Endangered VU: Vulnerable

Kaz Lake and its surroundings constitute an important area in terms of biodiversity, with 20 endemic and 1 rare taxa identified along the lakeshore, steppe habitats, roadsides, and field margins (Figure 6). 18 of the endemic plants are Least Concern (LC) due to their wide distribution and large population, and therefore do not currently require any immediate conservation measures.



Figure 6. Some endemic plants identified in the study area.

However, grazing activities may have adverse effects on *Morina persica* var. *decussatifolia* (endemic-EN), *Onobrychis stenostachya* subsp. *krausei* (endemic-VU), and *Astragalus deinacanthus* (rare-VU). The taxa classified as Least Concern (LC) identified in the Kaz Lake region are as follows: *Heracleum incanum*, *Ferulago platycarpa*, *Helichrysum aucheri*, *Scorzonera tomentosa*, *Taraxacum revertitans*, *Nonea stenosolen*, *Isatis glauca* subsp. *iconia*, *Dianthus zederbaueri*, *Minuartia corymbulosa* var. *corymbulosa*, *Astragalus melanophrurius*, *Astragalus pennatulus*, *Astragalus*

tokatensis, *Ebenus laguroides*, *Hedysarum pestalozzae*, *Linaria corifolia*, *Salvia cyanescens*, *Stachys iberica* subsp. *iberica* var. *densipilosa*, and *Thymus pectinatus*.

Habitat Types

There are two main habitat types in the Kaz Lake ecosystem: aquatic (wetland) and terrestrial.

Aquatic ecosystem

The *Phragmites australis*–*Typha latifolia* association (Figure 7) is abundant in areas of Kaz Lake with high water availability. In these zones, *Phragmites australis* is dominant, while *Typha angustifolia* and *Schoenoplectus lacustris* subsp. *lacustris* occasionally join this community.



Figure 7. *Phragmites australis*–*Typha latifolia* association.

The taxa that dominate the marsh-reed areas on the shores around the lake are; *Phragmites australis*, *Typha angustifolia*, *Blysmus compressus*, *Schoenoplectus lacustris* subsp. *lacustris*, *Bolboschoenus maritimus*, *Carex distans*, *Cyperus longus*, *Juncus articulatus*, *Juncus bufonius*, and *Juncus gerardi* subsp. *gerardi*. Additionally, a rich plant cover has developed in these areas, where species such as *Alisma plantago-aquatica* and *Butomus umbellatus* are also locally dominant.

The taxa that dominate the marsh-reed areas on the shores around the lake are; In-water vegetation along the margins of Kaz Lake (Figure 8), taxa such as *Agrimonia eupatoria*, *Ranunculus trichophyllus*, *Equisetum arvense*, *Alisma plantago-aquatica*, *Juncus articulatus*, *Juncus bufonius*, *Juncus gerardi* subsp. *gerardi*, *Hippuris vulgaris*, *Aeluropus littoralis*, *Epilobium minutiflorum*, *Mentha aquatica*, *Mentha longifolia* subsp. *longifolia*, *Veronica anagallis-aquatica*, *Butomus umbellatus*, and *Typha angustifolia* were commonly observed.



Figure 8. In-water vegetation.

The most common taxa in grassland areas: *Allium vineale*, *Amaranthus albus*, *Anthriscus nemorosa*, *Bromus danthoniae*, *Bromus tomentellus*, *Poa timoleontis*, *Polygala anatolica*, *Potentilla geranioides*, *Colchicum kotschyi*, *Lathyrus hirsutus*, *Lotus corniculatus* var. *corniculatus*, *Ononis spinosa*, *Pedicularis commosa*, *Ranunculus repens*, *Ranunculus cuneatus*, *Trifolium campestre*, *Trifolium repens* var. *repens*, *Euphrasia pectinata*, *Barbarea plantaginea*, *Muscari commosum*, *Bidens tripartita*, *Gagea villosa* var. *hermonis*, *Plantago major*, *Plantago lanceolata*, *Sanguisorba minor* subsp. *minor*, *Taraxacum revertitans*, *Teucrium scordium* subsp. *scordium*, *Vicia balansae*, and *Vicia hybrida* (Figure 9).



Figure 9. Grassland areas.

Terrestrial ecosystem

The terrestrial ecosystem around Kaz Lake is predominantly characterized by steppe formation. There are no natural forest formations in the areas adjacent to the study site. However, small patches of cultivated tree species, such as *Salix* and *Populus*, are present. In the steppe areas, shrub species such as *Berberis crataegina*, *Bryonia aspera*, *Atraphaxis billardieri* var. *billardieri*, *Pyrus elaeagnifolia* subsp. *kotschyana*, and *Rosa canina* are occasionally observed (Figure 10).



Figure 10. Kaz Lake.

The best-developed steppe vegetation is found in a limited number of natural pasture areas, which are subjected to early and intensive grazing by the local population. In agriculturally suitable areas, cereal cultivation is dominant, while vegetable and fruit production is carried out on a smaller scale.

Kaz Lake is one of the rare and uniquely beautiful ecosystems of the region and draws attention with its biological diversity. As a result of floristic research conducted in the lake and its surroundings, a total of 218 plant taxa belonging to 44 families and 157 genera were identified. Among these taxa, 20 are endemic and 1 is rare. 18 of the endemic taxa are in the Least Concern (LC) category, 1 is Endangered (EN) *Morina persica* var. *decussatifolia*, and the other is *Onobrychis stenostachya* subsp. *krausei* with Vulnerable (VU) status. *Astragalus deinacanthus*, which was identified as a rare taxon, is also in the Vulnerable (VU) category. The presence of 20 endemic and 1 rare plant taxa highlights the floristic significance of Kaz Lake and emphasizes its status as a valuable natural habitat in need of conservation.

An analysis of the distribution of taxa in the flora of Kaz Lake and its surroundings according to plant families reveals that the ten families with the highest number of taxa are as follows: Asteraceae with 40 taxa (18.34%), Fabaceae with 27 (12.38%), Lamiaceae with 17 (7.8%), Brassicaceae with 14 (6.42%), Caryophyllaceae and Poaceae each with 10 (4.58%), Apiaceae with 8 (3.7%), Ranunculaceae with 7 (3.21%), and both Boraginaceae and Plantaginaceae with 6 taxa each (2.75%) (Table 2).

Table 2. Top 10 families with the highest number of taxa and their percentages in the study area

Order No.	Familia	Number of Taxa	Percentage of Total Taxa (%)
1	Asteraceae	40	18,34
2	Fabaceae	27	12,38
3	Lamiaceae	17	7,8
4	Brassicaceae	14	6,42
5	Caryophyllaceae	10	4,58
6	Poaceae	10	4,58
7	Apiaceae	8	3,7
8	Ranunculaceae	7	3,21
9	Boraginaceae	6	2,75
10	Plantaginaceae	6	2,75
	Others	73	33,48
	Total	218	100.00

In our study area, the top three plant families with the highest number of taxa were identified as Asteraceae, Fabaceae, and Lamiaceae, respectively. When this ranking is compared with the results of other floristic studies conducted within the borders of Sivas Province, a notable similarity was observed (Table 3).

Table 3. Comparison of the top three families in floristic studies from Sivas Province and the present study.

RESEARCH AREA	TOP THREE FAMILIA
The Flora of Kaz Lake (Zara/Sivas) and Its Surroundings	Asteraceae-Fabaceae-Lamiaceae
Flora of the region between Ulaş-Kangal (Sivas, Türkiye)	Asteraceae-Lamiaceae-Fabaceae
Lota Gölleri florası	Asteraceae-Fabaceae-Lamiaceae
Flora of Gürün district (Sivas)	Asteraceae-Fabaceae-Brassicaceae
Flora of Düynükkaya Hill and Surroundings (Ulaş-Sivas)	Asteraceae-Lamiaceae-Brassicaceae
Flora between Sivas and Celalli	Asteraceae-Fabaceae-Lamiaceae
Flora of Karababa Mountain, Sivas-Şarkışla	Asteraceae-Brassicaceae-Fabaceae
Flora of Tödürge Lake (Sivas) and Surroundings	Asteraceae-Fabaceae-Brassicaceae
Flora of Kovalı-Hanlı Area (Sivas)	Asteraceae-Fabaceae-Lamiaceae
Flora of the Sivas-Sıcak Çermik Region	Asteraceae-Fabaceae-Brassicaceae
Flora of the Çamlıbel-Yıldız Mountains	Asteraceae-Fabaceae-Brassicaceae
Flora of the Tecer Mountains (Sivas)	Asteraceae-Lamiaceae-Brassicaceae

According to current data, Asteraceae, Fabaceae, Brassicaceae, Poaceae, Lamiaceae, Caryophyllaceae, Apiaceae, and Scrophulariaceae are among the plant families with the highest number of taxa in the flora of Turkey. When the top 10 plant families with the highest number of taxa in the study area are compared with those in other regions of Sivas Province, it is observed that the Asteraceae family ranks first in all regions. Asteraceae is one of the most families both globally and within the flora of Turkey. Its strong representation worldwide, as well as in the present study area, can be attributed to its broad ecological tolerance, high adaptability to diverse habitats, and considerable dispersal potential.

Table 4. Top 10 families with the most genera in the research area and their percentages

No	Familia	Number of Genera	Percentage of Total Genera (%)
1	Asteraceae	25	15,92
2	Fabaceae	13	8,28
3	Brassicaceae	10	6,36
4	Lamiaceae	10	6,36
5	Apiaceae	8	5,09
6	Caryophyllaceae	8	5,09
7	Poaceae	8	5,09
8	Boraginaceae	5	3,18
9	Ranunculaceae	5	3,18
10	Rosaceae	5	3,18
	Others	60	38,21
	Total	157	100.00

The top 10 families with the most genera in Kaz Lake and its surroundings are; Asteraceae 25 (15.92%), Fabaceae 13 (8.28%), Brassicaceae 10 (6.36%), Lamiaceae 10 (6.36%), Apiaceae 8 (5.09%), Caryophyllaceae 8 (5.09%), Poaceae 8 (5.09%), Boraginaceae 5 (3.18%), Ranunculaceae is 5 (3.18%), Rosaceae is 5 (3.18%) (Table 4).

Table 5. Comparison of the number of taxa, phytogeographic regions, and endemism status identified in our study and other studies conducted in Sivas Province

Research area	Total number of taxa	Iran-Turan %	Europe-Siberian %	Mediterranean %	Multi-regional and phytogeographical region unknown %	Endemism Rate %
The Flora of Kaz Lake (Zara/Sivas) and Its Surroundings	218	31.34	10.6	3.71	54.37	9.21
Flora of the region between Ulaş-Kangal (Sivas, Türkiye)	218	41,3	3,7	8,7	46,3	26,1
Lota Gölleri florası	256	41,8	3,1	3,9	51,2	23
Flora of Gürün district (Sivas)	661	28	6,4	3	62,6	14,67
Flora of Düynükkaya Hill and Surroundings (Ulaş-Sivas)	581	36	6	3,4	54,6	20,5
Flora between Sivas and Celalli	456	38,6	5,4	4,1	51,9	20.6
Flora of Karababa Mountain, Sivas-Şarkışla	680	27,6	10,9	5,2	56,3	18,9
Flora of Tödürge Lake (Sivas) and Surroundings	189	42,8	4,2	4,2	48,8	26,4
Flora of Kovalı-Hanlı Area (Sivas)	373	36,7	6,2	5,1	52	19,9
Flora of the Çamlıbel and Yıldız Mountains	361	34,9	5,82	4,98	54,3	18,56

Table 5. Comparison of the number of taxa, phytogeographic regions, and endemism status identified in our study and other studies conducted in Sivas Province (Continued)

Research area	Total number of taxa	Iran-Turan %	Europe-Siberian %	Mediterranean %	Multi-regional and phytogeographical region unknown %	Endemism Rate %
Flora of the Sivas-Sıcak Çermik Region	341	31,3	5,6	5,2	57,9	17,8
Flora of the Çamlıbel-Yıldız Mountains	973	25,1	16,1	3,3	55,5	14,1
Flora of the Tecer Mountains (Sivas)	926	37,8	7,8	4,4	50	23,2

In this study conducted at Kaz Lake within the borders of Sivas Province, the floristic composition of the region was examined in light of previous fundamental floristic research. The total number of taxa identified, the distribution of phytogeographic elements, and levels of endemism were presented in Table 5.

The dominant character of the steppe vegetation in the study area, which is located within the borders of the Iran-Turan phytogeographic region, provided the highest representation of the Iran-Turan region elements.

Conclusion and Recommendations

As a result of the floristic study conducted in and around Lake Kaz, a total of 218 taxa belonging to 44 families and 157 genera were identified. Among these, one taxon belongs to the division *Pteridophyta*, while the remaining 217 taxa are classified under *Spermatophyta*. All *Spermatophyta* taxa fall within the subdivision *Angiospermae*, including 27 taxa (11.44%) in the class *Monocotyledoneae* and 190 taxa (87.1%) in *Dicotyledoneae*. Among the specimens collected during fieldwork, 20 taxa (9.21%) were identified as endemic, and one taxon was recorded as rare. Additionally, 21 plant taxa with known medicinal, pharmacological, or biotechnological economic value were identified in the Lake Kaz region and its surroundings.

Among the endemic taxa, 18 are classified as Least Concern (LC), while *Morina persica* var. *decussatifolia* is listed as Endangered (EN), and *Onobrychis stenostachya* subsp. *krausei* as Vulnerable (VU). The rare taxon *Astragalus deinacanthus* is also categorized as Vulnerable (VU). Endemic plant species classified as Least Concern (LC) do not currently require specific conservation measures due to their wide distribution and large population sizes. However, *Morina persica* var. *decussatifolia*, which is categorized as Endangered (EN), as well as the endemic *Onobrychis stenostachya* subsp. *krausei* and the rare *Astragalus deinacanthus*, both listed as Vulnerable (VU), may be adversely affected by grazing pressure. The remote location of Lake Kaz and its surroundings helps minimize anthropogenic impacts on the region's floristic diversity.

When Kaz Lake and its surroundings were evaluated from a floristic perspective, no seriously degraded areas were encountered. In the context of environmental protection, it is imperative to prohibit the cutting and burning of reed beds, particularly in areas rich in water resources. These wetlands play a crucial ecological role by acting as natural filters and providing essential habitats for numerous species, supporting biodiversity through shelter, breeding, and feeding functions. The uncontrolled use of steppe ecosystems for fuel collection or animal fodder poses a significant threat to the sustainability of these habitats. Furthermore, early and intensive grazing activities in the

area (Figure 11) may cause substantial degradation of the vegetation over time. Therefore, minimizing all forms of anthropogenic disturbance in the region is of paramount importance.



Figure 11. Early grazing activities initiated in and around Lake Kaz.

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Soft Symmetric Difference-lambda Product of Groups

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Abstract

Soft set theory offers a mathematically robust and algebraically expressive formalism for modeling systems characterized by epistemic uncertainty, vagueness, and parameter-dependent variability—core features of decision theory, engineering, economics, and information sciences. Building upon this foundation, the present study introduces and investigates a novel binary operation, referred to as the soft symmetric difference–lambda product, defined over soft sets whose parameter domains are endowed with group-theoretic structure. This operation is rigorously formalized within an axiomatic framework that ensures compatibility with generalized soft subsethood and soft equality relations, thereby preserving the internal consistency and structural coherence of the induced algebraic system. A comprehensive algebraic analysis is carried out to establish the fundamental properties of the proposed operation, including closure, associativity, commutativity, and idempotency. The behavior of the product with respect to identity and absorbing elements, as well as its interactions with the null and absolute soft sets, is explicitly characterized. To situate the proposed operation within the broader algebraic landscape of soft set theory, a comparative study is conducted with existing binary soft products, highlighting its expressive strength, structural alignment, and integrability within established soft subset hierarchies. The results demonstrate that the soft symmetric difference–lambda product satisfies the axiomatic requirements imposed by group-parameterized domains and induces a well-behaved, formally consistent algebraic structure over the space of soft sets. Two principal contributions emerge from this investigation. First, the introduction of this product enriches the algebraic toolkit of soft set theory by embedding it in a rigorous, operation-preserving environment. Second, it provides a foundational platform for the development of a generalized soft group theory, wherein soft sets indexed by group-structured parameters simulate classical group-theoretic behavior through soft operations. Beyond its theoretical significance, the algebraic framework proposed herein offers a principled basis for the construction of soft computational models grounded in abstract algebra, with potential applications in multi-criteria decision-making, algebraic classification systems, and uncertainty-aware data analysis. Accordingly, the formal structure developed in this study not only advances the theoretical generalization of soft algebra but also reinforces its practical utility across both abstract and applied domains.

Keywords Soft sets; Soft subsets; Soft equalities; Soft symmetric difference–lambda product.

Grupların Esnek Simetrik Fark-Lambda Çarpımı

Özet

Esnek küme teorisi, epistemik belirsizlik, anlamsal belirsizlik ve parametreye bağlı değişkenlik gibi niteliklerle karakterize edilen sistemlerin modellenmesi için matematiksel açıdan sağlam ve cebirsel olarak ifade gücü yüksek bir kuramsal yapı sunar. Bu çalışmada, parametre kümeleri grup kuramı ile yapılandırılmış esnek kümeler üzerinde tanımlanan esnek simetrik fark–lambda çarpımı adı verilen yeni bir ikili işlem önerilmiş ve ayrıntılı olarak incelenmiştir. Önerilen işlem, genelleştirilmiş esnek altkümelik ve esnek eşitlik ilişkileriyle tam uyum sağlayan bir aksiyomatik çerçevede biçimsel olarak tanımlanmıştır; böylece ortaya çıkan cebirsel sistemin iç tutarlılığı ve yapısal bütünlüğü korunmuştur. Çalışma kapsamında, önerilen işlemin kapalılık, birleşme, değişme ve idempotentlik gibi temel cebirsel özellikleri kapsamlı bir biçimde analiz edilmiştir. Ayrıca, birim ve yutan elemanlara göre davranışı ile boş ve evrensel esnek kümelerle etkileşimi açıkça karakterize edilmiştir. Önerilen işlemin esnek küme

teorisinin genel cebirsel yapısı içindeki yerini göstermek amacıyla mevcut ikili esnek işlemlerle karşılaştırmalı bir analiz yapılmış; ifade gücü, yapısal uyumu ve yerleşik esnek altkümelik hiyerarşilerine entegrasyonu vurgulanmıştır. Elde edilen bulgular, esnek simetrik fark-lambda çarpımı işleminin grup-parametrelili alanların aksiyomatik gereklerini sağladığını ve esnek kümeler uzayı üzerinde iyi tanımlı, tutarlı bir cebirsel yapı oluşturduğunu ortaya koymaktadır. Bu bağlamda çalışma iki temel katkı sunmaktadır: Birincisi, söz konusu işlem, esnek küme teorisinin cebirsel araç setini işlem-koruyucu biçimde genişletmektedir. İkincisi, grup-yapılı parametrelerle dizilenmiş esnek kümeler aracılığıyla klasik grup kuramı davranışını taklit eden genelleştirilmiş bir esnek grup kuramı geliştirilmesine zemin hazırlamaktadır. Kuramsal öneminin ötesinde, önerilen cebirsel yapı; çok kriterli karar verme, cebirsel sınıflandırma sistemleri ve belirsizlik odaklı veri analizleri gibi alanlarda kullanılabilecek soyut cebir temelli esnek hesaplama modelleri için ilkeli bir altyapı sunmaktadır. Bu bağlamda çalışma, hem esnek cebirin kuramsal genelleştirilmesini ilerletmekte hem de uygulamalı ve soyut alanlarda pratik faydayı güçlendirmektedir.

Keywords Esnek kümeler; Esnek altkümeler; Esnek Eşitlikler; Esnek simetrik fark-lambda çarpım.

Introduction

A wide array of mathematically advanced frameworks has been developed to represent and analyze phenomena governed by uncertainty, vagueness, and indeterminacy—conditions that frequently arise in diverse disciplines such as engineering, economics, social sciences, and medical diagnostics. Despite their theoretical sophistication, classical models such as fuzzy set theory and probability theory are constrained by inherent epistemological and algebraic limitations. For instance, fuzzy set theory, as introduced by Zadeh (1965), fundamentally depends on the subjective determination of membership functions, while probabilistic models assume the presence of repeatable events and well-defined probability distributions—assumptions that often collapse in real-world contexts characterized by epistemic opacity and non-repeatability.

In response to such limitations, Molodtsov (1999) introduced soft set theory as an axiomatically minimal yet structurally versatile formalism that encodes uncertainty through parameter dependence rather than probabilistic estimations or fuzzy memberships. Since its introduction, the algebraic foundation of soft set theory has been extensively expanded. Maji et al. (2003) initiated the development of basic operations, including union, intersection, and AND/OR-products, which were later reinterpreted by Pei and Miao (2005) through an information-theoretic lens to facilitate applications in multivalued and relational systems. Ali et al. (2009) subsequently enhanced the operational expressiveness of the theory by formulating restricted and extended variants of classical operations, thus refining the granularity and flexibility of soft algebraic frameworks. A substantial body of follow-up literature—including contributions by Yang (2008), Feng et al. (2010), Jiang et al. (2010), Ali et al. (2011), Neog and Sut (2011), Fu (2011), Ge and Yang (2011), Singh and Onyeozili (2012a, 2012b, 2012c, 2012d), Zhu and Wen (2013), Onyeozili and Gwary (2014), and Sen (2014)—has enriched the theory further by resolving semantic ambiguities, introducing generalized soft equalities, and defining novel binary operations. More recently, the algebraic scope of soft set theory has expanded significantly through the formal introduction of rigorously defined operations and their systematic investigation. Particularly impactful contributions have been made by Eren and Çalışıcı (2019), Stojanović (2021), Sezgin et al. (2023a, 2023b), Sezgin and Dağtoros (2023), Sezgin and Demirci (2023), Sezgin and Çalışıcı (2024), Sezgin and Yavuz (2023a, 2023b; 2024), Sezgin and Çağman (2024), Sezgin and Sarıalioğlu (2024a, 2024b), and Sezgin and Şenyiğit (2025), whose work has established a robust, extensible,

and internally coherent algebraic framework for the continued advancement of soft set theory.

