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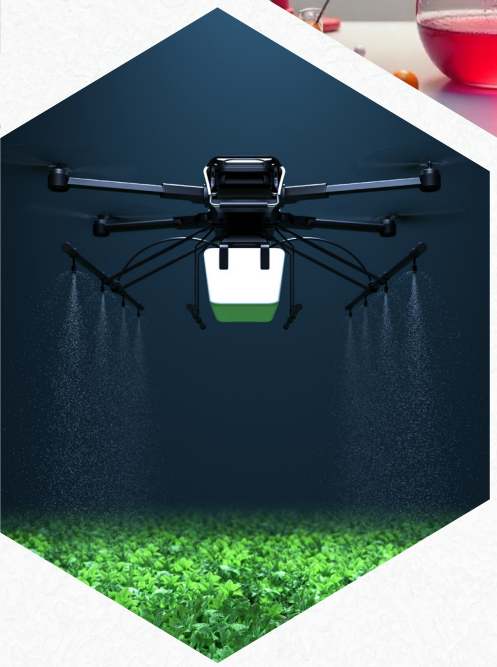

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Fritillaria fleischeriana Stearn & P.H.Davis'nın Biyolojisi ve Ekonomik Değeri

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Özet: Fritillaria fleischeriana Stearn & P.H.Davis, Liliaceae familyasına ait, endemik ve nadir bulunan bir geofit türüdür. Türkiye'nin özellikle Güney Anadolu bölgesinde yayılış gösteren bu bitki, genellikle jipsli ve kalkerli topraklarda yetişmektedir. Morfolojik olarak soğanlı bir yapıya sahip olan tür 10-30 cm arasında değişen gövde uzunluğuna ve genellikle tek, nadiren iki sarkık çiçeğe sahiptir. Çiçekleri koyu kahverengi-mor renkte olup iç yüzeyinde sarımsı damarlar barındırır. Ekolojik olarak, F. fleischeriana kurak ve taşlık alanlara uyum sağlamış, düşük besin içeriğine sahip topraklarda yetişebilen bir bitkidir. Habitat tahribatı, aşırı otlatma ve iklim değişikliği gibi faktörler nedeniyle populasyonu tehdit altındadır. Bununla birlikte, tıbbi ve süs bitkisi olarak kullanımı potansiyel ekonomik değer sunmaktadır. Özellikle Fritillaria türlerinde bulunan alkaloidlerin tıbbi önemi bilinmekte olup bu türün farmakolojik özellikleri araştırılmaya açıktır. Bu çalışma, F. fleischeriana'nın morfolojisini, ekolojisini ve potansiyel ekonomik değerini ele alarak korunmasına yönelik öneriler sunmayı amaçlamaktadır.

The Biology and Economic Value of Fritillaria fleischeriana Stearn & P.H.Davis

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Abstract: Fritillaria fleischeriana Stearn & P.H.Davis is a rare and endemic geophyte species belonging to the Liliaceae family. This plant is mainly distributed in the southern Anatolian region of Türkiye and typically grows in gypsum and calcareous soils. Morphologically, it has a bulbous structure, with a stem length ranging from 10 to 30 cm, and usually bears a single, rarely two, pendulous flowers. The flowers are dark brownish-purple in color with yellowish veins on the inner surface. Ecologically, F. fleischeriana is adapted to arid and rocky environments, thriving in soils with low nutrient content. However, its population is under threat due to habitat destruction, overgrazing, and climate change. Despite these threats, the species holds potential economic value as a medicinal and ornamental plant. Alkaloids found in Fritillaria taxa are known for their pharmacological importance, and the medicinal properties of this species remain open to further research. This study aims to examine the morphology, ecology, and potential economic value of F. fleischeriana, while also proposing conservation strategies for its protection.

1.Giriş

Liliaceae (Zambakgiller) familyası, dünya genelinde yaklaşık 250 cins ve 3.500 civarında tür ile temsil edilen geniş bir bitki grubudur (Seçmen ve ark., 1995). Bu familyanın üyeleri genellikle tropikal ve ılıman bölgelerde yayılış gösteren soğanlı ve otsu bitkilerden oluşmaktadır. Türkiye florasında *Liliaceae* familyasına ait 35 cins ve 400'den fazla tür bulunmaktadır (Seçmen ve ark., 1995). Bu familya içinde yer alan *Fritillaria* cinsi morfolojik çeşitliliği ve ekolojik adaptasyonları ile dikkat çekmektedir. Dünya genelinde yaklaşık 170

Fritillaria taksonu bulunmakta olup bunların 44'ü Türkiye'de yetişmektedir (Day ve ark., 2014; Tekşen ve ark., 2010). Bu türler Kuzey Yarımküre'nin ılıman bölgelerinde yayılış göstererek Kuzey Amerika'dan Avrupa'ya, Akdeniz Bölgesi'nden Orta Asya'ya, Çin ve Japonya'ya kadar geniş bir coğrafyada doğal olarak yetişirler. Türkiye, *Fritillaria* cinsinin gen merkezi olarak kabul edilmekte ve ülkede bulunan 45 taksonun 23'ü endemik olarak rapor edilmektedir (Tekşen ve Aytaç, 2011; Özhatay ve ark., 2011; Koçyiğit ve ark., 2016). Bu durum, Türkiye'deki *Fritillaria* türlerinin yüksek oranda endemizm gösterdiğini ortaya koymaktadır. Eskişehir'de *F. serpenticola* (Rix) Tekşen ve Aytaç, *F. fleischeriana* Steud. & Hochst. ex Schult. & Schult.f. ve *F. pinardii* Boiss. olmak üzere 3 tür yayılış göstermektedir.

F. fleischeriana Stearn & P.H.Davis, *Liliaceae* familyasının nadir ve endemik türlerinden biridir. Türkiye'nin özellikle Güney Anadolu bölgesinde yayılış gösteren bu tür genellikle jipsli ve kalkerli topraklarda yetişmektedir. *Soğanlı* yapısı ile morfolojik açıdan dikkat çekerken 10-30 cm arasında değişen gövde uzunluğuna ve genellikle tek, nadiren iki sarkık çiçeğe sahiptir. Çiçekleri koyu kahverengi-mor renkte olup iç yüzeyinde sarımsı damarlar barındırır (Rix, 2001). Habitat tercihi açısından kurak ve taşlık alanlara adapte olan bu bitki, düşük besin içeriğine sahip topraklarda yetişebilir. Ancak habitat tahribatı, aşırı otlatma ve iklim değişikliği gibi faktörler nedeniyle popülasyonu tehdit altındadır (Tekşen ve Aytaç, 2011).

Ekonomik açıdan değerlendirildiğinde, *Fritillaria* türleri geleneksel tıpta öksürük, bronşit, astım ve solunum yolu hastalıklarının tedavisinde yaygın olarak kullanılmaktadır (Kaneko ve ark., 1981; Farooq ve ark., 1994; Zhou ve ark., 2010). *Fritillaria* türlerinden elde edilen alkaloidlerin farmakolojik önemi bilinmekte olup bu bileşiklerin tıbbi kullanım potansiyeli çeşitli araştırmalarla desteklenmiştir (Hao ve ark., 2013). Ayrıca, bazı *Fritillaria* türleri süs bitkisi olarak yetiştirilmektedir ve özellikle peyzaj mimarlığında değerlendirilmektedir (Day ve ark., 2014).

Bu çalışmada, *F. fleischeriana*'nın morfolojisi, ekolojisi ve potansiyel ekonomik değeri ele alınarak korunmasına yönelik öneriler sunulmuştur. Aynı zamanda, bu türün farmakolojik ve peyzaj açısından kullanım potansiyeli incelenerek, biyolojik çeşitliliğin korunmasına yönelik bilimsel temeller oluşturulması hedeflenmektedir.

2. Materyal ve Yöntem

Bu çalışmada, *F. fleischeriana*'nın morfolojik, ekolojik ve ekonomik özellikleri incelenmiştir. Araştırma kapsamında, türün doğal yayılış gösterdiği habitatlardan örnekler K 39° 48′ 06′′, D 31° 06′ 33′′, 917 m Bozan, Eskişehir'de marnlı alanları içeren lokaliteden toplanmıştır. Araştırma, Eskişehir'in farklı lokasyonlarında gerçekleştirilmiştir. Türün yayılış gösterdiği jipsli ve kalkerli topraklara sahip alanlar belirlenmiş ve bu bölgelerde flora çalışmaları yapılmıştır. *F. fleischeriana* bireylerinin popülasyon yoğunluğu, bitki boyu, çiçek sayısı ve çiçeklenme dönemi gibi morfolojik özellikleri kayıt altına alınmıştır. Toplanan bitki örnekleri herbaryum standartlarına uygun şekilde preslenmiş ve teşhis edilmiştir. Morfolojik karakterlerin detaylı analizi için canon marka fotoğraf makinası kullanılmıştır. Türün ekolojik adaptasyonları, çevresel faktörlerle ilişkilendirilerek yorumlanmıştır. Türün ekonomik potansiyelini belirlemek amacıyla literatürde yer alan etnobotanik ve farmakolojik çalışmalar incelenmiştir. Türün korunmasına yönelik öneriler geliştirilerek, sürdürülebilir kullanım stratejileri tartışılmıştır.

3. Bulgular ve Tartışma

Arazi çalışmaları ve laboratuvar analizleri sonucunda *F. fleischeriana*'nın morfolojik karakterleri detaylı olarak incelenmiştir. Tür, soğanlı ve çok yıllık otsu bir bitki olup, gövde boyu 15-40 cm arasında değişmektedir. Yapraklar mızrak biçimli ve genellikle 3-5 adet olup sarmal dizilimlidir. Çiçekler tek ya da nadiren iki adet olup, çan şeklinde ve koyu mor renklidir.

Çiçek periant segmentleri genellikle 3-4 cm uzunluğunda olup, iç yüzeyinde belirgin damarlanmalar gözlemlenmiştir (Şekil 1).

Şekil 1. *Fritillaria fleischeriana*, A. Habitat görünüşü, B. Genel görünüş, C. Çiçek kısımları, D. vejetatif kısımları, D.1. Tepal, D.2. Stamen, D.3. Filament, D.4. Soğan, D.5. Yaprak üst yüzey, D.6. Yaprak alt yüzey

Tablo 1. *Fritillaria fleischeriana* türünün morfolojik karakterleri

Bitki Formu	Geofit, soğanlı
Soğan	Yumurtamsı, 10-25 mm çapında, kahverengi ve ince zar tabakalı tuniklerle kaplı
Gövde	Dikey, 10-30 cm uzunluğunda, tüysüz, bazen morumsu lekeli
Yaprak Sayısı	3-5 adet, nadiren daha fazla
Yaprak Dizilişi	Alternatif veya alt kısımda neredeyse sarmal
Yaprak Şekli	Şeritsi-mızraksı, 4-15 cm uzunluğunda, 2-10 mm genişliğinde
Yaprak Rengi	Yeşil, bazen gri-yeşil veya hafifçe morumsu tonlu
Çiçek Durumu	Genellikle tek çiçekli, nadiren iki çiçekli, çiçekler sarkık
Çiçek Rengi	Dış yüzü koyu kahverengi-mor, iç yüzü sarımsı veya yeşilimsi tabanlı, koyu damarlı
Tepaller	6 adet, eşit büyüklükte, 15-30 mm uzunluğunda, yumurtamsı-mızraksı
Tepal Kenarları	Hafifçe içbükey veya kıvrımlı
Nektaryumlar	Her tepalin tabanında, belirgin, çukurlu yapı
Stamenler	6 adet, tepallerin yaklaşık yarısı uzunluğunda
Filamentler	Hafifçe tüylü veya tüysüz, bazen tabanda şişkin
Anterler	Sarı veya sarımsı-turuncu, polen üretici
Ovaryum	Üst durumlu, 3 gözlü, silindirik
Stil	İnce, 3 parçalı uçlu
Meyve Tipi	Kapsül, üç köşeli, kanatlı, olgunlaştığında açılan
Tohumlar	Düz veya hafifçe kanatlı, kahverengi
Çiçeklenme Zamanı	Mart-Mayıs
Habitat	Kalkerli ve jipsli topraklar, taşlık yamaçlar, kayalık alanlar
Rakım Aralığı	800-2000 m
Coğrafi Yayılış	Türkiye (özellikle Güney Anadolu)
Ekoloji	Kuraklığa dayanıklı, iyi drenajlı toprakları tercih eder
Koruma Durumu	Nadiren görülen endemik bir tür, habitat tahribatı riski altında olabilir

Literatür taraması sonucunda, epidermis hücrelerinin papillalı yapıda olduğu ve stoma tipinin anomositik olduğu belirlenmiştir. Polen analizleri sonucunda polenlerin monokolpat tipte olduğu ve genellikle elipsoid morfolojide olduğu tespit edilmiştir (Alan, 2008; Demirpolat 2022; Kandemir ve ark., 2022; Has ve ark., 2023; Kandemir ve ark., 2024).

F. fleischeriana , Türkiye'de Akdeniz ve İç Anadolu Bölgeleri'nde, özellikle 1000-2000 m rakımlı, taşlık ve kayalık alanlarda yayılış göstermektedir. Arazi çalışmaları sırasında gözlemlenen popülasyonlar genellikle kurak iklime sahip kireç bakımından zengin topraklarda yetişmektedir.

Toprak analizleri sonucunda, türün yetiştiği habitatlarda pH değerinin 7.4-8.1 arasında değiştiği, organik madde içeriğinin düşük olduğu belirlenmiştir. Bununla birlikte toprak numunelerinde yüksek kalsiyum içeriği tespit edilmiş, bu durum türün kireçli topraklara adaptasyonunu destekleyen önemli bir faktör olarak değerlendirilmiştir.

İklim verileri incelendiğinde, türün yayılış gösterdiği bölgelerde yıllık ortalama sıcaklığın 10-16°C arasında değiştiği, yıllık yağış miktarının ise 400-800 mm olduğu belirlenmiştir. Tür, yaz kuraklığına dayanıklı olup, genellikle ilkbahar aylarında çiçeklenmektedir.

Literatür taraması sonucunda, *Fritillaria* cinsine ait birçok türün geleneksel tıpta öksürük, bronşit ve solunum yolu hastalıklarının tedavisinde kullanıldığı belirlenmiştir. Ancak, *F. Fleischeriana* 'ya özgü farmakolojik çalışmalar oldukça sınırlıdır (Xio ve arkl., 2007; Türktaş ve ark., 2012; Wang ve arkl., 2017).

Etnobotanik mülakatlar sonucunda, türün bazı yerel halk tarafından boğaz enfeksiyonlarını gidermek için kullanıldığı bilgisine ulaşılmıştır. Ancak bu kullanımın bilimsel olarak doğrulanmadığı ve farmakolojik analizlerle desteklenmesi gerektiği vurgulanmıştır.

Arazi çalışmaları sırasında türün popülasyonlarının oldukça sınırlı alanlarda yoğunlaştığı ve düşük birey sayısına sahip olduğu belirlenmiştir. *F. Fleischeriana* habitat kaybı, aşırı otlatma ve iklim değişikliği gibi tehditlerle karşı karşıyadır.

Habitat kaybı: Tarım ve yerleşim alanlarının genişlemesi nedeniyle türün bazı yayılış alanlarında habitat daralması tespit edilmiştir.

Otlatma baskısı: Özellikle koyun ve keçi gibi otlayan hayvanlar, genç sürgünleri tüketerek popülasyonların sürdürülebilirliğini tehdit etmektedir.

İklim değişikliği: Artan sıcaklık ve azalan yağış miktarları, türün yaşam alanlarını olumsuz etkilemektedir.

IUCN kriterlerine göre yapılan değerlendirme sonucunda, türün "Tehlike Altında" (Endangered, EN) kategorisine alınmasının uygun olabileceği düşünülmektedir.

Morfolojik ve ekolojik özellikleri dikkate alındığında, *F. Fleischeriana* 'nın süs bitkisi olarak kullanılma potansiyeline sahip olduğu belirlenmiştir. Özellikle *F. imperialis* ve *F. persica* gibi süs bitkisi olarak yetiştirilen türlerle benzer dekoratif özelliklere sahip olması peyzaj uygulamalarında değerlendirilme ihtimalini artırmaktadır. Ancak, bu türün doğal popülasyonlarının korunması gerektiğinden peyzaj amaçlı kullanım için kontrollü üretim ve kültivasyon çalışmalarının başlatılması önerilmektedir.

4.Sonuçlar

Bu çalışma, *Fi fleischeriana*'nın morfolojik, ekolojik ve ekonomik önemini ortaya koyarak, türün korunmasına yönelik bilimsel bir temel oluşturmayı amaçlamıştır. Yapılan morfolojik analizler, türün *Fritillaria* cinsi içindeki diğer türlerden belirgin özelliklerle ayrıldığını göstermektedir. Çiçek yapısı, periant segmentlerinin mor renkte olması ve polen

morfolojisi gibi kriterler, bu türün taksonomik açıdan farklılaşmasını destekleyen önemli bulgulardır.

Ekolojik analizler, türün özellikle taşlık, kurak ve kireçli topraklara adapte olduğunu göstermektedir. Habitat kaybı, aşırı otlatma ve iklim değişikliği gibi faktörler, türün sürdürülebilirliği açısından ciddi riskler oluşturmaktadır. Farmakolojik açıdan literatürde *F. fleischeriana*'nın tıbbi kullanımı üzerine yeterli bilgi bulunmamaktadır. Ancak, *Fritillaria* türlerinin geleneksel tıpta yaygın kullanımı göz önüne alındığında bu türün farmakolojik potansiyelinin araştırılmasının da gerektiği vurgulanmaktadır.

Koruma durumu açısından, türün popülasyon büyüklüğü oldukça sınırlıdır ve korunması için acil eylem planlarına ihtiyaç duyulmaktadır. Ayrıca peyzaj ve süs bitkisi olarak kullanım potansiyeli değerlendirilmiş ve bu kullanımın sürdürülebilir şekilde yapılması gerektiği vurgulanmıştır. Bu doğrultuda, *F. fleischeriana*'nın habitatlarının koruma altına alınması, uzun vadeli popülasyon izleme çalışmalarının yapılması ve kontrollü kültivasyon yöntemlerinin geliştirilmesi önerilmektedir. Türün farmakolojik özellikleri üzerine biyokimyasal çalışmalar yapılmalı ve potansiyel tıbbi kullanımı araştırılmalıdır.

Sonuç olarak, *F. fleischeriana*, Türkiye florası açısından önemli ve korunması gereken nadir bir türdür. Bu türün biyolojik çeşitlilik içindeki yeri ve ekolojik işlevleri göz önüne alındığında, korunmasına yönelik bilimsel çalışmaların artırılması büyük önem taşımaktadır.

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Human Health and Selenium

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Disease

Abstract: Selenium (Se) is a trace element essential for human reproductive and growth functions. The term " Se" originates from the Greek word selene, meaning "moon." Se is represented by the chemical symbol Se, has an atomic number of 34, and an atomic mass of 78.96. It is located in period 4 and group 6A of the periodic table. In nature, Se exists in various oxidation states, including -2, +2, +4, and +6. The -2 oxidation state is typically found in selenides, the +4 state in selenites, and the +6 state in selenates. Additionally, a +1 state can be observed in some sel Se enium compounds, such as s Se elenium chlorides. Plant-based foods contain Se primarily in its organic form, selenomethionine (SeMet), which has a bioavailability of approximately 90%. Inorganic forms such as selenate and selenite also exist in foods and are known for their high bioavailability. The antioxidant properties of selenoproteins play a crucial role in preventing cellular damage caused by free radicals. It is estimated that there are approximately 30–50 selenoproteins in the human body. Of these, about 12 are believed to be involved in processes related to viral infections, cancer, and immune function. The primary Se -containing protein in tissues is glutathione peroxidase (Gpx), which serves as a key biomarker for determining Se status at the cellular level. Furthermore, Gpx plays a vital role in protecting cells from oxidative stress-induced damage.

1. Introduction

Selenium (Se) is an essential trace element involved in the regulation of reproductive and growth functions in living organisms (Küçük, 2014; Zachara, 2018; Berzelius, 2020). In plant-based foods, selen Se is predominantly present in its organic form, selenomethionine (SeMet), which demonstrates approximately 90% bioavailability. Additionally, Se supplements often utilize inorganic forms such as selenate and selenite, which also exhibit high bioavailability.

Se exerts its biological effects in tissues primarily through selenoproteins. These are Se -containing enzymes and proteins that play critical roles in various physiological processes. In animals, Se acts as a constituent of these selenoproteins, contributing to DNA synthesis, reproductive and thyroid function, and overall metabolic regulation. Moreover, Se has a protective role against oxidative cellular damage and infections, underscoring its significance in immune defense and antioxidant systems (Shreenath et al., 2023).

Se deficiency in plants is closely linked to the Se content of the soil in which they grow. Research has shown that children from families residing in areas with Se -deficient soils tend to exhibit slower growth rates compared to those living in Se -rich regions. Furthermore, certain types of cancer have been reported to occur more frequently in populations living in Se -poor regions compared to those in Se -abundant areas.

In addition to its role in plant and human development, Se deficiency has been associated with significant physiological consequences. It can lead to severe muscle weakness and decreased elasticity of the heart and blood vessels. Notably, Se deficiency has been confirmed as a causative factor in the development of fetal cardiomyopathy in children (Minich, 2022).

1.1. Selenocysteine

In the scientific literature, selenocysteine (Se-Cys) is commonly abbreviated as Se-Cys. It is structurally analogous to the amino acid cysteine, in which a Se atom replaces the sulfur atom. Se-Cys is primarily derived from animal sources and serves as an essential component of various selenoproteins.

Se-Cys is present as a residue within many enzymes, including Se-Cys -containing Gpx, tetraiodothyronine 5'-deiodinases, and thioredoxin reductases. These enzymes play crucial roles in redox regulation, thyroid hormone metabolism, and cellular antioxidant defense mechanisms. Selenoproteins typically contain a single Se-Cys residue, which is integral to their catalytic activity.

Containing Se-Cys residues are predominantly classified as selenoproteins, and those involved in enzymatic reactions are referred to as selenoenzymes. Importantly, the redox potential of Se-Cys is lower than that of cysteine, enhancing its reactivity and making it particularly suitable for incorporation into antioxidant enzymes. This unique chemical property renders Se-Cys especially valuable in biochemical systems that require efficient redox regulation (Hariharan and Dharmaraj, 2020).

1.2. Selenomethionine

Selenomethionine (SeMet) is a naturally occurring Se -containing amino acid. The biologically active L-enantiomer, L-SeMet, is considered the principal dietary form of Se. This form is commonly found in cereal grains, Brazil nuts, pasture legumes, and soybeans. Another significant Se compound, Se-methyl Se-Cys (along with its γ-glutamyl derivative), constitutes the main Se source in plant species belonging to the genera *Brassica*, *Allium*, and *Astragalus*.

In biological systems, SeMet can be nonspecifically incorporated into proteins in place of methionine during protein synthesis. This substitution occurs due to the chemical similarity between Se and sulfur. However, SeMet is also highly susceptible to oxidation, a characteristic that influences its stability and metabolic processing in vivo (Hadrup and Ravn-Haren, 2020).

Additionally, Se can be considered as an element that is stored in the form of selenomethionine (SeMet). When Se absorption in the body is impaired due to any physiological or pathological condition, SeMet serves as a Se reservoir, supplying Se to the organism as needed. SeMet is primarily obtained from plant-based sources (Hadrup and Ravn-Haren, 2020; Çakına, 2022).

The scientific literature identifies approximately 30 to 50 selenoproteins, with at least 12 of them known to play critical roles in viral pathogenesis, carcinogenesis, and immune system regulation. Among these, Gpx is recognized as the major selenoprotein present in a wide range of tissues. Gpx incorporates Se into its structure and is frequently used as a biomarker for evaluating Se status at the cellular level.

Gpx plays a pivotal role in protecting cells from oxidative stress by neutralizing reactive oxygen species (ROS). Its activity is particularly important in maintaining the function of muscle tissues, male reproductive biology, and the central nervous, endocrine, immune, and cardiovascular systems. The antioxidant capacity of SeMet is attributed to its ability to scavenge ROS. Moreover, both Se and methionine contribute to the synthesis and recycling of glutathione, a key endogenous antioxidant in the body (Küçük, 2014; Uslu and Aktac, 2020).

1.3. Pharmacokinetics

Following oral administration, Se is absorbed primarily in the small intestine and subsequently transported to the liver, where it is metabolized and incorporated into selenoproteins. From the liver, Se is distributed to peripheral tissues via the bloodstream. This transport is facilitated through binding to specific plasma proteins, including serum albumin, selenoprotein P (SEPP1), and glutathione peroxidase-3 (Gpx-3).

The bioavailability of Se from dietary sources is estimated to be approximately 14% of the ingested amount, with adult daily Se intake typically ranging between 2 to 20 mg. Se levels in the body can also be monitored through biological samples such as urine, nails, and hair.

Studies indicate that measurable increases in enzyme activity related to Se intake, such as Gpx activity, become apparent only after 4–6 weeks. Se also plays a crucial role in the activity of deiodinase enzymes, which are responsible for the activation of thyroid hormones. Notably, over 80% of the thyroid hormone thyroxine (T4) is converted into its active form, triiodothyronine (T3), in a Se -dependent process. In states of Se deficiency, an elevation in T4 levels accompanied by a reduction in T3 concentrations has been observed, indicating impaired hormone activation.

Finally, Se is primarily excreted from the body via the urinary system, which plays a key role in maintaining Se homeostasis (Kaya et al., 2013; Uslu and Aktac, 2020).

1.4. Selenium deficiency

Se deficiency has been associated with various impairments in the human immune system (Avery and Hoffmann, 2018). During pregnancy, insufficient Se levels and reduced antioxidant enzyme activity may lead to increased oxidative stress in maternal tissues, contributing to adverse outcomes such as miscarriage, premature birth, preeclampsia, and intrauterine growth restriction (Zachara, 2018).

Studies have shown that children residing in regions with Se -deficient soils exhibit slower physical development compared to those from Se-rich areas. These children often present with significant muscle weakness and reduced elasticity of cardiac and vascular tissues, increasing their risk of developing fetal cardiomyopathy.

Furthermore, Se deficiency has been linked to a higher prevalence of psychological disorders in humans. It is also associated with increased mortality rates among individuals suffering from chronic hepatitis and acquired immunodeficiency syndrome (HIV). Research indicates that Se deficiency contributes to a higher incidence of microbial infections and elevates the risk of various cancers, including those of the colon, lymphatic system, lungs, breasts, skin, prostate, liver, and stomach (Aktaş and Yahyazadeh, 2022).

In addition to these effects, Se deficiency has been associated with an increased incidence of common infections such as influenza and the common cold, as well as a heightened risk of contracting viral agents such as the human papillomavirus and herpes simplex virus. It is also linked to increased sensitivity to environmental chemicals and a greater predisposition to autoimmune diseases.

The thyroid gland plays a key role in regulating essential physiological functions, including body temperature, appetite, weight, sleep, and energy levels. Se contributes significantly to thyroid health by protecting the membrane regions of thyroid cells where autoantibodies tend to bind and initiate immune-mediated damage. Therefore, Se is essential for the regulation of thyroid hormone synthesis and concentration.

Although iodine is the primary element responsible for the prevention of thyroid gland enlargement, Se deficiency—particularly in individuals with adequate iodine intake—can lead to the development of thyroid gland hypertrophy and goitrous nodules.

Se deficiency is also associated with certain endemic diseases. Keshan disease (KD), a type of cardiomyopathy, and Kashin-Beck disease, a condition affecting joint and bone health, are both strongly linked to insufficient Se intake. Moreover, Se is vital for muscle function, and its deficiency may result in muscle weakness and myopathy.

Finally, Se plays a role in reproductive health, and its deficiency has been reported to contribute to infertility in both men and women (Kieliszek, 2021).

1.5. Side effects and toxicity

Chronic excessive intake of Se can result in elevated blood Se levels exceeding 100 μg/dL. Oral doses linked to lethal toxicity range between 1–100 mg Se per kilogram of body weight. Fatal outcomes have been associated with blood Se concentrations above 300 μg/L (normal range: ~100 μg/L) and urinary Se levels exceeding 170 μg/L (normal: 20–90 μg/L) (Hadrup and Ravn-Haren, 2020).

The primary mechanism underlying Se toxicity involves structural alterations in proteins due to the substitution of sulfur with Se in sulfur-containing amino acids, thereby disrupting normal protein function (Minich, 2022). This biochemical interference can contribute to the onset of chronic diseases, including diabetes.

Caution is advised when administering Se to individuals with chronic health conditions such as skin cancer, hypothyroidism, or chronic kidney disease, as dose adjustments may be necessary. Se supplementation should be discontinued approximately two weeks prior to surgical procedures. Additionally, concurrent use of Se and vitamin E is not recommended in individuals with allergy sensitivities due to potential adverse reactions.

Clinical manifestations of Se toxicity (selenosis) may include gastrointestinal disturbances (abdominal pain, nausea, vomiting), dental anomalies, a characteristic garlic-like odor on the breath, alopecia (hair loss), brittle nails, splenomegaly (enlarged spleen), hepatotoxicity (liver deformation), fatigue, irritability, and mild neurological symptoms. More severe signs include dizziness, muscle pain, tremors, flushing of the face, a burning sensation, paresthesia (numbness and tingling), altered reflexes, and partial paralysis (Spiller and Pfiefer, 2007; Uslu and Aktac, 2020).

1.6. Daily selenium requirement

Se intake requirements vary by age, sex, and physiological condition. The recommended dietary allowances are as follows:

- Children aged 1–3 years: 20 μg/day
- Children aged 4–8 years: 30 μg/day
- Children aged 9–13 years: 40 μg/day
- Individuals aged 14 and above: 55 μg/day
- Women: 60 μg/day
- Men: 75 μg/day
- Lactating women: 70 μg/day

Although the optimal serum Se concentration is approximately 85 μg/dL, intakes exceeding 400 μg/day may pose toxicological risks. Moreover, studies have indicated that when serum Se levels exceed 137 μg/dL, the risk of developing type 2 diabetes may increase.

Primary dietary sources of Se include cereal grains, meat, and seafood. Specifically:

- Beef and lamb: 20–35 μg Se/100 g
- Chicken: 10–24 μg Se/100 g
- Dairy products: ~3.7 μg Se/100 mL
- Bovine kidney: up to 155.3 μg Se/100 g
- Freshwater fish: >12 μg Se/100 g
- Canned tuna: >70 μg Se/100 g

Gpx, which accounts for over 60% of total Se content in serum and plasma, is considered the most reliable biomarker for assessing Se status in humans (Uslu and Aktaç, 2020).

Se intake and serum levels vary considerably among different countries and regions, influenced by dietary habits and soil Se content. For instance, Se supplementation programs have been implemented in Se -deficient regions such as the Keshan area in China and certain parts of Central Asia and Europe, including Finland. These interventions have led to significant improvements in public health by preventing Se -related disorders. In countries like China, soil heterogeneity results in regional variations in both dietary Se intake and serum Se concentrations (Minich, 2022).

Table 1. Selenium use and blood levels in different regions of the world

Country	**Daily intake (μg)**	**Blood/serum (μg/liter)**
Russia	15-130	67-106
Germany	38-47	89-98
USA	60-160	100-350
China*	2-6990	5-7800
Japan	27-89	80-155
Canada	113-220	143
Tibet	5-15	5-47
Finland until 1984	40	69
Finland after 1984	80	109

1.7. Alternative medicine

In contemporary complementary and alternative medicine practices, Se is utilized for its potential therapeutic effects in various conditions. One of its primary uses is in the management of hypercholesterolemia (high cholesterol levels), where Se's antioxidant properties may contribute to cardiovascular health.

Another common application is in the treatment of Hashimoto's thyroiditis (HD), an autoimmune disorder affecting the thyroid gland. Se supplementation in patients with Hashimoto's disease has been shown to reduce thyroid peroxidase antibody (TPOAb) levels, which may alleviate the progression of the disease. Furthermore, Se is used to assist in the regulation and reduction of elevated thyroid hormone levels, particularly in cases of subclinical hyperthyroidism or autoimmune-related thyroid dysfunction.

These alternative uses underscore Se's emerging role in integrative medicine, especially for patients seeking complementary approaches to chronic endocrine and metabolic disorders.

1.8. Storage

The total Se content in the human body is estimated to range between 13 and 30 milligrams. A significant portion of this Se —approximately 28% to 46%—is stored in skeletal muscle tissue, highlighting the importance of muscle as a primary Se reservoir.

Plasma Se concentrations of 8 μg/dL or higher are considered sufficient to support optimal protein synthesis, particularly the synthesis of selenoproteins, which are critical for various physiological functions, including antioxidant defense and thyroid hormone metabolism.

1.9. Vitamin E

Vitamin E is a potent antioxidant that serves as the first line of defense against the peroxidation of membrane phospholipids. A critical contributor to this protective mechanism is Se, specifically through its role as an integral component of the Gpx enzyme. Within the Gpx molecule, the Se ion maintains enzymatic activity, thereby assisting in neutralizing lipid hydroperoxides and indirectly reducing the antioxidant burden on vitamin E.

Furthermore, Se plays a supportive role in the exocrine function of the pancreas, which is essential for proper digestion and nutrient absorption (Aktaş et al., 2020). Se enhances the absorption and metabolism of dietary fats and vitamin E, while also promoting the retention of vitamin E within plasma lipoproteins.

By exerting its antioxidant function, particularly in sulfur-containing amino acids such as cysteine, Se helps reduce the overall demand for vitamin E in maintaining cellular redox balance (Akici et al., 2012).

1.10. Biochemical effects of selenium

1.10.1. Antioxidant

Oxidative stress refers to the destruction of normal cells caused by the excessive production of ROS in damaged cells (Aktaş and Sevimli, 2020). This condition arises when reactive species such as hydroxyl radicals, metal-oxygen complexes, superoxide anions, and hydrogen peroxide interact with metal ions, resulting in cellular damage (Aktaş and Bayram, 2020). Cells in human tissues possess complex detoxification systems that neutralize these reactive intermediates and prevent oxidative injury (Aktaş and Gür, 2021). Among these systems, Se plays a crucial role due to its incorporation into key antioxidant enzymes. Organic Se forms, such as Se -enriched yeast, have been shown to offer superior protection against oxidative damage compared to inorganic forms like sodium selenite (Gür and Bilgiç, 2022). Moreover, organic Se has been demonstrated to be less toxic while retaining effective antioxidant capacity (Hosnedlová et al., 2017; Çakına, 2022).

Several Se -dependent enzymes—such as thioredoxin reductase, Gpx, and iodothyronine deiodinase—function as intracellular antioxidants, playing a pivotal role in mitigating oxidative damage. Consequently, Se supplementation is considered to enhance the endogenous antioxidant defense mechanisms of the body (Wang et al., 2017).

1.11. Selenium and its relationship with diseases

1.11.1. Immunity

Elevated Se concentrations have been observed in immune-related organs such as the lymph nodes, spleen, and liver during disease states. Supplementation with Se, in conjunction

with standard therapeutic approaches, has been shown to enhance immune responses and improve clinical outcomes. In Se -deficient individuals, the progression and severity of viral infections, including influenza, tend to worsen.

Se has been reported to reduce the risk of hepatocellular carcinoma induced by hepatitis B and C viruses. Regular dietary intake of Se -rich foods is therefore essential for sustaining a robust and responsive immune system.

Moreover, Se exhibits a protective role against DNA damage and mutagenesis by interacting with other antioxidants such as vitamin E. It is actively involved in modulating inflammatory responses and mitigating oxidative stress. The enzyme Gpx, a Se -dependent protein, protects lipid-containing organelles and cell membranes by neutralizing peroxidative damage through its redox functions.

Together with vitamin E, Se contributes to maintaining cellular integrity by strengthening cell membranes and neutralizing hydrogen peroxide via redox reactions involving glutathione. This mechanism also contributes to decelerating the aging process at the cellular level. In conditions of Se deficiency, the toxicity of redox by-products increases, resulting in significant oxidative damage to cell membranes.

Furthermore, Se is critical for individuals living with HIV, as it facilitates the differentiation of CD4+ T lymphocytes into T-helper 1 cells. This transformation plays a role in reducing the incidence of opportunistic mycobacterial co-infections. Se also enhances the cytotoxic activity of natural killer cells, T lymphocytes, and macrophages.

In addition to its immunomodulatory properties, Se has been found to reduce the toxicity of various harmful substances, including heavy metals (lead, cadmium, arsenic, mercury) and environmental toxins such as paraquat herbicides (Shreenathet al., 2023).

1.11.2. Selenium-cancer relationship

Scientific literature has identified Se -containing compounds found in garlic, particularly γ-glutamyl-Se-methyl Se-Cys and Se-methyl Se-Cys, as having notable anticancer properties (Taban et al., 2013). These compounds have demonstrated potential in inhibiting carcinogenesis through various mechanisms, including antioxidant activity and modulation of cellular redox balance.

Se plays a significant role in the prevention of several cancer types—most notably breast, liver, lung, colon, and prostate cancers—due to its ability to neutralize free radicals and protect cellular DNA from oxidative damage. Clinical studies have confirmed that a daily Se intake of approximately 200 µg (not mg) can reduce the risk of cancer development associated with genetic mutations and oxidative stress.

Furthermore, epidemiological data indicate that cancer incidence is higher in populations living in regions with low soil and dietary Se levels. Adequate antioxidant intake through diet has been shown to protect healthy cells from transformation into malignant forms.

Garlic, in particular, is a rich source of Se, as well as vitamins E and C—both of which possess strong antioxidant capabilities. These nutrients collectively contribute to cellular defense mechanisms against oxidative stress and DNA damage, reinforcing the importance of a Se -rich diet in cancer prevention strategies (Vinceti et al., 2018).

1.11.3. Selenium and alzheimer’s disease

Alzheimer’s disease (AD) is a progressive neurodegenerative disorder primarily associated with the accumulation of amyloid-β plaques, which contribute to neurotoxicity. A key mechanism underlying this neurotoxicity is oxidative stress, often accompanied by

neuroinflammation. In addition, AD has been linked to disruptions in the intestinal microbiota, suggesting a potential gut-brain axis involvement in disease progression (Ferrari, 2020).

Aging is accompanied by a physiological decline in Se levels in the human body. This reduction in Se compromises the antioxidant defense system, contributing to structural and functional impairments in brain tissues. As Se is preferentially utilized by the brain in deficiency states, insufficient levels can lead to decreased turnover of neurotransmitters, adversely affecting cognitive processes.

Se intake has been shown to alleviate lipid peroxidation-related damage at neuronal synapses and to enhance neurotransmitter transport. These effects collectively support improved central nervous system (CNS) function. Dietary sources rich in Se —such as Brazil nuts and seafood—have demonstrated potential benefits in improving cognitive performance in individuals with mild cognitive impairment.

Gpx, a Se -dependent antioxidant enzyme, plays a critical role in protecting neural tissues by catalyzing the reduction of hydrogen peroxide and limiting lipid peroxidation. Other selenoproteins, including thioredoxin reductase and various GPx isoforms, contribute to cellular defense mechanisms by mitigating oxidative stress and preserving neuronal integrity.

Thus, Se supplementation and adequate dietary intake may offer neuroprotective benefits and contribute to the maintenance of cognitive function, particularly in the aging population (Uslu and Aktac, 2020; Shreenath et al., 2023).

1.11.4. Selenium and thyroid function

Among all tissues in the human body, the thyroid gland contains the highest concentration of Se per gram of tissue, primarily due to its abundance of selenoproteins. The thyroid gland plays a crucial role in regulating fundamental physiological functions, including body temperature, metabolism, appetite, weight, energy levels, and sleep cycles.

Se is essential for the synthesis and regulation of thyroid hormones. A deficiency in Se can disrupt thyroid function and lead to clinical conditions such as hypothyroidism, hyperthyroidism, and thyroiditis (inflammation of the thyroid gland) (Wang et al., 2023).

Of the 35 known human selenoproteins, three are iodothyronine deiodinases that are directly involved in thyroid hormone metabolism. These enzymes catalyze the activation and inactivation of thyroid hormones:

1. **Type I Deiodinase (D1):** Converts the inactive form of the hormone, T4, into its active form, T3, facilitating hormonal balance.
2. **Type II Deiodinase (D2):** Highly expressed in the CNS, skeletal muscle, and brown adipose tissue, D2 plays a major role in intracellular T3 production and local thyroid hormone activation.
3. **Type III Deiodinase (D3):** Inactivates excess thyroid hormone by converting T4 and T3 into their inactive metabolites, thus maintaining thyroid hormone homeostasis.

These Se -dependent enzymes are critical in maintaining a balanced thyroid hormone environment and ensuring proper endocrine function. Therefore, adequate Se intake is essential for optimal thyroid health and overall metabolic stability (Bilgic et al. 2024; Shreenath et al. 2023).

1.11.5. Hashimoto's thyroiditis

HT, also known as autoimmune thyroiditis, is a chronic inflammatory condition of the thyroid gland characterized by immune-mediated destruction of thyroid tissue. The disease is

primarily marked by the presence of autoantibodies, particularly anti-thyroid peroxidase antibodies (TPOAb) and anti-thyroglobulin antibodies (TgAb). Among individuals diagnosed with HT, approximately 90% exhibit elevated levels of TPOAb in circulation. Although TgAb may also be present, it is generally considered less sensitive and less specific than TPOAb for diagnostic purposes.

As inflammation progresses, thyroid follicles are gradually destroyed and replaced by infiltrating lymphocytes, leading to impaired hormone production and often resulting in hypothyroidism.

Se, particularly in the form of SeMet, has been investigated for its potential therapeutic role in patients with HT. Studies suggest that Se supplementation may help reduce TPOAb titers and modulate the autoimmune response. Such supplementation is especially recommended for individuals with adequate iodine intake but who are Se -deficient, as Se supports thyroid hormone metabolism and enhances antioxidant defenses within thyroid tissue (Yang, 2009; Bilgiç and Aktaş, 2022).

1.11.6. Heart

Se plays a vital role in cardiovascular health, primarily due to its potent antioxidant properties that reduce oxidative stress—a key contributor to endothelial dysfunction and atherosclerosis. By enhancing antioxidant enzyme activity, Se helps protect myocardial tissue and vascular structures from oxidative damage (Aktaş et al., 2024).

Se also supports cardiovascular function by promoting healthy blood flow and inhibiting platelet aggregation, thereby reducing the risk of thrombosis and related cardiovascular complications.

Se deficiency has been consistently linked to an increased incidence of cardiovascular diseases. One well-documented example is KD, an endemic cardiomyopathy first identified in Se -deficient regions of China. This condition is characterized by myocardial necrosis, heart enlargement, and, in severe cases, sudden cardiac death, particularly among children and women of reproductive age (Bilgic et al., 2021).

Therefore, adequate Se intake is considered essential for maintaining cardiovascular health and preventing Se -deficiency–related heart disorders (Bomer et al., 2020; Gür et al., 2022).

1.11.7. Keshan disease

KD is a form of congestive cardiomyopathy predominantly observed in Se -deficient regions. It is clinically characterized by symptoms such as cardiac enlargement, heart failure, arrhythmias, electrocardiographic abnormalities, and in severe cases, cardiogenic shock. In addition to its cardiac manifestations, KD may also result in musculoskeletal complications, including deformities in cartilage, bones, and joints, often leading to restricted mobility due to joint enlargement. Intermittent myalgia is also reported as a common symptom.

The disease primarily affects children and women of reproductive age and is associated with a high morbidity rate, estimated at approximately 50%, along with significant mortality.

Research suggests that environmental and viral cofactors—such as exposure to toxic chemicals and infection with the Coxsackie virus—may exacerbate the severity and progression of KD. Importantly, public health interventions using Se -enriched salt have demonstrated a significant reduction in the incidence of KD, particularly in endemic regions (Wang et al., 2023).

These findings underscore the essential role of Se in cardiovascular and musculoskeletal health, and highlight its importance in preventing endemic deficiencies that can lead to severe clinical outcomes (Bilgic et al., 2023).

1.11.8. Fertility

Se is a crucial micronutrient in male and female reproductive health. It plays a fundamental role in testosterone biosynthesis and contributes to the formation, maturation, and motility of spermatozoa. Testicular tissue contains relatively high concentrations of Se, which is vital for maintaining sperm integrity and functionality, primarily through its involvement in antioxidant defense mechanisms that protect sperm cells from oxidative damage.

In males, Se deficiency has been linked to reduced sperm count, impaired sperm motility, and infertility. Similarly, in females, insufficient Se levels are associated with an increased risk of miscarriage, impaired follicular development, and reduced embryo viability.

Interestingly, both deficient and excessive Se levels can negatively affect reproductive outcomes. Elevated Se concentrations may lead to toxicity and hormonal imbalance, while deficiency compromises sperm quality and female reproductive success. Therefore, maintaining an optimal Se status is essential for fertility in both sexes (Gür et al., 2022; Shreenath et al., 2023).

1.12. Rich foods containing selenium

Se is an essential trace element found naturally in a variety of foods. The Se content of these foods can vary depending on factors such as soil Se concentration, geographic origin, and food processing methods. According to the literature, the following foods are recognized as rich sources of Se:

- Eggs
- Liver (particularly from beef and poultry)
- Walnuts
- Organ meats (offal)
- Dairy products
- Whole wheat flour and whole grain breads
- Fresh vegetables and fruits
- Red meats (beef, lamb)
- Sunflower seeds
- Mushrooms
- Poultry (especially chicken breast and turkey)
- Seafood, including rockfish, tuna, herring, and salmon
- Brazil nuts (noted as the richest natural source of Se)
- Onions and garlic

These foods, when included in a balanced diet, contribute significantly to meeting daily Se requirements and supporting antioxidant, thyroid, immune, and reproductive health (Berzelius, 2020).

Table 2. Se concentrations in foods

Sources	***Se density (mg/kg)***	***Types of Se***
Brazil nuts	*0.03–515*	*SeMet*
Bread	0.01–30	SeMet/selenate
Cereals	0.02–35	SeMet/selenate
Rice	0.05–0.08	SeMet
Onions	0.02–0.05	SeMet/Sec
Garlic	0.05–1.0	SeMet/Sec
Broccoli	0.5–1.0	SeMet/selenate
Potatoes	0.12	SeMet
Lentils	0.24–0.36	SeMet/selenate
Meat and meat products		
Beef	0.42–0.142	SeMet
Chicken	0.081–0.142	SeMet/Sec
Fish	0.1–5.0	SeMet/selenite/selenate
Eggs	3–25	SeMet/Sec
Lamb	0.033–0.260	SeMet
Milk and dairy products	0.01–0.03	Sec/selenite
Yeast	0.6–15	SeMet

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1.12.1. Brazil nuts

Brazil nuts (*Bertholletia excelsa*) are widely recognized as the most Se -rich food source known in human nutrition. It is recommended to consume 1–4 Brazil nuts per day, as this amount is generally sufficient to meet or exceed the recommended daily Se intake.

Beyond their exceptional Se content, Brazil nuts are nutritionally dense and contain:

- Fat (60–70%)
- Protein (~17%)
- Dietary fiber
- Minerals: magnesium, zinc, phosphorus, iron, calcium, copper, potassium
- Vitamins: niacin, thiamine, vitamin B6, and various forms of tocopherol (vitamin E)

Brazil nuts also contain phenolic compounds and flavonoids in both free and bound forms, contributing to their strong antioxidant capacity. Additionally, they are rich in phytosterols such as squalene and tocopherol, which are known to support cardiovascular and metabolic health.

Due to their antiproliferative and antioxidant properties, Brazil nuts may reduce the risk of chronic diseases such as cancer and atherosclerosis, supporting their inclusion in preventive nutrition strategies (Yang, 2009; Ferrari, 2020).

1.12.2. Fortified foods

Fortified foods are an important dietary strategy for addressing micronutrient deficiencies, including Se. Various cereal products—such as whole wheat breads, breakfast cereals, and pasta—are commonly enriched with Se and other essential minerals to improve their nutritional value.

Grains naturally contain Se in variable amounts depending on the Se content of the soil in which they are cultivated. However, in many countries with low soil Se levels, Se

fortification of grain-based products has become a standard public health practice. These fortified products serve as an effective Se supplement, particularly for populations at risk of deficiency (Azirak et al., 2019).

Therefore, regular consumption of Se-enriched grains can contribute significantly to maintaining adequate Se status and supporting overall health (Tanbek et al., 2017).

1.12.3. Garlic

Garlic (*Allium sativum L.*) is widely utilized both as a culinary ingredient and in traditional medicine due to its numerous health-promoting properties. One of the primary bioactive compounds in raw garlic is allicin, which is responsible for its characteristic pungent taste and odor. Allicin is formed enzymatically when garlic is crushed or chopped, and it contributes to garlic's well-documented antimicrobial and antioxidant effects.

Garlic is also a natural source of Se, which acts synergistically with its sulfur-containing compounds to enhance its antioxidant capacity. These compounds play a role in neutralizing free radicals, reducing oxidative stress, and modulating inflammatory responses.

According to the scientific literature, regular consumption of Se-rich garlic may provide protective effects against several types of cancer, including:

- Brain tumors
- Skin cancer
- Esophageal cancer
- Colorectal cancer
- Prostate cancer
- Gastric (stomach) cancer
- Thyroid cancer

These protective effects are attributed to garlic's ability to modulate carcinogen metabolism, promote DNA repair, and support the immune system, in addition to its Se content (Akan, 2014; Tanbek et al., 2017).

2. Discussion

Scientific research has consistently demonstrated that Se is an essential trace element required for the proper regulation of reproductive and growth functions in living organisms. Beyond these fundamental roles, Se is also recognized for its pleiotropic effects, notably its anti-inflammatory and antioxidant properties (Mikulska et al., 2022).

Despite these known benefits, neither the American nor European Thyroid or Endocrinology Societies currently recommend Se supplementation for the treatment of HT (Iraz et al., 2015; Filipowicz et al., 2021). However, individual clinical trials have reported promising outcomes. For instance, a study administering 100 μg of Se daily for six months to 29 women with newly diagnosed, untreated HT demonstrated a significant reduction in TPOAb levels. This suggests that Se may play a protective role in delaying or preventing the progression to hypothyroidism in such patients (Van Zuuren et al., 2014; Kryczyk-Kozioł et al., 2021). Nevertheless, further large-scale, randomized controlled trials are required to confirm the clinical efficacy of Se supplementation in HT management.

In relation to KD —a cardiomyopathy endemic in Se -deficient regions—multiple studies have demonstrated that Se supplementation significantly reduces disease incidence (Zhou et al., 2018). In a notable clinical trial conducted in China, the administration of sodium selenite to

KD patients resulted in an increase in Gpx activity and marked clinical improvement, further supporting Se's therapeutic potential in Se -deficiency-related conditions.

These findings collectively emphasize the crucial role of Se in human health. However, they also highlight the need for context-specific guidelines and further scientific evidence, particularly for its therapeutic use in autoimmune and cardiovascular diseases (Chen, 2012).

In general, Se supplementation is considered an immunostimulatory agent, enhancing immune system functions (Huang et al., 2012). Research indicates that the prevalence of autoimmune thyroiditis, including HT, is higher in regions with low Se levels, suggesting a possible correlation between Se deficiency and the development of autoimmune disorders (Wichman et al., 2016).

Moreover, Se has been shown to modulate inflammatory pathways, particularly those associated with inflammation-related carcinogenesis. It appears to influence the molecular mechanisms underlying chronic inflammation, thereby reducing the progression of inflammation-driven cancers (Gao et al., 2016).

Epidemiological and clinical studies further suggest that individuals with higher Se intake and tissue Se levels are at lower risk for developing various cancers. Additionally, Se has been shown to exert antiproliferative effects by inhibiting the growth of cancer cells through mechanisms that include induction of apoptosis, suppression of angiogenesis, and modulation of cellular redox status.

These findings underscore Se's potential role as a preventive and therapeutic agent in immune regulation and cancer biology, while also highlighting the need for controlled clinical trials to validate its efficacy in diverse populations (Vinceti, 2018; Li et al., 2021; Yuan et al., 2022).

Se is a critical micronutrient for brain function, yet its effects are dose-dependent and may be neurotoxic at excessive levels. Although the brain contains only approximately 2.3% of the total Se found in the human body, this small amount is vital for maintaining neuronal integrity and function.

Se deprivation can lead to irreversible damage to neuronal tissue, particularly due to increased susceptibility to oxidative stress. This mechanism is of particular concern in the pathogenesis of neurodegenerative diseases such as AD. Oxidative stress is a well-established contributor to neuronal degeneration in AD and similar conditions.

Selenoproteins, which act as endogenous antioxidants, may help prevent or slow the progression of AD by neutralizing ROS and protecting neurons from oxidative damage. However, while Se supplementation may offer neuroprotective benefits, it must be approached with caution.

Excessive Se intake has been associated with adverse neurological effects, including neurotoxicity, as well as a heightened risk of developing type II diabetes and amyotrophic lateral sclerosis. These findings emphasize the importance of maintaining optimal Se levels, as both deficiency and excess can negatively impact neurological and systemic health (Solovyev et al., 2018).

There is a positive correlation between sperm count and Se concentration in seminal fluid. Studies have shown that sperm count reaches its optimal level when seminal Se concentration is within the range of 50 to 69 μg. Deviations from this range—whether lower or higher—have been associated with reduced sperm motility, which consequently increases the risk of asthenospermia, a condition characterized by impaired sperm movement (Hansen and Deguchi, 1996).

Women, Se deficiency has also been linked to adverse pregnancy outcomes. These include an increased risk of low birth weight, spontaneous abortion, and developmental damage to the fetal nervous and immune systems. Furthermore, Se deficiency during pregnancy may contribute to various maternal health risks and complications, such as gestational hypertension, preeclampsia, and preterm birth.

These findings highlight the critical importance of maintaining adequate Se levels in both men and women to support fertility, healthy pregnancy, and fetal development (Lima et al., 2022; Bilgic et al., 2022).