A key dimension of this progression involves the formal refinement and generalization of soft subsethood and soft equality. The foundational notion of soft subsets introduced by Maji et al. (2003) was extended by Pei and Miao (2005) and Feng et al. (2010), while Qin and Hong (2010) introduced soft congruences that embed equivalence structures within the soft universe. Jun and Yang (2011) further contributed to the theoretical apparatus by proposing J-soft equalities alongside related distributive principles. Liu et al. (2012) extended this line of inquiry by introducing the notions of L-soft subsets and L-equality, revealing violations of classical distributive laws in generalized soft environments. Feng and Li (2013) developed a comprehensive classification of soft subsets under L-equality, demonstrating that certain quotient structures exhibit semigroup properties such as associativity, commutativity, and distributivity. Broader generalizations—such as g-soft, gf-soft, and T-soft equalities—were later proposed by Abbas et al. (2014, 2017), Alshami (2019), and Alshami and El-Shafei (2020), who explored congruence-based and lattice-theoretic approaches to soft algebraic systems.

A pivotal restructuring of the theory was realized through the axiomatic reformulation introduced by Çağman and Enginoğlu (2010), which eliminated structural inconsistencies in the original formulation and provided a logically coherent and algebraically tractable foundation for further developments. Parallel research has explored the extension of binary soft products across various algebraic domains. Notably, the soft intersection–union product has been generalized to rings (Sezer, 2012), semigroups (Sezgin, 2016), and groups (Muştuoğlu et al., 2016), resulting in the formulation of soft rings, soft semigroups, and soft groups. Its dual, the soft union–intersection product, has similarly been analyzed in group-theoretic (Kaygısız, 2012), semigroup-theoretic (Sezer et al., 2015), and ring-theoretic (Sezgin et al., 2017) frameworks, with the resulting algebraic behaviors shown to depend on the presence or absence of structural elements such as identities and inverses in the parameter domain.

Building upon this rich foundational corpus, the present study introduces a novel binary operation—termed the soft symmetric difference–lambda product—defined on soft sets whose parameter domains are endowed with group-theoretic structure. The operation is formally axiomatized and subjected to exhaustive algebraic investigation. We establish its fundamental properties, including closure, associativity, commutativity and idempotency. Moreover, we examine its interaction with identity and absorbing elements and verify its compatibility with generalized soft subsethood and soft equality relations, thereby ensuring full integration into the existing algebraic infrastructure of soft set theory. A comparative analysis is also undertaken vis-à-vis existing soft binary operations, focusing on representational expressiveness and algebraic coherence across stratified soft subset classifications. The product’s interaction with null and absolute soft sets is also rigorously characterized. Our findings demonstrate that the Soft symmetric difference–lambda product operation satisfies all requisite axiomatic conditions and constitutes a structurally robust and algebraically expressive mechanism for aggregating soft information over group-structured parameter domains. In doing so, it generalizes classical group-theoretic constructs within the soft set paradigm and establishes a conceptual foundation for a generalized soft group theory—one in which soft sets emulate the behavior of classical algebraic systems under newly defined soft operations. The remainder of this manuscript is organized as follows: Section 2 provides the foundational

definitions and preliminaries; Section 3 introduces and develops the algebraic theory of the Soft symmetric difference–lambda product; and Section 4 consolidates the main results and identifies directions for future research in soft algebraic structures and their applications in abstract algebra and uncertainty modeling.

Preliminaries

This section provides a rigorous and systematic reformulation of the foundational definitions and algebraic principles that underpin the theoretical framework developed in the subsequent sections. Originally introduced by Molodtsov (1999), soft set theory was conceived as a parameter-dependent formalism for modeling systems marked by epistemic uncertainty and contextual ambiguity. However, the original model lacked the algebraic rigor necessary for sustained theoretical development and structural coherence. Addressing these limitations, the axiomatic reconstruction proposed by Çağman and Enginoğlu (2010) constituted a critical advancement—resolving intrinsic inconsistencies and establishing a logically coherent, algebraically robust foundation. The present study adopts this refined axiomatic structure as the foundational framework upon which all subsequent theoretical constructions are based. Unless explicitly stated otherwise, all references to soft sets, their operations, and associated algebraic properties are to be understood within the context of this revised and rigorously articulated framework.

Definition 2.1. (Çağman and Enginoğlu, 2010) Let E be a parameter set, U be a universal set, $P(U)$ be the power set of U , and $\mathcal{H} \subseteq E$. Then, the soft set $f_{\mathcal{H}}$ over U is a function such that $f_{\mathcal{H}}: E \rightarrow P(U)$, where for all $w \notin \mathcal{H}$, $f_{\mathcal{H}}(w) = \emptyset$. That is,

$$f_{\mathcal{H}} = \{(w, f_{\mathcal{H}}(w)) : w \in E\}$$

From now on, the soft set over U is abbreviated by $\mathcal{SS}$.

Definition 2.2. (Çağman and Enginoğlu, 2010) Let $f_{\mathcal{H}}$ be an $\mathcal{SS}$. If $f_{\mathcal{H}}(w) = \emptyset$ for all $w \in E$, then $f_{\mathcal{H}}$ is called a null $\mathcal{SS}$ and indicated by $\emptyset_E$, and if $f_{\mathcal{H}}(w) = U$, for all $w \in E$, then $f_{\mathcal{H}}$ is called an absolute $\mathcal{SS}$ and indicated by U_E .

Definition 2.3. (Çağman and Enginoğlu, 2010) Let $f_{\mathcal{H}}$ and $g_{\mathcal{K}}$ be two $\mathcal{SS}$ s. If $f_{\mathcal{H}}(w) \subseteq g_{\mathcal{K}}(w)$, for all $w \in E$, then $f_{\mathcal{H}}$ is a soft subset of $g_{\mathcal{K}}$ and indicated by $f_{\mathcal{H}} \subseteq g_{\mathcal{K}}$. If $f_{\mathcal{H}}(w) = g_{\mathcal{K}}(w)$, for all $w \in E$, then $f_{\mathcal{H}}$ is called soft equal to $g_{\mathcal{K}}$, and denoted by $f_{\mathcal{H}} = g_{\mathcal{K}}$.

Definition 2.4. (Çağman and Enginoğlu, 2010) Let $f_{\mathcal{H}}$ and $g_{\mathcal{K}}$ be two $\mathcal{SS}$ s. Then, the union of $f_{\mathcal{H}}$ and $g_{\mathcal{K}}$ is the $\mathcal{SS}$ $f_{\mathcal{H}} \cup g_{\mathcal{K}}$, where $(f_{\mathcal{H}} \cup g_{\mathcal{K}})(w) = f_{\mathcal{H}}(w) \cup g_{\mathcal{K}}(w)$, for all $w \in E$.

Definition 2.5. (Çağman and Enginoğlu, 2010) Let $f_{\mathcal{H}}$ be an $\mathcal{SS}$. Then, the complement of $f_{\mathcal{H}}$ denoted by $f_{\mathcal{H}}^c$, is defined by the soft set $f_{\mathcal{H}}^c: E \rightarrow P(U)$ such that $f_{\mathcal{H}}^c(e) = U \setminus f_{\mathcal{H}}(e) = (f_{\mathcal{H}}(e))'$, for all $e \in E$.

Definition 2.6. (Sezgin et al., 2025b) Let $f_{\mathcal{K}}$ and $g_{\mathcal{K}}$ be two $\mathcal{SS}$ s. Then, $f_{\mathcal{K}}$ is called a soft S-subset of $g_{\mathcal{K}}$, denoted by $f_{\mathcal{K}} \subseteq_S g_{\mathcal{K}}$ if for all $w \in E$, $f_{\mathcal{K}}(w) = \mathcal{M}$ and $g_{\mathcal{K}}(w) = \mathcal{D}$, where $\mathcal{M}$ and $\mathcal{D}$ are two fixed sets and $\mathcal{M} \subseteq \mathcal{D}$. Moreover, two $\mathcal{SS}$ s $f_{\mathcal{K}}$ and $g_{\mathcal{K}}$ are said to be soft S-equal, denoted by $f_{\mathcal{K}} =_S g_{\mathcal{K}}$, if $f_{\mathcal{K}} \subseteq_S g_{\mathcal{K}}$ and $g_{\mathcal{K}} \subseteq_S f_{\mathcal{K}}$.

It is obvious that if $f_K =_S g_K$, then f_K and g_K are the same constant functions, that is, for all $w \in E$, $f_K(w) = g_K(w) = \mathcal{M}$, where $\mathcal{M}$ is a fixed set.

Definition 2.7. (Sezgin et al., 2025b) Let f_K and g_K be two $\mathcal{SS}$ s. Then, f_K is called a soft A-subset of g_K , denoted by $f_K \tilde{\subseteq}_A g_K$, if, for each $a, b \in E$, $f_K(a) \subseteq g_K(b)$.

Definition 2.8. (Sezgin et al., 2025b) Let f_K and g_K be two $\mathcal{SS}$ s. Then, f_K is called a soft S-complement of g_K , denoted by $f_K =_S (g_K)^c$, if, for all $w \in E$, $f_K(w) = \mathcal{M}$ and $g_K(w) = \mathcal{D}$, where $\mathcal{M}$ and $\mathcal{D}$ are two fixed sets and $\mathcal{M} = \mathcal{D}'$. Here, $\mathcal{D}' = U \setminus \mathcal{D}$.

From now on, the symmetric difference complement of the family $\mathfrak{B} = \{C_i: i \in I\}$ such that I is an index set, is denoted by

$$\coprod \mathfrak{B} = \coprod_{i \in I} C_i = (C_1 \Delta C_2 \Delta \dots \Delta C_n)'$$

Definition 2.9. (Durak and Sezgin, 2025) Let $\mathfrak{S}_G$ and $\wp_G$ be two $\mathcal{SS}$ s. Then, the soft symmetric difference complement-gamma product $\mathfrak{S}_G \otimes_{s'/g} \wp_G$ is defined by

$$(\mathfrak{S}_G \otimes_{s'/g} \wp_G)(x) = \coprod_{x=yz} (\mathfrak{S}_G(y) \gamma \wp_G(z)) = \coprod_{x=yz} (\mathfrak{S}_G^c(y) \cap \wp_G(z)), \quad y, z \in G$$

for all $x \in G$.

For more on gamma (γ) operation, we refer to Sezgin et al (2023c), for more on $\mathcal{SS}$ s, we refer to we refer to Aktas and Çağman (2007), Alcantud et al. (2024), Ali et al. (2015), Ali et al. (2022), Atagün et al. (2019), Atagün and Sezgin (2015), Atagün and Sezer (2015), Atagün and Sezgin (2017), Atagün and Sezgin (2018), Atagün and Sezgin (2022), Feng et al. (2008), Gulistan and Shahzad (2014) Gulistan et al. (2018); Jana et al. (2019), Karaaslan (2019), Khan et al. (2017), Mahmood et al. (2015), Mahmood et al. (2018), Manikantan et al. (2023), Memiş (2022), Özlü and Sezgin (2020), Riaz et al. (2023), Sezer and Atagün (2016), Sezer et al. (2017), Sezer et al. (2013), Sezer et al. (2014), Sezgin et al. (2019), Sezgin and İlgin (2024a, 2024b), Sezgin et al. (2022), Sezgin and Onur (2024), Sezgin et al. (2024a, 2024b), Sezgin and Orbay (2022), Sezgin et al., 2025a), Sezgin et al. (2019), Sun et al. (2008), Tunçay and Sezgin (2016), Ullah et al. (2018).

Soft symmetric difference-lambda product of groups

In this section, we introduce and formally define a novel binary operation on soft sets, referred to as the Soft symmetric difference–lambda product, constructed over parameter domains equipped with an intrinsic group-theoretic structure. The operation is subjected to a detailed and rigorous algebraic investigation aimed at systematically delineating its core structural properties—namely, closure, associativity, commutativity, idempotency, and compatibility with generalized notions of soft equality and soft subsethood. Particular emphasis is placed on examining the operation’s behavior within established hierarchies of soft inclusion and assessing its alignment with the broader algebraic taxonomy of soft set operations. To reinforce the theoretical exposition, a carefully selected set of illustrative examples is provided, each designed to expose nuanced operational features and underscore nontrivial algebraic phenomena inherent in

the proposed formulation. Taken together, these results affirm that the soft symmetric difference-lambda product constitutes a structurally sound and algebraically rich operation. It is capable of functioning as a foundational mechanism in the ongoing algebraic expansion and conceptual refinement of soft set theory.

Definition 3.1. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s. Then, the soft symmetric difference-lambda product $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G$ is defined by

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \lambda \mathcal{G}_G(z)) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup (\mathcal{G}_G(z))'), \quad y, z \in G$$

for all $x \in G$.

Note here that since G is a group, there always exist $y, z \in G$ such that $x = yz$, for all $x \in G$. Let the order of the group G be n , that is, $|G| = n$. Then, it is obvious that there exist n distinct representations for each $x \in G$ such that $x = yz$, where $y, z \in G$. Besides, for more lambda (λ) operation of sets, we refer to Sezgin et al. (2023c).

Note 3.2. The soft symmetric difference-lambda product is well-defined in $S_G(U)$. In fact, let $\mathcal{F}_G, \mathcal{G}_G, \mathcal{m}_G, \mathcal{k}_G \in S_G(U)$ such that $(\mathcal{F}_G, \mathcal{G}_G) = (\mathcal{m}_G, \mathcal{k}_G)$. Then, $\mathcal{F}_G = \mathcal{m}_G$ and $\mathcal{G}_G = \mathcal{k}_G$, implying that $\mathcal{F}_G(x) = \mathcal{m}_G(x)$ and $\mathcal{G}_G(x) = \mathcal{k}_G(x)$, for all $x \in G$. Thereby, for all $x \in G$,

$$\begin{aligned} (\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(x) &= \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z)) \\ &= \bigtriangleup_{x=yz} (\mathcal{m}_G(y) \cup \mathcal{k}_G^c(z)) \\ &= (\mathcal{m}_G \otimes_{s/l} \mathcal{k}_G)(x) \end{aligned}$$

Hence, $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \mathcal{m}_G \otimes_{s/l} \mathcal{k}_G$.

Example 3.3. Consider the group $G = \{\sigma, \rho\}$ with the following operation:

$\cdot$	σ	ρ
σ	σ	ρ
ρ	ρ	σ

Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s over $U = D_2 = \{< x, y >: x^2 = y^2 = e, xy = yx\} = \{e, x, y, yx\}$ as follows:

$$\mathcal{F}_G = \{(\sigma, \{x, yx\}), (\rho, \{e, x, y\})\} \text{ and } \mathcal{G}_G = \{(\sigma, \{e, y, yx\}), (\rho, \{e, x\})\}$$

Since $\sigma = \sigma\sigma = \rho\rho$, $(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(\sigma) = (\mathcal{F}_G(\sigma) \cup \mathcal{G}_G^c(\sigma)) \Delta (\mathcal{F}_G(\rho) \cup \mathcal{G}_G^c(\rho)) = \{e, y\}$, and since $\rho = \sigma\rho = \rho\sigma$, $(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(\rho) = (\mathcal{F}_G(\sigma) \cup \mathcal{G}_G^c(\rho)) \Delta (\mathcal{F}_G(\rho) \cup \mathcal{G}_G^c(\sigma)) = \{e, yx\}$ is obtained. Hence,

$$\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \{(\sigma, \{e, y\}), (\rho, \{e, yx\})\}$$

Proposition 3.4. The set $S_G(U)$ is closed under the soft symmetric difference-lambda product. That is, if $\mathcal{F}_G$ and $\mathcal{G}_G$ are two $\mathcal{SS}$ s, then so is $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G$.

PROOF. It is obvious that the soft symmetric difference-lambda product is a binary operation in $S_G(U)$. Thereby, $S_G(U)$ is closed under the soft symmetric difference-lambda product.

Proposition 3.5. The soft symmetric difference-lambda product is not associative in $S_G(U)$.

PROOF. Consider the group G and the $\mathcal{SS}$ s $\mathcal{F}_G$ and $\mathcal{G}_G$ in Example 3.3. Let $\mathcal{H}_G$ be an $\mathcal{SS}$ over $U = \{e, x, y, yx\}$ such that $\mathcal{H}_G = \{(\sigma, \{x, yx\}), (\rho, \{y\})\}$.

Since $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \{(\sigma, \{e, y\}), (\rho, \{e, yx\})\}$, then

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G) \otimes_{s/l} \mathcal{H}_G = \{(\sigma, \{x, y, yx\}), (\rho, \{x\})\}$$

Moreover, since $\mathcal{G}_G \otimes_{s/l} \mathcal{H}_G = \{(\sigma, \{x, y\}), (\rho, \{yx\})\}$, then

$$\mathcal{F}_G \otimes_{s/l} (\mathcal{G}_G \otimes_{s/l} \mathcal{H}_G) = \{(\sigma, \{y, yx\}), (\rho, \emptyset)\}$$

Thereby, $(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G) \otimes_{s/l} \mathcal{H}_G \neq \mathcal{F}_G \otimes_{s/l} (\mathcal{G}_G \otimes_{s/l} \mathcal{H}_G)$.

Proposition 3.6. The soft symmetric difference-lambda product is not commutative in $S_G(U)$.

PROOF. Consider the $\mathcal{SS}$ s $\mathcal{F}_G$ and $\mathcal{G}_G$ over $U = \{e, x, y, yx\}$ in Example 3.3. Then,

$$\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \{(\sigma, \{e, y\}), (\rho, \{e, yx\})\} \text{ and } \mathcal{G}_G \otimes_{s/l} \mathcal{F}_G = \{(\sigma, \{x, y\}), (\rho, \{x, yx\})\}$$

implying that $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G \neq \mathcal{G}_G \otimes_{s/l} \mathcal{F}_G$.

Proposition 3.7. The soft symmetric difference-lambda product is not idempotent in $S_G(U)$.

PROOF. Consider the $\mathcal{SS}$ $\mathcal{F}_G$ in Example 3.3. Then,

$$\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G = \{(\sigma, \emptyset), (\rho, \{e, y, yx\})\}$$

implying that $\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G \neq \mathcal{F}_G$.

Proposition 3.8. Let $\mathcal{F}_G$ be a constant $\mathcal{SS}$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G = U_G$, where $|G| = r$ and r is a positive odd integer.
- ii. $\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ be a constant $\mathcal{SS}$ such that, for all $x \in G$, $\mathcal{F}_G(x) = A$, where A is a fixed set.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{F}_G^c(z)) = \left(\underbrace{U \Delta U \Delta \dots \Delta U}_{r \text{ times } U, \text{ where } r \text{ is odd}} \right) = U_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G = U_G$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{F}_G^c(z)) = \left(\underbrace{U \Delta U \Delta \dots \Delta U}_{r \text{ times } U, \text{ where } r \text{ is even}} \right) = \emptyset_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \mathcal{F}_G = \emptyset_G$.

Remark 3.9. Let $S_G^*(U)$ be the collection of all constant $\mathcal{SS}$. Then, the soft symmetric difference-lambda product is not idempotent in $S_G^*(U)$ either.

Proposition 3.10. Let $\mathcal{F}_G$ be an $\mathcal{SS}$. Then,

- i. $U_G \otimes_{s/l} \mathcal{F}_G = U_G$, where $|G| = r$ and r is a positive odd integer.
- ii. $U_G \otimes_{s/l} \mathcal{F}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ be an $\mathcal{SS}$.

- i. Let $x \in G$ and $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,

$$(U_G \otimes_{s/l} \mathcal{F}_G)(x) = \bigtriangleup_{x=yz} (U_G(y) \cup \mathcal{F}_G^c(z)) = \bigtriangleup_{x=yz} (U \cup \mathcal{F}_G^c(z)) = U_G(x)$$

Thus, $U_G \otimes_{s/l} \mathcal{F}_G = U_G$.

- ii. Let $x \in G$ and $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,

$$(U_G \otimes_{s/l} \mathcal{F}_G)(x) = \bigtriangleup_{x=yz} (U_G(y) \cup \mathcal{F}_G^c(z)) = \bigtriangleup_{x=yz} (U \cup \mathcal{F}_G^c(z)) = \emptyset_G(x)$$

Thus, $U_G \otimes_{s/l} \mathcal{F}_G = \emptyset_G$

Remark 3.11. U_G is the left absorbing element of the soft symmetric difference-lambda product in $S_G(U)$, where $|G| = r$ and r is a positive odd integer.

Note 3.12. U_G is not the right absorbing element of the soft symmetric difference-lambda product in $S_G(U)$, where $|G| = r$ and r is a positive odd integer. In fact, consider the group $G = \{a, b, c\}$ with the following operation:

$\cdot$	a	b	c
a	a	b	c
b	b	c	a
c	c	a	b

Let $\mathcal{F}_G$ be an $\mathcal{SS}$ over $U = D_2 = \{ \langle x, y \rangle : x^2 = y^2 = e, xy = yx \} = \{e, x, y, yx\}$ as follows:

$$\mathcal{F}_G = \{(a, \{e, x, y\}), (b, \{y\}), (c, \{x\})\}$$

Then,

$$\mathcal{F}_G \otimes_{s/l} U_G = \{(a, \{e\}), (b, \{e\}), (c, \{e\})\} \neq U_G$$

Remark 3.13. U_G is not the absorbing element of the soft symmetric difference-lambda product in $S_G(U)$, where $|G| = r$ and r is a positive odd integer.