3. Conclusion

Adequate daily intake of Se is essential for maintaining overall health, preventing various diseases, and potentially slowing the aging process. The biological effects of Se are primarily mediated by selenoproteins that contain the amino acid Se-Cys. Dietary Se intake is influenced by both the amount of food consumed and the Se content of those foods, which can vary depending on geographic and environmental factors.

Se plays a vital role in several key physiological systems, including immune function, antioxidant defense, and thyroid hormone metabolism. According to the Turkish Nutrition Guide, the recommended daily Se intake for both adult women and men is 70 μg.

In recent years, research on Se has expanded significantly. The identification and characterization of numerous new selenoproteins—ranging from plants to humans—have enhanced our understanding of Se's roles in biological systems. These discoveries have underscored the multifaceted importance of Se in health and disease.

Se compounds have shown promising potential in the diagnosis and treatment of cancer, and are expected to play a critical role in cancer prevention and therapy in the near future. Moreover, the development of new Se -based pharmaceuticals may provide effective treatment options for various Se -related deficiencies and diseases.

In conclusion, ensuring optimal Se intake through balanced nutrition and, when necessary, supplementation can contribute significantly to public health and medical advancements.

Declaration of Author Contributions

All authors declare that they have contributed equally to this manuscript, have reviewed the final version, and have approved it for publication.

Declaration of Conflicts of Interest

The authors declare that there is no conflict of interest regarding this study.

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Lutein's Protection Against Cisplatin's Pulmonary Toxicity

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Abstract: One of the biggest problems of cancer treatment is the harmful effects of these drugs on the healthy tissues and organs of the organism. The aim is to determine the possible protective effects of Lutein (L) against Cisplatin (CS) toxicity in rat lungs by biochemical tests. In our study, lutein (L) (orally, 100 mg/kg) was administered for CS-induced lung toxicity (intraperitoneally (i.p.), 10 mg/kg). The study was completed with a total of 28 rats from 4 groups, each consisting of 7 subjects. Control, L, CS and CS + L. Lung damage induced by CS was a dose-limiting side effect of CS and caused an increase in PCO2 level and a decrease in PO2 and SaO2 levels. In our study, a significant decrease in PCO2 levels and an increase in SaO2 and PO2 levels were observed in L application ($p< 0.05$). In the CS + L group, there was an increase in CAT, SOD and GSH levels and a decrease in MDA levels compared to the CS group. A significant decrease in body weight was observed in the CS-treated group compared to the control. L supplementation in these rats caused a significant increase in body weight, bringing this value closer to normal ($p< 0.05$). It is understood from the study that L alleviates the results of oxidative stress, increases antioxidant functions and positively supports lung functions. It also demonstrates the ability of L to prevent CS-induced lung damage. Ultimately, L appears to be a applicable pharmacological agent in this injury.

1. Introduction

Chemotherapy is a method used in the treatment of cancer (Aktaş and Yahyazadeh, 2022). Cisplatin (CS) is applied as an antineoplastic drug in the treatment of various tumors in cancer patients. However, it also causes side effects on the body's normally functioning organs. CS affects the lungs and other tissues and organs, causing oxidative stress. Side effects include kidney toxicity, nausea, vomiting, as well as fibrosis, interstitial inflammation, structural lung damage (Badreldin and Al Moundhri, 2006). In patients with lung injury, CS chemotherapy increases perioperative complications by inducing bronchitis-associated fibrosis and interstitial inflammation (Leo et al., 2018). As a side effect of CS, the antioxidant system is negatively affected and harmful radicals are produced that cause oxidative damage (Badary et al., 2005). The occurrence of genotoxicity and myelosuppression limits the use of CS therapy. Additionally, there is a significant dose-dependent increase in DNA damage. It interferes with the synthesis of DNA, resulting in cross-linking of DNA that stimulates cell cycle progression. As a result, it induces apoptosis of tumor-forming cells (Bakır et al., 2018). In addition, CS reduces the scavenging of free radicals by binding to the sulfhydryl of glutathione. In addition, the CS-sulfhydryl structure damages enzyme function and cell membranes, ultimately causing damage to mitochondria and increased lipid peroxidation.

It is known that cells in the organism create many mechanisms to prevent oxidative stress-based damages. Studies aimed to eliminate the toxic effects of drugs through antioxidants administered together with the drug (Caffrey and Frenkel, 2000; Aktaş and Armağan, 2019; Aktas and Bayram, 2020; Aktaş and Sevimli, 2020; Aktas and Ozgocmen, 2020). Lutein (L) has been used in many studies due to its antioxidant properties. They are carotenoids (do not contain vitamin A) that cannot be synthesized in the organism and are synthesized by algae, bacteria and plants. It reacts with free oxygen radicals formed in the body due to its hydroxyl structure. Due to this feature, it has a strong free radical scavenging function (Ojima et al., 1999; Krishnaswamy et al., 2010). Additionally, L has anti-cancer and anti-inflammatory effects (Chucair et al., 2007). L also protects against stomach lesions and gastrointestinal ulcers (Jávor et al., 1983; Mozsik et al., 2001). In general terms, its low toxicity makes it advantageous in conventional treatment.

In the literature, it is seen that a sufficient number of antioxidant supporting substances have been studied in order to eliminate the undesirable damages of CS in lung treatment. For this purpose, the fact that the protection of L against the side effects of CS has not yet been investigated makes our study unique. Therefore, in our study, the protection of L against toxic damage caused by CS in the lung tissues of rats was investigated.

2. Material and Methods

2.1. Chemicals

Chemical L in this study was supplied by Solgar (USA). The others were purchased from Sigma Chemical Co. (St. Louis, MO).

2.2. Animals

This research was conducted with 28 Sprague-Dawley male rats. Rats weighed (W) 210-265 g and were 11 weeks old. Animals were taken from the Experimental Animal Research Center of the institution where we work. The procedures were carried out according to the protocol (Protocol 2022/056) received from the ethics committee of the same center. In the experiment, care was taken to ensure that the humidity and temperature in the environment were at optimal levels (55% ± 5, 22 ± 2°C, respectively). Water and feed supplements were provided to the animals according to their average needs.

2.3. Experimental protocol

In this research, 4 groups, each containing 7 rats, were randomly created (n = 7).

1. Control group: This group was offered 1 ml of physiological saline orally daily.

2. L group: L was given to subjects daily by gavage (100 mg/kg/day) (Katyal et al., 2013).

3. CS group: CS was administered as a single dose (by i.p., 10 mg/kg) on the 4th day of the experiment (Capasso et al., 1990).

4. L + CS group: In the experiment, L and CS were administered as in their respective groups.

The experiment was completed in 7 days. Then, anesthesia (xylazine and ketamine) and decapitation procedures were performed on the rats. Blood and lung samples were taken for biochemical study.

2.4. Body weight and relative lung weight

The animals were weighed on the 1st and 7th days of the study. Lung tissues were washed with saline, dried and weight. The W of lungs/body weight ratio was determined by this formula (Aktaş and Yahyazadeh, 2022):

$$\text{Relative Organ W (\%)} = \frac{\text{Organ W} \times 100}{\text{Body W}}$$

2.5. Arterial blood gas analysis

For blood gas analysis, 2 ml of blood was taken from the carotid artery and centrifuged (3000 rpm, r: 15 cm) (Abbott, USA). The amount of protein in the obtained serum was measured by the bicinchoninic acid method (Liu et al., 2015).

2.6. Biochemical analysis

Homogenization of the samples was carried out in a cold environment for 1-2 minutes at 12,000 rpm (IKA, Germany). The ideal temperature for targeted procedures is 4°C. Homogenates were designed to be 0.5-1.0 g in size to be used in analyses. Lung tissues were prepared for use in the analysis of glutathione (GSH), catalase (CAT), superoxide dismutase (SOD) and malondialdehyde (MDA). Protein values were determined using the method of Lowry et al. (1951).

MDA was evaluated using the Uchiyama and Mihara (1978) method. Therefore, the thiobarbituric acid reaction was established at pH 3 and 95°C for 15 min. Then, pink pigment was obtained as a result of maximum absorption and measurements at 532 nm.

GSH was assessed by the method of Ellman (1959). Chemicals were included in the samples to cause the reaction (yellow green color). The results were obtained by spectrophotometer with 410 nm absorbance.

SOD was measured by the method of Marklund and Marklund (1974). This process occurred by preventing the autoxidation of pyrogallol. Enzyme activity was measured at a wavelength of 440 nm for 180 seconds. Results were defined as U/mg Hb.

To detect CAT activity, 0.9% NaCl was mixed into 10% homogenate using phosphate buffer. Afterwards, hydrogen peroxide hydrolysis was examined at pH 7.0. Results were reported as nmol/mg protein measured with maximum absorbance at 240 nm (Aebi, 1984).

2.7. Statistical analysis

The analyses in this study were carried out with SPSS version 20.0. Data are expressed as mean ± SEM. Body weight analyses were performed by applying paired samples t-test to the groups at both the beginning and end of the study. Comparing the means of more than two sample groups was done using analysis of variance (ANOVA), and comparing the means of two sample groups was done using t-tests. Intergroup and intragroup comparisons of parametric values in antioxidant parameters were made with one-way ANOVA and LSD post-hoc test. Non-parametric values were analyzed using the Kruskal-Wallis test. A p-value of ≤ 0.05 was considered statistically significant.

3. Results

3.1. Body and organ weights

The effects of L treatment on lung and body weight before and after CS application are in Table 1. According to the available data, rats treated with CS alone exhibited a significant reduction in final body weight compared with the control and L treatment group ($p< 0.001$). L supplementation to CS-treated animals resulted in a significant increase in final body weight ($p< 0.001$). A significant ($p< 0.001$) increase in lung weight was observed in CS-treated rats compared with the control and L treatment groups. L treatment significantly corrected the fluctuations in lung weight, in contrast to the CS-only treated group.

Table 1. Effect of CS and L treatment on body and lung weight of rats

	Group Body weight (g)		
	First	Last	Lung weight
Control	221.1 ± 0.781	263.9 ± 0.483	0.627 ± 0.05
L	216.3 ± 0.479	264.1 ± 0.572	0.745 ± 0.10
CS	220.8 ± 0.485	227.3 ± 0.589	0.959 ± 0.04
CS + L	218.9 ± 0.714	249.3 ± 0.585	0.721 ± 0.014
Statistical comparison (Initial of study vs final of study) (p)			
Control			0.002
L			0.005
CS			0.024
CS + L			0.030

Changes in the body and lung weight of experimental rats. Values are expressed as mean ± SEM. The groups were compared with the paired-samples T-test at the beginning and end of the treatment p <0.05.

3.2. Blood gas parameters in the artery

Compared to the other groups, a significant increase in arterial carbon dioxide pressure (PCO_2) level and a significant decrease in partial oxygen pressure (PO_2) and arterial oxygen saturation (SaO_2) levels were observed in the CS group (p< 0.05). In the CS + L group, PCO_2 levels significantly decreased, PO_2 and SaO_2 levels significantly increased compared to the CS group (p< 0.05). The results are in Table 2.

3.3. Biochemical parameters in tissue

Tissue biochemical parameter results are in Table 1. Compared with the other groups, a significant increase in MDA level was observed in the CS group (p< 0.05). A significant decrease in MDA level was detected in the CS + L group compared to the CS group (p< 0.05). A significant decrease was found in GSH, SOD and CAT parameters when compared to the CS group, L and control groups (p <0.05). Lung tissue GSH, CAT and SOD levels in the CS + L group were significantly increased compared to the CS group (p< 0.05) (Table 1).

Table 2. Biochemical parameters and tissue oxidative stress parameters in the lung

	Control	L	CS	CS + L
Serum biochemical biomarkers				
Arterial blood gases				
PCO_2 (mmHg)	36.41 ± 1.14^{c}	42.16 ± 1.11	53.58 ± 1.08^{a,d}	44.74 ± 1.12^{c}
PO_2 (mmHg)	88.17 ± 0.42^{c}	94.13 ± 0.41	69.04 ± 0.45^{a,d}	81.3 ± 1.18^{c}
SaO_2 (%)	91.25 ± 1.12^{c}	98.56 ± 1.27	78.08 ± 1.16^{a,d}	82.14 ± 1.54^{c}
Lung tissue oxidative stress biomarkers				
SOD (U/g)	2.99 ± 0.18^{c}	3.22 ± 0.13	1.88 ± 0.24^{a,d}	3.41 ± 2.12^{c}
CAT (µmol H_2O_2/g)	0.61 ± 0.08^{c}	0.68 ± 0.23	0.29 ± 0.12^{a,d}	0.59 ± 0.14^{c}
GSH (µmol/g)	0.59 ± 0.25^{c}	0.62 ± 0.47	0.28 ± 0.26^{a,d}	0.64 ± 0.19^{c}
MDA (nmol/g)	0.41 ± 0.49^{c}	0.51 ± 0.47	0.88 ± 0.74^{a,d}	0.47 ± 0.15^{c}

Data are mean ± SEM, n = 7. CS, cisplatin; L, lutein; MDA, malondialdehyde; GSH, glutathione; SOD, superoxide dismutase; CAT, catalase. a: Significant difference from control, b: Significant difference from L, c: Significant difference from CS, d: Significant difference from CS + L.

4. Discussion

Chemotherapeutic drugs have been found to cause side effects in healthy organs in addition to their therapeutic effects. A large number of chemotherapeutic drugs are widely used in the treatment of cancer patients. CS is an important anticancer drug applied in laboratory and clinical research. More effective drugs must be developed to cure cancer cases (Iraz et al., 2015). Although CS is effective in some tumors, it causes serious side effects in normal organs. Therefore, CS has a strong anti-proliferative effect against tumor cells. CS also stabilizes microtubules, blocks mitosis, and shows its functions by inducing apoptosis. All of these cases limit the use of CS as a chemotherapeutic agent (Tutun et al., 2019; Bilgiç and Aktaş, 2022). The effectiveness of chemotherapeutics increases when used together with vitamins or antioxidants. Therefore, this study demonstrated that CS treatment with L protects against CS-induced damage in the lungs of rats (Geyikoğlu et al., 2017). It was determined that there was a significant decrease in body weight of rats treated only with CS. Additionally, in our study, a significant increase in body weight was reported in animals in which L supplementation was administered along with CS. In a study on this subject, Afsar et al. (2018) aimed to evaluate the protection of Acacia hydaspica (polyphenol-rich ethyl acetate extract) against CS-induced pulmonary toxicity. The decrease in body weight and increase in lung weight due to CS-induced toxicity obtained here coincide with our results (Afsar et al., 2018).

Lung injury induced by CS is a dose-limiting side effect of CS and causes an increase in PCO_2 level and a decrease in PO_2 and SaO_2 levels. In our study, blood gas analysis results show that the PCO_2 level of the CS group increased, while the PO_2 and SaO_2 levels decreased. The fact that these results in the CS group are significantly different from the control group proves that CS damages the alveolar-capillary membrane (ACM) and therefore affects gas exchange. Due to the disorder in the barrier function of ACM, permeability increases significantly and the transmembrane transport process of the substance cannot be regulated. Additionally, due to this disorder, water and proteins leak from the capillaries of the cells into the alveolar interstitium and alveolar space. This causes both the thickening of the ACM and the slowing down of CO_2 and O_2 diffusion (Liu et al., 2015). In our study, as a result of L application, there was a significant decrease in PCO_2 level and an increase in PO_2 and SaO_2 levels. In this case, it can be said that with the effect of L, there is a significant improvement in the parameters, the damage caused by CS is reduced, and the disorder in the barrier function of the ACM is improved (Mitchell et al., 2011).

There is evidence from previous studies that lung damage caused by CS occurs as a result of the formation of free radicals. Increased oxidants such as superoxide anion and hydrogen peroxide due to mitochondrial dysfunction caused by reactive oxygen species play a role in the pathogenesis of CS-induced lung injury. It has also been reported that antioxidant enzyme activities decreased (Chen et al., 2020). In addition, CS reduces the excretion of glutathione from the body by binding sulfhydryl groups (free oxygen radicals). Another situation is that CS-sulfhydryl formation damages the enzyme function and the cell membrane. Then, it causes mitochondrial damage as a result of lipid peroxidation (Bilgic et al. 2023). Some studies have also reported that CS reduces lung SOD, CAT enzyme activities and GSH levels (Liu et al., 2015). Other studies have reported that CS reduces antioxidant capacity in the lungs and increases MDA levels, causing lipid peroxidation in lung epithelial cells.

Previous studies have identified undesirable effects of drugs used in anti-cancer treatment on normal tissues. Therefore, many different agents with antioxidant properties have been used to prevent these negative effects (Azirak et al., 2019). In the study, MDA levels increased with the accumulation of CS-derived lipid peroxides, and antioxidant enzymes related to SOD, CAT and GSH were depleted. This situation shows the role of CS-derived oxidative stress in lung

toxicity. CS has been reported in different studies to increase MDA and decrease antioxidant parameters (GSH, SOD and CAT) in the lung (Geyikoğlu et al., 2017; Afsar et al., 2018; Mammadov et al., 2019). In this case, it may cause a decrease in the lungs' ability to cope with peroxides. In the study of Chen et al. (2020), it was found that MDA increased and SOD and GSH decreased in rats administered particulate matter (Tanbek et al., 2017). As a result of L application, it was observed that this situation approached normal values. In addition, these results appear to be compatible with the results obtained from our study (Chen et al., 2020). On the other hand, in our study, the application of L together with CS caused a decrease in the MDA parameter as a result of the increase in antioxidant capacity in rats. This result demonstrates the protection of L against CS-induced lung toxicity. In this case, it can be said that the oxidative stress-increasing effects of CS are prevented through the antioxidant properties of L. In this case, it is understood that L protects the lung from the toxic effects of oxidative stress (Bilgic et al., 2016; Bilgic et al., 2021).

5. Conclusion

As a result, in the current study, It was determined that L removes harmful radicals and activates the antioxidant system with its antioxidant effect. According to the data in the study; It was observed that the undesirable effects of CS on lung tissues could be reduced with the combination of CS + L. Therefore, it can be recommended to apply these two drugs together in order to continue cancer treatment effectively and without interruption.

Declaration of Author Contributions

All authors declare that they have contributed equally to this manuscript, have reviewed the final version, and have approved it for publication.

Declaration of Conflicts of Interest

The authors declare that there is no conflict of interest regarding this study.

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Foods Containing Vitamin C and Their Health Benefits

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Abstract: Vitamin C (VC) is a water-soluble vitamin essential for human health. Since humans lack the ability to synthesize VC endogenously, it must be obtained through dietary intake. Absorption primarily occurs in the small intestine. When administered at pharmacological doses, VC has been shown to alleviate oxidative stress and inflammation, thereby contributing to the restoration of endothelial and organ function. In cases of deficiency, a potentially fatal disease called scurvy can develop, which is characterized by impaired collagen synthesis. This condition is effectively treated only through VC supplementation. This study focuses on the antioxidant properties of VC and its roles in immune function, as well as its effects on common colds, sepsis, and organ damage. Additionally, the health benefits of VC-rich vegetables and fruits particularly rose hips, citrus fruits, parsley, and tomatoes are highlighted.

1. Introductıon

Vitamin C (VC), also known as L-ascorbic acid or ascorbate, is a water-soluble vitamin (Travica et al., 2017). It is synthesized from glucose in many living organisms. In mammals, this biosynthesis occurs in the liver, while in reptiles, it takes place in the kidneys. However, in humans, the gene responsible for encoding the enzyme L-gulono-γ-lactone oxidase, which is involved in the final step of VC biosynthesis, has lost its functionality (Kaplan and Gönül, 2010). Consequently, humans are unable to synthesize VC and must obtain it through dietary intake. VC is absorbed in the gastrointestinal tract through a saturable transport mechanism. At a dosage of 1 gram, the absorption rate is approximately 75%; however, bioavailability decreases inversely at higher doses. After absorption, VC is widely distributed throughout the body, including within intracellular compartments. The typical plasma concentration is around 1 mg/dL, with significantly higher concentrations found in platelets and leukocytes compared to plasma. When administered at daily doses of 75 mg or more, VC saturates body tissues (Akıcı et al., 2012). Excess VC is filtered through the glomeruli of the kidneys, and any amount that exceeds the reabsorption threshold is excreted in the urine. VC is eliminated slowly, with a half-life of approximately 16 days. This slow elimination accounts for the delayed onset of scurvy symptoms in cases of deficiency. A portion of VC is converted to oxalic acid in the liver, contributing to urinary oxalate levels. Additionally, VC is partially metabolized through sulfation (Akıcı et al., 2012).

VC as an Antioxidant; VC is recognized as the most important antioxidant in extracellular fluids, where it plays a critical role in protecting tissues from oxidative damage. In addition to its extracellular activity, VC also exhibits intracellular antioxidant functions. Its antioxidant

effect is primarily achieved through its ability to bind strongly to reactive oxygen species (ROS)—such as hydrogen peroxide, singlet oxygen, hydroxyl radicals, and superoxide anions—effectively neutralizing these harmful free radicals. By doing so, VC contributes to maintaining cellular integrity and preventing oxidative stress-related cellular dysfunction (Aktaş and Armağan, 2019; Aktaş al., 2020; Aktas and Bayram, 2020; Aktas and Ozgocmen, 2020; Aktaş and Sevimli, 2020; Aktas and Gur, 2021).

2. Vitamin C and Immune Function

The immune system is composed of specialized organs, tissues, cells, proteins, and signaling molecules that collectively function to protect the host from pathogens such as bacteria, viruses, parasites, and fungi. Given the limited storage capacity of VC in the human body, regular and sufficient dietary intake is essential to prevent hypovitaminosis (Carr and Maggini, 2017; Aktaş and Satılmış, 2025).

A daily intake of 100–200 mg of VC is considered sufficient to saturate plasma concentrations and has been associated with a reduced risk of chronic diseases. During disease states, VC contributes to immune defense through several mechanisms:

- Enhancing chemotaxis and supporting lymphocyte proliferation
- Promoting bactericidal activity of leukocytes
- Exhibiting bacteriostatic effects by inhibiting bacterial replication
- Reducing lipopolysaccharide-induced lung injury in sepsis
- Preventing apoptosis of endothelial progenitor cells, thereby maintaining vascular health and immune surveillance

In conditions of VC deficiency, natural killer cell-mediated cytotoxicity is delayed, primarily due to suppressed cytotoxic T cell activity, which impairs effective bacterial clearance. These findings highlight the critical role of VC in both innate and adaptive immunity, and its importance in supporting host defense, especially during infection and inflammation (Teng et al., 2018).

3. The Health Importance and Sources of Vitamin C

In experimental models of trauma, ischemia-reperfusion injury, and sepsis, VC administered at pharmacological doses has been shown to restore endothelial and organ function by alleviating oxidative stress and inflammation (Spoelstra-de Man et al., 2018). In cases of deficiency, scurvy, a potentially fatal condition characterized by impaired collagen synthesis and connective tissue damage, develops. Notably, scurvy can be fully reversed with VC supplementation alone (Padayatty and Levine, 2016). VC is naturally found in a variety of plant-based foods, including: Tomatoes, citrus fruits (oranges and lemons), green leafy vegetables, various fruits, mMilk (in smaller amounts). However, it is important to note that pasteurization significantly reduces the VC content in milk due to its heat sensitivity. For example, orange and lemon juices contain approximately 0.5 mg of VC per milliliter (Kaya et al., 2013). This study highlights the importance of VC for human health, its therapeutic effects in various diseases, and identifies key fruits and vegetables that serve as rich dietary sources of this essential nutrient.

4. Vitamin C and Diseases

During periods of infection and physiological stress, the concentration of VC in the body rapidly declines due to increased metabolic demand. Supplementation under these conditions has been shown to enhance immune system function and increase resistance to infections (Ran et al., 2018).

In the context of bacterial infections, VC contributes to the immune response by:

- Enhancing chemotactic activity of immune cells
- Supporting lymphocyte proliferation, which strengthens adaptive immunity
- Assisting leukocytes (especially neutrophils) in the phagocytosis and destruction of bacteria

Furthermore, VC exhibits bacteriostatic activity by inhibiting bacterial replication, which limits the spread and severity of infection. These effects collectively underscore the critical role of VC in host defense, particularly during infectious disease processes (Teng et al., 2018).

4.1. Vitamin C in common cold, covid-19, and wound healing

The common cold is primarily characterized by symptoms such as nasal congestion, fever, sore throat, cough, and fatigue. Clinical studies have shown that the incidence and duration of colds can be reduced with VC supplementation. Specifically, the administration of 1 g/day of VC to school-aged children significantly decreased the frequency and duration of cold episodes (Hemilä, 2017). In the context of COVID-19, which can lead to acute respiratory distress syndrome (ARDS), the disease mechanism involves free radical formation, cellular damage, and ultimately multi-organ failure and death (Carr, 2020). In such cases, high-dose intravenous VC has been found to exert protective effects, particularly in sepsis-induced ARDS. It does so by:

- Strengthening the alveolar epithelial barrier
- Supporting protein channels that regulate alveolar fluid clearance, thereby improving pulmonary function (Kakodkar et al., 2020)

For general health maintenance and chronic disease prevention, a daily dietary intake of 100–200 mg of VC is recommended. Since VC is water-soluble and has limited storage capacity in the body, regular and adequate consumption is essential to avoid hypovitaminosis (Carr and Maggini, 2017). VC also plays a vital role in wound healing by stimulating collagen synthesis, an essential process in tissue repair. To accelerate healing in such cases, daily doses of 500 mg to 1.0 g of VC are recommended (Naidu, 2003).

4.2. Obesity and the role of vitamin C

Obesity is defined as an excess accumulation of adipose tissue in the body. In adults, the normal fat mass is approximately 15–18% in men and 20–25% in women. When this percentage exceeds 25% in men and 35% in women, the condition is classified as obesity (Gülcan and Özkan, 2006). Obesity typically results from excessive energy intake combined with insufficient energy expenditure, leading to an increase in white adipose tissue. The expansion of white adipocytes is often accompanied by elevated oxidative stress, which plays a key role in the development of metabolic syndrome complications (Garcia-Diaz et al., 2014). This condition is a major risk factor for chronic diseases, including type 2 diabetes**,** cancer, and cardiovascular diseases (CVDs) (Ellulu, 2017). VC, through its antioxidant properties, can modulate several pathophysiological mechanisms associated with obesity. Its beneficial effects include:

- Scavenging of ROS generated during free fatty acid oxidation
- Regulating nitric oxide synthesis
- Inhibiting excessive ROS production
- Enhancing the activity of antioxidant enzymes

These mechanisms contribute to the protective effects of VC against oxidative damage, inflammation, and metabolic disturbances commonly observed in obesity. Therefore, maintaining sufficient VC levels may play a supportive role in obesity management and the prevention of its associated comorbidities (Ellulu, 2017).

4.3. Cardiovascular diseases and the role of vitamin C

CVDs encompass a range of conditions, including coronary heart disease, cerebrovascular disease, and rheumatic heart disease. It is estimated that four out of every five CVD-related deaths are caused by heart attacks and strokes. The primary underlying mechanism of CVD is atherosclerosis**,** a condition characterized by the narrowing and hardening of arteries due to the accumulation of atheromatous plaques. These plaques can eventually lead to partial or complete arterial blockage caused by blood clots**,** which restrict blood and oxygen flow to tissues. This ischemia may result in tissue damage or organ failure.