Proposition 3.14. Let $\mathcal{F}_G$ be a constant $\mathcal{SS}$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} U_G = \mathcal{F}_G$, where $|G| = r$ and r is a positive odd integer.
- ii. $\mathcal{F}_G \otimes_{s/l} U_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ be a constant $\mathcal{SS}$ such that, for all $x \in G$, $\mathcal{F}_G(x) = A$.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,
- $$(\mathcal{F}_G \otimes_{s/l} U_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup U_G^c(z)) = \mathcal{F}_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} U_G = \mathcal{F}_G$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,
- $$(\mathcal{F}_G \otimes_{s/l} U_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup U_G^c(z)) = \emptyset_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} U_G = \emptyset_G$.

Proposition 3.15. Let $\mathcal{F}_G$ be a constant $\mathcal{SS}$. Then,

- i. $U_G \otimes_{s/l} \mathcal{F}_G = U_G$, where $|G| = r$ and r is a positive odd integer.
 ii. $U_G \otimes_{s/l} \mathcal{F}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. The proof follows from Proposition 3.10.

Remark 3.16. U_G is the right identity and the left absorbing element of the soft symmetric difference-lambda product in $S_G^*(U)$, where $|G| = r$ and r is a positive odd integer, by Proposition 3.14 (i) and 3.15 (i).

Proposition 3.17. Let $\mathcal{F}_G$ be an $\mathcal{SS}$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} \emptyset_G = U_G$, where $|G| = r$ and r is a positive odd integer.
 ii. $\mathcal{F}_G \otimes_{s/l} \emptyset_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ be an $\mathcal{SS}$.

- i. Suppose that $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,
- $$(\mathcal{F}_G \otimes_{s/l} \emptyset_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \emptyset_G^c(z)) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup U) = U_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \emptyset_G = U_G$.

- ii. Suppose that $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,
- $$(\mathcal{F}_G \otimes_{s/l} \emptyset_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \emptyset_G^c(z)) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup U) = \emptyset_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \emptyset_G = \emptyset_G$. $\square$

Note 3.18. By Proposition 3.17 (ii), $\emptyset_G$ is the right absorbing element of the soft symmetric difference-lambda product in $S_G(U)$, where $|G| = r$ and r is a positive even integer; however, $\emptyset_G$ is not the left absorbing element of the soft symmetric difference-lambda product in $S_G(U)$, where $|G| = r$ and r is a positive even integer. In fact, consider the $\mathcal{SS}$ $\mathcal{F}_G$ in Example 3.3. Then,

$$\emptyset_G \otimes_{s/l} \mathcal{F}_G = \{(\sigma, \{e, y, yx\}), (\rho, \{e, y, yx\})\} \neq \emptyset_G$$

Thus, $\emptyset_G$ is not the absorbing element of the soft symmetric difference-lambda product in $S_G(U)$, where $|G| = r$ and r is a positive even integer.

Proposition 3.19. Let $\mathcal{F}_G$ be a constant $\mathcal{SS}$. Then,

- i. $\emptyset_G \otimes_{s/l} \mathcal{F}_G = \mathcal{F}_G^c$, where $|G| = r$ and r is a positive odd integer.
 ii. $\emptyset_G \otimes_{s/l} \mathcal{F}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{f}_G$ be a constant $\mathcal{SS}$ such that, for all $x \in G$, $\mathcal{f}_G(x) = A$, where A is a fixed set.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,
- $$(\emptyset_G \otimes_{s/l} \mathcal{f}_G)(x) = \bigtriangleup_{x=yz} (\emptyset_G(y) \cup \mathcal{f}_G^c(z)) = \bigtriangleup_{x=yz} (\emptyset \cup \mathcal{f}_G^c(z)) = \mathcal{f}_G^c(x)$$

Thereby, $\emptyset_G \otimes_{s/l} \mathcal{f}_G = \mathcal{f}_G^c$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,
- $$(\emptyset_G \otimes_{s/l} \mathcal{f}_G)(x) = \bigtriangleup_{x=yz} (\emptyset_G(y) \cup \mathcal{f}_G^c(z)) = \bigtriangleup_{x=yz} (\emptyset \cup \mathcal{f}_G^c(z)) = \emptyset_G(x)$$

Thereby, $\emptyset_G \otimes_{s/l} \mathcal{f}_G = \emptyset_G$. $\square$

Remark 3.20. $\emptyset_G$ is the absorbing element of the soft symmetric difference-lambda product in $S_G^*(U)$, where $|G| = r$ and r is a positive even integer, by Note 3.18 and 3.19 (ii).

Proposition 3.21. Let $\mathcal{f}_G$ be a constant $\mathcal{SS}$. Then,

- i. $\mathcal{f}_G \otimes_{s/l} \mathcal{f}_G^c = \mathcal{f}_G$, where $|G| = r$ and r is a positive odd integer.
 ii. $\mathcal{f}_G \otimes_{s/l} \mathcal{f}_G^c = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{f}_G$ be a constant $\mathcal{SS}$ such that, for all $x \in G$, $\mathcal{f}_G(x) = A$, where A is a fixed set.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,
- $$(\mathcal{f}_G \otimes_{s/l} \mathcal{f}_G^c)(x) = \bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup (\mathcal{f}_G^c)^c(z)) = \bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup \mathcal{f}_G(z)) = \mathcal{f}_G(x)$$

Thereby, $\mathcal{f}_G \otimes_{s/l} \mathcal{f}_G^c = \mathcal{f}_G$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,
- $$(\mathcal{f}_G \otimes_{s/l} \mathcal{f}_G^c)(x) = \bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup (\mathcal{f}_G^c)^c(z)) = \bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup \mathcal{f}_G(z)) = \emptyset_G(x)$$

Thereby, $\mathcal{f}_G \otimes_{s/l} \mathcal{f}_G^c = \emptyset_G$.

Proposition 3.22. Let $\mathcal{f}_G$ be a constant $\mathcal{SS}$. Then,

- i. $\mathcal{f}_G^c \otimes_{s/l} \mathcal{f}_G = \mathcal{f}_G^c$, where $|G| = r$ and r is a positive odd integer.
 ii. $\mathcal{f}_G^c \otimes_{s/l} \mathcal{f}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{f}_G$ be a constant $\mathcal{SS}$ such that, for all $x \in G$, $\mathcal{f}_G(x) = A$, where A is a fixed set.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,
- $$(\mathcal{f}_G^c \otimes_{s/l} \mathcal{f}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{f}_G^c(y) \cup \mathcal{f}_G^c(z)) = \mathcal{f}_G^c(x)$$

Thereby, $\mathcal{f}_G^c \otimes_{s/l} \mathcal{f}_G = \mathcal{f}_G^c$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,
- $$(\mathcal{f}_G^c \otimes_{s/l} \mathcal{f}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{f}_G^c(y) \cup \mathcal{f}_G^c(z)) = \emptyset_G(x)$$

Thereby, $\mathcal{f}_G^c \otimes_{s/l} \mathcal{f}_G = \emptyset_G$.

Proposition 3.23. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s such that $\mathcal{G}_G \widetilde{\subseteq}_A \mathcal{F}_G$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = U_G$, where $|G| = r$ and r is a positive odd integer.
- ii. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s and $\mathcal{G}_G \widetilde{\subseteq}_A \mathcal{F}_G$. Then, $\mathcal{G}_G(y) \subseteq \mathcal{F}_G(z)$, for each $y, z \in G$.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z)) = U_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = U_G$. Here note that, $\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z) = (\mathcal{G}_G(z) \setminus \mathcal{F}_G(y))'$, for all $y, z \in G$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z)) = \emptyset_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \emptyset_G$. Here note that $\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z) = (\mathcal{G}_G(z) \setminus \mathcal{F}_G(y))'$ for all $y, z \in G$.

Proposition 3.24. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s such that $\mathcal{G}_G \widetilde{\subseteq}_S \mathcal{F}_G$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = U_G$, where $|G| = r$ and r is a positive odd integer.
- ii. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. The proof is similar to the proof of Proposition 3.23.

Proposition 3.25. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s such that $\mathcal{F}_G \widetilde{\subseteq}_S (\mathcal{G}_G)^c$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \mathcal{G}_G^c$, where $|G| = r$ and r is a positive odd integer.
- ii. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s and $\mathcal{F}_G \widetilde{\subseteq}_S (\mathcal{G}_G)^c$. Then, for all $x \in G$, $\mathcal{F}_G(x) = A$, $\mathcal{G}_G(x) = B$, where A and B are two fixed sets and $A \subseteq B'$.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z)) = \mathcal{G}_G^c(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \mathcal{G}_G^c$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,

$$(\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{F}_G(y) \cup \mathcal{G}_G^c(z)) = \emptyset_G(x)$$

Thereby, $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \emptyset_G$.

Proposition 3.26. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s such that $(\mathcal{G}_G)^c \widetilde{\subseteq}_S \mathcal{F}_G$. Then,

- i. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \mathcal{F}_G$, where $|G| = r$ and r is a positive odd integer.
- ii. $\mathcal{F}_G \otimes_{s/l} \mathcal{G}_G = \emptyset_G$, where $|G| = r$ and r is a positive even integer.

PROOF. Let $\mathcal{F}_G$ and $\mathcal{G}_G$ be two $\mathcal{SS}$ s and $(\mathcal{G}_G)^c \widetilde{\subseteq}_S \mathcal{F}_G$. Then, for all $x \in G$, $\mathcal{F}_G(x) = A$, $\mathcal{G}_G(x) = B$, where A and B are two fixed sets and $B' \subseteq A$.

- i. Let $|G| = r$, where r is a positive odd integer. Then, for all $x \in G$,

$$(\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup \mathcal{g}_G^c(z)) = \mathcal{f}_G(x)$$

Thereby, $\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G = \mathcal{f}_G$.

- ii. Let $|G| = r$, where r is a positive even integer. Then, for all $x \in G$,
- $$(\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G)(x) = \bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup \mathcal{g}_G^c(z)) = \emptyset_G(x)$$

Thereby, $\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G = \emptyset_G$.

Proposition 3.27. Let $\mathcal{f}_G$ and $\mathcal{g}_G$ be two $\mathcal{SS}$ s. Then, $(\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G)^c = \mathcal{f}_G \otimes_{s'/g} \mathcal{g}_G$.

PROOF. Let $\mathcal{f}_G$ and $\mathcal{g}_G$ be two $\mathcal{SS}$ s. Then, for all $x \in G$,

$$\begin{aligned} (\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G)^c(x) &= \left(\bigtriangleup_{x=yz} (\mathcal{f}_G(y) \cup \mathcal{g}_G^c(z)) \right)' \\ &= \prod_{x=yz} (\mathcal{f}_G(y) \cup \mathcal{g}_G^c(z))' \\ &= \prod_{x=yz} (\mathcal{f}_G^c(y) \cap \mathcal{g}_G(z)) \\ &= (\mathcal{f}_G \otimes_{s'/g} \mathcal{g}_G)(x) \end{aligned}$$

Thereby, $(\mathcal{f}_G \otimes_{s/l} \mathcal{g}_G)^c = \mathcal{f}_G \otimes_{s'/g} \mathcal{g}_G$.

Conclusion

This study commences with the formal introduction of a novel binary operation on soft sets, termed the Soft symmetric difference–lambda product, defined over parameter domains endowed with intrinsic group-theoretic structure. Anchored in this foundational formulation, we undertake a comprehensive algebraic examination of the operation, placing particular emphasis on its structural behavior across stratified hierarchies of soft subsethood and its alignment with generalized notions of soft equality. The operation is further subjected to a rigorous comparative analysis vis-à-vis previously established binary soft products, systematically situated within the lattice of soft subset classifications. This comparative framework yields deeper theoretical insights into the relative expressive strengths and algebraic compatibilities of alternative soft operations. In parallel, we conduct a detailed structural investigation into the behavior of the Soft symmetric difference–lambda product with respect to both the null and absolute soft sets, as well as its interaction with other binary operations defined over soft sets indexed by group-structured parameter domains. These inquiries further illuminate the foundational role of the proposed operation within the overarching algebraic topology of soft set theory. The analysis is developed within a strictly axiomatic paradigm, adhering to core principles of abstract algebra, wherein algebraic invariants—such as closure, associativity, commutativity and idempotency, and the presence or absence of identity, inverse, and absorbing elements—are systematically assessed. The algebraic regularities and structural consistencies uncovered through this study affirm the internal coherence and formal rigor of the Soft symmetric difference–lambda product and underscore its

capacity to generalize classical algebraic constructs within the soft set framework. Specifically, the proposed operation serves as both a conceptual and operational cornerstone for the formulation of a generalized soft group theory, wherein soft sets defined over group-parameterized domains reproduce key axiomatic features of classical group structures through newly devised soft operations. Beyond its foundational significance, the algebraic apparatus developed herein opens new pathways for future research, particularly in the construction of novel soft algebraic operations and the refinement of generalized soft equalities. In doing so, it broadens the theoretical scope and methodological applicability of soft set theory within algebraic modeling, formal logic, computational frameworks, and decision-making environments characterized by uncertainty.

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İron Sazlığı Sulak Alanı (Bitlis)'nın Floristik Özellikleri ve Antropojenik Etkiler

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Özet

İron Sazlığı Sulak Alanı, Bitlis il sınırı içerisinde, Nemrut Volkanı'nın batısında, Bitlis-Muş karayolunun kuzeyinde yer almaktadır. Bu çalışma ile 2023-2024 yılları arasında İron Sazlığı Sulak Alanı'nın florası, habitat tipleri, taksonların fitocoğrafik dağılımları ve alan üzerindeki antropojenik etkilerin belirlenmesi amaçlanmıştır. Yapılan arazi çalışmaları sonucunda alanda 41 familyaya ait toplam 212 takson tespit edilmiştir. Bu taksonlardan biri Pteridophyta, geri kalan 211 takson ise Angiospermae'ye aittir. *Anchusa leptophylla* Roem. & Schult. subsp. *incana* (Ledeb.) D.F.Chamb. (Boraginaceae) ve *Dianthus plumbeus* Schischk. (Caryophyllaceae) Türkiye için endemik türler olarak belirlenmiştir. İran-Turan bölge elementleri (%14,6) alanın temel fitocoğrafik karakterini yansıtmaktadır. Çalışma sonuçları; tarımsal faaliyetlerin, hayvancılığın ve habitat bozulmasının alanın floristik yapısını tehdit ettiğini göstermektedir.

Anahtar kelimeler: Bitlis, biyolojik çeşitlilik, endemik, flora, sulak alan

Floristic Composition and Anthropogenic Impacts of İron Reeds Wetland (Bitlis)

Abstract

Iron Reeds Wetland is located within the borders of Bitlis province, to the west of Mount Nemrut, and north of the Bitlis-Muş highway. The aim of this study, conducted between 2023 and 2024, was to investigate the flora, habitat types, phytogeographic distribution of taxa, and anthropogenic effects on the area. As a result of fieldwork conducted for this purpose, 212 taxa from 41 families were identified in the area. One of these taxa belongs to Pteridophyta, while the remaining 211 taxa are Angiospermae. Two taxa, *Anchusa leptophylla* Roem. & Schult. subsp. *incana* (Ledeb.) D.F. Chamb. (Boraginaceae) and *Dianthus plumbeus* Schischk. (Caryophyllaceae), were identified as endemic to Turkey. The Iran-Turan region elements (14,6%) reflect the primary phytogeographic character of the region. The results of the study indicate that agricultural activities, livestock farming, and habitat degradation are threatening the floristic structure of the area.

Keywords: Bitlis, biological diversity, endemic, flora, wetland

Giriş

Sulak alanlar; çoğu canlının hayata tutunduğu, çeşitlendiği, yan yana oldukları karasal ekosistemleri etkileyen ve aynı zamanda balıklar, kuşlar, planktonlar, su bitkileri açısından oldukça zengin alanlardır (Mitsch ve Gosselink, 2007). Sulak alanlar, suyun korunması, ekolojik dengenin sürdürülmesi ve biyolojik çeşitliliğin güvence altına alınmasında kritik bir role sahip oldukları gibi, bulundukları yöreye ve ülke ekonomisine de büyük katkılar sunan ekosistemlerdir. 21. yüzyılda ortaya çıkması beklenen büyük kriz ve çatışmaların su kaynakları ile sulak alanlar üzerinde yoğunlaşacağı öngörüsü dikkate alındığında, bu alanların önemi daha da belirginleşmektedir. Tatlı su kaynaklarının hızla

azalması ve su ile sulcul ekosistemlerin günümüzün en temel ilgi alanlarından biri hâline gelmesi, sulak alanların korunmasını ve gelecek kuşaklara sağlıklı bir şekilde aktarılmasını zorunlu kılmaktadır. Bu nedenle sulak alanların sürdürülebilirliği, kuşkusuz bir ulusal güvenlik meselesi olarak değerlendirilmelidir (Can ve Taş, 2012).

Türkiye'nin Asya ile Avrupa arasındaki geçiş kuşağında konumlanması ve Akdeniz, Avrupa-Sibirya ile İran-Turan fitocoğrafik bölgelerinin kesişim hattında yer alması, ülkenin farklı vejetasyon formasyonlarına ve yüksek düzeyde floristik çeşitliliğe sahip olmasını sağlamıştır. Çeşitli topoğrafik özellikleriyle çok sayıda bitki türüne doğal habitat oluşturan Bitlis ilinde ise, bugüne kadar yürütülmüş sınırlı sayıdaki floristik araştırma (Behçet, 1991; Altıok ve Behçet, 2005; Kürşat ve Karataş, 2017; Keser ve Özgökçe, 2019; Arslan, 2023; Demir ve Özabay, 2025) nedeniyle, bölgenin potansiyel florasının önemli bir bölümünün henüz bilimsel olarak kayıt altına alınamadığı değerlendirilmektedir.

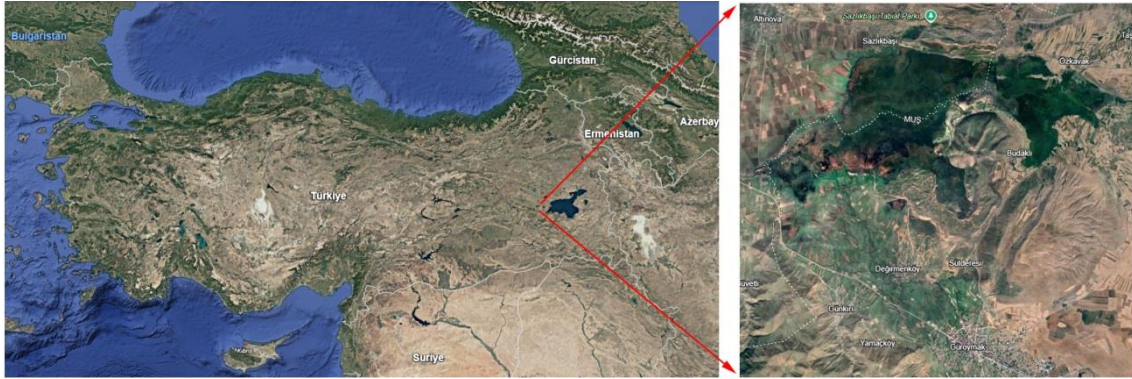
Sulak alan çevresinde yer alan ve sulak alanla yan yana karasal ekosistemler, tür çeşitliliği açısından oldukça zengindir. Sulak alanların ekolojik şartlarına uyum sağlamış bitki toplulukları, özgün floristik kompozisyonlarıyla dikkati çekerler ve farklı tipteki sulak alan ekosistemlerinde farklı fitososyolojik birimler oluşturmuşlardır. Anadolu'da doğal özelliğini koruyabilmiş az sayıdaki sulak alan ekosistemlerinden birisi de İron Sazlığı'dır (Şekil 1).

İron Sazlığı Nemrut Volkanı'nın batısında, Bitlis-Muş karayolunun kuzeyinde yer almaktadır. İron Sazlığı, Bitlis il merkezi ile Bitlis iline bağlı Güroymak, Ahlat, Tatvan, Mutki ilçeleri ile Muş ili Korkut ve Hasköy ilçe sınırları içerisinde bulunmaktadır. Alanın büyük çoğunluğu Bitlis ili Güroymak sınırları içerisinde yer alır (Eken ve ark., 2006). Davis'in Grid kareleme sistemine göre B9 karesi içinde bulunan, havza sınırlarının toplam alanı yaklaşık 16.091 ha yüz ölçümüne sahiptir (Şekil 2).



Şekil 1. Alan içerisinde bulunan tepelerden İron sazlığının genel görüntüsü.

Alanın su toplama alt havzası oldukça geniş bir alanı kaplamakta ve farklı ekosistem tiplerini içermektedir. Bu ekosistemler alansal büyüklük bakımından sırası ile tarım ekosistemi, çalılık ekosistemi, step ekosistemi, sulak alan ekosistemi, yerleşim yerleri ekosistemi, kıyı ekosistemi ve orman ekosistemi olarak ayrılmaktadır. Sulak alan ekosistemi alansal olarak alt havzanın % 4,9'unu kaplamaktadır. Bununla birlikte, sulak alanın son 30 yılda büyük ölçüde küçüldüğü, eskiden sulak alan ekosistemi içerisinde yer alan birçok alanı bugün tarım alanı ve mera olarak kullanılmaktadır (Anonim, 2012).



Şekil 2. İron Sazlığı Sulak Alanı [Google Earth (2025)'den alınmıştır.