- Major risk factors for atherosclerosis include: Aging-related arterial stiffness
- Smoking
- Hyperglycemia and hyperlipidemia
- Obesity
- Hypertension

In the development of atherosclerosis, macrophages absorb low-density lipoprotein (LDL) cholesterol and convert it into foam cells, which contribute to vascular blockage. VC helps prevent CVD by inhibiting LDL oxidation, thereby slowing down the formation of foam cells (Al-Khudairy et al., 2017). Furthermore, in the early stages of atherosclerosis, monocytes adhere to the endothelial wall, leading to thickening and reduced elasticity of the vascular lining. VC intake has been shown to decrease monocyte adhesion, thereby helping preserve vascular integrity (Al-Khudairy et al., 2017).

VC also contributes to cardiovascular health through additional mechanisms:

- Stimulating type IV collagen production in the vascular basement membrane
- Promoting endothelial cell proliferation
- Preserving nitric oxide (NO) bioavailability in endothelial cells
- Preventing endothelial apoptosis
- Scavenging ROS, thus reducing oxidative stress

Collectively, these effects highlight VC 's protective role in cardiovascular health and its potential as a supportive nutrient in the prevention and management of CVD (Al-Khudairy et al., 2017).

4.4. Cancer and the role of vitamin C

Cancer is a complex disease characterized by uncontrolled cell proliferation, and it arises from the interaction of both genetic predispositions and environmental influences (Uçak and Kızıltan, 2021). In many individuals with advanced-stage cancer**,** VC deficiency is frequently observed. This deficiency may be attributed to multiple factors, including:

- Inadequate dietary intake of VC-rich foods
- Reduced gastrointestinal absorption or bioavailability
- Increased metabolic consumption of VC due to disease burden

- Elevated oxidative stress levels in cancer-affected tissues (Chen et al., 2015)

VC exhibits several well-documented anti-cancer mechanisms, such as:

- Protecting against DNA and molecular damage
- Modulating gene expression
- Inducing apoptosis in malignant cells via regulation of cellular signaling pathways
- Inhibiting abnormal cell proliferation and metastasis (Schlueter et al., 2011)

In addition to its direct effects on tumor biology, VC may improve the quality of life in cancer patients. Clinical studies have reported that VC supplementation can alleviate common symptoms associated with both cancer and chemotherapy, including: Fatigue, insomnia, loss of appetite, nausea, pain (Carr et al., 2014). These findings underscore VC's potential as a complementary agent in cancer management—both in slowing disease progression and in symptom relief, thereby improving patient well-being and treatment outcomes**.**

4.5. Diabetes mellitus

Diabetes mellitus is a metabolic disorder characterized by impaired insulin secretion from the β-cells of the pancreatic islets of Langerhans and hyperglycemia resulting from decreased sensitivity to insulin. The underlying mechanisms include defects in insulin action in peripheral tissues, insufficient insulin secretion, or a reduced cellular response to insulin (Aktaş and Gür, 2021b). Over time, chronic hyperglycemia can lead to severe complications, including damage to blood vessels, the heart, kidneys, eyes, and nervous system (Franke et al., 2013). VC supplementation has been shown to mitigate glucose-induced oxidative stress (glucotoxicity) and may help preserve pancreatic β-cell function (Dakhale et al., 2011). Moreover, a diet rich in VC-containing fruits and vegetables is considered beneficial for diabetes prevention and overall metabolic health (Christie-David and Gunton, 2017).

4.6. Eye diseases

VC plays a vital role in maintaining the structural integrity of blood vessels and connective tissues within the eye. Due to the high metabolic activity in ocular tissues, the eye is particularly vulnerable to oxidative stress. VC acts as a powerful antioxidant by neutralizing free radicals and preventing oxidative damage (McCusker et al., 2016). As a result, adequate VC intake has been associated with a reduced risk of developing advanced cataracts, age-related macular degeneration, and glaucoma (Raman et al., 2017).

4.7. Neurodegenerative diseases and psychiatric disorders

VC plays a crucial role in the body's response to stress and is found in high concentrations in the adrenal cortex. Its levels fluctuate according to adrenal activity, with stimulation by adrenocorticotropic hormone and increased steroidogenesis leading to a reduction in VC content (Akıcı et al., 2012). During periods of stress and infection, VC contributes to hormonal regulation, supporting the body's stress response. Oxidative stress is a significant contributing factor to the development of cognitive impairments such as memory loss, impaired reasoning, and decreased problem-solving ability, particularly in older adults. The brain is highly susceptible to oxidative stress due to its high oxygen consumption and abundance of oxidation-prone polyunsaturated fatty acids. As a potent antioxidant, VC is considered an essential neuroprotective molecule (Tardy et al., 2020).

VC influences several components of the nervous system, including neurotransmitter receptors, glial cells, myelin synthesis, and the processes of neuronal maturation and differentiation (Ballaz et al., 2019). The brain's neuroendocrine tissues contain the highest concentrations of VC in the body. In neurological disorders—often marked by excessive free

radical production—VC has shown therapeutic potential by modulating oxidative damage and preserving neuronal function (Kocot et al., 2017).

Moreover, VC has been found to reduce the accumulation of amyloid-beta, enhance the differentiation of neural stem cells into dopaminergic neurons, and protect neurons against glutamate-induced excitotoxicity, thereby slowing the progression of neurodegenerative conditions such as Parkinson's disease and dementia (Uğur et al., 2020). In multiple sclerosis, characterized by damage to the myelin sheath of neurons, VC supports collagen synthesis, a process linked to myelination, and may thus contribute to slowing disease progression (Eldridge et al., 1987). VC deficiency is also associated with psychological disturbances, including depression, melancholy, and mood disorders. These effects may be related to impaired dopamine synthesis, oxidative stress, disrupted neurotransmitter activity, and altered cortisol regulation (De Oliveira et al., 2015).

4.8. Bone diseases

VC is essential for the development and maintenance of tissues of mesenchymal origin, including bone, connective tissue, dentin, and cartilage. It plays a crucial role in collagen synthesis, particularly type I collagen, which is the primary structural component of the extracellular matrix in bone. VC also contributes to the structural integrity of capillaries by facilitating the interconnection of endothelial cells and the formation of the pericapillary matrix. Moreover, VC stimulates both collagen production and the differentiation of osteoblasts—the cells responsible for bone formation. Through its antioxidant properties, VC helps to neutralize free radicals, thereby reducing oxidative stress that contributes to bone resorption and the progression of osteoporosis (Malmir et al., 2018). In addition to its structural and antioxidant roles, VC is necessary for the activity of two dioxygenase enzymes involved in carnitine biosynthesis, which is critical for energy production through mitochondrial β-oxidation. Inadequate VC intake can impair carnitine metabolism, potentially leading to fatigue and musculoskeletal pain due to compromised energy delivery to muscle tissue attached to bones (Johnston, 2012).

4.9. Skin diseases

When applied topically, VC plays a protective and therapeutic role in skin health by neutralizing ROS generated from environmental factors such as ultraviolet (UV) radiation, cigarette smoke, and air pollution. This antioxidant activity aids in the repair of oxidative damage and supports skin regeneration. VC is also effective in the treatment of hyperpigmentation disorders, including melasma and sunspots. This effect is attributed to its ability to inhibit the enzyme tyrosinase, a key regulator in the melanogenesis pathway, thereby reducing melanin synthesis (Caritá et al., 2020). In addition to its anti-pigmentation properties, VC contributes to skin resilience by stimulating collagen synthesis, which improves skin elasticity and reduces the appearance of photoaging (Pullar et al., 2017). VC deficiency can lead to delayed wound healing, which is associated with impaired collagen production. It also results in epidermal thickening and subcutaneous hemorrhage due to weakened connective tissue structure (Ellinger et al., 2009). Prolonged exposure of the skin to UV radiation leads to inflammation, pigmentation changes, structural degradation, and, in severe cases, the development of skin cancer. VC provides a protective barrier against such damage, making it an essential nutrient for maintaining skin integrity and preventing photoinduced dermal disorders (Blume-Peytavi et al., 2016).

4.10. Reproductive system diseases

The testes are particularly sensitive to fluctuations in VC levels. Adequate VC intake has been shown to significantly enhance male reproductive health by improving sperm quality.

Specifically, increased VC levels contribute to greater sperm viability, enhanced motility, and a higher total count of mature sperm. In contrast, VC deficiency is associated with increased sperm abnormalities and agglutination (stickiness), which can impair fertility. These findings highlight the importance of VC as an antioxidant that protects spermatozoa from oxidative stress and supports overall reproductive function (Millar, 1992).

4.11. Scurvy

Scurvy is a clinical condition resulting from a prolonged deficiency of VC in the diet. The primary pathological mechanism is impaired collagen synthesis and accelerated degradation of tissues of mesenchymal origin. This leads to increased capillary fragility, resulting in ecchymosis, petechiae, intra-tissue hemorrhages, and delayed wound healing. Clinically, scurvy manifests with symptoms such as gingival inflammation and bleeding, loosening and loss of teeth, perifollicular hyperkeratosis of the skin, impaired bone calcification, epiphyseal swelling, periosteal hemorrhages, and an increased susceptibility to bone fractures. In children, VC deficiency may also cause growth retardation, increased bone resorption, and bleeding into muscles and joints. Additionally, macrocytic anemia may occur due to impaired iron absorption and metabolism. If left untreated, scurvy can progress to severe complications including convulsions, coma, and death. Lobular pneumonia is the most frequently encountered complication, and the primary cause of death is often secondary bronchopneumonia. The minimum daily requirement of VC to prevent the onset of scurvy is approximately 10 mg (Carr and Maggini, 2017).

4.12. Anemia

Anemia is a common manifestation of VC deficiency. In conditions such as scurvy, increased excretion of oxidized folate derivatives contributes to folate deficiency, while capillary fragility leads to recurrent microhemorrhages and hemolysis, further exacerbating the anemic state. VC plays a key role in hematopoiesis through its involvement in the reduction of dietary folic acid to its active form, tetrahydrofolic acid. Additionally, it enhances the absorption of non-heme iron by reducing ferric iron (Fe^{3+}) to the more bioavailable ferrous form (Fe^{2+}) in the acidic environment of the stomach. Through these mechanisms, VC facilitates the uptake of both folic acid and non-heme iron into the bloodstream, thereby helping to prevent and correct anemia associated with its deficiency (Tardy et al., 2020; Uğur et al., 2020).

Table 1. Recommended vitamin C to be taken daily.

Men women stages	**Required daily intake (mg)**
0/6 months	40 mg
Children 7/12 months	50 mg
Children 1/3 years old	15 mg
Children 4/8 years old	25 mg
Children 9/13 years old	45 mg
14/18 years old women	65 mg
14 - 18 years old men	75 mg
Women 19 years and over	75 mg
Men 19 years and over	90 mg
Pregnant women	80/85 mg
Pacifiers	115/120 mg

(Onganer et al., 2020)

5. Foods Containing Vitamin C

5.1. Dietary sources and stability of vitamin C

VC is most abundant in a variety of fruits and vegetables, particularly citrus fruits such as orange, grapefruit, and lemon. It is also richly present in green leafy vegetables including lettuce, spinach, and parsley**,** as well as in tomatoes, rose hips, green peppers, cabbage, broccoli,

strawberries, grapes, melons, blackberries, bananas, watermelons**,** and new (young) potatoes**.** For example, freshly squeezed orange juice contains approximately 0.5 mg of VC per milliliter. However, packaged orange nectars are typically diluted and contain significantly lower concentrations of VC.

The stability of VC is influenced by several environmental and processing factors:

- Acidic environments enhance the stability and preservation of VC.
- Exposure to heat, oxygen, and light**,** as well as chopping or long storage of fresh plant-based foods**,** leads to significant degradation of VC content.
- Interestingly, canned vegetables, when properly processed and stored, retain a substantial portion of their original VC content (Akıcı et al., 2012).

Examples of VC -rich fruits include: Black currant, orange, kiwi, papaya, strawberry, lemon, pineapple, grapefruit, mango, pea.

VC -rich vegetables include: Tomato, green and red bell pepper, cauliflower, broccoli, brussels sprouts, parsley (Anonymous, 2021a). These foods are essential components of a VC-rich diet and contribute significantly to maintaining antioxidant defenses and overall health.

Table 2. Average amount of vitamin C in foods (Onganer et al., 2020).

Foods	**Amount of VC in foods (mg)**
1 (piece) medium-sized kiwi	70 mg
1 large slice of melon	59 mg
1/2 cup cooked brussels sprouts	48 mg
1 medium sized orange	90 mg
1 glass of orange juice	97 mg
1 glass of tomato juice	33 mg
1/2 serving red pepper, raw	95 mg
1 serving of cooked broccoli	74 mg
1/2 serving of strawberries	49 mg
1/2 serving of green pepper	60 mg
1/2 serving of red cabbage	40 mg

5.2. Rosehip (Rosa spp.) and its nutritional properties

Rosehip is the fruit of plants belonging to the *Rosa* genus, within the Rosaceae family. It has long been utilized for both nutritional and medicinal purposes due to its rich content of bioactive compounds**.** Rosehip exhibits potent antioxidant and antimicrobial properties. These biological activities are primarily attributed to its high levels of: Polyphenols, vitamin C, Vitamin E, Vitamin B complex.

In addition to its antioxidant capacity, rosehip also demonstrates anti-inflammatory, anti-diabetic, and anticancer effects (Mármol et al., 2017). Its fruit is a notable source of lycopene and a significant concentration of VC, which contributes to its therapeutic potential. Rosehip products, such as marmalade or nectar, are particularly valuable from a nutritional standpoint. They are capable of meeting the entire daily VC requirement, while also supplying a substantial portion of the daily needs for various minerals and other vitamins. Therefore, rosehip can be considered a functional food with broad applications in health promotion and disease prevention (Öz et al., 2018; Aktaş et al., 2024).

5.3. Citrus fruits: nutritional composition and health benefits

Citrus fruits, members of the Rutaceae family, are cultivated extensively in tropical and subtropical regions. Among them, the sweet orange (*Citrus sinensis*) represents approximately 70% of total global citrus production and consumption. Other widely cultivated and consumed

citrus varieties include: Tangerine (*Citrus reticulata*), grapefruit (*Citrus vitis*), lime (*Citrus aurantifolia*), lemon (*Citruslimonum*) (Sharma et al., 2017). Citrus fruits are particularly noted for their high VC content, which constitutes about 51% of their total vitamin composition. In addition to VC, citrus fruits are rich in carotenoids, such as: β-cryptoxanthin (68% of total carotenoids), zeaxanthin (43%). Citrus fruits and their juices are excellent sources of bioactive compounds, including: Flavonoids, carotenoids, limonoids, coumarin-related compounds, folates, essential oils, pectins.

Among citrus juices, VC is the key contributor to their antioxidant capacity. Antioxidant contribution rates of VC in various citrus juices are as follows: Grapefruit juice: 8.60%, orange juice: 8.16%, lemon juice: 6.15%.

These findings emphasize the nutritional and therapeutic value of citrus fruits, not only as a major source of VC but also as carriers of a wide range of bioactive compounds with antioxidant, anti-inflammatory, and immune-supporting properties (Martí et al., 2009).

5.4. Parsley (*Petroselinum crispum*)

Parsley is a vascular green plant species belonging to the Apiaceae family. Its fruit contains a flavonoid glycoside known as apiin, as well as a volatile essential oil. The root of parsley also contains essential oil, apiin, and mucilage, contributing to its traditional medicinal uses (Anonymous, 2021b). Due to its rich antioxidant content, parsley exhibits tumor-preventive properties. Additionally, it has been used to relieve symptoms of: Indigestion, gallstones, constipation, kidney Stones, edema.

However, because parsley has the potential to stimulate uterine contractions and increase bleeding, its consumption should be limited during pregnancy due to the risk of miscarriage (Anonymous, 2021b).

5.5. Tomato (*Solanum lycopersicum*)

Tomato is a member of the Solanaceae (nightshade) family and is widely recognized for its nutritional density and health-promoting properties (Anonymous, 2021c). Tomatoes are rich in VC, lycopene, beta-carotene, and various polyphenolic compounds that contribute to their antioxidant and anti-inflammatory effects. Reported health benefits include:

- Strengthening the immune system
- Reducing asthma symptoms
- Acting as a hematopoietic (blood builder) agent
- Lowering LDL ("bad") cholesterol
- Protecting against cardiovascular diseases
- Preventing certain cancers
- Reducing the risk of cataract development
- Improving oral health by preventing tooth decay and tartar accumulation
- Providing a cooling and thirst-quenching effect

Given their broad spectrum of bioactive components, tomatoes serve as a functional food in the prevention and management of various chronic diseases (Anonymous, 2021d).

6. Discussion

Numerous studies have demonstrated the protective and therapeutic effects of VC in a range of diseases, particularly infections and metabolic disorders. In a notable study conducted

at a boarding school, VC supplementation was associated with a 45–91% reduction in the incidence of the common cold and an 80–100% reduction in pneumonia cases (Hemilä, 2004). During respiratory tract infections, plasma leukocyte levels and urinary VC concentrations decrease, suggesting increased metabolic utilization. This decline is believed to stimulate the activity of VC-dependent phagocytes, thereby neutralizing oxidative damage caused by infection (Hemilä, 2003).

In another clinical study involving 50 patients with moderate to severe COVID-19, the administration of 10 to 20 g/day intravenous VC over 8–10 hours resulted in significant clinical improvement, suggesting its potential as a supportive therapy in viral pneumonia and ARDS) (Cheng, 2020). Beyond its immune-modulating properties, VC has been studied for its role in obesity and metabolic regulation. In an experimental study on obese rats, VC administration led to increased levels of:

- Glutathione in brown adipose tissue
- Superoxide dismutase activity in liver cells
- Catalase enzyme activity in blood cells

These results suggest that VC may protect against obesity by enhancing antioxidant enzyme activity, thereby reducing oxidative stress associated with adipose tissue expansion (Drehmer et al., 2019). Furthermore, in guinea pigs, VC supplementation resulted in body weight reduction, while in rats, direct injection of VC into adipose tissue significantly decreased the number of adipocytes. Supporting these findings, a long-term observational study reported that diets rich in VC prevented weight gain and abdominal fat accumulation in obese individuals over a three-year follow-up period (Garcia-Diaz, 2014). Taken together, these findings highlight the multifaceted benefits of VC in both infectious and metabolic diseases, reinforcing its value as a therapeutic and preventive agent in clinical nutrition and public health.

The cardiovascular benefits of VC have been well-documented in both clinical and observational studies. For instance, Sadeghpour et al. (2015) administered a 2 g bolus of VC to 290 patients following cardiac surgery and observed a significant reduction in the length of hospital stay, highlighting VC's role in postoperative recovery. Similarly, another study found that individuals who consumed 400 mg/day of VC experienced a 25% lower incidence of coronary heart disease compared to non-supplement users. These findings suggest that cardioprotective effects of VC become more pronounced with intakes exceeding 400 mg/day (Schlueter and Johnston, 2011). Further evidence supports that even moderate daily intake of 100 mg of VC can lead to a reduction in cardiovascular mortality (Naidu, 2003). These results underscore the preventive potential of VC in managing cardiovascular disease risk.

VC has also been linked to gastrointestinal and cancer prevention mechanisms. Correa (1992) reported that VC concentrations in gastric juice were significantly higher than in plasma, and that VC inhibited the formation of mutagenic N-nitroso compounds, which are known contributors to gastric carcinogenesis. Epidemiological studies have further associated high dietary VC intake with a reduced risk of cancers in various organs, including the: Oral cavity, esophagus, colon, lung (Paoletti, 1998).

Moreover, Naidu (2003) reported that a daily intake of 100 mg of VC significantly lowered cancer-related mortality, affirming the potential of VC as an adjunctive nutrient in cancer prevention and patient survival. Collectively, these findings provide robust support for the therapeutic and preventive value of VC across multiple disease domains, particularly in cardiovascular health and oncological outcomes.

Emerging evidence from both animal and clinical studies supports the role of VC in glucose metabolism and diabetes management. In an experimental model, oral VC supplementation improved insulin sensitivity in hyperglycemic ob/ob mice, although no change in body weight was observed (Garcia-Diaz, 2014). Complementary findings in humans suggest that high-dose VC supplementation—beginning with 1 g/day for 4 weeks, followed by a week off, and then 3 g/day for another 4 weeks—contributed to improved glycemic control in diabetic patients (Park and Lee, 2003).

Further epidemiological evidence by Zhou et al. (2016) indicated that individuals with VC intake exceeding 140 mg/day had a reduced risk (<5%) of developing diabetes, likely due to the amelioration of insulin resistance. These findings support the view that VC supplementation may play an adjunctive role in the prevention and management of type 2 diabetes. VC also exhibits significant benefits in ocular health, particularly in preventing age-related eye diseases. According to Robertson et al. (1989), a daily intake exceeding 300 mg of VC reduced the risk of cataract formation by 70%. Supporting this, Jacques et al. (1991) reported that individuals consuming more than 490 mg of VC per day had a 75% lower risk of developing cataracts compared to those consuming less than 125 mg/day.

In the context of age-related macular degeneration (AMD), Aoki et al. (2016) found a significant association between higher VC intake and reduced AMD risk, suggesting a protective effect of VC on retinal health and visual function. Together, these findings reinforce the broad therapeutic potential of VC, not only in metabolic diseases such as diabetes, but also in the prevention of degenerative ocular conditions, underlining its value in long-term dietary strategies and preventive medicine. Beyond its known antioxidant and metabolic effects, VC also plays a crucial role in neurological protection and bone health. In an experimental study conducted on rats exposed to neurotoxic substances, VC administration significantly improved memory impairments and reversed neuropathological and neurodegenerative changes. These neuroprotective effects are attributed to VC's capacity to neutralize superoxide radicals, thereby mitigating oxidative neuronal damage (Olajide et al., 2017). VC has also been implicated in bone metabolism and osteoporosis prevention. Epidemiological data indicate that VC deficiency is associated with reduced bone formation, leading to an increased risk of osteoporosis and bone fractures (Aghajanian et al., 2015). In a long-term prospective cohort study with a 17-year follow-up, Sahni et al. (2009) found that individuals with higher dietary intake of VC experienced significantly fewer hip fractures and non-vertebral osteoporotic fractures compared to those with lower intake.

These findings highlight the multifunctional role of VC, not only in supporting immune, metabolic, and cardiovascular health, but also in protecting neural function and maintaining skeletal integrity, particularly in aging populations. VC also exhibits dermatological and protective cellular effects through its potent antioxidant properties. For instance, Darr et al. (1992) demonstrated that VC reduces oxidative damage induced by UV radiation, highlighting its photoprotective capacity. In skin-related metabolic disorders such as Porphyria Cutanea Tarda, VC has been shown to reduce hepatic accumulation of urinary porphyrins, support keratinocyte differentiation, and maintain skin barrier integrity. These effects extend to inflammatory skin diseases, including atopic dermatitis, where VC contributes to skin protection and regeneration (Wang et al., 2018).

Sarı Kılıçaslan et al. (2009) evaluated the effects of VC on diabetic dermal complications, including dermal thickening, elastic fiber aggregation, and fibroblast degeneration. VC treatment was found to significantly ameliorate these pathological changes, with outcomes approaching those observed in healthy control groups. VC’s protective role also extends to the reproductive system. In a study conducted by Artıran et al. (2017), VC was found to alleviate

testicular damage induced by gentamicin administration in rats. Gentamicin caused extensive degeneration in spermatogenic cells, thickening of the basal lamina, tubular atrophy, interstitial expansion, and vascular congestion. VC treatment significantly mitigated these histopathological effects, supporting its use as a protective agent against drug-induced reproductive toxicity. These findings collectively emphasize the broad cytoprotective roles of VC, ranging from skin health and detoxification to reproductive tissue preservation, and strengthen its position as a versatile therapeutic micronutrient in various systemic conditions.

Citrus fruit consumption remains one of the most effective preventive strategies against scurvy, a disease resulting from prolonged VC deficiency (Granger and Eck, 2018). Oral supplementation with 100–300 mg/day of VC has been shown to replenish serum VC levels and restore tissue stores. Clinical manifestations such as gingival lesions begin to resolve within 2 to 4 days of initiating VC therapy, with complete healing typically achieved within 2 to 3 weeks (Popovich et al., 2009). In the context of physical exertion and athletic performance, Koçyiğit et al. (2011) found that iron (Fe^{2+}) losses through sweat increased with exercise intensity. This loss was significantly minimized when VC intake exceeded the standard daily requirement, supporting its role in iron absorption and conservation, particularly in physically active populations.

7. Conclusion

VC plays a fundamental role in the structural and physiological functions of the human body. Through its diverse mechanisms—most notably its antioxidant, anti-inflammatory, immune-modulating, and tissue-protective effects— VC contributes to the prevention and treatment of various acute and chronic conditions. The requirement for VC may increase under certain conditions, including: Environmental pollution, smoking, pregnancy and lactation, infections, chronic diseases.

Given these factors, healthcare professionals are increasingly advocating for targeted VC supplementation as a preventive and therapeutic strategy. When administered appropriately, VC supports immune competence, helps combat oxidative stress, and contributes to the maintenance of systemic health. Future research and public health policies should further address optimal dosing strategies, bioavailability, and clinical outcomes associated with VC to ensure its effective use in preventive medicine and therapeutic interventions.

Declaration of Author Contributions

All authors declare that they have contributed equally to this manuscript, have reviewed the final version, and have approved it for publication.

Declaration of Conflicts of Interest

The authors declare that there is no conflict of interest regarding this study.

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Determination of Muscimol Alpha Amanitin and Metal Ions in Some Poisonous Mushrooms

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Muscimol,
Alpha Amanitin

Abstract: Mushrooms are an important nutritional source due to their richness in proteins, carbohydrates, fatty acids, vitamins, and minerals. They offer numerous health benefits, including blood pressure regulation, antitumor activity, immune system enhancement, cholesterol control, antioxidant properties, and the regulation of heart rhythm. However, cases resulting in severe bodily harm and even death have been reported due to the consumption of wild mushrooms by individuals lacking expertise in mushroom identification and relying on hearsay or inaccurate information. Even low doses of certain mushroom toxins can lead to poisoning. Given that the levels of compounds such as muscimol, alpha-amanitin, and various metals vary depending on the mushroom species and their growing environment, this study was conducted. Used for centuries as poisons, medicines, and food, mushrooms are now recognized as an indispensable source of protein. In addition to mushroom toxins, heavy metals present in mushrooms can damage various organs, lead to more severe health outcomes, and accelerate death. In this study, a quantitative analysis of different toxins and the metal content in various mushroom species was carried out. For this purpose, both edible and toxic mushroom species were analyzed, including Agaricus bisporus (J.E. Lange) Imbach, commonly consumed as a cultivated mushroom, and the toxic species Amanita phalloides (Vaill. Ex Fr.) Link, Amanita pantherina (DC.) Krombh., and Amanita muscaria (L.) Lam., collected from the provinces of Rize, Trabzon, and Düzce. The toxins alpha-amanitin in Amanita phalloides and muscimol in Amanita pantherina and Amanita muscaria were analyzed using High-Performance Liquid Chromatography (HPLC).The concentrations of elements Ag (ng/kg), Al (µg/kg), As (ng/kg), Ba (ng/kg), Ca (µg/kg), Cd (ng/kg), Co (ng/kg), Cr (ng/kg), Cu (ng/kg), Fe (µg/kg), K (µg/kg), Mg (µg/kg), Mn (ng/kg), Mo (ng/kg), Na (µg/kg), Ni (ng/kg), P (µg/kg), Pb (ng/kg), Sb (ng/kg), Sn (ng/kg), Sr (ng/kg), Ti (ng/kg), V (ng/kg), and Zn (ng/kg) in mushrooms were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), while Hg (µg/kg) was analyzed using graphite furnace Atomic Absorption Spectroscopy (AAS). Additionally, the elemental composition C, N, H, S, and O in terms of percentage was determined using an elemental analyzer. The binding forms of the metals were identified using X-ray Diffraction (XRD).