İron sazlığı çevresinde bulunan köylerde ana geçim kaynağı tarım ve hayvancılık olup, göl çevresindeki tarım alanlarında çoğunlukla buğday ekilmektedir. Ekili alanlarda yoğun ilaç ve gübre kullanımı söz konusu değildir. Hayvancılığın başında da mandacılık önemli bir yer tutmaktadır. Sulak alan çevresindeki çayırılık alanlar hayvanlar için biçenek olarak kullanılmaktadır.

Bu çalışma sonucunda, öncelikle tespit edilen bitki taksonlarının sistematik sınıflandırılması ve bu taksonların ait oldukları fitocoğrafik bölgeler saptanarak havzanın bitki coğrafyası açısından taşıdığı karakter ve önemin ortaya konulması hedeflenmiştir. İron Sazlığı sulak alanında yayılış gösteren bitkilerin listesi, endemizm durumları, fitocoğrafik bölgeleri ve tehlike kategorileri tablo halinde verilmiştir. Elde edilen floristik, ekolojik ve biyocoğrafik veriler, havzanın coğrafi karakteristikleri bakımından ele alınmış ve karşı karşıya olduğu antropojenik baskılar çerçevesinde değerlendirilmiştir. Dolayısıyla, sulak alanın floristik çeşitliliği vurgulanmış ve sürdürülebilir yönetim hedefi doğrultusunda koruma odaklı öneriler sunulmuştur.

Materyal ve Yöntem

Materyal

Bu çalışmanın materyalini İron sazlığı sulak alanı ve çevresinden toplanan bitki örnekleri oluşturmaktadır. Bitki örnekleri toplamak için alanda 2023-2024 yıllarında arazi çalışmaları yapılmıştır. Arazi çalışmaları; çalışma alanının floristik ve habitat özellikleri yönüyle gözlenmesi, bitki türlerinin teşhis edilmesi amacıyla laboratuvar örneklerinin toplanması, toplanan örneklerin ve habitat tiplerinin fotoğraflarının çekilmesi ve çalışma noktalarının kayıtlarının alınması şeklinde gerçekleştirilmiştir. Toplanan bitki örneklerinin teşhisinde daha kolay yol alınabilmesi amacıyla bitki örnekleri çiçek, meyve, tomurcuk, yaprak, kök ve gövde organlarını taşıyacak şekilde toplanmıştır.

Yöntem

Floristik çalışmalar için izlenecek yol literatür araştırması ve arazi çalışmaları şeklinde planlanmıştır. Arazi çalışmalarında toplanan bitki örnekleri preslenip numara verilerek herbaryum örneği haline getirilmiş, habitat ve bitkilerin ayrıntılı fotoğrafları çekilmiştir. Toplanan örneklerin teşhisleri Türkiye Floralarına (Davis, 1965-1985; Davis ve ark., 1988) göre yapılmış, ayrıca Flora Iranica (Rechinger, 1965-1977), Flora Europaea (Tutin ve ark., 1964-1981), Flora of Iraq (Towsend ve Guest, 1966-1985) ve Flora Palaestina (Zohary, 1966-1986) gibi komşu ülke flora kitaplarından da yararlanılmıştır. Türlerin güncel, geçerli bilimsel ve Türkçe adları Türkiye Bitkileri Listesi'ne (Güner ve ark., 2012) göre verilmiştir. Ayrıca "World Checklist of Selected Plant Families (Govaerts, 2017)", "International Plant Name Index (IPNI, 2021)" ve Published on the Internet (The Plant List, 2021) gibi kaynaklardan da yararlanılmıştır.

Floristik listede yer alan familyalar, cinsler ve türler alfabetik sıraya göre yazılmıştır (Çizelge 1). Buna göre sırayla familya adı, tür adı, Türkçe adı, habitat, endemizm durumu ve fitocoğrafik bölgesi verilmiştir.

Fitocoğrafik analiz

Alanda tespit edilen taksonların coğrafi kökenleri ve yayılış alanları, Türkiye'nin bitki coğrafyası bölgelendirmesi temel alınarak analiz edilmiştir. Sınıflandırmada Davis (1965-1985) tarafından yapılan ve Türkiye florası için genel kabul gören üç ana fitocoğrafik bölge (Avrupa-Sibirya, Akdeniz, İran-Turan) esas alınmıştır. Bununla birlikte her bir taksonun ait olduğu fitocoğrafik element dağılım bilgileri, "<https://bizimbitkiler.org.tr>" internet adresi incelenerek belirlenmiştir. Birden fazla fitocoğrafik bölgede yayılış gösteren ya da geniş yayılım alanına sahip türler "Çok Bölge ve Geniş Yayılışlı (ÇBGY)" kategorisinde değerlendirilmiştir.

Endemizm ve koruma durumu

Çalışma sahasında tespit edilen taksonlar içerisinde Türkiye için endemik ve nadir bitkiler için taksonların tehlike kategori ve kriterleri, başta "Türkiye Bitkileri Kırmızı Kitabı" (Ekim ve ark., 2000) olmak üzere IUCN (2001;2011) çalışmalarından yararlanılarak durumlarının değerlendirilmesi yapılmıştır.

Bulgular

İron Sazlığı Sulak Alanının floristik listesi ve habitat özellikleri

İron sazlığı sınırları içerisinde yer alan ekosistemde yapılan floristik araştırmalar sonucu toplam 41 familyaya ait 212 takson tespit edilmiştir. Bu taksonlardan bir tanesi tohumuz bitkilere (Pteridophyta), geri kalan 211 takson ise açık tohumlulara (Angiospermae) aittir. Alanda 2 endemik bitki türünün yayılış gösterdiği belirlenmiştir. Alanda tespit edilen taksonların familyaları, bilimsel adları, ait oldukları taksonomik sınıfları, endemizm durumları ve fitocoğrafik bölgeleri altta tablo halinde sunulmuştur (Çizelge 1).

Çizelge 1. İron sazlığı ve çevresinin flora tablosu

Familya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
PTERIDOPHYTA				
EQUISETACEAE				
<i>Equisetum giganteum</i> L.	Kırkkilitotu	Nemli alanlar	Endemik Değil	ÇBGY
SPERMATOPHYTA				
ALISMACEAE				
<i>Alisma plantago-aquatica</i> L. subsp. <i>plantago-aquatica</i>	Çakalkulağı	Sulak çayır	Endemik Değil	Avrupa-Sibirya
AMARANTHACEAE				
<i>Amaranthus deflexus</i> L.	Sarkıkibik	Çayır	Endemik Değil	ÇBGY
<i>Chenopodium botrys</i> L.	Kızılbacak	Çayır	Endemik Değil	ÇBGY
<i>Chenopodium chenopodioides</i> (L.) Aellen	Kazsirkeni	Sulak çayır	Endemik Değil	ÇBGY
<i>Suaeda prostrata</i> Pall.	Yatıkcirim	Çayır, kumlu topraklar	Endemik Değil	ÇBGY
AMARYLLIDACEAE				
<i>Allium cepa</i> L.	Soğan	Tarla	Endemik Değil	ÇBGY
<i>Allium fuscoviolaceum</i> Fomin	Kara sirmo	Çayır	Endemik Değil	İran-Turan
APIACEAE				
<i>Conium maculatum</i> L.	Baldıran	Çayır	Endemik Değil	ÇBGY
<i>Daucus carota</i> L.	Yabanihavuç	Çayır	Endemik Değil	ÇBGY
<i>Eryngium campestre</i> L. var. <i>virens</i> Link	Yerkestanesi	Çayır, kumlu topraklar	Endemik Değil	ÇBGY
<i>Scandix pecten-veneris</i> L.	Zühretarağı	Yol kenarları, çayırlar	Endemik Değil	ÇBGY
<i>Scandix stellata</i> Banks & Sol.	Dağ kişkişi	Tarla kenarları, Çayırılık	Endemik Değil	ÇBGY
<i>Torilis arvensis</i> (Huds.) Link	Dercikotu	Çayır	Endemik Değil	ÇBGY
ARACEAE				
<i>Lemna gibba</i> L.	Yamuksumercimeği	Durgun sular	Endemik Değil	ÇBGY
ASPARAGACEAE				
<i>Muscari armeniacum</i> Leichtlin ex Baker	Gâvurbaşı	Çayır	Endemik Değil	ÇBGY
<i>Ornithogalum narbonense</i> L.	Akbaldır	Çayır	Endemik Değil	Akdeniz
ASTERACEAE				
<i>Achillea arabica</i> Kotschy	Hanzabel	Çayır	Endemik Değil	İran-Turan
<i>Achillea kotschyi</i> Boiss. subsp. <i>kotschyi</i>	Ayvadana	Çayır	Endemik Değil	ÇBGY
<i>Achillea setacea</i> Waldst. & Kit.	Ayvabala	Çayır	Endemik Değil	Avrupa-Sibirya
<i>Achillea millefolium</i> L. subsp. <i>millefolium</i> var. <i>millefolium</i>	Civanperçemi	Orman açıklığı	Endemik Değil	Avrupa-Sibirya
<i>Arctium minus</i> (Hill) Bernh.	Löşlek	Çayır	Endemik Değil	Avrupa-Sibirya
<i>Artemisia campestris</i> L. var. <i>campestris</i>	Karayavşan	Step	Endemik Değil	ÇBGY
<i>Bellis perennis</i> L.	Koyungözü	Çayır	Endemik Değil	Avrupa-Sibirya
<i>Carduus nutans</i> L. subsp. <i>nutans</i>	Eşekdikeni	Çayır, yol kenarı	Endemik Değil	ÇBGY
<i>Carduus pycnocephalus</i> L. subsp. <i>albidus</i> (M.Bieb.) Kazmi	Eşeksoymacı	Çayır	Endemik Değil	ÇBGY
<i>Carthamus lanatus</i> L.	Sarıdiken	Çayır	Endemik Değil	ÇBGY
<i>Centaurea iberica</i> Trev. ex Sprengel	Deligözdikeni	Çayır	Endemik Değil	ÇBGY
<i>Centaurea pseudoscabiosa</i> Boiss. & Buhse subsp. <i>araratica</i> (Azn.) Wagenitz	Engin kavgalaz	Çayır	Endemik Değil	İran-Turan

Familya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
<i>Centaurea solstitialis</i> L.subsp. <i>solstitialis</i>	Çakırdiken	Çayır	Endemik Değil	ÇBGY
<i>Centaurea virgata</i> Lam.	Acisüprüge	Çayır	Endemik Değil	İran-Turan
<i>Chondrilla juncea</i> L.	Karakavuk	Çayır, kumlu alanlar	Endemik Değil	ÇBGY
<i>Cichorium intybus</i> L.	Hindiba	Çayır	Endemik Değil	ÇBGY
<i>Cirsium arvense</i> (L.) Scop.	Köygöçüren	Çayır	Endemik Değil	ÇBGY
<i>Cirsium vulgare</i> (Savi) Ten.	Yaygıncakal	Çayır	Endemik Değil	ÇBGY
<i>Cota tinctoria</i> (L.) J.Gay var. <i>tinctoria</i>	Boyacıpapatyası	Çayır	Endemik Değil	ÇBGY
<i>Crepis foetida</i> subsp. <i>rhoeadifolia</i> (M.Bieb.) Çelak.	Sakarkanak	Çayır	Endemik Değil	ÇBGY
<i>Cyanus depressus</i> (M.Bieb.) Soják	Gökbaş	Çayır	Endemik Değil	ÇBGY
<i>Echinops ritro</i> L.	Topuz	Çayır	Endemik Değil	ÇBGY
<i>Filago pyramidata</i> L.	Ateşpamuğu	Step	Endemik Değil	ÇBGY
<i>Gundelia tournefortii</i> L. var. <i>tournefortii</i>	Kenger	Çayır, yol kenarı	Endemik Değil	İran-Turan
<i>Onopordum acanthium</i> L.	Galagan	Çayır	Endemik Değil	ÇBGY
<i>Picnemon acarna</i> (L.) Cass.	Kılçık diken	Çayır	Endemik Değil	ÇBGY
<i>Senecio vernalis</i> Waldst. & Kit.	Kanaryaotu	Kumlu alanlar	Endemik Değil	ÇBGY
<i>Taraxacum butleri</i> Soest	Karahindiba	Çayır	Endemik Değil	ÇBGY
<i>Tragopogon bupththalmoides</i> var. <i>latifolius</i> Boiss.	Tarlayemliği	Çayır	Endemik Değil	ÇBGY
<i>Tripleurospermum disciforme</i> (C.A.Mey.) Sch.Bip.	Kel beybunuk	Çayır	Endemik Değil	İran-Turan
<i>Xanthium spinosum</i> L.	Pıtrak	Çayır	Endemik Değil	ÇBGY
<i>Xeranthemum annuum</i> L.	Kağıtçiçeği	Step	Endemik Değil	ÇBGY
BORAGINACEAE				
<i>Alkanna orientalis</i> (L.) Boiss. var. <i>orientalis</i>	Sarı somuk	Çalılık	Endemik Değil	İran-Turan
<i>Anchusa azurea</i> Mill. var. <i>kurdica</i> (Guşul.) D.F.Chamb.	Sığırdili	Çalılık	Endemik Değil	ÇBGY
<i>Anchusa leptophylla</i> Roem. & Schult. subsp. <i>incana</i> (Ledeb.) D.F.Chamb.	Emzidili	Çalılık	Endemik (LC)	İran-Turan
<i>Buglossoides arvensis</i> (L.) I. M. Johnst. subsp. <i>sibthorpiana</i> (Griseb.) R.Fern.	Tarlataşkeseni	Çalılık	Endemik Değil	ÇBGY
<i>Echium italicum</i> L.	Kurtkuyruğu	Çayır	Endemik Değil	Akdeniz
<i>Heliotropium dolosum</i> De Not.	Bambul	Çalılık, çayır	Endemik Değil	ÇBGY
<i>Heliotropium europaeum</i> L.	Akrepotu	Kumlu alanlar	Endemik Değil	İran-Turan
<i>Onosma sericea</i> Willd.	Kağıt emcek	Step çayır	Endemik Değil	İran-Turan
BRASSICACEAE				
<i>Alyssum strigosum</i> Banks & Sol. subsp. <i>strigosum</i>	Dökükkuduzotu	Step	Endemik Değil	ÇBGY
<i>Brassica elongata</i> Ehrh.	Uzun şalgam	Çayır	Endemik Değil	ÇBGY
<i>Capsella bursa-pastoris</i> (L.) Medik.	Çobançantası	Çayır, kumlu alanlar	Endemik Değil	ÇBGY
<i>Crambe orientalis</i> L.	Akyumak	Çayır	Endemik Değil	ÇBGY
<i>Descurainia sophia</i> (L.) Webb ex Prantl subsp. <i>sophia</i> (L.) Webb ex Prantl	Sadırotu	Çayır	Endemik Değil	ÇBGY
<i>Erysimum crassipes</i> Fisch. & C.A.Mey.	Zarifeotu	Çayır	Endemik Değil	ÇBGY
<i>Lepidium draba</i> L.	Diğnik	Çayır	Endemik Değil	ÇBGY
<i>Lepidium latifolium</i> L.	Nujdar	Çayır	Endemik Değil	ÇBGY
<i>Microthlaspi perfoliatum</i> (L.) F.K.Mey.	Giyle	Çayır	Endemik Değil	ÇBGY
<i>Nasturtium officinale</i> R.Br.	Suteresi	Sulak çayır, sazlık	Endemik Değil	ÇBGY

Familiya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
<i>Neslia paniculata</i> (L.) Desv. subsp. <i>thracica</i> (Velen.) Bornm.	Göçmenhardalı	Çayır	Endemik Değil	ÇBGY
<i>Raphanus raphanistrum</i> L. subsp. <i>raphanistrum</i>	Eşekturpu	Çayır, kumlu alanlar	Endemik Değil	ÇBGY
<i>Sinapis arvensis</i> L.	Hardal	Sulak çayır	Endemik Değil	ÇBGY
<i>Sisymbrium loeselii</i> L.	Bülbülotu	Yol kenarı	Endemik Değil	ÇBGY
<i>Sisymbrium orientale</i> L.	Tarlabülbülotu	Yol kenarı	Endemik Değil	ÇBGY
<i>Strigosella africana</i> (L.) Botsch.	Keçeteresi	Kumul	Endemik Değil	ÇBGY
CANNABACEAE				
<i>Celtis planchoniana</i> K.I.Chr.	Dahum	Meşe açıklıkları	Endemik Değil	ÇBGY
CAPRIFOLIACEAE				
<i>Cephalaria syriaca</i> (L.) Schrad.	Pelemir	Çayır	Endemik Değil	ÇBGY
<i>Dipsacus laciniatus</i> L.	Fesçitarağı	Çayır	Endemik Değil	ÇBGY
<i>Scabiosa argentea</i> L.	Yazısüpürgesi	Çayır	Endemik Değil	ÇBGY
CARYOPHYLLACEAE				
<i>Cerastium glomeratum</i> Thuill.	Boynuzotu	Çayır	Endemik Değil	ÇBGY
<i>Dianthus floribundus</i> Boiss.	Kırk karanfil	Çayır	Endemik Değil	İran-Turan
* <i>Dianthus plumbeus</i> Schischk.	Kızhanım	Çalılık, meşe açıklığı	Endemik (VU)	İran-Turan
<i>Holosteum umbellatum</i> L. var. <i>umbellatum</i>	Şeytanküpesi	Çayır	Endemik Değil	ÇBGY
<i>Silene conica</i> L.	Sivrinakıl	Çayır	Endemik Değil	ÇBGY
<i>Silene dichotoma</i> Ehrh. subsp. <i>dichotoma</i>	Çatalnakıl	Çayır	Endemik Değil	ÇBGY
<i>Silene latifolia</i> Poir. subsp. <i>ericalycinae</i> (Boiss.) Greuter & Burdet	Gıcıcıcı	Tarla kenarı	Endemik Değil	ÇBGY
<i>Silene vulgaris</i> (Moench) Garcke var. <i>vulgaris</i> (Moench) Garcke	Ecibüctü	Çayır	Endemik Değil	ÇBGY
<i>Vaccaria hispanica</i> (Mill.) Rauschert	Ekinebesi	Çayır	Endemik Değil	ÇBGY
CERATOPHYLLACEAE				
<i>Ceratophyllum submersum</i> L.	Su boynuzu	Durgun sular	Endemik Değil	Avrupa-Sibirya
CONVOLVULACEAE				
<i>Convolvulus arvensis</i> L.	Tarlasarmaşığı	Çayır	Endemik Değil	ÇBGY
<i>Cuscuta campestris</i> Yunck.	Kafırsaçı	Çayır	Endemik Değil	ÇBGY
CYPERACEAE				
<i>Bolboschoenus maritimus</i> (L.) Palla subsp. <i>maritimus</i>	Sandalyesazı	Sulak çayır	Endemik Değil	ÇBGY
<i>Carex acutiformis</i> Ehrh.	Çayırsazı	Çayır, dere kenarı	Endemik Değil	Avrupa-Sibirya
<i>Carex diluta</i> M.Bieb. subsp. <i>diluta</i>	Küpelisaz	Sulak çayır	Endemik Değil	İran-Turan
<i>Cyperus fuscus</i> L.	Maydanozbağı	Sulak çayır, dere kenarı	Endemik Değil	Avrupa-Sibirya
<i>Cyperus glaber</i> L.	Kösnüotu	Sazlık	Endemik Değil	ÇBGY
<i>Cyperus longus</i> L. subsp. <i>longus</i>	Karatopalak	Sazlık	Endemik Değil	ÇBGY
<i>Cyperus pannonicus</i> Jacq.	Macarhasırotu	Sazlık	Endemik Değil	ÇBGY
<i>Eleocharis palustris</i> (L.) Roem. & Schult. subsp. <i>palustris</i>	Delisaz	Su kenarı, bataklık	Endemik Değil	ÇBGY
<i>Schoenus nigricans</i> L.	İnekgözü	Dere kenarı, sazlık	Endemik Değil	ÇBGY
<i>Scirpoides holoschoenus</i> (L.) Soják subsp. <i>holoschoenus</i>	Vurla	Dere kenarı, sazlık	Endemik Değil	ÇBGY
EUPHORBIACEAE				
<i>Euphorbia heteradena</i> Jaub. & Spach	Kerigan	Çayır	Endemik Değil	İran-Turan
<i>Euphorbia macroclada</i> Boiss.	Neblul	Çayır, yol kenarı	Endemik Değil	İran-Turan

Familya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
<i>Euphorbia esula</i> L. subsp. <i>tommasiniana</i> (Bertol.) Kuzmanov	Eşek sütleğeni	Çalılık	Endemik Değil	ÇBGY
FABACEAE				
<i>Astragalus brachycalyx</i> Fisch. ex Boiss. subsp. <i>brachycalyx</i>	Yağlı geven	Step	Endemik Değil	İran-Turan
<i>Astragalus gummifer</i> Labill.	Sakızlı geven	Meşe açıklığı, step	Endemik Değil	İran-Turan
<i>Glycyrrhiza echinata</i> L.	Ptırakmeyan	Çalılıklar	Endemik Değil	ÇBGY
<i>Lathyrus sativus</i> L.	Mürdümük	Çayır	Endemik Değil	Akdeniz
<i>Lotus corniculatus</i> L. var. <i>tenuifolius</i>	Gazalboynuzu	Çayır	Endemik Değil	ÇBGY
<i>Medicago sativa</i> L. subsp. <i>sativa</i>	Karayonca	Çayır	Endemik Değil	ÇBGY
<i>Medicago x varia</i> T. Martyn	Yabanyoncası	Çayır	Endemik Değil	ÇBGY
<i>Melilotus officinalis</i> (L.) Desr.	Kokuluyonca	Çayır	Endemik Değil	ÇBGY
<i>Ononis spinosa</i> L. subsp. <i>leiosperma</i> (Boiss.) Širj.	Demirdelen	Yol kenarı	Endemik Değil	ÇBGY
<i>Securigera orientalis</i> (Mill.) Lassen subsp. <i>orientalis</i>	Alakörigen	Çayır	Endemik Değil	ÇBGY
<i>Securigera varia</i> (L.) Lassen	Körigen	Çayır	Endemik Değil	Akdeniz
<i>Trifolium arvense</i> L. var. <i>arvense</i>	Tavşanayağı	Çayır	Endemik Değil	ÇBGY
<i>Trifolium campestre</i> Schreb. subsp. <i>campestre</i> var. <i>campestre</i>	Üçgül	Çayır	Endemik Değil	ÇBGY
<i>Trifolium dubium</i> Sibth.	Tatlıyonca	Çayır	Endemik Değil	ÇBGY
<i>Trifolium hirtum</i> All.	Deliyonca	Çayır	Endemik Değil	Akdeniz
<i>Trifolium pratense</i> L. var. <i>pratense</i>	Çayırgülü	Çayır, çalılık, orman kenarı	Endemik Değil	ÇBGY
<i>Trifolium repens</i> L. var. <i>repens</i>	Aküçgül	Çayır	Endemik Değil	ÇBGY
<i>Trifolium resupinatum</i> L. var. <i>resupinatum</i>	Anadolüçgülü	Çayır	Endemik Değil	ÇBGY
<i>Vicia cracca</i> L. subsp. <i>cracca</i>	Kuşfiği	Çayır, çalılık	Endemik Değil	Avrupa-Sibirya
<i>Vicia noeana</i> Boiss. & Reut. ex Boiss. var. <i>noeana</i>	Salkım bakla	Çayır, çalılık	Endemik Değil	İran-Turan
<i>Vicia sativa</i> L. subsp. <i>sativa</i>	Fiğ	Çayır, çalılık	Endemik Değil	ÇBGY
FAGACEAE				
<i>Quercus robur</i> L. subsp. <i>pedunculiflora</i> (K.Koch) Menitsky	Akmeşe	Bozulmuş Orman	Endemik Değil	İran-Turan
GERANIACEAE				
<i>Erodium cicutarium</i> (L.) L. Hér. subsp. <i>cicutarium</i>	İğnelik	Çayır	Endemik Değil	ÇBGY
<i>Geranium rotundifolium</i> L.	Helilok	Çayır	Endemik Değil	ÇBGY
HALORAGACEAE				
<i>Myriophyllum spicatum</i> L.	Sucivanperçemi	Durgun sular	Endemik Değil	ÇBGY
HYPERICACEAE				
<i>Hypericum perforatum</i> L. subsp. <i>veronense</i> (Schränk) H.Linb.	Sarıkantaron	Çayır, orman kenarı	Endemik Değil	ÇBGY
JUNCACEAE				
<i>Juncus articulatus</i> L. subsp. <i>articulatus</i>	Camışotu	Sazlık	Endemik Değil	Avrupa-Sibirya
<i>Juncus bufonius</i> L.	Kamır	Sazlık	Endemik Değil	ÇBGY
<i>Juncus gerardii</i> Loisel. subsp. <i>gerardii</i>	Erkek kofa	Sazlık	Endemik Değil	ÇBGY
<i>Juncus heldreichianus</i> T.Marsson ex Parl. subsp. <i>orientalis</i>	Kısadombay	Sazlık	Endemik Değil	ÇBGY
<i>Juncus inflexus</i> L. subsp. <i>inflexus</i>	Sazak	Sazlık	Endemik Değil	ÇBGY
<i>Triglochin maritima</i> L.	Dağ suçengeli	Bataklıklar	Endemik Değil	ÇBGY
LAMIACEAE				
<i>Lamium amplexicaule</i> L. var. <i>amplexicaule</i>	Baltutan	Çayır	Endemik Değil	ÇBGY

Familya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
<i>Marrubium parviflorum</i> Fisch. & C.A.Mey. subsp. <i>parviflorum</i>	Bozotu	Çayır	Endemik Değil	İran-Turan
<i>Mentha longifolia</i> (L.) L. subsp. <i>typhoides</i> (Briq.) Harley	Derenanesi	Çayır	Endemik Değil	ÇBGY
<i>Salvia nemorosa</i> L.	Gehareş	Çayır	Endemik Değil	İran-Turan
<i>Salvia microstegia</i> Boiss. & Balansa	Yağlambaç	Çayır	Endemik Değil	İran-Turan
<i>Salvia virgata</i> Jacq.	Fatmananotu	Çayır	Endemik Değil	İran-Turan
<i>Scutellaria albida</i> L. subsp. <i>condensata</i> (Rech.f.) J.R.Edm.	Kırk kaside	Çayır	Endemik Değil	İran-Turan
<i>Teucrium orientale</i> L. var. <i>glabrescens</i> Hausskn. ex Bornm.	Kirveotu	Çayır	Endemik Değil	İran-Turan
<i>Teucrium polium</i> L. subsp. <i>polium</i>	Acıyavşan	Çalılık	Endemik Değil	ÇBGY
<i>Thymus kotschyanus</i> Boiss. & Hohen. subsp. <i>kotschyanus</i>	Kekik	Step	Endemik Değil	İran-Turan
<i>Ziziphora clinopodioides</i> Lam.	Dağreyhanı	Çayır	Endemik Değil	İran-Turan
LYTHRACEAE				
<i>Lythrum salicaria</i> L.	Hevhulma	Sulak çayır	Endemik Değil	Avrupa-Sibirya
MALVACEAE				
<i>Alcea calvertii</i> (Boiss.) Boiss.	Hıraçiçeği	Çalılık	Endemik Değil (LC)	İran-Turan
<i>Alcea kurdica</i> (Schltdl.) Alef.	Devegülü	Çalılık	Endemik Değil	İran-Turan
<i>Malva sylvestris</i> L.	Ebegümece	Yol kenarı	Endemik Değil	ÇBGY
NYMPHAEACEAE				
<i>Nuphar lutea</i> (L.) Sm.	Sarınılüfer	Sığ durgun sular	Endemik Değil	ÇBGY
<i>Nymphaea alba</i> L.	Nilüfer	Sığ durgun sular	Endemik Değil	ÇBGY
ONAGRACEAE				
<i>Epilobium parviflorum</i> Schreb.	İrazyakıotu	Sulak çayır	Endemik Değil	ÇBGY
PAPAVERACEAE				
<i>Fumaria officinalis</i> L. subsp. <i>officinalis</i>	Şahtere	Tarla kenarı	Endemik Değil	ÇBGY
<i>Glaucium flavum</i> Crantz	Gündürmelâlesi	Dere kenarı	Endemik Değil	ÇBGY
<i>Papaver dubium</i> L. subsp. <i>dubium</i>	Köpekyacı	Yol kenarı, tarla kenarı	Endemik Değil	ÇBGY
<i>Papaver rhoeas</i> L.	Gelincik	Yol kenarı, tarla kenarı	Endemik Değil	ÇBGY
PLANTAGINACEAE				
<i>Plantago lanceolata</i> L.	Damarlıca	Çayır	Endemik Değil	ÇBGY
<i>Plantago major</i> L. subsp. <i>major</i>	Sinirotu	Çayır, kumlu alanlar	Endemik Değil	ÇBGY
<i>Veronica anagallis-aquatica</i> L.	Sugedemesi	Sulak çayır	Endemik Değil	ÇBGY
POACEAE				
<i>Agrostis stolonifera</i> L.	Tavusotu	Sulak çayır	Endemik Değil	Avrupa-Sibirya
<i>Alopecurus myosuroides</i> Huds. subsp. <i>myosuroides</i>	Tarlatilkikuyruğu	Orman	Endemik Değil	Avrupa-Sibirya
<i>Bromus scoparius</i> L.	İbubukekini	Çayır	Endemik Değil	ÇBGY
<i>Bromus tectorum</i> L.	Kırbromu	Çayır	Endemik Değil	ÇBGY
<i>Calamagrostis canescens</i> (G.H.Weber) Roth	Ak kandıraotu	Sazlık	Endemik Değil	Avrupa-Sibirya
<i>Catabrosa aquatica</i> (L.) P. Beauv.	Çipil	Çayır	Endemik Değil	ÇBGY
<i>Cynodon dactylon</i> (L.) Pers. var. <i>dactylon</i>	Köpekdişi	Sulak çayır, çayır	Endemik Değil	ÇBGY
<i>Dactylis glomerata</i> L. subsp. <i>glomerata</i>	Domuzayrığı	Çayır	Endemik Değil	Avrupa-Sibirya
<i>Echinochloa crus-galli</i> (L.) P.Beauv.	Darıcan	Sulak çayır	Endemik Değil	ÇBGY

Familya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
<i>Hordeum geniculatum</i> All.	Yatıkarpa	Çayır	Endemik Değil	Avrupa-Sibirya
<i>Hordeum murinum</i> L. subsp. <i>glaucum</i> (Steud.) Tzvelev	Duvararпасı	Çayır	Endemik Değil	ÇBGY
<i>Lolium perenne</i> L.	Çim	Çayır, çalılık	Endemik Değil	Avrupa-Sibirya
<i>Phalaris arundinacea</i> L.	Kanyaş	Sazlık, dere kenarı	Endemik Değil	ÇBGY
<i>Phleum pratense</i> L.	Çayır itkuyruğu	Çayır	Endemik Değil	ÇBGY
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Kamış	Sazlık	Endemik Değil	Avrupa-Sibirya
<i>Poa annua</i> L.	Salkımotu	Çayır	Endemik Değil	ÇBGY
<i>Poa bulbosa</i> L.	Yumrulusalkım	Çayır	Endemik Değil	ÇBGY
<i>Poa pratensis</i> L.	Çayırsalkımotu	Çayır	Endemik Değil	ÇBGY
<i>Polypogon monspeliensis</i> (L.) Desf.	Hıtır	Sulak çayır	Endemik Değil	ÇBGY
<i>Puccinellia distans</i> (Jacq.) Parl. subsp. <i>sevangensis</i> (Grossh.) Tzvelev	Kaf tuzçimi	Dere kenarı	Endemik Değil	ÇBGY
<i>Rostraria cristata</i> (L.) Tzvelev var. <i>cristata</i>	Gagaotu	Çayır	Endemik Değil	ÇBGY
<i>Setaria viridis</i> (L.) P.Beauv.	Yeşil sıçansaçı	Çayır	Endemik Değil	ÇBGY
<i>Taeniatherum caput-medusae</i> (L.) Nevski subsp. <i>crinitum</i> (Schreb.) Melderis	Kılçıkarpası	Çayır	Endemik Değil	İran-Turan
<i>Triticum aestivum</i> L.	Ekmeklik buğday	Tarla	Endemik Değil	ÇBGY
POLYGONACEAE				
<i>Polygonum amphibium</i> L.	Yerdeğıştiren	Durgun sular	Endemik Değil	ÇBGY
<i>Polygonum bistorta</i> L. subsp. <i>bistorta</i>	Çimeneveleği	Sazlık	Endemik Değil	Avrupa-Sibirya
<i>Polygonum cognatum</i> Meissn.	Madımak	Çalılık	Endemik Değil	ÇBGY
<i>Polygonum lapathifolium</i> L.	Tırşon	Çalılık	Endemik Değil	ÇBGY
<i>Polygonum setosum</i> Jacq. subsp. <i>luzuloides</i> (Jaub. & Spach) Leblebici	Uzunebemekmeği	Çalılık	Endemik Değil	İran-Turan
<i>Rumex conglomeratus</i> Murray	Ekşikulak	Kumul	Endemik Değil	ÇBGY
<i>Rumex crispus</i> L.	Labada	Çayırılık	Endemik Değil	ÇBGY
POTAMOGETONACEAE				
<i>Potamogeton gramineus</i> L.	Çimsusümbülü	Durgun sular	Endemik Değil	ÇBGY
<i>Potamogeton natans</i> L.	Suotu	Durgun sular	Endemik Değil	ÇBGY
RANUNCULACEAE				
<i>Ranunculus arvensis</i> L.	Mustafaçiçeği	Çayırılık	Endemik Değil	ÇBGY
<i>Ranunculus repens</i> L.	Tiktakdana	Çayır	Endemik Değil	ÇBGY
<i>Ranunculus sceleratus</i> L.	Batakdüğünçiçeği	Sığ sular	Endemik Değil	ÇBGY
<i>Ranunculus trichophyllus</i> Chaix ex Vill.	Suluçanak	Durgun sular	Endemik Değil	ÇBGY
ROSACEAE				
<i>Crataegus orientalis</i> Pall. ex M.Bieb. subsp. <i>orientalis</i>	Alıç	Terkedilmiş alanlar	Endemik Değil	ÇBGY
<i>Potentilla reptans</i> L.	Reşatınotu	Sulak çayır	Endemik Değil	ÇBGY
RUBIACEAE				
<i>Galium aparine</i> L.	Çobansüzgeci	Orman	Endemik Değil	ÇBGY
<i>Galium humifusum</i> M.Bieb.	Çimen iplikçiği	Çayır	Endemik Değil	ÇBGY
<i>Galium verum</i> L. subsp. <i>verum</i>	Boyalık	Çayır	Endemik Değil	Avrupa-Sibirya
SALICACEAE				
<i>Populus alba</i> L. var. <i>alba</i>	Akkavak	Orman	Endemik Değil	Avrupa-Sibirya
<i>Populus tremula</i> L. subsp. <i>tremula</i>	Titrekkavak	Dere kenarı	Endemik Değil	ÇBGY

Familya ve Tür Adı	Türkçe Adı	Habitat	Endemizm Durumu (Tehlike kategorisi)	Fitocoğrafik Bölge
<i>Salix alba</i> L. subsp. <i>alba</i>	Aksöğüt	Dere kenarı	Endemik Değil	Avrupa-Sibirya
<i>Salix caprea</i> L.	Sorgun	Dere kenarı	Endemik Değil	Avrupa-Sibirya
SCROPHULARIACEAE				
<i>Verbascum speciosum</i> Schrad.	Zelve	Çayırılık	Endemik Değil	ÇBGY
SOLANACEAE				
<i>Datura stramonium</i> L.	Boruçiçeği	Çayır	Endemik Değil	ÇBGY
<i>Solanum dulcamara</i> L.	Sofur	Nemli alanlar	Endemik Değil	Avrupa-Sibirya
TYPHACEAE				
<i>Sparganium erectum</i> L. subsp. <i>microcarpum</i> (Neuman) Domin	Küçük kındıra	Sazlık	Endemik Değil	Avrupa-Sibirya
<i>Typha angustifolia</i> L.	Saz	Sazlık	Endemik Değil	ÇBGY
<i>Typha laxmannii</i> Lepech.	Papur	Sazlık	Endemik Değil	Avrupa-Sibirya
URTICACEAE				
<i>Urtica dioica</i> L. subsp. <i>dioica</i>	Isırgan	Nemli alanlar	Endemik Değil	Avrupa-Sibirya

(*Arazi çalışmalarında rastlanmamış, literatür verilerine göre listeye eklenmiştir. ÇBGY - Çok Bölge ve Geniş Yayılışlı)

Habitat Tipleri:

Çalışma alanının sınırları içerisinde bitkiler için başlıca beş tip habitat bulunmaktadır. Bunlar:

1. Sazlıklar - Bataklık

İron Sazlığı içerisinde en geniş alanı kaplayan sulak habitat tipi olan sazlıklar, alanda kuşların üreme alanı olarak kullanma potansiyeline sahip en önemli habitatır. Merkez alanın özellikle batı kesimlerini kaplayan sazlıklar yaz ayları dâhil her zaman su içeren bataklık karakterinde bir taban yapısına sahiptir (Şekil 3. A,B, Şekil 4. A,B). İron Sazlığı'nın kuzeyinde yer alan kesimlerde ve fazlaca derin olmayan yerlerde, sazlık ve bataklıklar mandalar tarafından otlama ve serinleme amacı ile kullanılmaktadır. Bu bitki gruplarına detaylı bakılacak olursa;

Sadece Dip Kısımları Su İçinde Olan Kıyı Bitkileri

Kökleri veya taban kısımları su içerisinde yer alırken gövdenin büyük çoğunluğu su dışında yer alan bitkilerden oluşmaktadır (Şekil 3. A, B). *Alisma plantago-aquatica* subsp. *plantago-aquatica*, *Equisetum giganteum*, *Triglochin maritima*, *Phragmites australis*, *Ranunculus scleratus*, *Typha laxmannii*, *Typha angustifolia*, *Eleocharis palustris* subsp. *palustris*, *Polygonum lapathifolium*, *Nasturtium officinale*, *Mentha longifolia* subsp. *typhoides*, *Veronica anagallis-aquatica*, *Sparganium erectum* subsp. *microcarpum*, *Scirpoides holoschoenus* subsp. *holoschoenus*.

Su İçi Bitkileri

Su içi bitkileri ve sadece dip kısımları batık bitkilerinden oluşmaktadır (Şekil 3. C,D,E,F). Bu habitatları göl aynası kıyıları, önceki yıllarda torf çıkartılmış göletlerde ve alana bağlanan akarsu kıyılarında görmekteyiz. Aşağıda sucul habitatlar için verilen türler

arasında istilacı bitki türü yapılan arazi çalışmalarında tespit edilmemiştir. Ancak alanın önümüzdeki yıllarda, vejetasyon dönemlerinde takip edilmesinde fayda vardır. Bu habitatta yayılış gösteren bitkiler; *Nymphaea alba*, *Nuphar lutea*, *Ranunculus trichophyllus*, *Lemna gibba*, *Ceratophyllum submersum*, *Myriophyllum spicatum*, *Polygonum amphibium*, *Potamogeton gramineus* ve *Potamogeton natans*.

2. Islak-Nemli Çayırhıklar

Sazlığın daha çok doğusu ve güneyinde yer alan sulak çayırlar, İron sazlığı'nın önemli habitat tiplerinden birisini oluşturmaktadır (Şekil 4. C, D). Alanda yer alan sulak çayırların çoğu mevsimsel olarak su altında kalan alanlardır, ancak yaz aylarında halen çamurlu ya da ıslak bir şekilde bulunan sulak çayırlar da mevcuttur. Bazı sulak çayır niteliğinde olan alanların ise bir süredir su altında kalmadığı, görece kuru bir toprağa sahip oldukları ve degrade olduğu gözlenmiştir. Sulak çayır habitatları, hem otlamaya uygunlukları hem de otlatma yapılan köylere daha yakın konumları nedeni ile gerek manda gerekse sığır otlamasına maruz kalmaktadır.

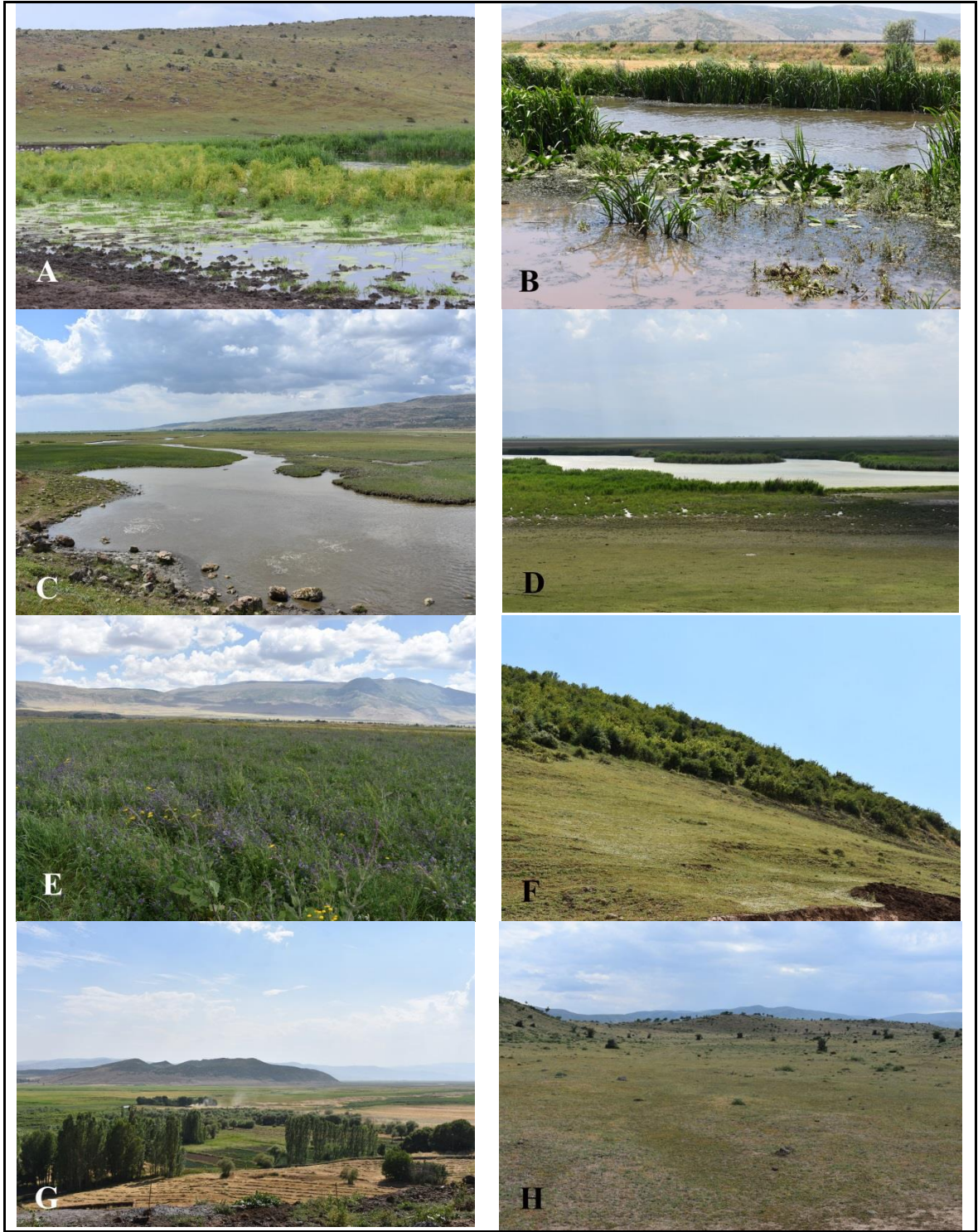


Şekil 3. A. *Phragmites australis* topluluğu, B. *Typha laxmannii* sazlığı, C. Sazlık içerisinde *Ceratophyllum submersum* ve *Phragmites australis* topluluğu, D. Göl aynası üzerinde aşırı artış göstermiş *Lemna gibba* topluluğu, E. *Nuphar lutea* (L.) Sm. (sarınılüfer) F. *Nymphaea alba* L. (nilüfer)

Arazi çalışmaları sırasında, daha önce sulak çayır olduğu açık olan bazı alanlarda, aşırı otlatma ve su çekilmesi sonucu toprakta sertleşmenin olduğu ve sulak çayır bitkilerinin aşırı derecede yıpranmış olduğu gözlenmiştir. Bu alanlarda sulak çayırın niteliğini kaybederek meraya dönüşmekte olduğu söylenebilir. Buralarda görülen bitkiler, *Allium fuscoviolaceum*, *Chenopodium chenopodioides*, *Lythrum salicaria*, *Bolboschoenus maritimus* subsp. *maritimus*, *Carex diluta* subsp. *diluta*, *Hordeum murinum* subsp. *glaucum*, *Cyperus fuscus*, *Agrostis stolonifera*, *Polypogon monspeliensis*, *Sinapis arvensis*, *Urtica dioica* subsp. *dioica*, *Solanum dulcamara*, *Epilobium parviflorum*, *Echinochloa crus-galli*, *Potentilla reptans*.