1. Introduction

Mushrooms, which have been used by humans as poisons, medicines, and nutritional substances, constitute one of the most important groups in the kingdom of living organisms. As they do not contain chloroplasts, they are not classified as plants; likewise, due to their lack of mobility, they are not considered animals. Instead, fungi are defined as a distinct kingdom separate from both plants and animals. Fungi are fundamentally divided into two groups:

microfungi and macrofungi. Macrofungi are further categorized into those that grow naturally in the wild and those that are cultivated. Wild-growing mushrooms are classified as either edible or poisonous. Poisonous mushrooms contain various toxic compounds such as ibotenic acid, muscimol, alpha-amanitin, beta-amanitin, gamma-amanitin, muscarine, and coprine, depending on the species. These toxins exert harmful effects on the nervous, respiratory, excretory, and gastrointestinal systems, varying by type. The latency period of these poisons also differs according to the species of the mushroom and the specific toxin involved. While the latency period can be as short as fifteen minutes in some species, it may extend up to one or two months in others. The amount of mushroom consumed and the individual's physiological resistance also play a critical role during the latency phase.

2. Materials and Methods

Among the mushroom species consumed as food, wild edible mushrooms are particularly rich in taste and aroma. Nevertheless, cultivated mushrooms are consumed more widely than wild mushrooms due to their scientific production processes, which ensure their non-toxic nature. Numerous studies have been conducted especially in East Asian countries on macrofungi used both as food and medicine, and the number of such studies continues to increase. Research on the medicinal properties of macrofungi encompasses a wide range of topics, including blood pressure regulation, antitumor activity, immune system enhancement, antimicrobial effects, cholesterol control, antibiotic properties, antioxidant activity, regulation of heart rhythm, antiulcer effects, influence on lipid metabolism, antidiabetic properties, anti-HIV activity, anti-obesity effects, protective functions on the liver and kidneys, antiviral effects, anti-aging properties, treatment of sexual hypofunction, and their impact on hematopoiesis (Erol, 2020).

The digestibility of mushroom protein ranges between 72% and 83%. In addition to essential amino acids required for human nutrition, mushrooms also contain all other amino acids. Although the fat content in mushrooms is very low, they include all types of fatty acids, including essential ones. Mushrooms are also an excellent source of folic acid, and diets containing mushrooms are used in the treatment of anemia caused by folic acid deficiency. Fresh mushrooms consist of approximately 92% water, while the remaining 8% is composed of protein, fat, carbohydrates, vitamins, calcium, phosphorus, potassium, iron, copper, fiber, and ash (Wang, 2023). Due to their significant mineral content, mushrooms may have beneficial effects for individuals with mineral deficiencies. Additionally, mushrooms are a source of thiamine (B1), riboflavin (B2), pantothenic acid (B5), nicotinic acid (B3, niacin), biotin (B7), ascorbic acid (C), and vitamin D (Assemie, 2022).

The macroelements found in the human body include calcium, phosphorus, potassium, sulfur, chlorine, sodium, and magnesium. Microelements consist of iron, manganese, cobalt, copper, zinc, molybdenum, vanadium, chromium, tin, fluorine, silicon, selenium, and iodine. Compared to microelements, macroelements are present in the body at higher concentrations. Among the trace elements found in living organisms, iron, manganese, cobalt, copper, zinc, molybdenum, vanadium, chromium, and tin are metals, whereas fluorine, silicon, selenium, and iodine are non-metals. Although these elements exist in relatively small amounts, they play crucial biological roles. Many of them are components of enzymes and are essential for vital physiological processes. Any imbalance either an increase or decrease in the levels of these elements in the human body can lead to serious health issues. Heavy metals exhibit increasing toxic effects on living organisms depending on their concentrations. In particular, cadmium (Cd), hexavalent chromium (Cr^{6+}), mercury (Hg), and lead (Pb) are not essential for biological systems and can exert toxic effects even at trace levels. The term "heavy metal" is used for metals with a density greater than 5 $g \cdot cm^{-3}$. This group includes over sixty metals such as

cadmium, chromium, lead, copper, iron, nickel, cobalt, mercury, molybdenum, tin, and zinc (Mood et al., 2021).

2.1. Researched fungi and the syndromes they cause amanita muscaria

The cap of *Amanita muscaria* ranges from 5 to 20 cm in diameter. Initially white in color, it develops red pigmentation as the partial veil disintegrates, leaving white remnants of the veil on the red surface. When young, the mushroom has a conical shape; as it matures, it becomes hemispherical, and in full maturity, it flattens. The cap surface is smooth and hairless, and its color can vary from red to orange. In immature specimens, the cap margin is inwardly curved, gradually flattening as the mushroom matures. The stipe (stem) ranges from 6 to 20 cm in length and is approximately 1 to 1.5 cm in diameter. *Amanita muscaria* is a gilled mushroom. The gills are initially white and transition to brownish hues with maturity. After the partial veil ruptures, a remnant known as the annulus remains on the upper part of the stipe. The spores are colorless, transparent, and measure approximately 9-11 µm in length and 6-9 µm in width. *Amanita muscaria* typically grows individually or in groups under both deciduous and evergreen trees, particularly pines and birches. It is especially fond of acidic soils. Fruiting bodies appear in late summer and autumn (Vendramin, 2014). In Türkiye, this species has been recorded in the Mediterranean region, the Eastern Black Sea part of the Black Sea region, and around Balıkesir, Bursa, Bolu, Düzce, and Istanbul. Red, Yellow Amanita muscaria, Amanita pantherina and Amanita phalloides are given in Figure 1.

Figure 1. Red, Yellow Amanita muscaria, Amanita pantherina and Amanita phalloides

2.2. Amanita pantherina

The cap diameter ranges between 5-10 cm. When young, the cap is hemispherical in shape; as it matures, it becomes convex and eventually flattens. In later stages of maturity, it may become depressed. The surface is shiny and sticky when moist, but turns matte when dry. It is light brown in color. Similar to *Amanita muscaria*, it bears white remnants of the partial veil on the cap. As the partial veil ruptures, an annulus, as seen in *Amanita pantherina*, forms on the upper part of the stipe. This species is lamellate, and the gills are white in color. The stipe is cylindrical, measuring 5-12 cm in height and 1-2 cm in width. When young, the stipe has a spongy texture, but it becomes grooved with age. The spores are colorless and elliptical, measuring 9-12 micrometers in length and 7-8 micrometers in width. Their walls are smooth. It is found singly or in groups under coniferous or deciduous trees during the summer and autumn months (Satora, 2006). This species has been observed in the Black Sea region, the Mediterranean region, and in the Bolu and Kaz Mountains.

Pantherina Syndrome is caused by Amanita muscaria and Amanita pantherina, with a latency period ranging from 30 minutes to 3 hours. This syndrome manifests with symptoms such as speech impairment, gastrointestinal cramps, visual and auditory disturbances, hallucinations, abdominal pain, vomiting, diarrhea, and deep sleep. As it belongs to the first group of mushroom poisoning classifications, fatal outcomes are rare in pantherina syndrome. However, death may occur in sensitive individuals, particularly children (Yardan et al., 2010).

Additionally, pantherina syndrome primarily affects the central nervous system. The toxic compounds responsible for this syndrome are ibotenic acid and muscimol. Given in Figure 2. Ibotenic acid (α-amino-3-hydroxy-5-isoxazoleacetic acid) undergoes decarboxylation to form muscimol (3-hydroxy-5-amino methylisoxazole). In the treatment of Pantherina syndrome, the specific antidote physostigmine is used. Additionally, symptomatic and supportive therapies are administered as auxiliary treatments.

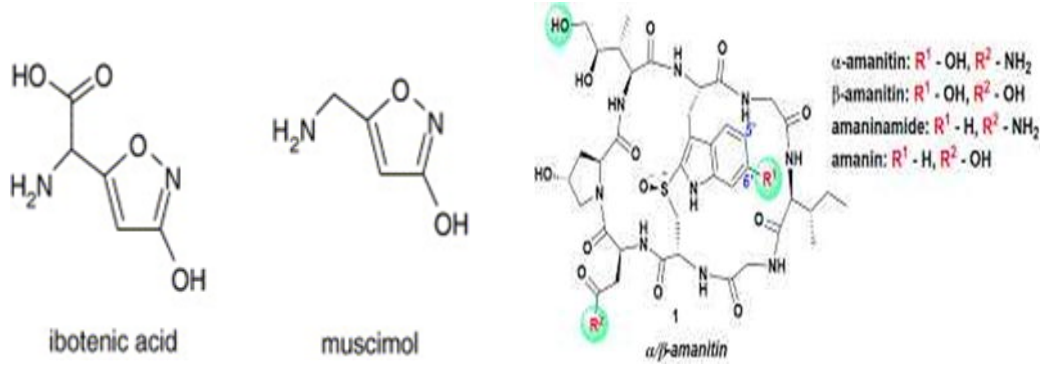

Figure 2. Molecular structure of Ibotenic acid, Muscimol and Chemical structure of α/β-amanitin and structure–activity relationships of natural and synthetic amatoxins with indole modifications

2.3. Amanita phalloides

The cap of *Amanita phalloides* (commonly known as the "death cap") measures 5-10 cm in diameter and has a yellowish to pale cream surface with a slightly rough texture. The stipe (stem) is cylindrical, 5-10 cm in length, 1-1.5 cm in width, and thicker at the base. As the mushroom matures, the central part of the stipe becomes hollow, resembling a tunnel. Like other *Amanita* species, it features an annulus. It is a gilled mushroom; the gills are white when young and gradually turn yellowish with age. The spores are colorless, elliptical, and have smooth walls, measuring 8-10 µm in length and 7-8.5 µm in width. *Amanita phalloides* typically grows under oak, beech, pine, and hornbeam trees, and is found during the summer and autumn months. In Türkiye, it has been recorded in regions such as Adana, Ordu, and Istanbul. *Amanita phalloides* is one of the most well-known toxic mushrooms and causes life-threatening illness due to liver and kidney failure.

Phalloides Syndrome The latency period in Phalloides syndrome is approximately one day. On the day the mushroom is consumed, no symptoms are observed. On the second day, poisoning symptoms emerge in the form of abdominal pain and diarrhea. These symptoms appear to subside by the third day, creating a deceptive sense of recovery. However, laboratory findings indicate severe liver damage. On the fourth day, gastrointestinal bleeding may occur; by the fifth day, neurological deterioration and the onset of coma are observed. Symptoms progress to kidney failure by the sixth day, and in most cases, result in death by the seventh day. Phalloides syndrome is classified into four degrees based on the severity of poisoning: First-degree poisoning involves the onset of gastrointestinal symptoms following the latent period, but no damage to the liver or kidneys is observed. Second-degree poisoning is characterized by moderate coagulopathy in the blood, with an increased white blood cell count, and gastrointestinal symptoms are also present. Third-degree poisoning results in severe liver damage, accompanied by elevated white blood cell count, while bilirubin levels remain unchanged. Fourth-degree poisoning shows increases in both white blood cell and bilirubin levels, accompanied by kidney failure and respiratory complications. The risk to life varies according to the degree of poisoning. First- and second-degree cases carry a low risk of fatality, whereas third-degree cases require more cautious management. In fourth-degree poisonings, due to kidney failure and respiratory distress, the chances of survival are significantly reduced.

The toxic agents responsible for Phalloides syndrome are amatoxins (Butera, 2004). Amatoxins are classified into various types based on their radical side groups. The most common type is α-amanitin, which inhibits RNA polymerase II, thereby halting protein synthesis and leading to cell death. The molecular formula of α-amanitin is $C_{39}H_{54}O_{14}S$. The molecular structure of α-amanitin and the general structures of amanitin compounds are presented in Figure 2. The mushroom species used in this study are listed in Table 1.

Table 1. Mushrooms Used in the Experiment

Mushroom species	**Collection area**
Amanita phalloides	Düzce-Gümüşova Yeşilyayla
Amanita pantherina	Düzce-Gölyaka Çamlıbel plateau
Amanita muscaria/Trabzon	Trabzon-Akçaabat Isabel plateau
Amanita muscaria/Rize	Rize-Ayder Konifer plateau
Amanita muscaria/Düzce	Düzce
Agaricus bisporus **(**Culture)	Bought from the market

The ICP-MS instrument, the AAS system with graphite furnace, and the HPLC device were used in the experiment. Technical specifications of the instruments are given in Table 2, Table 3, and Table 4.

Table 2. Specifications and operating conditions of the ICP-MS device

Carrier gas	Argon
Flow rate	1.2 L/min.
Power	1350 W
Sampling depth	6,7 mm
Spraying chamber	Double chamber, quartz
Spraying temperature	2^0C
Internal standards	6Li, 45Sc, 72Ge, 89Y, 115In, 159Tb, 209Bi

Table 3. Features and operating conditions of the AAS device

System used	Graphite furnace
Lamp used	c-EDL Hg lamp
Matrix used	Pd, $Mg(NO_3)_2$
Carrier gas	Argon
Detector	5973 N
Temperature program	130^0C-150^0C for cleaning purposes 1150^0C-2450^0C output
Cleaning solution	0.2% nitric acid
Current	185 mA
Wavelength	253,7 λ

Table 4. HPLC device specifications and operating conditions

Column	Agilent Zorbax eclipse XDB-CB 4,6* 150mm 5µm column
Eluent	65% water, 10% methanol, 25% acetonitrile mixture
Eluent flow rate	0,5 mL/min
Intracolumn pressure	33 bar

3. Results and Discussions

The mushrooms, which were first left to dry at room temperature in open air for five days and then ground into powder using a glass mortar, were further dried in an oven at 50 °C for one hour and subsequently weighed. For metal determination, acid mixtures were added to each sample, followed by microwave-assisted digestion. To analyze the elemental composition of the mushroom samples using ICP-MS, six different digestion methods were tested by varying the types of acids and the ratios of the same acids. The acids were added to 0.4 grams of weighed mushroom powder.

1. 8 mL 65% HNO_3 ve 5 mL 35% H_2O_2

2. 12 mL 65% HNO_3

3. 12 mL 65% HNO_3 ve 5 mL 70% $HClO_4$

4. 8 mL 65% HNO_3, 4 mL 70% $HClO_4$, 1 mL 35% H_2O_2, 1 mL 37% HCl

5. 8 mL 65% HNO_3, 2 mL 95%-98% H_2SO_4, 1 mL 35% H_2O_2

6. Aqua regia was used. 9 mL 37% HCl ve 3 mL 65% HNO_3

In all six mixtures, the final volumes were brought up to 25 mL using deionized water. Complete dissolution of the prepared mushroom solutions was achieved using a microwave digestion system. The digestion process was carried out under a pressure of 1500 psi, with a stepwise temperature increase in the microwave oven: 100 °C for the first 10 minutes, 150 °C for the next 10 minutes, and 200 °C for the final 10 minutes, totaling 30 minutes. The samples were analyzed using ICP-MS, the specifications of which are given in Table 2, and the operating conditions of the AAS device in Table 3. Based on the sample results presented in Table 1, the elemental analyses obtained using the six solvent mixtures are shown in Table 5. Among these, Solvent Mixtures 1 and 3 were determined to be the most suitable. For *Amanita pantherina*, Mixture 1 was optimal, while Mixture 3 was the most appropriate for the other mushroom species. A graphical representation of the ICP-MS-determined concentrations of Ca (µg/kg), Al (µg/kg), P (µg/kg), and K (µg/kg) is provided in Figure 3, and the elemental concentrations for the six mushroom samples are presented in Table 7.

Mercury (Hg) analysis was performed using Graphite Furnace Atomic Absorption Spectrometry (GFAAS) on samples prepared from the following mushroom species: cultivated mushrooms, *Amanita phalloides*, *Amanita pantherina*, and *Amanita muscaria* collected from Rize, Trabzon, and Düzce. The results are presented in Table 6. According to the findings, the most effective digestion method for mercury analysis was the mixture of 9 mL of 37% pure HCl and 3 mL of %65 pure HNO_3. However, for *Amanita phalloides*, the most suitable method was found to be the mixture of 8 mL of 65% pure HNO_3 and 5 mL of 35% pure H_2O_2. As shown in Table 6, high levels of mercury were detected in all mushroom species, with *Amanita phalloides* exhibiting the highest mercury concentration. In a comparable study, the mercury level detected in cultivated mushrooms was lower than the levels observed in the present study. Mercury (Hg), which is a liquid at room temperature, exists in both inorganic and organometallic forms. All mercury compounds are toxic and pose significant risks to living organisms.

Table 5 Suitable Solvents and Analysed Elements in Elemental Analysis

Sample Solvent Mixture	**Element suitable for analysis**
1. 8mL 65% HNO_3 and 5mL 35% H_2O_2	Al,Ca,Co,Cd.Cu,Fe,K,Mg,Mn,Mo,Na,Ni,P,Zn
2. 12mL 65% HNO_3	Ba,K,Mn
3. 12mL 65% HNO_3 and 5mL 70% $HClO_4$	Al,Ca,Co,Cd,Cr, Cu,Fe,Mg,Mn,Pb,Sb,Sr,Ti,V
4. 8mL 65% HNO_3, 4mL 70% $HClO_4$, 1mL 35% H_2O_2, 1mL 37% HCl	Mn
5. 8mL 65% HNO_3, 2mL 95%-98% H_2SO_4, 1mL 35% H_2O_2	K,Mn,P
6. 9mL 37% HCl and 3 mL 65% HNO_3	Ag,As,Cr,K,Mn,Zn

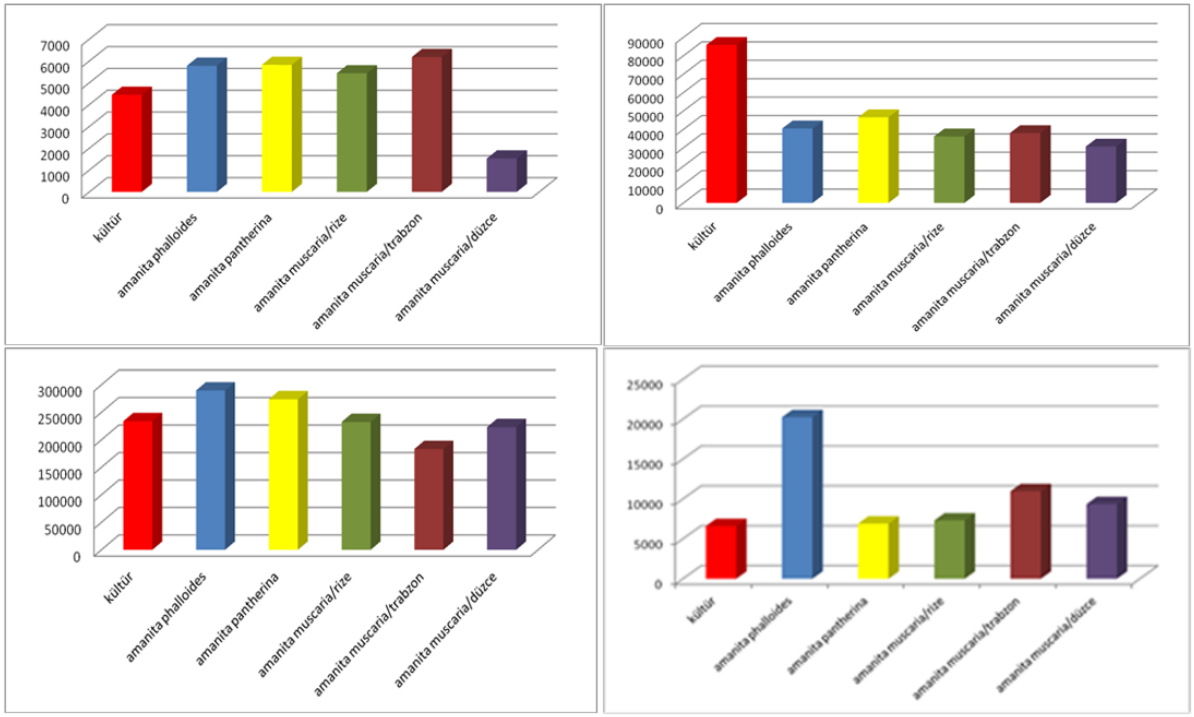

Figure 3 Graphical representation of the amount of Ca(µg/kg) P (µg/kg) K(µg/kg) element determined by ICP-MS and Hg(µg/kg) element analyzed by AAS

In particular, methylmercury and other alkyl mercury compounds are highly toxic. Although poisoning from inhalation of metallic mercury or mercury vapor is rare, such cases can lead to severe health issues and even death. Mercury compounds tend to persist in the body, accumulating primarily in the liver and kidneys. Mercury also accumulates in the brain, where it particularly affects motor function systems, potentially leading to neurological syndromes. According to the World Health Organization (WHO), acceptable ambient mercury concentrations are 0.1-5 ng·m^{-3} in urban areas, 0.5-20 ng·m^{-3} in industrial zones, and 0.001-6 ng·m^{-3} in rural areas (Cocchi et al., 2006). Furthermore, mercury can cross the placenta, and even at very low doses, chronic exposure in pregnant women may adversely affect the developing fetus.

Table 6. Hg (µg/kg) concentrations determined by AAS

Mushroom Type	**Hg (µg/kg)**
Agaricus bisporus (Culture)	6600±23
Amanita phalloides	20236±101
Amanita pantherina	6908±22
Amanita muscaria/Rize	7292±18
Amanita muscaria/Trabzon	10960±23
Amanita muscaria/Düzce	9340±18

The toxins α-amanitin in *Amanita phalloides* and muscimol in *Amanita pantherina* and *Amanita muscaria* were analyzed using HPLC. The mushrooms, previously dried and ground into powder, were extracted in a methanol–water mixture at room temperature for approximately one hour. The extracts were then filtered through filter paper and prepared for analysis. For the extraction, 5 mL of methanol and 5 mL of deionized water were used. Standards for α-amanitin and muscimol analysis were similarly prepared using 2.5 mL of methanol and 2.5 mL of deionized water. Standard solutions were prepared for the analysis of the muscimol toxin. Peak areas were identified by HPLC. A calibration curve of concentration versus peak area was plotted for the standards. The calibration graph for muscimol is presented in Figure 4.a and for α-amanitin in Figure 4.b Using these calibration graphs, the concentrations

of muscimol and α-amanitin in the mushroom samples were calculated based on the obtained peak areas. The results are provided in Table 8. The graphical representation is given in Figure 5.

Table 7. Quantities of elements determined in mushroom samples by ICP-MS

	Agaricus bisporus (Culture)	**Amanita phalloides**	**Amanita pantherina**
Ag (ng/kg)	*	5,14±1,08	*
Al (µg/kg)	49,38±5,92	1111,81±28,99	3211,15±287,5
As(ng/kg)	18,42±1,69	20,26±1,1	23,95±1,71
Ba(ng/kg)	9,73±1,54	28,97±1,5	12,48±1,54
Ca(µg/kg)	4449±209,01	5778,7±1287,59	5819,7±118,78
Cd(ng/kg)	0,75±0,05	9,6±0,13	99,30±0,53
Co(ng/kg)	0,16±0,03	0,1±0,07	0,93±0,15
Cr(ng/kg)	9,44±3,06	10,28±1,85	8,68±2,04
Cu (ng/kg)	196,37±6,51	237,77±6,04	175,63±6,03
Fe(µg/kg)	*	1687,3±176,4	3054,7±455,5
K(µg/kg)	233733,3±27226,2	289633,3±26339	273600±43350,1
Mg(µg/kg)	10353,3±125,03	10396,7±179,26	9150,3±274,5
Mn(ng/kg)	34,06±0,9	234,1±10,07	154,13±5,02
Mo(ng/kg)	*	*	*
Na(µg/kg)	3727,8±97,61	287,3±62,62	2677,8±272,32
Ni(ng/kg)	*	*	0,036±0,06
P (µg/kg)	85830±1300	40430±384,32	46530±451,77
Pb (ng/kg)	158,2±17,45	242,77±4,25	254,6±7,89
Sb (ng/kg)	7,07±0,57	6,75±0,03	7,2±0,45
Sn(ng/kg)	87,07±28,73	90,14±102,68	33,63±25,17
Sr(ng/kg)	7,65±0,11	0,5±0,72	1,08±0,64
Ti (ng/kg)	121,58±1,18	77,36±0,9	133,08±1,14
V (ng/kg)	*	*	*
Zn (ng/kg)	389,48±27,37	431,62±23,82	1482,75±204,86
	Amanita muscaria/Rize	**Amanita muscaria/Trabzon**	**Amanita muscaria/Düzce**
Ag (ng/kg)	5,55±0,55	2,33±0,85	3,23±2,23
Al (µg/kg)	2401,48±264,86	659,28±65,76	1670,81±51,43
As(ng/kg)	26,01±0,78	23,55±1,6	22,96±2,33
Ba(ng/kg)	26,58±1,54	7,48±0,77	9,56±0,87
Ca(µg/kg)	5432,3±663,56	6177,7±434,36	1527±308,39
Cd(ng/kg)	88,45±1,9	51,52±1,74	51,45±1,86
Co(ng/kg)	1,45±0,61	0,29±0,06	*
Cr(ng/kg)	8,65±0,9	7,08±0,7	7,06±1,01
Cu (ng/kg)	223,23±0,95	144,37±8,05	127,53±5,49
Fe(µg/kg)	2727,3±289,86	527,23±279,46	349,6±71,96
K(µg/kg)	232333,3±40802,25	183100±6816,89	232033,3±8533,66
Mg(µg/kg)	7404,7±145,22	5816±324,73	6106±289,45
Mn(ng/kg)	137,37±3,11	72,36±17,26	53,7±2,00
Mo(ng/kg)	*	*	*
Na(µg/kg)	1677,1±487,01	628,8±92,29	779,8±316,75
Ni(ng/kg)	*	*	*
P (µg/kg)	36086,7±707,27	37943,3±1905,37	30633,3±1179,38
Pb (ng/kg)	190.07±6,11	207,9±5,96	226,13±3,79
Sb (ng/kg)	7,01±0,39	6,86±0,06	6,67±0,11
Sn(ng/kg)	137,68±17	52,18±7,9	109,67±8,9
Sr(ng/kg)	4,26±1,56	*	*
Ti (ng/kg)	131,14±12,9	92,918±4,31	75,582±1,66
V (ng/kg)	1374,7±20,1	537,8±29,6	896,4±36,00
Zn (ng/kg)	876,4±45,2	753,58±31,73	1084,08±68,65

*below the determination limit

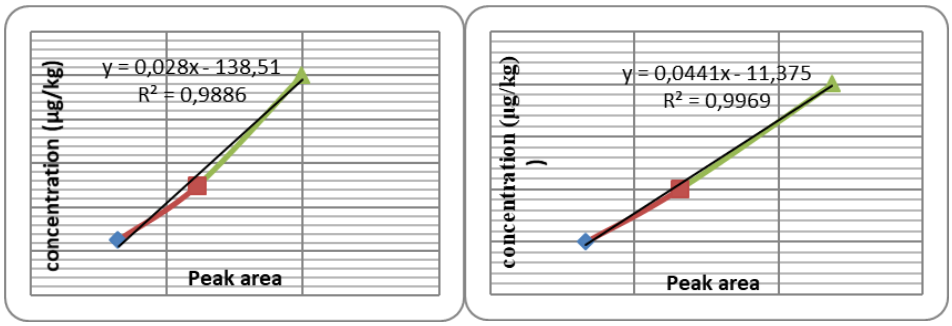

Figure 4. a-Muscimol calibration graph **b** -Alpha amanitin calibration graph

Table 8. Muscimol and Alpha Amanitin determined amounts by HPLC

Mushroom Type	**Muscimol (µg/kg)**
Amanita muscaria/Rize	1493,74
Amanita muscaria/Trabzon	2048,02
Amanita muscaria/Düzce	1387,28
Amanita pantherina	-
	Alfa amanitin (µg/kg)
Amanita phalloides	1223,21

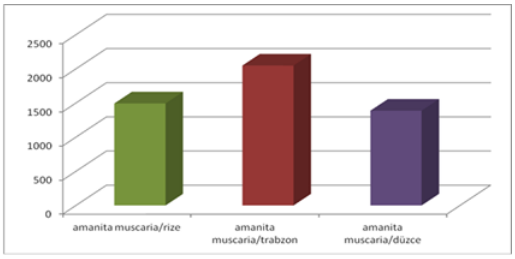

Figure 5. Graphical representation of muscimol amounts in Amanita muscaria / Rize, Amanita muscaria / Trabzon, Amanita muscaria/Düzce

An elemental analyzer was used to determine the percentage composition of carbon, hydrogen, and sulfur in our mushroom samples using an infrared absorption detector, while nitrogen was quantified using a thermal conductivity detector. The results are presented in Table 9. The elemental analyzer is capable of simultaneously analyzing the percentage composition of carbon, hydrogen, nitrogen, and sulfur in pharmaceuticals, chemicals, plastics, resins, rubbers, and all homogeneous organic compounds using approximately 2 mg of sample within an average of 3 minutes. In the case of toxic mushrooms, the results were relatively similar, with only slight differences observed in *Agaricus bisporus* (cultivated mushroom).