3. Doğal Çayırliklar, Segetal ve Ruderal Habitatlar

Bu başlık altında sulak olmayan doğal ya da bozulmuş tüm çayırlik alanlarda bulunan taksonlar listelenmiştir (Şekil 4. E). Burada tarla sınırlarında kendiliğinden yetişen türler, yol, inşaat, park vs. ile bozulan habitatlardaki ruderal (insanlar tarafından bitki yaşamına elverişsiz hale getirilmiş alanlar) türler de verilmiştir. Genellikle sazlığın etrafında, yol ve tarla kenarlarında ve sazlığın güney kısımlarında bu vejetasyon tipi görülmektedir. Burada bulunan bitkiler; *Fumaria officinalis* subsp. *officinalis*, *Torilis arvensis*, *Euphorbia heteradena*, *Euphorbia macroclada*, *Euphorbia esula* subsp. *tommasiniana*, *Tripleurospermum disciforme*, *Crambe orientalis*, *Papaver dubium* subsp. *dubium*, *Papaver rhoeas*, *Alcea kurdica*, *Alcea calvertii*, *Malva sylvestris*, *Lepidium draba*, *Lepidium latifolium*, *Capsella bursa-pastoris*, *Silene latifolia* subsp. *ericalycinae*, *Silene vulgaris* var. *vulgaris*, *Amaranthus deflexus*, *Chenopodium botrys*, *Hypericum perforatum* subsp. *veronense*, *Lathyrus sativus*, *Lotus corniculatus* var. *tenuifolius*, *Medicago sativa* subsp. *sativa*, *Medicago x varia*, *Melilotus officinalis*, *Ononis spinosa* subsp. *leiosperma*, *Securigera orientalis* subsp. *orientalis*, *Securigera varia*, *Trifolium arvense*, *Trifolium campestre* subsp. *campestre* var. *campestre*, *Trifolium dubium*, *Trifolium hirtum*, *Trifolium pratense* var. *pratense*, *Trifolium repens* var. *repens*, *Trifolium resupinatum* var. *resupinatum*, *Vicia cracca* subsp. *cracca*, *Vicia noeana* var. *noeana*, *Vicia sativa* subsp. *sativa*, *Conium maculatum*, *Daucus carota*, *Achillea arabica*, *Bellis perennis*, *Carduus nutans* subsp. *nutans*, *Carduus pycnocephalus* subsp. *albidus*, *Carthamus lanatus*, *Centaurea iberica*, *Centaurea solstitialis* L. subsp. *solstitialis*, *Centaurea virgata*, *Chondrilla juncea*, *Cichorium intybus*, *Cirsium arvense*, *Cirsium vulgare*, *Cyanus depressus*, *Echinops ritro*, *Onopordum acanthium*, *Senecio vernalis*, *Taraxacum buttleri*, *Tragopogon bupthalmoides* var. *latifolius*, *Xanthium spinosum*, *Anchusa azurea* var. *kurdica*, *Echium italicum*, *Heliotropium dolosum*, *Heliotropium europaeum*, *Marrubium parviflorum* subsp. *parviflorum*, *Salvia nemorosa*, *Salvia microstegia*, *Salvia virgata*, *Scutellaria albida* subsp. *condensata*, *Teucrium orientale* var. *glabrescens*, *Dipsacus laciniatus*, *Plantago lanceolata*, *Plantago major* subsp. *major*, *Lolium perenne*, *Cynodon dactylon* var. *dactylon*, *Poa annua*, *Poa bulbosa*, *Poa pratensis*, *Phleum pratense*, *Verbascum speciosum*, *Datura stramonium*, *Ornithogalum narbonense*.



Şekil 4. A. *Typha laxmannii* ve *Ranunculus sceleratus* birliği, B. *Typha angustifolia*, *Phragmites australis*, *Nuphar lutea* ve *Ceratophyllum submersum* bitkilerinin bir arada bulunduğu bir sazlık, C. Budaklı köyü civarı sulak çayırliklar, D. Budaklı ile Değirmenköy arasındaki sulak çayırlik ve sazlık alanlar, E. Değirmenköy civarında yer alan doğal çayırliklar. F. Otlatma sonucu tahrip edilmiş meşe çalılık-ları, G. Sazlıkbaşı civarında kavak ve söğüt ağaçları, H. Iron sazlığı içerisinde aşırı otlatma baskısı altında kalmış step alanlar.

4. Ağaç Formasyonları ve Ormanlar

İron sazlığı çevresinde, hemen göl aynasını çevreleyen sazlık alanlar ve nemli ıslak çayırıklardan sonra *Salix alba* subsp. *alba* (aksöğüt) ve *Salix caprea* (sorgun) taksonlarının oluşturduğu doğal söğütlükler bulunmaktadır. Ayrıca sınırlı alanlarda dikimi yapılan *Populus alba* var. *alba* (akkavak) ve *Populus tremula* subsp. *tremula* (titrekavak) ağaçlandırma alanları bulunmaktadır (Şekil 4. G). Ayrıca alanın merkezi dışındaki tepeliklerde yoğunluğu *Quercus robur* subsp. *pedunculiflora* (akmeşe) olmak üzere seyrek olarak da *Crataegus orientalis* subsp. *orientalis* (alıç) taksonlarının oluşturduğu, çoğu aşırı otlatma nedeni ile orman niteliğini yitirmiştir ve çalılık durumunda olan kısa boylu, kapalılığı düşük çalılıklar yer almaktadır (Şekil 4. F). Birçok yerde, meşe ormanlarının tahribi sonucu antropojenik bir bozkır vejetasyonu alana hâkim olmuştur. Sulak alanın kuzeyinde yer alan, muhtemelen o bölgede eski bir mezarlık bulunmasından ve bu alanın halk tarafından kutsal görüldüğü için, ağaçları kesmemelerinden dolayı kalıntı halde yaşlı meşe ağaçları bulunmaktadır. Bu yaşlı ve kadim ağaçların varlığı sazlığın etrafının bir zamanlar meşe ormanları ile kaplı olduğunu göstermektedir.

5. Step (Dağ bozkırı)

Sulak alanın kuzey ve güney kesimlerinde hâkim olan, alan içerisinde çalılıkların olmadığı kısımlarda ve Nemrut Dağı'nın alt havzaya bakan kesimlerindeki dik yamaçlarda step habitatu bulunmaktadır. Step alanların sulak alana yakın olan kesimleri aşırı otlatma baskısı nedeni ile doğal yapısını kaybetmiştir. Bu alanlar aşırı otlatma baskısı altındadır (Şekil 4. H). Step vejetasyonu, otlatmanın görece daha az yapıldığı tepelik kesimlerde daha doğal ve bitki çeşitliliği daha fazla bir yapıda bulunmaktadır. Özellikle alanın çalılık kesimlerinde, açıklarda yer alan bozkır alanları, daha çok sekonder bir step vejetasyonu olup tepelerdeki çalılık ve ağaçlıkların tahribi ile ortaya çıkmışlardır. Bu alanlarda bulunan bitki türleri; *Astragalus gummifer*, *Astragalus brachycalyx* subsp. *brachycalyx*, *Alyssum strigosum* subsp. *strigosum*, *Filago pyramidata*, *Gundelia tournefortii* var. *tournefortii*, *Xeranthemum annuum*, *Cota tinctoria* var. *tinctoria*, *Artemisia campestris* var. *campestris* ve *Thymus kotschyanus* subsp. *kotschyanus*'dur.

Floranın taksonomik analizi

Yapılan arazi çalışmaları sonucunda alanda 41 familyaya ait 148 cins ve 212 taksonun yayılış gösterdiği tespit edilmiştir (Çizelge 1). Araştırma sonuçlarına göre en fazla tür ve tür altı taksona sahip ilk beş familya; Asteraceae (32 takson), Poaceae (24 takson), Fabaceae (21 takson), Brassicaceae (16 takson) ve Lamiaceae (11 takson) olarak tespit edilmiştir.

Cins düzeyinde yapılan analizde ise en fazla taksona sahip cinslerin *Trifolium* (7 takson), *Polygonum* ve *Juncus* (5 takson), *Ranunculus*, *Centaurea*, *Achillea*, *Cyperus*, *Silene* (4 takson) olduğu belirlenmiştir.

Fitocoğrafik analiz

Çalışma alanından tespit edilen taksonların fitocoğrafik bölgelere dağılımı ve oranları ise İran-Turan elementleri 31 (%14,6), Avrupa-Sibirya elementleri 27 (%12,7),

Akdeniz elementleri 5 (%2,4) türle temsil edilmektedir. Çok bölgeli veya fitocoğrafik bölgesi bilinmeyenler ise 149'dur (%70,3).

Florayı oluşturan taksonların coğrafi kökenlerine göre dağılımı, bölgenin fitocoğrafik karakterini ve diğer floristik bölgelerle olan ilişkisini ortaya koymaktadır. Çalışma alanının fitocoğrafik karakterini belirleyen ana element 31 takson (%14,6) ile temsil edilen element grubudur. Bu bulgu, çalışma alanının İran-Turan fitocoğrafik bölgesi içinde yer aldığını ortaya koymaktadır. Alanda tespit edilen 212 taksonun fitocoğrafik bölgelere göre dağılımına bakıldığında çok bölgeli ve geniş yayılışlı (kozmpolit) elementlerin 149 takson (%70,3) ile en büyük grubu oluşturduğu görülmektedir.

Endemik ve nadir türler

Yapılan literatür araştırmalarında İron Sazlığı sulak alan sınırları içerisinde 3 endemik türün varlığı belirtilmiştir (Eken, 2006; Anonim, 2012). Yapılan arazi çalışmaları ve araştırmalar sonucu bu üç endemikten biri olan *Alcea calvertii* (Boiss.) Boiss. türünün artık ülkemiz için endemik olmadığı görülmüştür. Dolayısıyla bu tür endemikler listesinden çıkarılmış, nadir bitki olarak değerlendirilmiştir ve bu türün tehlike kategorisinin düşük riskli (LC) olması uygun görülmüştür.

Geri kalan 2 endemik taksondan bir tanesi olan *Anchusa leptophylla* Roem. & Schult. subsp. *incana* (Ledeb.) D.F.Chamb. taksonu İç Anadolu'dan Doğu Anadolu ve Ermenistan sınırına kadar geniş bir alanda yayılış göstermektedir. Temel olarak step ve kayalık habitatlarında bulunan bu takson, İron Sazlığı'nın kuzeyinde yer alan step tepelikler ve çayırliklar boyunca seyrek olarak ancak geniş bir alanda dağılım göstermektedir. Bu bitki üzerinde herhangi bir baskı olmadığı için tehlike kategorisi düşük riskli (LC) olarak belirlenmiştir.

Diğer endemik tür olan *Dianthus plumbeus* Schischk. taksonu alanda yapılan arazi çalışmalarında sulak alan sahası içerisinde gözlemlenememiş ve fotoğrafı elde edilememiştir. Bu türe ilişkin 2012 yılında gerçekleştirilen İron Sazlığı Sulak Alan Yönetim Planı Projesi Sulak Alan Alt Havzası Biyolojik Çeşitlilik Araştırma Alt Projesi izleme raporu kapsamında yapılan arazi çalışmaları sırasında da rastlanmadığı ve alandaki varlığı ilgili raporda literatür kaydı olarak belirtilmiştir (Anonim, 2012). Bu endemik türün yalnızca Doğu Anadolu'da Erzurum ve Bitlis illerinde kaydı vardır ve dar yayılışlı bir türdür. Bu türün 1916 yılında Bitlis ilinde toplandığına dair tek bir lokalite kaydı Türkiye Florasında yer almaktadır (Davis ve ark., 1967). Daha sonra da Eken ve arkadaşlarına (2006) göre İron Sazlığı içerisinde var olduğu bildirilmiştir. Temel olarak meşe orman habitatında yayılış gösteren bu türün son yıllarda bölgede meşe ormanlarının yoğun bir şekilde tahrip edilmesi neticesinde, türün alan ve civarından yok olmuş olabileceği ileri sürülebilir. Bu tür literatür kayıtlarında yer aldığı için flora listesine eklenmiştir. Tehlike kategorisi Türkiye Bitkileri Kırmızı Listesi'nde (Ekim ve ark. 2000) değerlendirildiği şekilde "(VU) (Vulnerable-Zarar görebilir)" statüsünde verilmiştir.

Antropojenik etkiler

İron Sazlığı sucul habitat özelliğine sahip olmakla beraber gölün çevresinde geniş bataklık-sazlık alanlar ve sulu çayırliklar mevcuttur. Alandaki ekosistemin temel bileşenlerinden ve sazlık-bataklık alanların en önemli elemanları olan *Phragmites australis* (Cav.) Trin. ex Steud., *Typha angustifolia* L. ve *Typha laxmannii* Lepech. türleri hızlı bir şekilde sürgün vererek yenilenebilme özelliğine sahiptir. Saha üzerinde insan

kaynaklı otlatma, kesme ve tarımsal faaliyetler için su rejimine yapılan müdahaleler bulunmaktadır. Bu döngü İron Sazlığı sulak alan ekosisteminde habitatların ve ekosistem süreçlerinin devamını sağlamaktadır. Bu baskı gittikçe artmaya devam ettiğinden, sulak alan habitatlarının bozulması ve degrade olması kaçınılmaz görünmektedir. Sulak alanın güneyinde step vejetasyonuna sahip tepeler ve geniş tarım arazileri yer almaktadır (Şekil 5. A,B).



Şekil 5. A. Değirmenköy civarında buğday (*Triticum aestivum* L.) tarlaları, B. Sazlıkbaşı mevkiinde *Allium cepa* (soğan) tarlası, C-D. Sazlık ve bataklık alanlar içerisinde manda sürüleri, E. Step alanlarda küçükbaş hayvan yetiştiriciliği ve otlatma, F. Gölbaşı civarında biçilmiş çayırliklar, G. İron sazlığı çevresinde büyükbaş hayvan otlatma baskısı, H. Torf çıkarılan maden sahasında habitat tahribatı.

Alanda hayvancılık temel geçim kaynağıdır. Özellikle manda yetiştiriciliği Gıda Tarım ve Hayvancılık Bakanlığı tarafından desteklenmektedir. Bu durum, manda yetiştiriciliğine talebi her geçen gün artırmaktadır. Hayvan sayısındaki artışın özellikle sulak alan habitatlarını olumsuz yönde etkileyeceği açıktır. Yoğun otlatma faaliyetleri, bitkilerin yenilme ve ezilme baskısına maruz kalmasına neden olmakta, ve bu da vejetasyon gelişimini olumsuz etkilemektedir. Bu nedenle alan için bir otlatma yönetim planı yapılarak bu sorunun kontrol altına alınması gerekmektedir. (Şekil 5. C,D,E,G).

Özellikle sulan alan çevresinde yer alan çayırılık alanlar halkın temel geçim kaynağı olan hayvancılık için biçim alanı olarak kullanılmaktadır (Şekil 5. F). Bitkiler tohumla geçmeden çiçekli haldeyken biçilmekte ve bu alanda yayılım gösteren çoğu bitkinin türünü devam ettirebilmek için yeni bir birey oluşturmada yok olmasına sebep olmaktadır. Özellikle bitkilerin tohum bağlama dönemi sonuna doğru biçilmesinin sağlanması ve planlamanın buna göre yapılması floristik açıdan olumlu olacaktır.

Doğal ekosistemler normal süreçlerinde süksesyon basamaklarını geçerek genelde klimaks düzeyinde bir dengeye otururlar. Fakat insan müdahalesi bu dengeleri bozabilmektedir. Özellikle *Phragmites australis*-*Typha laxmannii*-*Typha longifolia* birlikteliğinin hâkim olduğu alanda göl suyunun drenajla yöre halkı tarafından tarım alanlarında kullanılması bu sahada dengesizlik meydana getirmektedir. Aynı zamanda saha içerisinde torf çıkarılan alanlarda yapılan faaliyetler bu bölgelerde alg yoğunluklarının artmasına ve sucül ekosistemin dengesinin bozulmasına neden olmaktadır. Torf çıkarılan bölgelerdeki bitki örtüsü ağır tahrip edilmekte ve ekosisteme büyük zararlar vermektedir (Şekil 5. H). Alan doğal kaynaklı değişimlere olumlu tepkiler verirken, insan kaynaklı değişimlere olumsuz ve düzelmesi uzun yıllar alabilecek tepkiler vermektedir. Özellikle alanın su varlığına yapılan müdahaleler başta kuşlar olmak üzere türlerin yaşam döngülerini olumsuz etkilemektedir.

Biyolojik zenginliklerimiz arasında yer alan sulak alanları önemsememek ve kısa vadeli bazı yararlar (tarla açma, otlatma, yakma vb.) uğruna yok olmalarına göz yummak, gelecek kuşaklara aktarabileceğimiz önemli bir ekolojik ve ekonomik potansiyelin kaybedilmesi anlamına gelmektedir.

Tartışma ve Sonuç

Yapılan literatür araştırmalarında İron Sazlığı ve çevresi ile ilgili daha önceden yapılmış detaylı bir floristik çalışmaya rastlanmamıştır. Eken ve arkadaşlarının editörlüğünde 2006 yılında yapılan “Türkiye’nin Önemli Doğa Alanları” isimli çalışmada alandan sadece endemik *Dianthus plumbeus* Schischk. taksonunun varlığından ve alanda geniş olarak *Phragmites australis* (Kamış) taksonunun yayılışından bahsedilmektedir. 2006 yılında Doğa Derneği tarafından yayınlanan Türkiye’nin Önemli Doğa Alanları isimli envanter çalışmasında, bu sulak alan Doğu Anadolu bölgesi içerisinde ‘DOG040’ Kodu ile ‘Korumaya Bağımlı’ Önemli Doğa Alanlarından birisi olarak tanımlanmaktadır (Eken ve ark., 2006).

2012 yılında o zamanki ismi ile Orman ve Su İşleri Bakanlığı tarafından yapılan İron Sazlığı Sulak Alan Yönetim Planı Projesi Sulak Alan Alt Havzası Biyolojik Çeşitlilik Araştırma Alt Projesi izleme raporunda alanın florası hakkında bilgiler sunulmuştur. Bu raporda 25 familya 50 cinse ait toplam 61 damarlı bitki türünün alanda bulunduğu tespit edilmiştir (Anonim, 2012).

Bu çalışma sonucunda tür çeşitliliği açısından alanda 41 familyaya ait 148 cins ve 212 takson yayılım göstermektedir. Alanda bulunan bitki taksonlarından 2’si endemik olup yalnızca Türkiye sınırları içerisinde bulunmaktadır. Ekim vd. (2000) ve IUCN

(2001; 2011)'e göre bu endemik taksonlardan bir tanesi LC (En az endişe verici) tehlike kategorisinde, bir tanesi ise VU (Hassas) kategorisinde yer almaktadır. VU (hassas) kategorisinde yer alan *Dianthus plumbeus* Schischk. türüne yapılan arazi çalışmalarında rastlanmamış ve bu türün alandaki varlığı literatür kaynaklarına göre belirtilmiştir. Araştırma alanının güncel durumunun belirlenmesi amacıyla arazi çalışmaları yürütülmüş; elde edilen veriler daha önce yapılmış olan çalışmalar ile birlikte değerlendirilmiştir. Yapılan değerlendirmeler alanın zengin bir biyolojik çeşitliliğe sahip olduğunu ortaya koymuştur.