Table 9. Elemental analysis results

Mushroom Type	C%	H%	N%	S%	O%
Agaricus bisporus (Culture)	37,78	6,109	3,761	0,212	52,138
Amanita phalloides	42,06	6,285	6,456	0,473	44,726
Amanita pantherina	44,02	6,583	4,812	0,260	44,325
Amanita muscaria/Düzce	45,41	6,813	4,230	0,222	43,325
Amanita muscaria/Rize	44,89	6,740	4,338	0,249	43,783
Amanita muscaria/Trabzon	44,54	6,582	4,851	0,236	43,791

X-ray diffraction (XRD) was used to determine the structural composition of the mushroom samples. Electromagnetic radiation of a specific wavelength was directed onto the surface of the material, and the reflected rays were interpreted according to Bragg's Law to obtain information about the structure. In addition to distinguishing whether the material is amorphous or crystalline, XRD can also determine the crystal parameters and unit cell types of

the formed crystals. However, in the analysis performed using the XRD device to observe the structural forms of elements in crystalline structures, no structural observations could be made due to the amorphous bonding of the elements. Only in *Amanita phalloides* was potassium detected in a crystalline form.

4. Conclusion

ICP-MS results showed the analysis of Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mn, Na, Ni, P, Pb, Sb, Sn, Sr, Ti, V, and Zn in samples prepared from the mushroom species *Agaricus bisporus* (cultivated), *Amanita phalloides*, *Amanita pantherina*, and *Amanita muscaria* collected from Rize, Trabzon, and Düzce. The concentrations of the elements were found at the µg/kg and ng/kg levels, as shown in Table 9. Additionally, suitable acid mixtures were determined for each element, as presented in Table 6. These six mixtures varied depending on the mushroom species and the element to be analyzed (Jasinska et al., 2024). Overall, the analysis results indicated that the mixture of 12 mL of 65% pure HNO_3 and 5 mL of 70% pure $HClO_4$ was the most suitable for metal analysis in mushroom species. In the cultivated *Agaricus bisporus*, which is consumed as food, no toxic elements were detected or were only found at trace levels, while essential and beneficial elements such as calcium, potassium, magnesium, sodium, and phosphorus were present in significant amounts. Although *Amanita muscaria* mushrooms collected from Rize, Trabzon, and Düzce belong to the same species, variations were observed in both muscimol content and elemental composition. Among these, the *Amanita muscaria* sample with the highest muscimol content was the one collected in Trabzon. Furthermore, the sample collected from Rize was observed to contain higher levels of all elements except calcium, mercury, lead, and zinc. The *Amanita muscaria* from Trabzon was found to contain higher amounts of calcium and mercury, while the one from Düzce had higher levels of lead and zinc. It was observed that all toxic mushroom species contained significant amounts of essential and beneficial elements such as calcium, potassium, magnesium, sodium, and phosphorus, indicating that these mushrooms possess high nutritional value from this perspective. However, due to both the elevated levels of metals such as aluminum, iron, mercury, and zinc, and the presence of lethal doses of toxins, these mushroom species are deemed entirely unsuitable for consumption as food. High levels of mercury were detected in all mushroom species, with *Amanita phalloides* showing the highest mercury content. In a similar study, the levels observed in cultivated mushrooms were lower than those found in our study (WHO, 1996). Muscimol analysis was conducted on samples prepared from Amanita pantherina, Amanita muscaria (collected from Rize, Trabzon, and Düzce), and α-amanitin analysis was performed on Amanita phalloides. The results showed that the highest muscimol concentration was found in Amanita muscaria collected from Trabzon (2048.02 µg/kg). Rize (1493.74µg/kg) and Düzce (1387.28 µg/kg) mushrooms contained higher amounts of Amanita muscaria, although the levels were lower than in Trabzon. Muscimol could not be detected in Amanita pantherina. In contrast, Amanita phalloides was found to contain a high concentration of α-amanitin. Among these highly toxic compounds, muscimol begins to exhibit toxic effects when 6 mg is ingested—an amount typically found in 2 to 20 mushroom caps. Amatoxins, including α-amanitin, are fatal when orally ingested at doses as low as 0.1 mg/kg. Given that a single Amanita phalloides cap contains approximately 10-15 mg of amatoxins, even one mushroom can be lethal (Cocchi, 2006; Tsujikawa, 2007). The muscimol levels determined in our study were found to be higher than those reported in similar studies. In recent years, studies have been carried out to isolate the poisons of poisonous mushrooms (Lee et al., 2024).

Declaration of Author Contributions

All authors declare that they have contributed equally to this manuscript, have reviewed the final version, and have approved it for publication.

Declaration of Conflicts of Interest

The authors declare that there is no conflict of interest regarding this study.

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İtalyan Çimi (*Lolium multiflorum Lam.*) ve Gelemen Üçgülü'nün (*Trifolium nigrescens* Viviani) Farklı Karışım Oranlarının Verim Unsurlarına Etkisi

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Anahtar Kelimeler
İtalyan Çimi,
Gelemen Üçgülü,
Karışım

Özet: Bu araştırma Şanlıurfa ekolojik koşullarında, 2021-2022 kış sezonunda, tesadüf blokları bölünmüş parseller deneme desenine göre 3 tekrarlamalı olarak yürütülmüştür. Çalışmada İtalyan çimi (*Lolium multiflorum*) ile Gelemen üçgülü (*Trifolium nigrescens* Viviani) türlerinin karışım oranlarının verim performansları, bitki boyu (cm), yaş ot verimi (kg/da), kuru ot verimi (kg/da), kuru madde verimi (kg/da), ham protein oranı ve ham protein verimi incelenmiştir. Araştırmadan elde edilen verim özellikleri kullanılarak yapılan varayans analiz sonuçlarına göre, saf ve karışım uygulamalarının yaş ot verimi (kg/da), kuru ot verimi (kg/da), kuru madde verimi (kg/da), ham protein oranı (%) ve ham protein verimine (kg/da) etkisinin önemli olduğu belirlenmiştir.

Effects of The Mixture Rates of Italian Ryegraas (*Lolium multiflorum Lam.*) and Small White Clover (*Trifolium nigrescens* Viviani) on The Forage Yield

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Abstract: This research, which will be carried out in order to determine effects of the mixture rates of Italian Ryegraas (*Lolium multiflorum* Lam.) and small white clover (*Trifolium nigrescens* Viviani) on the forage yield in Şanlıurfa conditions, will be carried out in 3 replications in Harran University Osmanbey Campus Agricultural Research and Application Field at 2021-2022 winter crop breeding period. In the study, Effects of the mixture rates of Italian Ryegraas (*Lolium multiflorum* Lam.) and small white clover (*Trifolium nigrescens* Viviani) on the forage yıeld, plant height (cm), wet grass yield (kg/da), dry grass yield (kg/da), dry matter yield (kg/da), crude protein ratio (%), crude protein yield (kg/da) will be examined. According to the results of the analysis using the yield characteristics obtained from the research, it was determined that the effects of pure and mixed applications on fresh grass yield (kg/da), dry grass yield (kg/da), dry matter yield (kg/da), crude protein ratio (%) and crude protein yield (kg/da) were significant.

1. Giriş

İnsanoğlunun beslenme sorunlarının çözümünde, sınırlı olan tarım alanlarımızda bitkisel ve hayvansal üretimi artırmak büyük önem taşımaktadır. Yapılan çalışmalar buğdaygil ve baklağillerin karışık ekimlerinin bu bitkilerin tekli ekimlerine göre, kuru madde miktarının artması, yemin protein oranı ve kalitesinin yükselmesi, gübre ihtiyacının azalması, hastalık, yabancı ot ve zaralı yoğunluğun azalması ve bir sonraki ürünün verim artışı gibi avantajları

olduğunu göstermiştir (Çakmakçı ve ark., 2005). Güneydoğu Anadolu Bölgesinde 3.1 milyon hektar tarım arazisi, 1.1 milyon hektar orman arazisi ve 2.3 milyon hektar çayır ve mera arazisi bulunmaktadır. Hayvancılığın bu bölgede önemli bir yeri vardır, genel olarak çiftçi gelirlerinin % 50'sini oluştururken, dağlık yörelerde yaşayanların tek geçim kaynağı durumundadır. Bölgedeki hayvan varlığı 6 milyon küçükbaş hayvandan oluşmaktadır. Bölgenin çayır ve meraları, ülkemiz genelinde olduğu gibi, kontrolsüz ve aşırı otlama nedeniyle verimleri düşük ve dejenere olmuş durumdadırlar. Tarla tarımı içerisinde hayvancılığın kaliteli kaba yem gereksiniminin karşılanması amacıyla yapılan yem bitkisi yetiştiriciliği, bir yem bitkisi türünün saf veya birden fazla türün bir arada karışım halinde yetiştirilmesi şeklinde yapılmaktadır. Bir türün saf halde yetiştirilmesinin ekim kolaylığı, amenajman kolaylığı gibi avantajları bulunmasına karşılık, genellikle yem bitkilerinin karışım halinde yetiştirilmesi tercih edilmektedir (Kökten ve ark., 2003). Güneydoğu Anadolu Bölgesinde GAP tamamlandığında ve sulanması planlanan 1.7 milyon hektar arazi sulu tarıma açıldığında, Bölgede işlenebilir tarım alanlarının % 51'i ve sulanabilir tarım topraklarının % 60'ı sulanacaktır. 1998 yılı itibariyle GAP alanında 183.000 hektar arazi (GAP ile sulanmaya açılacak alanın % 11'i) devlet tarafından sulu tarıma açılmıştır (Karlı ve ark., 1999). Bölgede sulu tarımın yaygınlaşması sonucu ortaya çıkacak problemlerin önlenmesi ve bölge hayvancılığının kaliteli kaba yem gereksiniminin karşılanması açısından, kış döneminde fiğ türleri, iskenderiye üçgülü, yem bezelyesi gibi bir yıllık baklagiller ve italyan çimi, arpa, yulaf ve tritikale gibi bir yıllık buğdaygillerin saf veya karışım halinde yetiştirilmesi büyük önem taşımaktadır (Hatipoğlu ve ark., 1999). Son yıllarda toprak kullanım etkinliği bakımından özellikle Akdeniz'e kıyısı olan ülkelerde tek yıllık baklagil ve buğdaygil yem bitkilerini karışık halde yetiştirmek, onları ayrı ayrı yetiştirmekten daha fazla benimsenen uygulamalardır (Papastylianou, 2004). Bu ekim şeklinde, ekim alanları daha iyi kullanılmakta, karışıma giren baklagiller de toprağa bıraktıkları azot ile buğdaygillerin ihtiyacını karşılayacak şekilde toprak verimliliğini artırıcı rol oynamaktadırlar. Baklagillerin bu etkisinden dolayı pestisit ve kimyasal gübrelerin kullanımı azalmakta ve tarımın çevreye verdiği zarar en aza inmektedir Birlikte ekim, hastalık ve zararlıların indirgenmesinin yanında ham protein verimini artırdığından dolayı yem kalitesini ve buna ek olarak verimi de artırmaktadır (Altın, 2009; Lithourgidis ve ark., 2011; Budaklı Çarpıcı ve Çelik, 2014). Karışımlarda, kışlık ara ürün yem bitkisi olarak kullanılabilecek en önemli baklagillerden biri, üretim bakımından dünyada ön sıralarda olduğumuz ve ülkemizde en fazla üretilen ikinci yem bitkisi olması özelliği ile yaygın fiğ (*Vicia sativa* L.) dir. Bir diğeri üretimi ve önemi günümüzde artış gösteren Yem bezelyesi (*Pisum sativum* ssp. arvense (L.) Asch.) olmaktadır. Buğdaygil familyasında karışımlarda kullanılabilecek türler; iyi bir verim sağlayabilen ve üretimi kolay olan yulaf (*Avena sativa* L.) ve ince sapları sebebiyle çabuk kuruma özelliğinin yanında yoğun kök yapısı ile toprağı koruması ile bilinen İtalyan Çimi (*Lolium multiflorum* Lam.) dir.

Bu çalışma ile klasik tek yıllık baklagil + tahıl karışımlarına alternatif olabilecek, verim ve kalite bakımından bölgede yetiştirilebilecek İtalyan çim + İskenderiye üçgülü karişim oranlarının belirlenmesi amaçlanmaktadır. Araştırma sonucunda, elde edilen verilerin Şanlıurfa ve bölge illerinin kaba yem açığının kapatılması için gereken bilgi birikimine katkısı bakımından önem arz edecektir. Son zamanlarda sınırlı tarım alanlarında hem verimi artırmak, daha sağlıklı ve dengeli yem üretimi için farklı familyalardan bitkilerin karışım halinde yetiştirilmesi çalışmaları yoğunlaşmıştır. Böylece, hem baklagil bitkilerinin toprakta biriktirdikleri azottan faydalanır, hem de besin maddeleri ve mineral maddeler açısından daha dengeli bir yem üretilmiş olunur. Ancak karışık ekimlerde tür içi ve türler arasında su, ışık ve besin maddesi yönünden rekabet söz konusu olduğunda, karışık ekimden beklenen yararın sağlanabilmesi için uygun bitki türleri ve çeşitlerinden en uygun karışım oranını belirlemek gerekmektedir. (Dordas ve ark., 2012; Uzun ve Aşık, 2012). Çok yıllık buğdaygil ve baklagil yem bitkilerini yalın olarak ve karışımlar halinde yetiştirmek suretiyle yapılan bir çalışmada,

buğdaygillerin baklagillerle birlikte yetiştirilmesinin daha avantajlı olduğunu, karışık ekimlerdeki buğdaygillerin yalın ekimlere göre ham protein oranı ve bitki boyu artışları gösterdiği saptamıştır Dubs (1971). Buğdaygiller genellikle karbonhidrat bakımından, baklağiller ise protein bakımında zengin olmasından dolayı ikili karışımlar oluşturulması sonucu hayvan beslenmesinde dengeli bir yem rasyonunu oluşturmaktadır. Bölge hayvancılığının yoğun olarak kalitesiz kaba yem olan anız ve samana dayalı oluşu, yanında bölgede kaliteli kaba yem açığının artmasına neden olmuştur. Yapılan bu çalışma ile bölgenin her geçen gün gittikçe büyüyen kaliteli yem açığını azaltacak alternatif yollardan birisi olduğu görülmektedir. Gelemen Üçgülü (*Trifolium nigrescens L.)* baklağiller (*Leguminoseae*) familyasından kışlık tek yıllık bir baklagiller yem bitkisidir. Morfolojik özellikleri bakımından yoncaya benzemekle birlikte biraz farklılık göstermektedir. İtalyan çimi (*Lolium multiflorum Lam.)* süt otu olarak da bilinen İtalyan çimi, hayvanlara yem olarak verilen yonca, arpa, yulaf, mısır silajı ve fiğ çeşitlerine göre besin değeri daha yüksek kaba yem olup bu yemle beslenen Hayvanlarda süt ve et verimindeki artış gözle görülür seviyelere ulaştığı gibi gebe kalma oranının da yükseldiği tecrübe edilmiştir. İlkbahar ve sonbahar ekimi yapılabilen İtalyan çiminde bölgemize en uygun olan ekim dönemi sonbahardır. Yıllık biçim sayısı sulu koşullarda 4-5, kurak, susuz koşullarda ise 2-3 biçim alınabilmektedir. Genelde yeşil ot ve silaj olarak değerlendirimektedir.

2. Materyal ve Yöntem

Tablo 1. Araştırmada kullanılan bitki materyali

Latince Bilimsel Adı	Türkçe Adı	Çeşit Adı
***Lolium multiflorum* Lam.**	İtalyan çimi (Helen Çeşidi)	**Alfa Tohum Tarım Gıda İnş. Hayv. Paz. San. Tic. Ltd. Şti.**
***Trifolium nigrescens* L.**	Gelemen üçgülü (Populasyon)	Karadeniz Araştırma Enst. Müd.

Araştırma, 2021 sonbahar yetiştirme sezonunda, Şanlıurfa Harran Üniversitesi Osmanbey kampüsünde yürütülmüştür. Deneme yeri, düz ve düze yakın, ağır tekstürlü olup, genelde derin, çok kireçli, kil tekstürlü, kuru koşullarda yazın çatlayan özelliğe sahiptir. Tüm profil kireçli, pH 7.4-7.6 arasında, organik madde (%0.4-0.09 arasında ve tuz içeriği çok düşük Katyon Değişme kapasitesi yüksek, killi bünyeli ve Na içeriği düşüktür. Şanlıurfa, Güneydoğu iklim bölgesine dahil olmakla beraber, Akdeniz iklimin etkisi altındadır. Yazları kurak ve sıcak, kışları ise ılık bir iklim özeliği göstermektedir (Tablo 2). Araştırmada, aynı dönemde yetişen tek yıllık buğdagil yem bitkisi olan İtalyan çimi (*Lolium multiflorum Lam.)'un* Helen çeşidi ile baklagil yem bitkilerinden tek yıllık Gelemen üçgülü (*Trifolium nigrescens L.), (populasyon)* kullanılmıştır (Tablo 1). Araştırmada, İtalyan çimi (*Lolium multiflorum Lam.)* ile Gelemen üçgülü (*Trifolium nigrescens L.)* karışımı ot verimine etkisinin incelenmesi için %100 saf Gelemen üçgülü, %80 gelemen üçgülü ile %20 italyan çimi, %60 gelemen üçgülü ile %40 italyan çimi, %40 gelemen üçgülü ile %60 italyan çimi, %20 gelemen üçgülü ile %80 italyan çimi ve %100 saf İtalyan çimi oranları belirlenerek ekimi yapılmıştır. Araştırma tesadüf blokları deneme desenine göre üç tekerürlü olarak yürütülmüş olup elde edilen veriler JMP paket programı kullanılarak varyans analizine ve LSD çoklu karşılaştırmasına tabi tutulmuştur. Araştırmada kullanılan parsel boyutları 2m x 3m = 6m^2, sıra arası 20 cm, parseller arası 0.5 m ve bloklar arasıda 2'şer m olacak şekilde kurulacaktır. Araştırma alanı ekim ayı başında pullukla derin sürümün ardından diskli kültivatör ile sürüp tapan çekildikten sonra dekara 3 kg tohum atılmıştır. Ekimden itibaren tohumlar çimleninceye kadar yağmurlama yöntemi ile sulama yapılmıştır. Gübre olarak toplam dekara 20 kg % 46 Üre, 6 kg triple süper fosfat gübresi kullanılmıştır. Yetiştirme süresince sulama, çapalama ve gerekli bakım işlemleri yapılmıştır. Gübre uygulaması % 20'si ekimle birlikte, % 20'si erken ilkbaharda, % 20'si 1. biçimden sonra, % 20'si 2. biçimden sonra, % 20'si 3. biçimden sonra verilmiştir. Bitkinin su ihtiyacına göre her biçimden sonra sulama yapılmıştır. Parsellerinde biçim işlemi, İtalyan çiminin başaklarının dolduğu bir dönemde yapılmıştır.

Tablo 2. Araştırma yerinin uzun yıllar ve deneme yılına ait bazı ortalama iklim değerleri*

Yıllar	Kasım	Aralık	Ocak	Şubat	Mart	Nisan	Mayıs	Haziran
Şanlıurfa			**Ortalama sıcaklık (°C)**					
2021-2022	19.4	11.6	6.8	11.7	19.7	21.0	23.8	26.7
Uzun yıllar**	13.1	7.6	5.6	7.1	10.9	16.2	22.1	28.1
			Ortalama nispi nem (%)					
2021-2022	53.5	45.2	35.8	36.3	45.4	31.1	35.6	42.70
Uzun yıllar**	59.9	69.9	70.3	66.9	60.4	56.2	54.1	33.20
			Toplam yağış miktarı (kg/m²)					
2021-2022	0.0	0.0	0.1	0.0	0.1	0.0	30.5	1.20
Uzun yıllar**	44.7	80.2	87.4	68.3	62.8	49.5	26.7	1.37

* MGM, (2021-2022) ** MGM, (1929-2022)

3. Bulgular ve Tartışma

3.1. İtalyan çimi bitki boyu (cm)

Tablo 3. Gelemen üçgülü + İtalyan çimi karışımında İtalyan çimine ait bitki boyu (cm) ortalamaları*****

	Tür ve Karışımlar	(cm)	Gruplar
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	52.60	Ö.D.
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	57.50	Ö.D.
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	57.51	Ö.D.
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	56.10	Ö.D.
5	%100 İtalyan Çimi	56.93	Ö.D.
	Ortalama	**56.13**	
	D.K.(%) :	**8.08**	
	LSD (0.05): (karışım uygulaması)	**Ö.D.**	

*) Ö.D.; önemli değildir

Tablo 3'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında italyan çimine ait bitki boyu ortalaması 56.13 cm olarak bulunmuştur. En yüksek biki boyu 57.50 cm ile %40 Gelemen üçgülü ile %60 İtalyan çimi karışım uygulamasında, en düşük bitki boyu 52.60 cm ile %80 Gelemen üçgülü ile %20 İtalyan çimi karışımı uygulamasında görülmüştür. Beş farklı karışım uygulamarının birbiri arasında önemli bir farkın bulunmadığı görülmektedir. Şanlıurfa koşullarında İtalyan çimi (*Lolium multiflorum Lam.*) ve İskenderiye üçgülü *(Trifolium alexandrium L.)* farklı karışım oranlarının verim ve verim unsurlara etkisini belirlemek amacıyla yapılan bir çalışmada İtalyan çiminin bitki boyu 76 cm olarak %100 İtalyan çimi saf ekiminden elde edilmiştir. Karışım ekimlerde ise en yüksek bitki boyu %80 İskenderiye üçgülü+ %20 İtalyan çimi karışımından elde edilmiş olup yapmış olduğumuz araştırma ile benzerlik göstermektedir (Polat ve ark., 2021).

3.2. Gelemen üçgülü bitki boyu (cm)

Tablo 4. Gelemen üçgülü + İtalyan çimi karışımında gelemen üçgülüne ait bitki boyu (cm) ortalamaları ve oluşan gruplar*

	Tür ve Karışımlar	(cm)	Gruplar
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	30.53	ab
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	29.40	ab
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	36.10	a
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	32.33	ab
5	%100 Gelemen Üçgülü	27.93	b
	Ortalama	**31.26**	
	D.K.(%) :	**12.48**	
	LSD (0.05): (karışım uygulaması)	**7.35**	

(*) Aynı sütunda benzer harf grubu ile belirtilen ortalamalar, Lsd (%5) değerine göre farklı değildir.

Tablo 4'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında Gelemen üçgülüne ait bitki boyu ortalaması 31.26 cm olarak bulunmuştur. En yüksek biki boyu 36.10 cm ile %40 Gelemen üçgülü ile %60 İtalyan çimi karışım uygulamasında, en düşük bitki boyu 27.93 cm ile saf Gelemen üçgülü uygulamasında görülmüştür. 5 farklı karışım uygulamarında iki farklı grubun oluştuğu, uygulamalar arasında önemli düzeyde bir farkın olduğu tespit edilmiştir.

Karadeniz Tarımsal Araştırma Enstitüsü'nün Ambarköprü deneme istasyonunda 2020–2021 yılları vejetasyon döneminde, Gelemen Üçgülü (*Trifolium meneghinianum Clem.)* ve tek yıllık çimde*(Lolium multiflorum L*.) ot verimi ve besin içeriği yönünden uygun karışım oranının belirlenmesi amacıyla yapılan bir çalışmada, bitki boyu bakımından, saf ve karışımlarda yer alan Gelemen üçgülü bitki boyları arasındaki farklılığın istatistiki olarak önemli olduğu belirlenmiştir. En yüksek bitki boyu 97.0 cm ile Gelemen üçgülünün yalın olarak yetiştirildiği parsellerde belirlenmiştir. Karışım olarak yetiştirilen uygulamalarda Gelemen üçgülünün bitki boyu 71.5-84.2 cm olarak bulunmuştur. Karışımlarda Gelemen üçgülü oranı arttıkça bitki boyunda da artış gözlenmiştir (Saraçoğlu, 2023), yaptığımız araştırmada ortalama bitki boyları ile benzerlik görülmediği ancak karışımlardaki boy artışında benzerlik görüldüğü tespit edilmiştir.