Sulak alanda çok bölgeli ve geniş yayılışlı taksonların ilk sırada yer alması, bu türler hakkında yeterli bilginin bulunmaması ile birlikte, alanın birçok türe uygun yaşam koşulları sunmasından kaynaklanabilir. İran-Turan elementlerinin ikinci sırada en fazla temsil edilen grup olması, bölgenin coğrafi konumu ve iklim özelliklerini yansıtmaktadır. Avrupa-Sibirya elementlerinin bunu takip etmesi ise alanın bu iklimsel özelliklere de sahip olduğuna işaret etmektedir. Ayrıca, çok bölgeli türlerin genellikle yayılıcı ve istilacı özellikler göstermesi, bu türlerin alanda yoğun olarak bulunmasının antropojenik baskıların bir sonucu olabileceği göstermektedir (Memariani ve ark., 2009).

Iron sazlığı sulak alanı içerisinde başlıca su içi toplulukları; özellikle ilkbahar aylarında su altında olan ıslak nemli çayırliklar, sazlık ve bataklık alanlar, çayırliklar, aşırı tahrip edilmiş meşe ormanları ve bozulmuş step formasyonlarıdır (Şekil 4. C,D,E,F,H). Bu doğal habitatlara ek olarak, kültür bitkilerinin ekildiği tarım alanları da bulunmaktadır (Şekil 5. A, B). Alanın güney kısmı hariç büyük bölümü, geniş sazliklarla çevrilidir. Bu sazliklar *Phragmites australis*, *Typha angustifolia* ve *Typha laxmannii* türlerinden oluşmaktadır. Sazliklardan dışarıya doğru ilerledikçe su basar çayırlikların yer aldığı görülmekte olup, bu habitat tiplerinin zaman içerisinde önemli bir değişim göstermediği anlaşılmaktadır.

Doğal habitatlar içerisinde geniş turbalık alanlar bulunmaktadır. Ancak bu alanlarda yürütülen madencilik faaliyetleri habitatların parçalanmasına yol açarak ekolojik sorunlar ortaya çıkarmaktadır. Bunun en belirgin örneği torf çıkarımı sebebiyle oluşan gölcüklerdir. Bu gölcükler, sazlık ve ıslak çayırlik habitatlarının küçülmesine ve bölünmesine sebep olmaktadır. Ayrıca torf çıkartılması amacıyla bitki örtüsünün tahrip edilmesi, su ortamındaki besin maddelerinin bitkiler tarafından filtrelenmesini engellemiş; bunun sonucunda göllerde alg yoğunluğunun belirgin şekilde arttığı gözlemlenmiştir. Dolayısıyla torf çıkartılması, habitat parçalanmasının yanında su kalitesinin bozulmasında da etkili bir faktör haline gelmiştir (Şekil 5. H).

Teşekkür

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A Review: Literature Summary on the Relationship Between Cutting Parameters and Machinability in Turning Operations

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Abstract

This study presents a comprehensive evaluation of machinability in turning operations by reviewing and synthesizing the literature based on the parameters of cutting forces, tool wear, and surface roughness. Previous studies clearly present the significance of cutting parameters. While an increase in speed mainly reduces the forces and roughness, increases in feed and depth tend to increase cutting forces, temperature, and wear by enlarging the contact area. Tool wear directly affects the surface integrity and process stability through flank/crater wear and BUE formation. In particular, austenitic stainless steels, titanium and nickel-based superalloys, and particle-reinforced composites are sensitive to the cutting mechanism, tool-material interaction, and speed. Environmentally sustainable cooling-lubrication strategies (MQL, plant-based oils, cryogenic/CO₂-based solutions) reduce wear by reducing friction and temperature, improving the surface quality. In the case of ultrasonic turning, similar benefits are provided by reducing instantaneous contact and average forces. In the examined studies, dynamometers, scanning electron microscopes, surface roughness measurement instruments, and various software were used. Additionally, optimum parameter windows were reported based on Taguchi/ANOVA/RSM methods. Consequently, the combination of appropriate parameter selection and environmentally friendly cooling and lubrication and/or auxiliary processes extends tool life, improves surface integrity, and increases energy and cost efficiency. This approach offers a repeatable and industrially applicable roadmap, even for materials that are difficult to machine.

Keywords: Turning process, Cutting forces, Surface roughness, Tool wear.

Bir İnceleme: Tornalama İşlemlerinde Kesme Parametreleri ile İşlenebilirlik Arasındaki İlişkiye İlişkin Literatür Özeti

Özet

Bu çalışma, kesme kuvvetleri, takım aşınması ve yüzey pürüzlülüğü parametrelerine dayalı literatür çalışmalarını inceleyip sentezleyerek tornalama işlemlerinde işlenebilirliğin kapsamlı bir değerlendirmesini sunmaktadır. Önceki çalışmalar, kesme parametrelerinin önemini açıkça ortaya koymaktadır. Kesme hızındaki artış esas olarak kuvvetleri ve pürüzlülüğü azaltırken, ilerleme ve derinlikteki artışlar temas alanını genişleterek kesme kuvvetlerini, sıcaklığı ve aşınmayı artırma eğilimindedir. Takım aşınması, flanş/krater aşınması ve BUE oluşumu yoluyla yüzey bütünlüğünü ve işlem kararlılığını doğrudan etkilemektedir. Özellikle östenitik paslanmaz çelikler, titanyum ve nikel bazlı süper alaşımlar ve parçacık takviyeli kompozitler kesme mekanizmasına, takım-malzeme etkileşimine ve hıza duyarlıdır. Çevresel olarak sürdürülebilir soğutma-yaglama stratejileri (MQL, bitkisel bazlı yağlar, kriyojenik/CO₂ bazlı

çözümler) sürtünmeyi ve sıcaklığı azaltarak aşınmayı azaltır ve yüzey kalitesini iyileştirir. Ultrasonik tornalama durumunda, anlık temas ve ortalama kuvvetler azaltılarak benzer faydalar sağlanır. İncelenen çalışmalarda dinamometreler, taramalı elektron mikroskopları, yüzey pürüzlülüğü ölçüm cihazları ve çeşitli yazılımlar kullanılmıştır. Ayrıca, Taguchi/ANOVA/RSM yöntemlerine dayalı olarak optimum parametre pencereleri raporlanmıştır. Sonuç olarak, uygun parametre seçimi ile çevre dostu soğutma ve yağlama ve/veya yardımcı işlemlerin birleşimi, takım ömrünü uzatır, yüzey bütünlüğünü iyileştirir ve enerji ve maliyet verimliliğini artırır. Bu yaklaşım, işlenmesi zor malzemeler için bile tekrarlanabilir ve endüstriyel olarak uygulanabilir bir yol haritası sunar.

Anahtar Kelimeler: Tornalama işlemi, Kesme kuvvetleri, Yüzey pürüzlülüğü, Takım aşınması.

Introduction

Turning is the most widely used primary machining method for shaping cylindrical objects (Binali, Demirpolat, Kuntoğlu, & Kaya; Hekimoğlu & Bayraktar, 2023; Kul & Yamaner; Kuntoğlu, Kaya, & Binali, 2023; Yamaner & Kul, 2025) along with other methods such as milling, drilling and grinding (Binali, 2023; Demirpolat, Kuntoğlu, & Binali, 2023; Makhesana, Patel, Ghetiya, Binali, & Kuntoğlu, 2024; Pimenov et al., 2025; Yaşar, Korkmaz, & Günay, 2017). Nowadays, with the development of the manufacturing industry, the machinability of materials with superior properties has become an important research topic and many studies have been done in this field (Binali, 2024; Binali, Patange, Kuntoğlu, Mikolajczyk, & Salur, 2022; Pul, 2023; Salur, 2022). Alloys and composites, particularly used in high-technology fields such as aerospace, automotive, defense and biomedical, are difficult to process due to their high strength, hardness and thermal resistance (Akgün & Demir, 2021; da Silva et al., 2025; Demirbaş, 2023). The most influential factors on the evaluation of the machinability on turning processes are the forces, wear, roughness and chip formation (Ağar, Mahmat, & Tosun; Bagga, Makhesana, Patel, & Patel, 2021; Binali, Korkmaz, Özdemir, & Günay, 2025; Barış Özlü, Akgün, & Demir, 2019; Pul, 2023; Salur et al., 2025). In addition to these fundamental factors, cutting vibrations, directly related to surface roughness and tool wear, increase the difficulty of machining, especially in alloys such as Ti6Al4V. Furthermore, positional deviations caused by clamping errors, which affect the desired form accuracy, are another machinability problem in the machining of small-diameter workpieces frequently used in the aerospace and automotive industries (Elsheikh, Guo, Bai, & Lee, 2020; Yi et al., 2020). The parameters of speed, feed and depth directly affect these outcomes. While an increase in the speed generally reduces the forces and surface roughness, increasing the feed increases these values (Hekimoğlu & Bayraktar, 2023; Korkmaz, Gupta, Çelik, Ross, & Günay, 2024; Yurtkuran et al., 2024). Thus, selecting the appropriate combination of parameters increases quality and decreases cost (Binali et al., 2022; Barış Özlü, Uğur, & Yıldız, 2023; Öztürk & Kara, 2025; Pul, 2023). In recent years, as well as classical turning methods, innovative methods such as cryogenic processing, minimum lubrication (MQL), and ultrasonic turning have gained prominence in order to increase tool life by decreasing the temperature, particularly when machining difficult-to-machine alloys, providing more environmentally sustainable solutions (Ağar et al.; Aydın, 2023; Demirbaş, 2023; Korkmaz & Gupta, 2024). In addition, even at high cost, the use of plant-based cutting fluids provides significant advantages in terms of machinability, environmental and human health. By continuing these, a production process with high recycling, high efficiency and minimal harm to human and environmental health will be realized (Aydın,

2023; Sivalingam et al., 2023; Şap, Usca, Uzun, Kuntoğlu, & Salur, 2022). Therefore, current studies on turning processes examine the effects of material properties, cutting parameters and cooling/lubrication methods on machinability criteria and their effects on human and environmental health in a multidimensional manner (Ağar et al.; Aydın, 2023; Demirbaş, 2023; Demirpolat, 2024; Erdem, Özdemir, Rafighi, & Yavuz, 2023; Kaya, Çetin, Binali, & Gündoğmuş, 2025; Kul; Ngoc, Duc, Tuan, Hoang, & Long, 2023). The main criteria taken into consideration in evaluating machinability in turning operations are forces, roughness, tool wear, chip formation and material removal rate (MRR). Since each of these criteria directly affects both production efficiency and product quality and cost, studies in the literature are mostly conducted on these parameters.

The novelty of this study lies in its provision of a holistic evaluation framework for machinability in turning operations, considering not only individual output parameters but also cutting forces, surface roughness, tool wear, and chip formation in conjunction with each other.

Cutting Forces: Cutting forces in turning operations occur as a result of the interaction between the cutting tool and the material, and are usually analyzed with cutting, feed and radial force components (F_x , F_y , F_z) (Akgün, Özlü, & Kara, 2023; Binali, Yaldız, & Neşeli, 2021; Hekimoğlu & Bayraktar, 2023; BARIŞ ÖZLÜ, 2022; Barış Özlü & Akgün, 2024). These forces have a direct effect on chip formation, tool wear and surface finish (Ağar et al.; Binali & Kuntoğlu, 2023; Gupta et al., 2022; Kuntoğlu et al., 2021; Makhesana et al., 2023; Ozlu & Ugur, 2021). While increasing the speed reduces the forces, increasing the feed and cutting depth increases the forces (Pul, 2023). In addition, methods such as MQL, cryogenic and ultrasonic turning reduce friction, reduce cutting forces and increase tool life (Binali, Demirpolat, Kuntoğlu, & Salur, 2023; Demirbaş, 2023).

Surface Roughness: Surface roughness is a critical factor in evaluating machinability during turning operations. It is a parameter that directly results from the direct contact between the cutting tool and the workpiece. Surface roughness is affected by the cutting tool geometry, feed rate, cutting speed, coolant, and stability of the machining conditions, and the resulting roughness values are a consequence of the influence of these factors. Increasing the feed rate increases the surface roughness value. Increasing the cutting speed decreases the roughness value. Increasing the depth of cut can negatively affect roughness by increasing cutting forces and vibration. Therefore, surface roughness is not only a definition of surface quality but also a machinability parameter that should be evaluated together with cutting forces, tool wear, and chip morphology (Binali et al., 2023; Ruban, Dev Wins, Raja Selvam, & S Rai, 2023; Tefera, Sinha, & Gupta, 2023).

Tool Wear: Cutting tools wear over time because of exposing to high temperatures and friction, and these wear types are generally classified as crater wear, flank wear, and corner wear (Ağar et al.; Bagga et al., 2021; Korkmaz et al., 2022). Tool wear is affected by factors such as temperature, forces and the hardness of the workpiece material during processing, and short tool life is one of the most important factors that increase production costs (Demirbaş, 2023; Mikolajczyk, Paczkowski, Kuntoglu, Patange, & Binali, 2022). Vibration-assisted processes such as ultrasonic turning, advanced cooling/lubrication strategies such as MQL and cryogenic cooling, and low-coefficient tool coatings (such as DLC) significantly reduce the friction between the cutting tool and the material and the

resulting cutting temperature, extending tool life (Ağar et al.; Airao, Nirala, Bertolini, Krolczyk, & Khanna, 2022; Khanna, Airao, Nirala, & Krolczyk, 2022).

Chip Formation: The chip removal mechanism occurs through plastic deformation of the workpiece. Chip formation occurs in various types, including continuous chips, interrupted chips, and accumulated chips. The type of chip varies depending on the material's mechanical properties, speed, feed, and the use of cutting fluid (Hekimoğlu & Bayraktar, 2023; Kuntoğlu, Binali, Demirpolat, & Makhesana, 2025; Pul, 2023). Particularly, accumulated chips adversely affect the surface quality and accelerate tool wear. (Hekimoğlu & Bayraktar, 2023; Korkmaz et al., 2023; Kuntoğlu, Binali, et al., 2025).

MRR: MRR, the volume of material removed in a given time, is one of the most important indicators of manufacturing efficiency. As speed, feed, and depth increase, so does MRR (Kuntoğlu, Demirpolat, et al., 2025; Pul, 2023; Ruban et al., 2023). However, because the increase in these parameters also increases the forces and tool wear, the selection of optimum parameters is critical (Hekimoğlu & Bayraktar, 2023).

Figure 1 shows a schematic representation of the topics discussed in general.

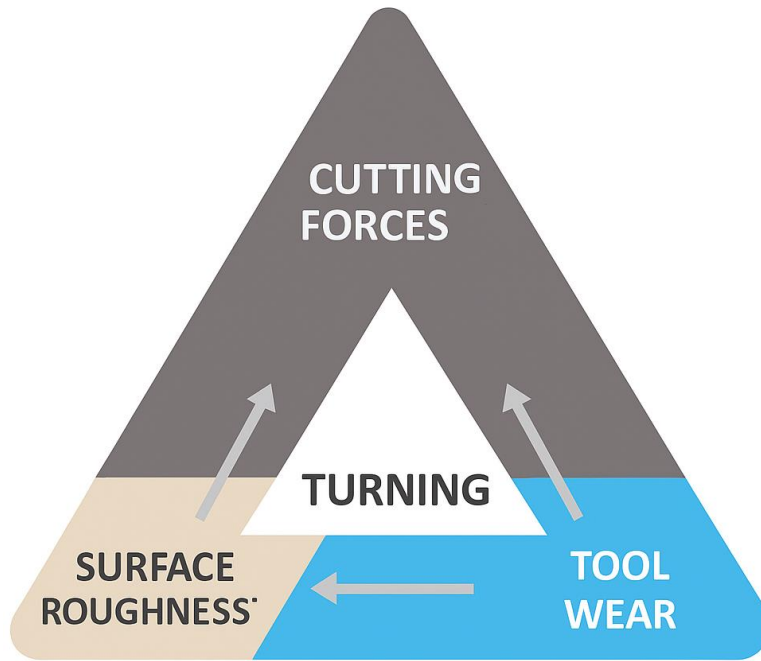


Figure 1. The Concept of Review.

Effect of the Turning Operation on Cutting Force

Cutting forces in turning operations are the most fundamental indicators of the mechanical interaction occurring at the tool-material interface and are of great importance in evaluating machinability (Hekimoğlu & Bayraktar, 2023; Turkes, Orak, Neşeli, Sahin, & Selvi, 2017). Cutting forces usually consist of three components: cutting, feed, and radial force directly affecting many output parameters, such as chip formation, tool life, surface finish, and energy consumption (Ağar et al.; Barış Özlü & Uğur, 2023a, 2023b). The cutting parameters of cutting speed, feed rate and depth of cut are the most important variables affecting the magnitude of cutting forces. In reference to previous studies,

increase in cutting speed reduces deformation resistance and reduces the forces (Kağıtçı & Neşeli, 2024; Pul, 2023). On the other hand, increasing the feed and depth increases the forces because it expands the tool-workpiece contact area (Hekimoğlu & Bayraktar, 2023). A study investigating the turning of DIN 1.2367 hot work tool steel concluded that the feed rate was the most effective factor, accounting for up to 97% of the influence on cutting forces. The study also observed that increasing the cutting speed resulted in a significant force reduction (Erdem et al., 2023; Uğur, Kazan, & Özlü, 2022). Similarly, in another study conducted on AISI 1050 steel, it was concluded that increasing the friction coefficient and depth of cut significantly increased the cutting forces, and the optimum friction coefficient was in the range of 0.4–0.5 (Sekmen, Kurt, & Şeker, 2023). In another study on the machinability of Al-Si-based alloys, the effects of speed, feed, and depth on forces were experimentally investigated, and a decrease in forces was observed with increasing speed and an increase in forces with increasing feed. Furthermore, the F_x , F_y , and F_z components were measured separately using a triaxial Kistler 9257A dynamometer, and the total cutting force was calculated from the resultant of the forces (Hekimoğlu & Bayraktar, 2023). Another study conducted on the turning of AISI 304 stainless steel compared the MQL method with dry machining conditions. The results showed that the MQL system reduced friction, resulting in a reduction in forces of up to 20%, and controlled temperature increases (Binali et al., 2023). Similarly, in machining AISI 304 austenitic stainless steel with minimal lubrication, it has been observed that nanofluids containing hybrid nanoparticles reduce both cutting force and friction coefficient compared to monofluids of a single type. In difficult-to-machine materials such as Ti6Al4V, the use of graphene oxide nanofluids has been reported to reduce cutting force and friction coefficient compared to conventional cooling. In a study conducted on AISI 1045 steel, the addition of plant-based aluminum oxide nanoparticles to the MQL fluid provided significant benefits in optimizing cutting force (Sharma, Tiwari, Dixit, & Singh, 2020; Yi et al., 2020). In experiments conducted on the machining of AISI 52100 bearing steel using ultrasonic turning, it was determined that the cutting forces decreased and the tool life extended with increasing vibration frequency. In this study, ultrasonic vibration (20–30 kHz, 10 μ m amplitude) reduced the tool-workpiece contact time, thus reducing the average force values (Ağar et al.).

In general, it is emphasized in the literature that forces decrease as cutting speed increases, whereas they increase with higher feed rates and depths. It is also noted that cooling and lubrication methods play a critical role in controlling cutting forces. A common finding for MQL, cryogenic, and ultrasonic-assisted methods is that they significantly reduce cutting forces by mitigating friction and temperature, consequently extending tool life and improving surface finish. An abstract of some of the studies conducted is given in Table 1.

Table 1. Literature review related to cutting forces

Process	Machine	Purpose	Used Material	Output Parameters	Measuring Tools	Reference
Turning	CNC horizontal lathe	To investigate the effect of different parameters on roughness and forces in turning of 1.2367 hardened (55 HRC) hot tool steel.	1.2367 hardened (55 HRC) steel	Surface roughness, cutting forces.	Mitutoyo SJ-201, Kistler 9129AA dynamometer.	(Erdem et al., 2023)

Turning	CNC horizontal lathe	To investigate the effects of friction occurring at the tool-chip interface during turning operation on machining performance and to investigate the effects of the change of friction coefficient on forces, cutting tool temperature and stresses occurring in the cutting tool.	AISI 1050 steel	Cutting force, cutting tool temperature, Cutting tool stresses, Tool wear areas.	Deform-3D Machining module, Mitutoyo CV Hexagon 3D coordinate measuring device, Kistler 9257B dynamometer	(Sekmen et al., 2023)
Turning	CNC horizontal lathe	To contribute to the optimization of parameters by defining the machinability behavior of this new Al-Si based alloy.	Al-9Si-0,1Sr-0,6Mg alloy	Cutting force, roughness, chip formation, tool wear.	Kistler 9257A dynamometer, Kistler 5070A amplifier, Mahr Perthometer, optical microscope, ICP-OES spectrometer	(Hekimoğlu & Bayraktar, 2023)
Turning	Universal lathe	To experimentally investigate the effects of machining method, speed, and vibration frequency on cutting tool life during the machining of AISI 52100 bearing steel by ultrasonic turning and conventional turning methods.	AISI 52100 bearing steel	Cutting speed, machining method, tool wear, tool life.	Optical microscope, vibration generator	(Ağar et al.)
Turning	Universal lathe	To compare dry and MQL conditions in turning AISI 304 austenitic stainless steel with a two-level full factorial design; to evaluate the effects of speed, feed and depth on tool tip temperature, cutting force and roughness (Ra); and to investigate chip morphology.	AISI 304 austenitic stainless steel	Cutting force, surface roughness, chip morphology, temperature.	Kistler 9275 dynamometer, InGaAs radiation sensor, Mahr Co. portable perthometer, Kar-tes STN15 MQL instrument, scanning electron microscope	(Binali et al., 2023)
Turning	Semi-automatic horizontal lathe	To investigate the effect of different cutting-edge radius on the machinability in the finishing pass of Ti6Al4V alloy.	Ti6Al4V rod	Roughness, tool wear, forces, chip morphology, temperature.	Kistler 9257B dynamometer, FLIR T540 infrared thermal camera, OLYMPUS measuring microscope, SURFCOM 1500 SD3 + ACC Tee software	(Selvakumar S & Raj. D, 2024)

Turning	CNC horizontal lathe	To examine the machinability performance of Inconel 718 under different microstructure conditions and to prepare the ground for both industrial cutting optimization and numerical modeling (simulation) studies with these data.	Inconel 718 nickel-based superalloy	Cutting forces, tool wear, tool life, MRR, chip morphology (SEM observations).	Piezoelectric Kistler 9129A dynamometer, Kistler 5070A dynamometer, kistler 5697A dynoware software, scanning electron microscope, instron 5900R tester, optical microscope.	(Matos et al., 2023)
Turning	Universal lathe	To reveal the effects of speed, feed, depth and reinforcement percentage on cutting forces and roughness in dry turning of AA6061/ZrB ₂ -ZrC hybrid; and also to investigate the tool, surface and chip morphology.	AA6061/ZrB ₂ -ZrC composite	Cutting forces, roughness, tool surface morphology, chip morphology, machined surface morphology.	Kistler 9257B dynamometer, Mitutoyo SJ-210, scanning electron microscope.	(Ruban et al., 2023)
Turning	Universal lathe	The aim is to optimize the main cutting force in turning AISI 1045 steel.	AISI 1045	Cutting force	Kistler piezoelectric dynamometer.	(Usha & Rao, 2020)
Turning	Universal lathe	The aim is to investigate the machining performance of Inconel 825 superalloy after dry cutting.	Inconel 825	Cutting force, tool tip temperature, chip morphology,	Dynamometer, optical microscope, electron microscope, scanning electron microscope, energy dispersion spectroscopy, tool tip temperature indicator.	(Behera, Thrinadh, & Datta, 2021)
Turning	Universal lathe	The aim is to investigate cutting forces and surface roughness in turning operations performed using cutting fluid enriched with hybrid nanoparticles.	AISI 304	Cutting force, surface roughness	Kistler piezoelectric dynamometer, Mitutoyo SJ-210	(Sharma et al., 2020)

Effect of Turning Process on Surface Roughness

In turning operations, roughness (Ra, Rz) is one of the most important criteria determining the geometric quality and functional performance of the machined surface. Surface quality directly affects not only the aesthetic appearance but also the part's wear resistance, fatigue life, corrosion resistance, and assembly compatibility (Binali et al., 2023; Mahapatro & Krishna, 2023; Ross et al., 2024).