3.3. Yaş ot verimi (kg/da)

Tablo 5. Tür ve karışımlarda Gelemen üçgülü ile İtalyan çimi yaş ot verimi (kg/da) ve oluşan gruplar*

	Tür ve Karışımlar	(kg/da)	Gruplar
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	2177.55	b
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	2066.64	b
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	2177.77	b
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	2110.87	b
5	%100 İtalyan Çimi	3383.31	a
6	%100 Gelemen Üçgülü	2488.88	b
	Ortalama	**2400.84**	
	D.K.(%) :	**11.50**	
	LSD (0.05): (karışım uygulaması)	**500.59**	

*) Aynı sütunda benzer harf grubu ile belirtilen ortalamalar, Lsd (%5) değerine göre farklı değildir.

Tablo 5'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında 2 saf uygulama ve 4 ayrı karışım uygulamasına ait yaş ot verimi ortalaması 2400.84 kg/da olarak bulunmuştur. En yüksek yaş ot verimi 3383.31 kg/da ile saf İtalyan çimi uygulamasında, en düşük yaş ot verimi ise 2066.64 kg/da ile %60 Gelemen üçgülü ie %40 İtalyan çimi karışım uygulamasında görülmüştür. Yeşil ot verimi bakımından 2 saf uygulama arasında ileri derecede bir farkın görüldüğü, Dört farklı karışım uygulamarında ise yaş ot verimi bakımından herhangi bir farkın görülmemiştir. Saf ve karşım uygulamaları arasında iki farklı grubun oluştuğu tespit edilmiştir. Şanlıurfa koşullarında İtalyan çimi (*Lolium multiflorum* Lam.) ve İskenderiye üçgülü *(Trifolium alexandrium* L.*)* farklı karışım oranlarının verim ve verim unsurlara etkisini belirlemek amacıyla yapılan bir çalışmada yalın tür ve karışımların yaş ot verimleri en yüksek %100 İtalyan çimi saf ekiminden elde edilmiştir. Karışım ekimlerde ise en yüksek yaş ot verimi %80 İskenderiye üçgülü + %20 İtalyan çimi karışımından elde edilmiş olup yapmış olduğumuz araştırma ile benzerlik göstermektedir (Polat ve ark., 2021).

3.4. Kuru ot verimi (kg/da)

Tablo 6. Tür ve karışımlarda Gelemen üçgülü ile İtalyan çimi kuru ot verimi (kg/da) ve oluşan gruplar*

	Tür ve Karışımlar	(kg/da)	Gruplar
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	939.00	c
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	946.67	c
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	872.00	c
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	1317.00	a
5	%100 İtalyan Çimi	1187.00	b
6	%100 Gelemen Üçgülü	680.00	d
	Ortalama	**990.28**	
	D.K. (%):	**6.46**	
	LSD (0.05): (karışım uygulaması)	**119.18**	

*) Aynı sütunda benzer harf grubu ile belirtilen ortalamalar, Lsd (%5) değerine göre farklı değildir.

Tablo 6'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında 2 saf uygulama ve 4 ayrı karışım uygulamasına ait kuru ot verimi ortalaması 990.28 kg/da olarak bulunmuştur. Kuru ot verimi bakımından, 2 saf uygulama ile 4 farklı karışım uygulamaları arasında ileri derecede bir farkın görüldüğü, Saf ve karşım uygulamaları arasında dört farklı grubun oluştuğu tespit edilmiştir. Şanlıurfa koşullarında İtalyan çimi (*Lolium multiflorum* Lam.) ve İskenderiye üçgülü *(Trifolium alexandrium* L.*)* farklı karışım oranlarının verim ve verim unsurlara etkisini belirlemek amacıyla yapılan bir çalışmada yalın tür ve karışımların kuru ot verimleri en yüksek %100 İtalyan çimi saf ekiminden elde edilmiştir. Karışım ekimlerde ise en yüksek kuru oto verimi %80 İskenderiye üçgülü + %20 İtalyan çimi karışımından elde edilmiş olup yapmış olduğumuz araştırma ile benzerlik göstermektedir (Polat ve ark., 2021).

3.5. Kuru madde verimi (kg/da)

Kalite analizleri için öğütülmüş materyalden alınan 5'er gram örnekler 105 °C'ye ayarlanmış fırında 24 saat tutulduktan sonra desikatörde soğutulmuş ve hassas terazide tartılarak kuru madde içerikleri belirlenmiştir. Belirlenen değerler kuru ot örneklerine göre oranlanarak dekara kuru madde verimleri hesaplanmıştır.

Tablo 7. Tür ve karışımlarda Gelemen üçgülü ile İtalyan çimine ait kuru madde verimi (kg/da) ve oluşan gruplar*

	Tür ve Karışımlar	(kg/da)	Gruplar
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	844.67	c
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	857.67	c
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	772.00	c
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	1189.33	a
5	%100 İtalyan Çimi	1056.00	b
6	%100 Gelemen Üçgülü	618.25	d
	Ortalama	**889.65**	
	D.K.(%) :	**6.62**	
	LSD (0.05): (karışım uygulaması)	**107.17**	

*) Aynı sütunda benzer harf grubu ile belirtilen ortalamalar, Lsd (%5) değerine göre farklı değildir.

Tablo 7'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında 2 saf uygulama ve 4 ayrı karışım uygulamasına ait kuru ot verimi ortalaması 889.65 kg/da olarak bulunmuştur. Kuru madde verimi bakımından, 2 saf uygulama ile 4 farklı karışım uygulamaları arasında ileri derecede bir farkın görüldüğü, Saf ve karşım uygulamaları arasında dört farklı grubun oluştuğu tespit edilmiştir.

3.6. Ham protein orani (%)

Kuru ot örneklerinin, öğütüldükten sonra yarı otomatik Tekatör marka Kjeldahl cihazıyla azot tespitleri yapılmıştır. Saptanmış azot oranları 6.25 dönüşüm katsayısı ile çarpılarak kuru ottaki % protein oranı belirlenmiştir.

Tablo 8. Tür ve karışımlarda Gelemen üçgülü ile İtalyan çimine ait ham protein oranı (%) ve oluşan gruplar*

	Tür ve Karışımlar	(%)	Gruplar
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	17.51	ab
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	15.68	bc
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	13.85	cd
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	12.02	de
5	%100 İtalyan Çimi	10.19	e
6	%100 Gelemen Üçgülü	19.36	a
	Ortalama	**14.77**	
	D.K. (%):	**9.15**	
	LSD (0.05): (karışım uygulaması)	**2.45**	

*) Aynı sütunda benzer harf grubu ile belirtilen ortalamalar, Lsd (%5) değerine göre farklı değildir.

Tablo 8'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında 2 saf uygulama ve 4 ayrı karışım uygulamasına ait ham protein oranları ortalaması %14.77 olarak bulunmuştur. Ham protein oranları bakımından, 6 farklı karşım uygulaması arasında ileri derecede bir farkın görüldüğü ve karşım uygulamaları arasında beş farklı grubun oluştuğu tespit edilmiştir. Şanlıurfa koşullarında İtalyan çimi (*Lolium multiflorum* Lam.) ve İskenderiye üçgülü *(Trifolium alexandrium* L.*)* farklı karışım oranlarının verim ve verim unsurlara etkisini belirlemek amacıyla yapılan çalışmada yalın tür ve karışımların ham protein oranı ortalaması %17.80 olarak saptanmıştır. Araştırmada karışım haldeki ekimlerde İskenderiye üçgülü oranı artıkça ham protein oranında da artış olduğu görülmüş olup yapmış olduğumuz araştırma ile benzerlik göstermektedir (Polat ve ark., 2021).

3.7. Ham protein verimi

Her parselde kuru ot saptanması amacı ile alınan ve kurutulan ot örneklerinde Kjehldal yöntemine göre azot analizi yapılmıştır. Örneklerde saptanan % azot değerleri 6.25 katsayısı ile çarpılarak her örnekteki % ham protein içeriği hesaplanmıştır. Saptanan ham protein içeriği değeri parselin kuru ot verimi ile çarpılarak ham protein verimi ve gerekli dönüşümler yapılarak dekara ham protein verimi hesaplanmıştır.

Tablo 9. Tür ve karışımlarda gelemen üçgülü ile İtalyan çimine ait ham protein verimi (kg/da) ve oluşan gruplar*

	Tür ve Karışımlar	(kg/da)	Harf
1	%80 Gelemen Üçgülü + %20 İtalyan Çimi	164.26	a
2	%60 Gelemen Üçgülü + %40 İtalyan Çimi	148.16	ab
3	%40 Gelemen Üçgülü + %60 İtalyan Çimi	120.56	c
4	%20 Gelemen Üçgülü + %80 İtalyan Çimi	158.80	a
5	%100 İtalyan Çimi	120.73	c
6	%100 Gelemen Üçgülü	131.79	bc
	Ortalama	**140.72**	
	D.K.(%) :	**9.99**	
	LSD (0.05): (karışım uygulaması)	**25.55**	

*) Aynı sütunda benzer harf grubu ile belirtilen ortalamalar, Lsd (%5) değerine göre farklı değildir.

Tablo 9'te görüldüğü üzere Gelemen üçgülü ile İtalyan çimine ait saf ve karşım uygulamasında 2 saf uygulama ve 4 ayrı karışım uygulamasına ait ham protein verimleri ortalaması 140.72 kg/da olarak bulunmuştur. Ham protein verimleri bakımından, 6 farklı

karşım uygulaması arasında farklılığın görüldüğü ve karşım uygulamaları arasında üç farklı grubun oluştuğu tespit edilmiştir. Şanlıurfa koşullarında İtalyan çimi (*Lolium multiflorum* Lam.) ve İskenderiye üçgülü (*Trifolium alexandrium* L.) farklı karışım oranlarının verim ve verim unsurlara etkisini belirlemek amacıyla yapılan çalışmada yalın tür ve karışımların ham protein verimi ortalaması 169.74 kg/da olarak saptanmıştır. Araştırmada karışım haldeki ekimlerde İskenderiye üçgülü oranı artıkça ham protein oranında da artış olduğu görülmüş olup yapmış olduğumuz araştırma ile benzerlik göstermektedir (Polat ve ark., 2021).

4. Sonuçlar

Tarımsal üretimin devamlılığı ve kaynakların israf edilmemesi bakımından elde edilen sonuçlar bir bütün olarak ele alındığında, araştırmada, aynı dönemde yetişen tek yıllık buğdagil yem bitkisi olan İtalyan çimi (*Lolium multiflorum* Lam.*)* ile baklagil yem bitkisi olan tek yıllık Gelemen üçgülü (*Trifolium nigrescens* L.)'nün saf ve farklı oranlardaki karışım uygulamalarından elde edilen yem değerlerine ve verim unsurlarına bakıldığında ortalama yeşil ot ve kuru ot verimlerinin İtalyan çiminin karışım oranlarındaki artışa parallel olarak arttığı, ham protein oranı ve ham protein verimlerinin Gelemen üçgülünün karışımlardaki oranın artışına parallel olarak arttığı tespit edilmiştir. Bu nedenle yüksek yaş ve kuru ot miktarı ile yüksek ham protein oranı ve ham veriminin olabilmesi için karşılıklı olarak buğdaygil yem bitkileri ile baklagil yem bitkilerinin belirli oranlarda karışım olarak yetiştirilmesi teşvik edilmelidir.

Açıklama

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Effect of Ti/Cr Ratio on Wear Performance of (Ti,Cr)N Coatings

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Abstract: The wear performance of CrN, TiN, and (Ti,Cr)N coatings on Cr12MoV steel was thoroughly investigated. This research also delved into the impact of the Ti/Cr ratio within the (Ti,Cr)N coating, as well as the effects of the applied wear test load and sliding speed on the wear behaviour. The wear behaviours in CrN, TiN, and (Ti,Cr)N coatings was sought through the examination of their hardness, steady friction coefficient, and wear rate. TiN coating showed superior hardness compared to CrN. The CrN coating consistently demonstrated the lowest friction coefficient, whereas TiN coating showed the highest. Despite its high hardness, the TiN coating exhibited the highest wear rate due to its high friction. The CrN coating, with lower hardness, showed the highest wear resistance. The hardness of (Ti,Cr)N coatings was significantly influenced by the Ti/Cr ratio. (Ti,Cr)N coatings enabled friction control, and reducing the Ti/Cr ratio led to a decrease in friction coefficients. This, combined with their high hardness, resulted in a notably competitive wear performance.

1. Introduction

Tool steels fulfil a critical role across a diverse spectrum of processes, encompassing the cutting, drilling, and forming of metals. Their unique combination of high mechanical strength, exceptional wear resistance, and the ability to retain hardness even at elevated temperatures makes them indispensable engineering materials across a broad array of applications (Wang et al., 2025). Tool steels are exposed to abrasive and high-pressure applications such as cutting and stamping dies (Trzepieciński, 2023; Mei et al., 2024). To effectively perform their designated tasks in these challenging and varied operational conditions with prolonged lifespan, reliability, and efficiency, tool steels must possess a suite of critical and complementary mechanical and physical properties. Foremost among these is high hardness and strength, which directly dictate the resistance of the material to permanent deformation and mechanical failure under applied cutting and forming forces. Wear resistance, another vital attribute, minimizes material loss during the continuous and repetitive interaction of the tool with the workpiece.

To further enhance the critical properties of tool steels outlined above, optimize their operational performance, and significantly extend their service life, a combination of heat treatments and surface engineering techniques is widely employed (Machado et al., 2024). Surface engineering techniques offer effective and innovative solutions to address surface-related failure mechanisms in tool steels, such as wear and corrosion. Surface modification processes, such as nitriding, carburizing, and various surface coating processes, are increasingly utilized to significantly enhance surface hardness, reduce the coefficient of friction, improve chemical and thermal resistance, and consequently, substantially extend operational performance and service life (Borgioli et al., 2024; Kumar and Choubey, 2024; Kank et al.,

2025). Among these surface engineering processes, one of the most significant and impactful is the precise application of coatings onto the critical working surfaces of tool steels. Executed through various sophisticated methods of physical vapour deposition (PVD) and chemical vapour deposition (CVD), this process imparts desirable properties such as high hardness, low coefficient of friction, superior wear resistance, and improved chemical stability to the tool surface, thereby significantly prolonging tool life and considerably enhancing machining performance (Bhise and Jogi, 2023; Jeje et al., 2025). Within the wide array of coating types employed in the industry, titanium nitride (TiN) and chromium nitride (CrN) coatings are widely preferred coatings due to their well-established performance, relatively reasonable costs, and broad applicability (Ghufran et al., 2020; Yin et al., 2022; Torsakul and Kuptasthien, 2024; Johny and Alphonse, 2024; Liu et al., 2024; Mandri et al., 2025). TiN coatings, owing to their high hardness and generally good wear resistance, provide effective and reliable protection, particularly in applications such as cutting, drilling, and forming operations (Nekouee and Elmkhah, 2018; Singhal et al., 2024). CrN coatings, in contrast to TiN coatings, stand out due to their superior corrosion resistance and generally lower coefficients of friction (Leonov et al., 2023; Narayana and Saleem, 2024). In applications where sliding wear and aggressive corrosive environments are significant factors, CrN coatings can exhibit longer service lives and more reliable operational performance compared to TiN, owing to their reduced friction and enhanced chemical stability (Vera et al., 2011).

Titanium chromium nitride (Ti,Cr)N coatings, which possess the potential to combine the high hardness and general wear resistance characteristics of TiN with the superior corrosion resistance and low coefficient of friction advantages of CrN, have garnered increasing interest through intensive research and development efforts (Uglov et al., 2011; Hangwei et al., 2014; Akbarzadeh et al., 2015; Poursaiedi et al., 2016). It is anticipated that (Ti,Cr)N coatings, through the synergistic interaction of titanium and chromium elements, can offer superior and more balanced property combinations compared to binary nitride coatings in specific application scenarios. Therefore, (Ti,Cr)N coatings are emerging as a promising and potentially alternative. In this context, it is understood that the titanium/chromium (Ti/Cr) ratio, which can be precisely controlled during the coating process, plays a critical and decisive role in determining the properties of (Ti,Cr)N coatings (Taweesup et al., 2019; Mohapatra and Oh, 2025). Variations in this ratio directly influence the microstructure of the coating, and consequently, its mechanical and tribological properties. Consequently, a systematic investigation into the effect of the Ti/Cr ratio on the coating properties is of critical importance for achieving the optimal (Ti,Cr)N coating design for a specific application.

This study investigated the wear behaviour of (Ti,Cr)N coatings with varying ratios of titanium and chromium deposited onto a commercially widely used tool steel substrate. The tribological performance of (Ti,Cr)N coatings with different Ti/Cr ratios will be compared with the wear performance of TiN and CrN coatings, aiming to elucidate the fundamental effects of the Ti/Cr ratio on the tribological properties and potential performance advantages of (Ti,Cr)N coatings. The findings of this research are expected to provide a significant body of knowledge for the potential applications of (Ti,Cr)N coatings and contribute to a deeper understanding of the role of this advanced coating type in enhancing the performance of tool steels. The results obtained are anticipated to provide guidance for the future design and development of higher-performance tool steel coatings tailored for specific applications.

2. Materials and Methods

Table 1 presents the elemental compositions of the CrN, TiN, and (Ti,Cr)N coatings with different Ti/Cr ratios, which were deposited onto the Cr12MoV steel substrate using physical vapour deposition.

Table 1. Chemical compositions (wt.%) of CrN, TiN, and (Ti,Cr)N coatings with different Ti/Cr ratios

Coating	Ti/Cr ratio	Chemical composition (wt.%)		
		Cr	Ti	N
CrN		49.35	–	50.65
TiN		–	50.61	49.32
(Ti,Cr)N	1.34	17.96	23.84	58.20
(Ti,Cr)N	1.07	20.10	21.49	58.41
(Ti,Cr)N	0.68	29.83	20.75	49.42

The hardness of the CrN, TiN, and (Ti,Cr)N coatings was evaluated using a Vickers microhardness tester. All tests were conducted at room temperature following the ASTM E384 standard. A diamond indenter with a square-based pyramidal shape and an angle of 136° was used to create indentations on the coated surfaces. For each coating type, a minimum of ten indentations were performed to ensure the reliability of the results. A test load of 50 gf was applied for a dwell time of 15 seconds. This specific load and dwell time were chosen to ensure sufficient indentation depth while minimizing the influence of the substrate material on the hardness measurements. Following the indentation, the lengths of the two diagonals of the resulting square-shaped indentation on the coating surface were measured using the integrated optical microscope of the Vickers hardness tester. The Vickers hardness number (HV) was calculated using the following formula (Eq. (1)):

$$\mathrm{HV} = \frac{2F\sin(\frac{136^\circ}{2})}{d^2} \quad (1)$$

where HV is the Vickers hardness number, F is the applied test load. The applied load was converted to kilograms-force for the calculation. d is the arithmetic mean of the lengths of the two diagonals of the indentation in millimetres.

To gauge the resistance to wear exhibited by CrN, TiN, and (Ti,Cr)N coatings applied to Cr12MoV steel substrates, a ball-on-disc tribometer was employed (Figure 1), adhering to the guidelines outlined in the ASTM G99 standard. Wear tests were carried out in a dry sliding regime at a load of 10 N, a speed of 0.3 m/s, and a sliding distance of 500 meters under the ambient atmospheric conditions. The opposing contact element consisted of a 6 mm diameter ball from tungsten carbide. Prior to the commencement of each wear test, both the coated specimen and the ball underwent a cleaning process to eliminate any potential surface contaminants that could influence the frictional and wear response. This cleaning procedure involved immersion in an ultrasonic bath containing analytical grade ethanol.

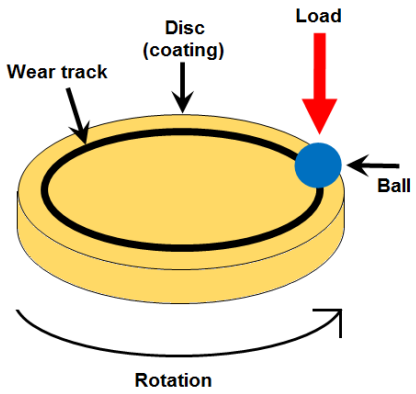

Figure 1. Schematic illustration of the ball-on-disc test

The steady-state friction coefficient was determined by averaging the instantaneous friction coefficient values recorded during the stable portion of the test. Typically, an initial run-in period is observed where the friction coefficient may fluctuate before stabilizing. Therefore, data from this initial run-in phase were excluded from the calculation. The average steady coefficient of friction was then calculated over the remaining steady-state region of the test. Each test was repeated a minimum of three times.

Following the evaluation of the wear test results, the wear behaviour of (Ti,Cr)N coatings with a Ti/Cr ratio of 0.68 was thoroughly investigated under varying loading and sliding speed conditions. An experimental design was strategically implemented to dissect the impact of two variables (factors): the applied normal load (5 N, 10 N, and 15 N), and the sliding speed (0.1 m/s, 0.3 m/s, and 0.5 m/s) with each test conducted at a sliding distance of 500 meters. To study the statistical significance of the parameters (factors) on wear behaviour of the (Ti,Cr)N coating with Ti/Cr ratio of 0.68, the statistical Design-Expert software was employed as the principal analytical platform for analysing of variance (ANOVA). This software not only facilitated the identification of statistically significant factors, but also enabled a granular investigation into the individual and interaction effects of the load and sliding speed on the wear characteristics of (Ti,Cr)N-coated Cr12MoV steel.

3. Results and Discussion

The Vickers hardness of TiN, CrN, and (Ti,Cr)N coatings with different Ti/Cr ratios of 1.34, 1.07, and 0.68 was evaluated in this study. The measured hardness values provide crucial insights into the resistance to localized plastic deformation, a key indicator of wear performance for these coatings.

Figure 2 depicts the hardness variation of TiN, CrN, and (Ti,Cr)N coatings with different Ti/Cr ratios. TiN coating demonstrated a higher hardness compared to CrN coating. The difference in hardness between these two coatings can be attributed to variations in their bond strengths and crystal structures (Zhang et al., 2018; Leonov et al., 2023).

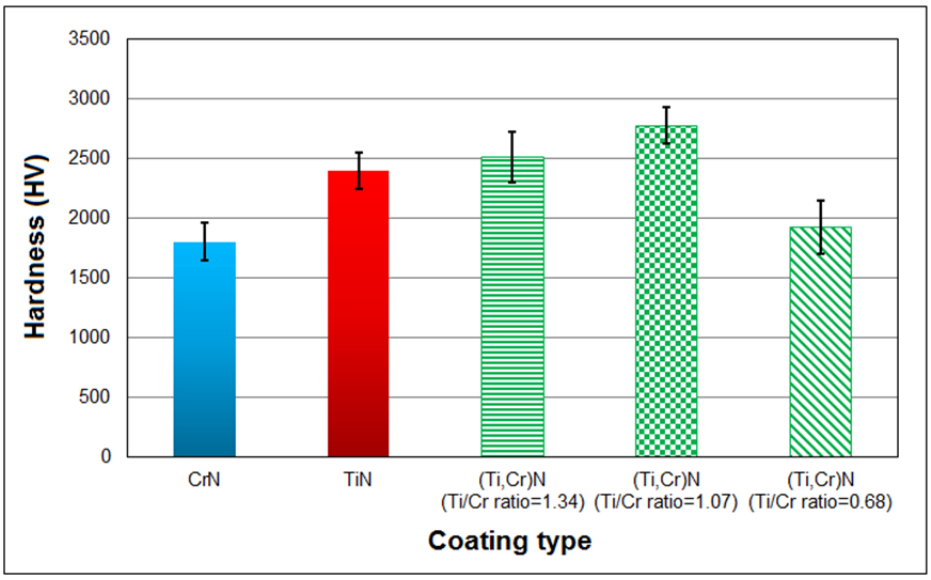

Figure 2. Vickers hardness values of TiN, CrN, and (Ti,Cr)N coatings with different Ti/Cr ratios (1.34, 1.07, and 0.68)

The (Ti,Cr)N coating with a Ti-rich composition (Ti/Cr = 1.34) exhibited a higher hardness than that of the TiN coating. The (Ti,Cr)N coating with a Ti/Cr ratio (1.07) displayed the highest hardness among the investigated compositions. Conversely, the (Ti,Cr)N coating with a Cr-rich composition (Ti/Cr = 0.68) exhibited the lowest hardness among (Ti,Cr)N

coatings studied. While the addition of Ti into the CrN lattice still induces some solid solution strengthening, the overall hardness remains closer to that of CrN. This suggests that at this specific composition, the influence of the CrN matrix and the level of lattice distortion achieved by the relatively lower titanium content may have resulted in a hardness value that is improved compared to pure CrN but does not reach the levels observed at higher Ti/Cr ratios. These findings indicate the significant role of chemical composition in tailoring the mechanical properties of (Ti,Cr)N coating. The observed trend demonstrates the enhancing the hardness of TiN by the incorporation of chromium, with the most pronounced effect achieved at a Ti/Cr ratio of 1.07.

The dry sliding friction behaviour of coatings is a critical aspect for many industrial applications, and the selection of the coating material significantly influences the overall tribological performance. Figure 3 shows the average steady coefficient of friction of TiN, CrN, and (Ti,Cr)N coatings with different Ti/Cr ratios. As seen in Figure 3, the TiN coating exhibited the highest average steady coefficient of friction. In contrast, the CrN coating demonstrated a significantly lower friction coefficient. This performance can be attributed to the formation of chromium oxide at the sliding interface (Zhou et al., 2000). The (Ti,Cr)N coatings revealed a compelling trend where the friction coefficient systematically decreased as the Ti/Cr ratio decreased, as illustrated in Figure 3. Compared to the TiN coating, the lower friction coefficient observed for the (Ti,Cr)N with a Ti/Cr ratio of 1.34 can be attributed to the beneficial effect of chromium in forming lubricating oxides. However, this effect was likely somewhat diluted by the greater titanium content. A decrease in the Ti/Cr ratio to 1.07 resulted in a lower friction coefficient. This indicates a more balanced contribution from both titanium and chromium. The lowest friction among the (Ti,Cr)N coatings was observed with a Ti/Cr ratio of 0.68 (Cr-rich). This result is notably close to that of CrN coating. These findings demonstrate that while TiN had the highest average steady coefficient of friction, CrN, on the other hand, provided superior low-friction characteristics. (Ti,Cr)N coatings offered a remarkable ability to tailor tribological performance through precise control of the Ti/Cr ratio. Decreasing the Ti/Cr within the (Ti,Cr)N consistently led to a reduction in the average steady coefficient of friction for the (Ti,Cr)N coating.