The primary factors affecting surface roughness in the turning process include cutting speed, cutting tool feed rate, depth, tool geometry, tool wear, and cooling/lubrication conditions. The effects of these parameters on surface quality have been extensively studied in the literature (Nas & Altan Özbek, 2020; Barış Özlü, 2021; Barış Özlü, Demir, Türkmen, & Gündüz, 2021). In a study, DIN 1.2367 hot work tool steel was hard turned and surface roughness values were measured at three different points. The experimental results showed that increasing the feed significantly increased surface roughness, while the effect of cutting speed was more limited (Erdem et al., 2023). Similarly, a study conducted on AISI 304 stainless steel using MQL assisted turning showed that surface roughness decreased by up to 25% compared to dry machining conditions, with feed rate being the most influential parameter. The MQL system reduces temperature and friction in the cutting zone, resulting in lower roughness (Binali et al., 2023). In cryogenic turning studies on Monel 400 superalloy, it was determined that the roughness values obtained using PVD-TiAlN-coated inserts were significantly reduced compared to uncoated inserts. This difference was reported to be due to reduced friction and temperature in the cutting zone, and under optimum conditions, the surface roughness value was reported to be 0.667 μm (Demirbaş, 2023). In a study conducted on dry turning of CuZr and CuCrZr alloys, the effects of depth of cut and feed on roughness were investigated. It was determined that roughness decreased with increasing cutting speed, but increased feed. The analyses indicated that the lowest roughness values were obtained at high speed (1200 rpm) and low feed (0.05 mm/rev) (Tefera et al., 2023). Another study conducted on the Ti6Al4V alloy focused the effect of cutting-edge radius on roughness and reported that the minimum Ra value was reached at an edge radius of 52 μm . Increasing the edge radius resulted in a polishing effect, improving surface quality, however, excessive increases in the edge radius resulted in a dominant drag effect, increasing roughness (Selvakumar S & Raj. D, 2024). Tool geometry has a significant effect on surface roughness. Studies on AISI 420 steel have shown that surface roughness decreases as the nose radius of the cutting tool increases (Palanisamy, Devaraju, Arulkirubakaran, & Manikandan, 2020). Surface quality is directly related not only to geometric parameters but also to cooling methods. In CO₂-based VTCS-assisted turning experiments, the highest roughness values were measured in a dry environment, while the lowest surface roughness was achieved with the dual-nozzle VTCS system. This is explained by the coolant's ability to lower the temperature at the chip-tool interface and reduce friction (Mahapatro & Krishna, 2023). However, experiments on turning MgO-reinforced Al2024 composites have shown that the reinforcement particle size directly affects the surface quality. Measurements with a MarSurf PS1 prototype roughness meter showed that Ra values decreased with smaller reinforcement sizes (Pul, 2023). Studies have shown that adding graphene to a canola oil-based MQL application improves the surface roughness of Ti6Al4V steel, which is difficult to machine (Singh et al., 2020). In general, the approaches suggested in the literature to reduce surface roughness in turning process are listed as;

- Reducing the feed rate,
- Increasing the cutting force,
- Use of coated cutting edges,
- Application of appropriate cooling methods (MQL, cryogenic, VTCS) (Binali et al., 2023; Demirbaş, 2023).

In addition to surface roughness, other important factors defining the surface integrity of a machined part are subsurface microhardness and residual stresses. Machining can cause

plastic deformation at and below the surface, leading to an increase in hardness. This has been observed in materials such as AISI 420 steel (Jiang, He, Ren, Shao, & Yuan, 2020; Palanisamy et al., 2020). These findings clearly demonstrate that surface roughness is not only an output parameter but also a quality indicator that is interrelated with other performance indicators such as tool wear, cutting temperature and cutting forces. An abstract of some of the studies conducted is given in Table 2.

Table 2. Literature review related to surface roughness studies.

Process	Machine	Purpose	Used Material	Output Parameters	Measurement Tools	Reference
Turning	CNC horizontal lathe	To investigate the effect of different parameters on roughness and cutting forces in turning 1.2367 hardened (55 HRC) hot tool steel.	1.2367 hardened (55 HRC) steel	Surface roughness, cutting forces	Mitutoyo SJ-201, Kistler 9129AA dynamometer	(Erdem et al., 2023)
Turning	Universal lathe	To compare dry and MQL conditions in turning AISI 304 austenitic stainless steel with a two-level full factorial design; to evaluate the effects of cutting speed, feed and depth of cut on tool tip temperature, force and roughness (Ra); and to investigate chip morphology.	AISI 304 austenitic stainless steel	Cutting force, roughness, chip morphology, cutting temperature	Kistler 9275 dynamometer, InGaAs radiation sensor, Mahr Co. portable perthometer, Kar-tes STN15 MQL instrument, scanning electron microscope	(Binali et al., 2023)
Turning	Lathe	To optimize the cutting parameters in the dry turning of C15000 (CuZr) and C18150 (CuCrZr) copper alloys and to investigate their effects on surface roughness, MRR, tool tip temperature and surface morphology.	C15000 (CuZr) and C18150 (CuCrZr)	Surface roughness, MRR, tool tip temperature, surface morphology	Portable OES	(Tefera et al., 2023)
Turning	Semi-automatic horizontal lathe	To investigate the effect of different cutting edge radius on the machinability in the finishing pass of Ti6Al4V alloy.	Ti6Al4V rod	Roughness, tool wear, forces, chip morphology, temperature	Kistler 9257B dynamometer, FLIR T540 infrared thermal camera, OLYMPUS measuring microscope, SURFCOM 1500 SD3 + ACC Tee software	(Selvakumar S & Raj. D., 2024)
Turning	Lathe	To reduce the cutting zone temperature in the turning of Ti-6Al-4V alloy by CO ₂ -based vortex tube cooling system (VTCS) and to investigate the effects on cutting force, temperature and roughness by comparing dry, compressed air, single-nozzle VTCS and double-nozzle VTCS conditions.	Ti-6Al-4V rod	Surface roughness, cutting force, cutting temperature	Kistler 5070 dynamometer, fluke TI400 thermal camera, Surtronic S128 roughness device	(Mahapatra & Krishna, 2023)
Turning	Universal lathe	To investigate the effect of MgO (magnesia) particles of different sizes on the machinability properties of Al 2024 matrix composites.	Al 2024 aluminum alloy	Surface roughness, chip form, cutting tool wear	MarSurf PS1 portable roughness meter, scanning electron microscope	(Pul, 2023)
Turning	Universal lathe	To reveal the effects of speed, feed, depth and reinforcement percentage on cutting forces and surface roughness in dry	AA6061/Zr B ₂ -ZrC composite	Cutting forces, roughness, tool surface morphology,	Kistler 9257B dynamometer, Mitutoyo SJ-210, scanning electron microscope	(Ruban et al., 2023)

		turning of AA6061/ZrB ₂ -ZrC hybrid; and also to investigate the tool, surface and chip morphology.		chip morphology, machined surface morphology		
Turning	Universal lathe	The aim is to investigate the effects of turning operations performed in dry, MQL, and graphene-assisted minimally lubricated environments on cutting force, surface roughness, coefficient of friction, and cutting angle.	Ti6Al4V	Surface roughness, tool wear, cutting angle, chip morphology, coefficient of friction	Mitutoyo SJ-210, tool microscope	(Singh et al., 2020)
Turning	CNC horizontal lathe	The aim is to examine the surface integrity of the workpiece during machining of AISI 420 workpieces.	AISI 420	Cutting force, surface roughness, microstructure	Kistler 9257B dynamometer, SJ-410, optical microscope	(Palanisamy et al., 2020)
Turning	Universal lathe	The aim is to compare machining conditions in dry and MQL environments when machining AISI 52100 steel alloy.	AISI 52100	Surface roughness, tool-workpiece interface temperature.	Mitutoyo SJ 310, thermocouple	(Rajaraj, Ramesh Kannan, & Dennison, 2022)

Effect of Tool Wear in Turning

Tool wear in turning determines the friction, temperature, and stress fields in the cutting zone, directly affecting process stability, surface integrity, and productivity. While flank wear and surface roughness increase in austenitic stainless steels under dry conditions due to low thermal conductivity and work hardening, appropriate lubrication (especially MQL) can significantly improve these trends. The significant effects of the cutting environment and cutting speed on surface finish and force output have been experimentally demonstrated (Binali et al., 2023; Kara, 2017; Kara, Karabatak, Ayyıldız, & Nas, 2020; Kara & Öztürk, 2019; Barış Özlü, Demir, & Türkmen, 2019; Barış Özlü, Demir, Türkmen, & Gündüz, 2018; Salur, 2022). Similar results are observed in materials that are difficult to machine. In experiments conducted on the TC21 titanium alloy, speed and depth had the greatest impact on tool wear and roughness, and wear was significantly reduced with appropriate parameter combinations (medium-high speed, medium feed, and depth) (Sobh, Sayed, Barakat, & Elshaer, 2023). Innovative approaches at the process level can also reduce wear load. Preheating the workpiece in laser-assisted hard turning has been shown to reduce forces and roughness; such load reduction creates an environment that positively influences wear tendency by limiting the thermo-mechanical stress to which the tool is exposed (Sahoo, Dutta, Bartarya, Mullick, & Nayak, 2023). The wear mechanism in particle reinforced Al matrix composites is mostly abrasive. In the turning of AA6061/(ZrB₂-ZrC) hybrid reinforced composites with PCD tools, tool wear was reported to accelerate as speed and depth, as well as as reinforcement content, increased; however, at low speeds, the formation of stuck edge (BUE) increased, changing the wear patterns (Ruban et al., 2023). These findings indicate that the mechanisms specific to the material-tool pair (abrasive wear/adhesion/BUE) are sensitive to the cutting speed, thus the correct selection of the parameter window is critical on the

life (Ruban et al., 2023). In machining Ti6Al4V alloy, tool geometry and cooling methods must be combined to manage tool and material interaction. The use of laser-textured tools in combination with graphene-reinforced MQL has increased tool life compared to dry conditions (Singh et al., 2020; Yi et al., 2020). The cutting environment and lubrication strategies significantly alter the course of tool wear. Extensive experiments on turning AISI 304 have shown that MQL reduces wear by producing lower temperatures and forces compared to dry cutting, while vegetable-based oils, as an alternative to mineral-based oils, provide additional improvements in wear and roughness (Binali et al., 2023). In this context, nanofluid MQL stands out. In the hard turning of 90CrSi, Al₂O₃/MoS₂ hybrid nanofluids significantly reduced cutting temperature, cutting and thrust forces, and surface roughness compared to single nanofluids and pure MQL. They also improved wear performance by reducing friction and thermal loads to which the tool was exposed through increased cooling and lubrication. Furthermore, studies have shown that the BUE tendency is suppressed under nanofluid MQL conditions due to tribo-film formation and the "micro-bearing" effect (Ngoc et al., 2023). Another demonstration of the parameter–temperature–wear relationship is dry turning of copper alloys, where the thermal load is directly monitored. When the combined effects of speed, feed and depth of cut on tool tip temperature and surface output are systematically optimized, it has been observed that the risk of wear can be controlled by reducing the process temperature (Tefera et al., 2023). When all these results are considered together, it can be seen that as cutting speed and depth of cut increase, the thermo-mechanical load increases and accelerates wear, that the mechanism transitions (abrasive-adhesion) depending on the material-tool match can be managed with speed and lubrication, and that load-reducing process innovations such as MQL, especially hybrid nanofluids, have the potential to reduce wear and extend tool life (Binali et al., 2023; Ngoc et al., 2023; Ruban et al., 2023; Sahoo et al., 2023). An abstract of some of the studies conducted is given in Table 3.

Table 3. Literature review on tool wear studies.

Process	Machine	Purpose	Used material	Output parameters	Measurement tools	Reference
Turning	Universal lathe	To experimentally investigate the effects of machining method, speed, and vibration frequency on cutting tool life during the machining of AISI 52100 bearing steel by ultrasonic turning and conventional turning methods.	AISI 52100 bearing steel	Cutting speed, machining method, tool wear, tool life	Optical microscope, vibration generator	(Ağar et al.)
Turning	CNC horizontal lathe	To examine the machinability performance of Inconel 718 under different microstructure conditions and to prepare the	Inconel 718 nickel-based superalloy	Cutting forces, tool wear, tool life, MRR, chip morphology (SEM observations)	Kistler 9129A dynamometer, Kistler 5070A dynamometer, Kistler 5697A dynoware software, scanning electron	(Matos et al., 2023)

		ground for both industrial cutting optimization and numerical modeling (simulation) studies with these data.			microscope, instron 5900R tester, optical microscope.	
Turning	CNC horizontal lathe	To contribute to the optimization of cutting parameters by defining the machinability behavior of this new Al-Si based alloy.	Al-9Si-0,1Sr-0,6Mg alloy	Cutting force, surface roughness, chip formation, tool wear	Kistler 9257A dynamometer, Kistler 5070A amplifier, Mahr Perthometer, optical microscope, ICP-OES spectrometer	(Hekimoğlu & Bayraktar, 2023)
Turning	Universal lathe	To focus the effect of MgO (magnesia) particles of different sizes on the machinability properties of Al 2024 matrix composites.	Al 2024 aluminum alloy	Surface roughness, chip form, cutting tool wear	MarSurf PS1 portable roughness measuring device, scanning electron microscope	(Pul, 2023)
Turning	Universal lathe	To reveal the effects of cutting speed, feed, depth of cut and reinforcement percentage on forces and roughness in dry turning of AA6061/ZrB ₂ -ZrC hybrid; and also to investigate the tool, surface and chip morphology.	AA6061/ZrB ₂ -ZrC composite	Cutting forces, surface roughness, tool surface morphology, chip morphology, machined surface morphology	Kistler 9257B dynamometer, Mitutoyo SJ-210, scanning electron microscope	(Ruban et al., 2023)
Turning	CNC horizontal lathe	The aim is to conduct an integrated experimental investigation using tool-based and coolant strategies for the sustainable machining of Ti6Al4V alloy.	Ti6Al4V	Cutting forces, tool wear, chip formation, chip morphology	Kistler 9129AA dynamometer, optical microscope, X-ray spectrometer (Bruker-ASX QuanTax200)	(Mishra, Ghosh, & Aravindan, 2020)
Turning	CNC milling machine	The aim is to experimentally investigate the performance of graphene oxide-based cutting fluid in turning Ti6Al4V workpieces.	Ti6Al4V	Cutting force, tool wear, cutting vibration	Kistler 9257B and Kistler 5070A dynamometers, scanning electron microscope, alicona microscope, energy dispersive spectroscopy	(Yi et al., 2020)

Turning	CNC horizontal lathe	The aim is to investigate the performance of a whisker-reinforced cutting tool in turning Co-based Haynes 25 alloy.	Co-based Haynes 25 alloy	Tool wear, surface roughness, cutting temperature, microhardness, surface topography, notch wear.	Scanning electron microscope, optical profilometer, Mahr Marsurf PS 10, thermal camera, hardness tester	(Sarıkaya, Şirin, Yıldırım, Kivak, & Gupta, 2021)
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Discussion and Results

The turning process initially determines the type and flow of the chip produced by the interaction between the tool and the workpiece. This interaction shapes the contact conditions, directly influencing the cutting mechanism and the primary output parameters (roughness, tool wear, and cutting forces). Correctly regulating the contact conditions, including speed, feed, depth, coolant selection, tool material, coating, and cutting environment (dry, cryogenic, etc.), determines the quality of the machining dynamics and the resulting output. Machined surface quality can be reliably predicted using predictive models that consider cutting conditions, vibration levels, and tool wear. When experiments using the appropriate parameters derived from these approaches are combined with in-cycle monitoring, process stability is increased and the need for rework is reduced.

Cutting forces are one of the most decisive indicators of surface integrity in turning. As edge sharpness decreases and local friction at the cutting-edge increases, these forces increase. This, combined with fluctuating contact conditions, can lead to increased roughness and increased surface undulations. As tool wear progresses (especially flank wear and crater wear), tool geometry changes dramatically. This disrupts cutting edge micromorphology, increasing forces, affecting chip continuity, and leading to irregularities in surface geometry. Utilizing optimal cutting parameters throughout the initial, steady-state, and accelerated wear stages is critical for both maintaining surface quality and extending tool life.

In turning operations, the evaluation of machinability is not limited solely to cutting forces, tool wear, and surface quality. Material removal rate, which directly represents machining efficiency and productivity, is also a critical evaluation criterion for machinability. Material removal rate reveals the economic dimension of the process by expressing the amount of material removed per unit time. In this respect, when interpreted together with quality-oriented indicators such as surface roughness and tool life, it offers a more realistic and holistic machinability assessment for the turning operation. However, in most scenarios, parameter selections aimed at increasing material removal rate in the literature increase cutting forces and the thermal load of the cutting zone, thus making material removal rate, surface roughness, and tool wear an integral part of machinability. Therefore, material removal rate should be evaluated within the framework of a multi-criteria optimization approach together with surface roughness, cutting forces, and tool wear. Furthermore, some studies have reported that "maximum metal removal rate" is achieved for certain parameter combinations in the turning of aluminum alloys, and such findings support the explicit discussion of productivity-oriented parameter selection in the conclusion section (Hekimoğlu & Bayraktar, 2023; Pul, 2023; Ruban et al., 2023).

In terms of real-time monitoring, dynamometers, infrared thermal imaging, accelerometers, and acoustic emission sensors are widely and effectively used to reliably

monitor both force-temperature fields and tool condition in turning. Tool microscopy and SEM observations play a complementary role in verifying wear mechanisms. Establishing effective tools based on physics and the resulting optimal parameters using these multiple data sources allows for successful prediction of surface roughness and power consumption through force/wear indicators, thereby improving process energy efficiency.

The use of coolant in turning operations directly affects the thermal and tribological conditions in the cutting zone, playing a significant role in determining machinability. Literature confirms that MQL with nanofluid additives, compared to dry conditions, reduces cutting temperature and tool wear, thereby improving surface quality. Studies using hybrid nanofluids have shown more stable cutting forces and higher-quality surfaces. Furthermore, cryogenic cooling has been found to significantly reduce cutting temperatures, extend tool life, and improve surface quality, especially for titanium-based and difficult-to-machine materials. However, some studies emphasize that the effect of cooling strategies on cutting forces can vary depending on the material type and process parameters. This suggests that cooling and lubrication methods should be considered as multiple performance criteria rather than a single output parameter in machinability evaluation (Aydın, 2023; Binali et al., 2023; Demirbaş, 2023; Singh et al., 2020).

Sustainability-focused cutting environments are crucial for managing tool wear. Strategies that provide minimal friction and adequate heat removal (MQL, plant-based oils, cryogenic/CO₂-assisted solutions) reduce both forces and temperatures at the tool-material interface, reducing wear rates and improving surface finish. In this context, in alloys with challenging machinability, particle-reinforced composites, and hybrid composites, chip type and flow are practical indicators of mechanism transitions. By selecting the optimal parameter range, undesirable chip forms and adverse contact conditions can be mitigated, leading to improved machining results.

As a result, the ways to achieve high and consistent surface quality and long tool life in turning are;

- Managing the cutting forces-temperature-wear triangle together
- Correct matching of tool geometry/coating and material pair
- The use of predictive modeling-design of experiments approaches fed by online sensor data.

This holistic approach reduces energy consumption and tool change costs while increasing process stability, providing a repeatable, economical and sustainable turning strategy on an industrial scale.

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