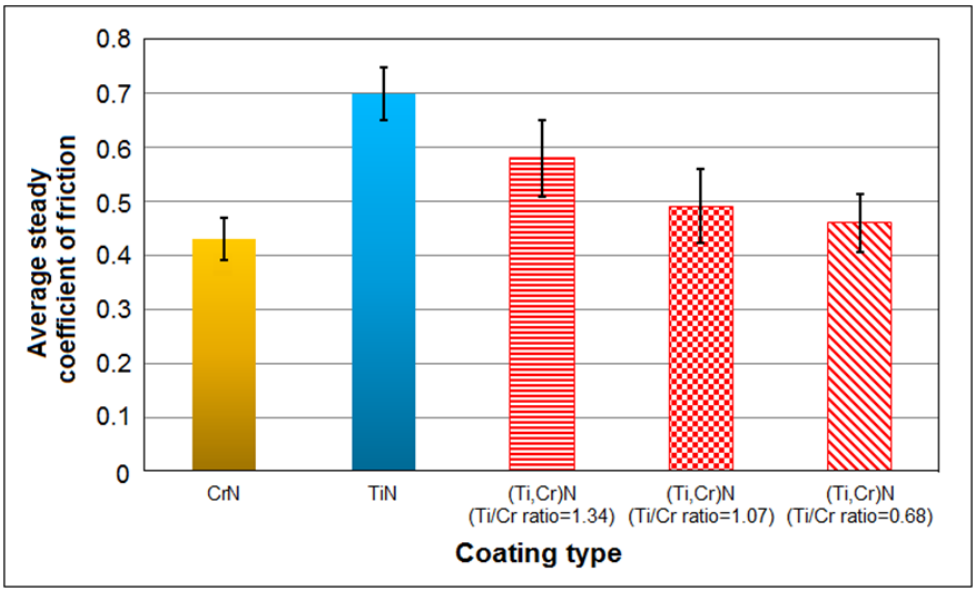

Figure 3. Average steady coefficient of friction of TiN, CrN, and (Ti,Cr)N coatings with different Ti/Cr ratios (1.34, 1.07, and 0.68)

Figure 4 illustrates the wear rate of TiN, CrN, and (Ti,Cr)N coatings with different Ti/Cr ratios. The observed trends in wear rates (Figure 4) directly correlated with the friction

coefficient (Figure 3), providing a unified perspective on the tribological performance of the coatings. Generally, lower friction indicates reduced energy dissipation as heat and less material removal, thus leading to a lower wear rate (Bhushan, 2013).

Although it possessed the highest hardness (Figure 2), the TiN coating also exhibited the highest coefficient of friction (Figure 3), and consequently, the highest wear rate (Figure 4). The CrN coating, which exhibited a low friction coefficient, demonstrated a lower wear rate than the TiN coating (Figure 4), despite having a lower hardness. It can be due to the fact that the Cr_2O_3 film formed during sliding provides the effective protective barrier (Li et al., 2025), profoundly minimizing material loss and surpassing the performance of TiN.

The wear rates of (Ti,Cr)N coatings with Ti/Cr ratios of 1.34 and 1.07 were higher than that of the CrN coating but lower than the TiN coating, even though they possessed higher hardness than the CrN coating. This result indicates that there is no direct correlation between the hardness and the wear resistance of these coatings. On the other hand, the wear resistance of the (Ti,Cr)N coating with a Ti/Cr ratio of 0.68 was very close to that of the CrN coating. While titanium generally has a less effective influence on wear resistance compared to chromium, which could lead to lower wear resistance in (Ti,Cr)N coatings than in CrN, the slightly higher hardness of the (Ti,Cr)N coating with a Ti/Cr ratio of 0.68 compared to CrN may have compensated for this disadvantage. These results indicate that there is no direct relationship between the hardness and the wear resistance of the coatings studied. However, optimizing the Cr content within (Ti,Cr)N coatings, even at the expense of peak hardness, proves to be an effective strategy for achieving superior tribological performance.

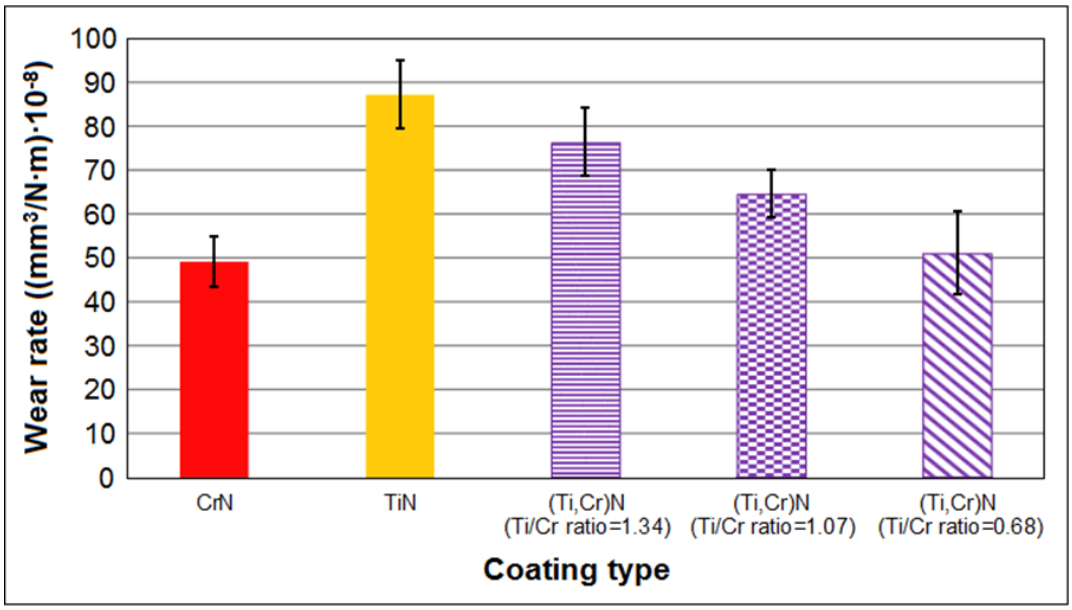

Figure 4. Wear rate of CrN, TiN, and (Ti,Cr)N coatings with Ti/Cr ratios of 1.34, 1.07, and 0.68

The findings show that the wear resistance of (Ti,Cr)N coating with a Ti/Cr ratio of 0.68 is competitive with CrN coating; therefore, the wear behaviour of (Ti,Cr)N coatings with a Ti/Cr ratio of 0.68 under varying loading and sliding speed conditions was investigated. An experimental design was implemented to dissect the influence of load and sliding speed (Table 1). A 2-factor, 3-level full factorial experimental design with five replicates was used. Following the experimental studies conducted according to the design, a statistical investigation utilized regression analysis and ANOVA to evaluate the significance of load, sliding speed, and their interaction effect on the wear rate.

Table 1. Experimental design and the wear rate results of (Ti,Cr)N coating with a Ti/Cr ratio of 0.68 as a function of load and sliding speed

Number of experiment	Coded value		Actual value		Wear rate ($(mm^3/N \cdot m) \cdot 10^{-8}$)
	Load	Sliding speed	Load (N)	Sliding speed (m/s)	
1	−1	−1	5	0.1	29.19
2	−1	0	5	0.3	33.81
3	−1	1	5	0.5	40.77
4	0	−1	10	0.1	42.22
5	0	0	10	0.3	51.13
6	0	0	10	0.3	52.05
7	0	0	10	0.3	51.87
8	0	0	10	0.3	50.90
9	0	0	10	0.3	51.94
10	0	1	10	0.5	63.66
11	1	−1	15	0.1	48.43
12	1	0	15	0.3	75.08
13	1	1	15	0.5	98.24

To estimate pure error, experiments numbered from 5 to 9 were replicated at the central levels of load and sliding speed. The regression model performed well, as evidenced by its high coefficients of determination. For the (Ti,Cr)N coating with a Ti/Cr ratio of 0.68, the R^2 value was a remarkable 0.9911. This means that 99.11% of the variations in wear rate can be statistically explained by the factors (load, sliding speed) and their interaction for the (Ti,Cr)N coating (Ti/Cr ratio 0.68). The ability of a model to predict improves significantly as its R^2 value gets closer to 1 (Chicco et al., 2021). Delving deeper into its fit, the adjusted R^2 for this coating was 0.9848. This value provides a more realistic view of the explanatory power of the model by accounting for the number of predictors. Moreover, the predicted R^2, which estimates how well the model will predict new data, stood at 0.9140 for the (Ti,Cr)N coating (Ti/Cr ratio 0.68).

The statistical significance of the developed regression model was thoroughly evaluated using Analysis of Variance (ANOVA), with the results summarized in Table 2. The model proved to be highly significant ($p < 0.0001$, $F=156.73$), indicating its strong ability to explain the observed variation in the response variable. A detailed examination of the individual factors revealed that both load ($F=472.62$, $p < 0.0001$) and sliding speed ($F=232.95$, $p < 0.0001$) had a highly significant impact on the response. Furthermore, the interaction effect (Load×Sliding speed) between load and sliding speed also demonstrated significant influence ($F=74.44$, $p < 0.0001$). This suggests that the effect of one factor on the response is dependent on the level of the other. Conversely, the quadratic terms, Load×Load ($p=0.1643 > 0.05$) and Sliding speed×Sliding speed ($p=0.6841 > 0.05$), were not statistically significant. This indicates that a linear relationship with respect to these individual factors adequately captures their contribution to the model within the experimental range, without requiring higher-order polynomial terms for their individual effects.

The Lack of Fit test was also found to be significant ($p=0.0019$, $F=40.33$), implying that the current model may not perfectly describe the experimental data and some unknown variability might still exist, or that a more complex model might provide a better fit. However, given the overall high significance of the model and the strong individual factor effects, the model remains a robust descriptor of the main relationships.

Table 2. Analysis of variance (ANOVA) for wear rate depending on the factors of load and sliding speed for (Ti,Cr)N coating with a Ti/Cr ratio of 0.68

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3846.50	5	769.30	156.73	< 0.0001	significant
Load	2319.88	1	2319.88	472.62	< 0.0001	
Sliding speed	1143.47	1	1143.47	232.95	< 0.0001	
Load×Sliding speed	365.38	1	365.38	74.44	< 0.0001	
Load×Load	11.84	1	11.84	2.41	0.1643	
Sliding speed× Sliding speed	0.8838	1	0.8838	0.1801	0.6841	
Residual	34.36	7	4.91			
Lack of Fit	33.26	3	11.09	40.33	0.0019	significant
Pure Error	1.10	4	0.2749			
Cor Total	3880.86	12				

The developed regression model, presented in coded factors (Table 1), quantifies the relationship between the independent variables and the wear rate. The model equation (Eq.(2)) to predict the wear rate of (Ti,Cr)N coating (Ti/Cr ratio 0.68) depending on load and sliding speed is given below:

$$\text{Wear rate} = 51.81 + 19.66 \cdot A + 13.80 \cdot B + 9.56 \cdot A \cdot B + 2.07 \cdot A^2 + 0.5657 \cdot B^2 \qquad \text{Eq.(2)}$$

Where A represents the coded value of load and B represents the coded value of sliding speed (Table 1). The equation reveals the distinct contributions of individual factors and their combined interactions. The positive coefficients for A (+19.66) and B (+13.80) indicate that both load and sliding speed increase the wear rate; an increase in either factor leads to a higher wear rate. The significant positive coefficient for the interaction term A·B (+9.56) suggests that the combined effect of load and sliding speed is more than just additive, meaning the influence of one factor is amplified by the presence of the other. The quadratic terms, A^2 (+2.07) and B^2 (+0.5657), while having smaller coefficients, indicate a slight curvature in the response surface.

Figure 5 presents a scatter plot where the predicted wear rate values demonstrate strong agreement with their experimental results. The close alignment of the actual data points with the regression line confirms the excellent fit of the model.

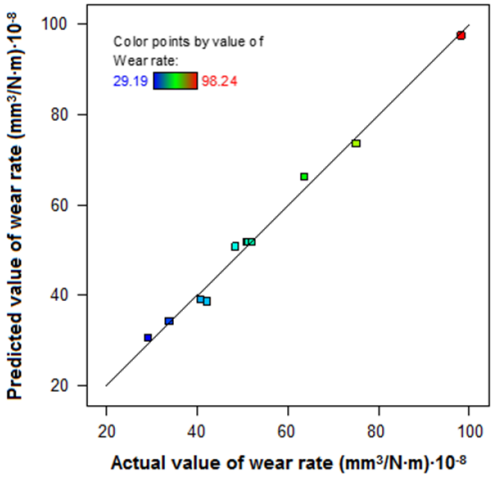

Figure 5. Correlation graph between the predicted and actual (experimental) values of wear rate of the (Ti,Cr)N with a Ti/Cr ratio of 0.68

Figure 6 illustrates the main impact of both load and sliding speed on the wear rate of (Ti,Cr)N with a Ti/Cr ratio of 0.68. The wear rate increased with both load and sliding speed, with a more pronounced effect observed at higher values of each. Notably, load exerted a more substantial influence on the wear rate than sliding speed. This trend is much more clearly observed in the three-dimensional response surface curve and two-dimensional contour plot presented in Figure 7(a) and (b), respectively.

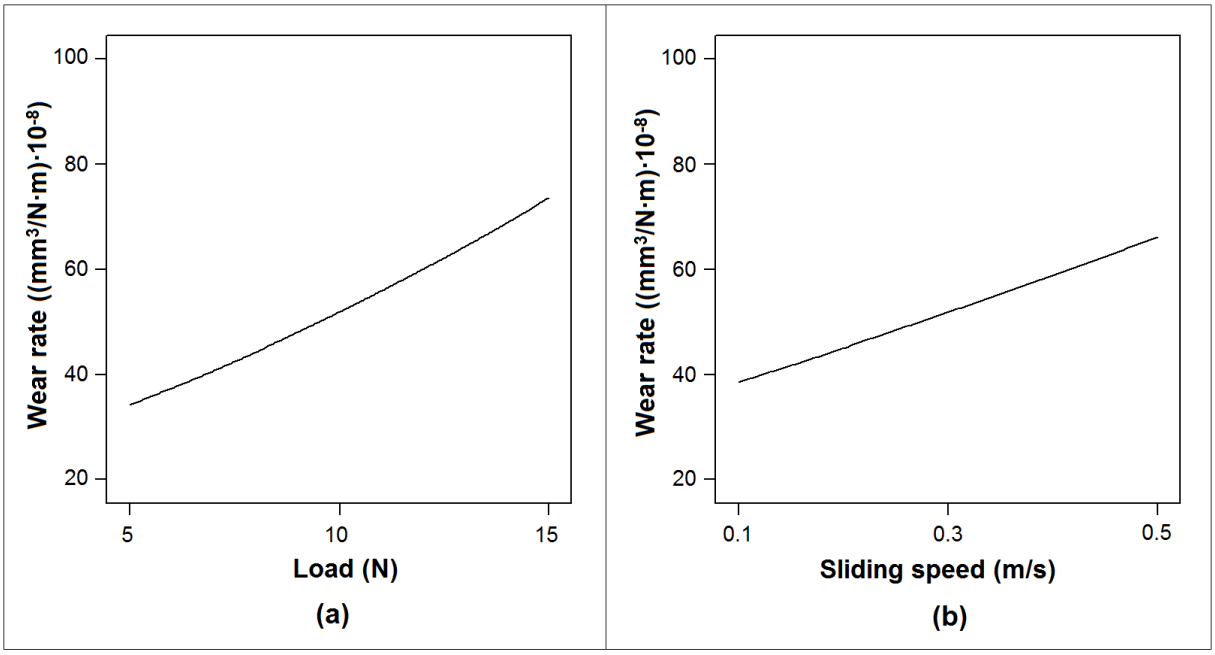

Figure 6. Main effect of **(a)** load and **(b)** sliding speed on the wear rate of the (Ti,Cr)N with a Ti/Cr ratio of 0.68

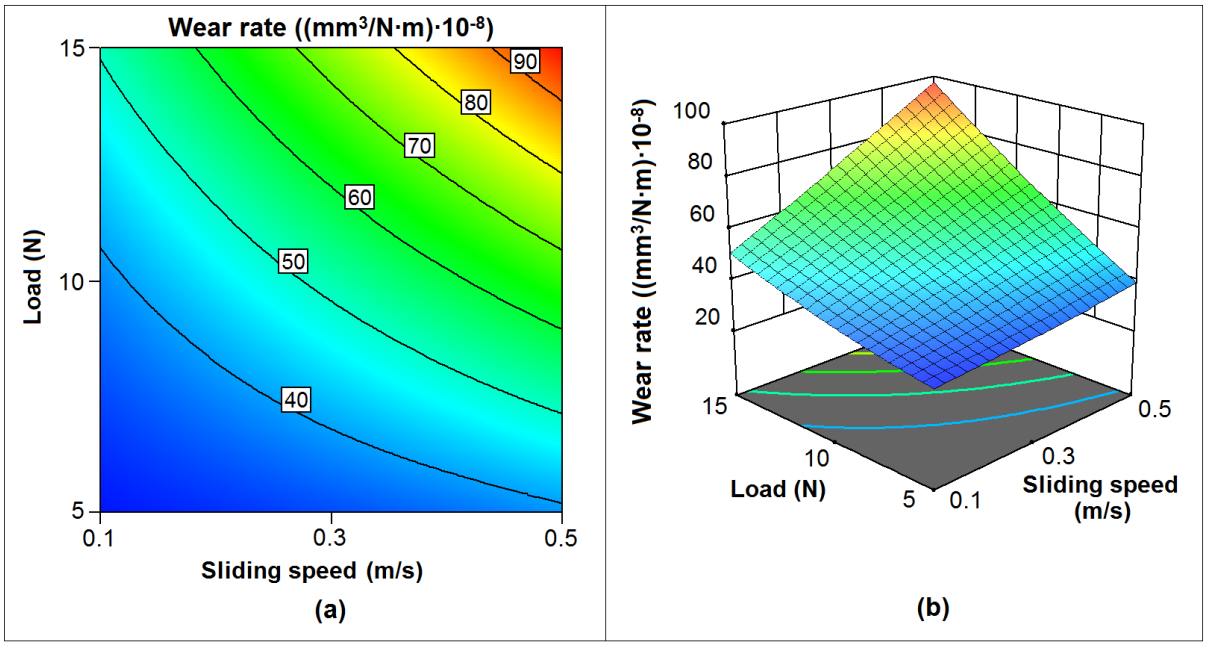

Figure 7. (a) Two-dimensional contour plot and **(b)** Three-dimensional response surface plot showing the interaction effect between load and sliding speed on the wear rate of (Ti,Cr)N with a Ti/Cr ratio of 0.68

4. Conclusions

The wear properties of CrN, TiN, and (Ti,Cr)N coatings with a different Ti/Cr ratios was investigated in this study. The results are presented below:

(1) TiN coating demonstrated higher hardness than CrN coating. For (Ti,Cr)N coatings, the hardness was highly dependent on the Ti/Cr ratio. This suggests a synergistic effect of combining titanium and chromium.

(2) CrN coating exhibited the lowest friction coefficient. Conversely, TiN coating showed the highest friction. (Ti,Cr)N coatings allowed for precise control over friction, with coefficients systematically decreasing as the Ti/Cr ratio was reduced. The Cr-rich (Ti,Cr)N coating (Ti/Cr = 0.68) achieved a friction coefficient remarkably close to that of CrN coating.

(3) The findings indicate no direct relationship between the hardness and wear rate of the coatings studied; however, observed wear rates correlated with the average steady coefficient of friction. Despite its high hardness, TiN coating exhibited the highest wear rate due to its high friction. While CrN coating, with its lower hardness, showed superior wear performance. For (Ti,Cr)N coatings, wear resistance improved with increasing Cr content.

(4) Furthermore, a detailed statistical analysis of the (Ti,Cr)N coating with a Ti/Cr ratio of 0.68 confirmed its promising wear behaviour. A robust regression model, validated by high R^2 values and significant ANOVA results, demonstrated that both load and sliding speed, as well as their interaction, significantly influence the wear rate. Higher values of load and sliding speed led to more pronounced increases in wear.

The results highlight the significant potential for tuning the Ti/Cr ratio in (Ti,Cr)N coatings, which directly impacts their tribological behaviour and offers a means to achieve specific wear characteristics for various applications.

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İç Mekan Süs Bitkileri Üretiminde Topraksız Tarım

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Anahtar Kelimeler
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Özet: İç mekan süs bitkileri, hayatımızı sürdürdüğümüz çoğu ortamda bulunan bitkilerdir. İç mekan süs bitkilerinde birbirlerinden çok farklı yaprak, çiçek ve gövde özelliklerine sahip bitki türleri bulunmaktadır. İç mekan süs bitkileri üretiminin her aşamasında, topraksız tarım kolaylık sağlamaktadır. Topraksız tarımda kullanılan katı ortamlar, köklendirme ile tohum çimlendirme ve fide üretim ortamı olarak çok fazla kullanılmaktadır. Katı ortam dediğimiz substrat kültürü organik ve inorganik katı ortam olmak üzere ikiye ayrılır. Organik katı ortamlar; torf, hindistancevizi kabuğu (cocopeat), yanmış pirinç kabukları, ağaç kabukları, talaş, bitki yaprakları gibi birçok organik maddeyi kapsamaktadır. İnorganik katı ortamlar, kaya yünü (rockwool), cam yünü, perlit, kum, pomza taşı, volkanik tüf gibi birçok inorganik maddeleri kapsamaktadır. Katı ortamların yanı sıra, su kültürü de süs bitkileri üretiminde yaygın olarak kullanılmaktadır. Katı ortam veya su kültüründe kullanılacak besin çözeltisi de oldukça önemlidir. Besin çözeltisi hazırlanırken, besin elementi kaynaklarının EC ve pH değeri, kullanılan suyun EC değerine ve kimyasal bileşimlere göre değişebilmektedir. Bu değerler, üretim yapılacak iç mekan süs bitkilerine göre farklılık gösterebilmektedir.

Soilless Agriculture in Indoor Ornamental Plant Production

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Abstract: Indoor ornamental plants are plants found in most environments we live in. There are plant species with very different leaf, flower and stem characteristics in indoor ornamental plants. In every stage of indoor ornamental plant production, soilless agriculture provides convenience. Solid media used in soilless agriculture are widely used as rooting, seed germination and seedling production media. Substrate culture, which we call solid media, is divided into two as organic and inorganic solid media. Organic solid media include many organic substances such as peat, coconut shells (cocopeat), burnt rice hulls, tree barks, sawdust, plant leaves. Inorganic solid media include many inorganic substances such as rockwool, glass wool, perlite, sand, pumice stone, volcanic tuff. In addition to solid media, water culture is also widely used in ornamental plant production. The nutrient solution to be used in solid media or water culture is also very important. When preparing the nutrient solution, the EC and pH values of the nutrient element sources may vary depending on the EC value of the water used and the chemical compositions. These values may vary depending on the indoor ornamental plants to be produced.

1. Giriş

İç mekân süs bitkileri, ev, ofis ve kapalı alan düzenlemelerinde yaygın olarak kullanılmaktadır. Bu bitkilerin üretiminde geleneksel olarak toprak kullanılmakla birlikte, son yıllarda ticari üretimde topraksız tarım sistemlerinin kullanımı artış göstermektedir. Topraksız

tarım, özellikle toprak kaynaklı yabancı ot, hastalık ve zararlıların önlenmesi, su ve besin maddelerinin daha verimli kullanılması gibi avantajları nedeniyle tercih edilmektedir.

Topraksız tarım uygulamalarında katı ortam kültürü (substrat kullanımı) ve su kültürü olmak üzere iki temel sistem ön plana çıkmaktadır. Bu sistemlerde, bitkilerin beslenmesi tamamen dışarıdan kontrollü olarak verilen besin çözeltileriyle sağlanmakta, böylece homojen ve dengeli beslenme ile yüksek verim ve kaliteli üretim mümkün olmaktadır.

Bu çalışmada, iç mekân süs bitkileri üretiminde topraksız tarım sistemlerinin yeri, kullanılan ortam türleri ve besin çözeltilerinin önemi ele alınmıştır. Topraksız tarım sistemleri genel olarak iki temel uygulamaya ayrılmaktadır: Katı ortam (substrat) kültürü ve su kültürü.

2. Katı Ortam Kültürü

İç mekan süs bitkilerinde tohum ekiminden fide üretimine kadar, fide dikiminden gelişim süreci boyunca, katı ortam kültürü yaygın olarak kullanılmaktadır. Katı ortam dediğimiz substrat kültürü organik ve inorganik katı ortam olmak üzere ikiye ayrılır. Organik katı ortamlar; torf, hindistancevizi kabuğu (cocopeat), yanmış pirinç kabukları, ağaç kabukları, talaş, bitki yaprakları gibi birçok organik maddeyi içermektedir. İnorganik katı oryamlar; kaya yünü (rockwool), cam yünü, perlit, kum, pomza taşı, volkanik tüf gibi birçok inorganik maddeyi içermektedir (Sevgican, 1999; Hazar ve Bakır, 2013; Kahraman 2014; Waiba ve ark., 2020; Arumugam ve ark., 2021).

Katı ortam kültüründe en çok tercih edilen torf, perlit, pomza, cocopeat ve bunların belli oranda karıştırılarak kullanılmasıdır.

3. Su Kültüründe Üretim

Su kültürü, bitki köklerinin doğrudan besin çözeltisi içinde yer aldığı, katı ortam kullanılmadan yapılan üretim sistemidir. Durgun su kültürü, besin film tekniği (NFT), derin su kültürü (DWC) ve fasılalı akış sistemleri gibi hidroponik sistemleri kullanılmaktadır. Ancak ofis ve ev gibi iç mekanlarda durgun su kültürü çoğunlıkla tercih edilmektedir.

Su kültüründe, hazırlanan besin çözeltilerinin deliksiz saksılara veya kaplara konularak yapılmaktadır. Saksıya konulan besin çözeltisi, 7 veya 10 gün arayla değiştirilmelidir. Ancak akvaryumda kullanılan hava filtreleri kullanılarak, bu süre 15 ile 18 güne çıkartılır. (Sevgican, 1999; Hazar ve Bakır, 2013; Kahraman 2014; Waiba ve ark., 2020; Arumugam ve ark., 2021).

Uzun süre değiştirilmeyen besin çözeltilerinde, oksijen oranı azaldığı için, oksijensiz solunum başlar. Bu durum bitkilerde, kök boğulmasına neden olur.

4. Topraksız Tarımda İç Mekan Süs Bitkileri Üretimi

İç mekan süs bitkilerinde üretim, tohum, spor, soğan, yaprak sürgün ve kök çelikleriyle, daldırma ve doku kültürü yöntemiyle yapılmaktadır. İç mekan süs bitkileri, gösterişli çiçek, renki yaprakları, sukulent ve kaktüsler olmak üzere sınıflandırılır.

Tablo 1. İç mekan süs bitkilerinde yaygın olarak tercih edilen çiçekli bitkilerden bazıları (Demirbaş, 2010)

Latince Adı	**Türkçe Adı**
Cylamen persicum	Sklamen
Pelergonium x hortorum	Sardunya
Saintpaulia ionantha Wandl	Afrika Menekşesi
Bouganvilla glabra	Gelin Duvağı, Rodos Gülü
Begonia tuberosa	Begonya
Camellia japonica Nois	Kamelya

Tablo 2. İç mekan süs bitkilerinde yaygın olarak tercih edilen yapraklı bitkilerden bazıları (Demirbaş 2010)

Latince Adı	Türkçe Adı
Codraeum juss.	Kroton
Dieffenbachia schott	Difenbahya
Sansevieria Thunb	Peygamber Kılıcı
Monstera schoott	Deve Tabanı
Nephrolepis	Aşk Merdiveni
Ficus L	Kauçuk
Philodendron schoott	Salon Sarmaşığı

Tohumla üretilen ve en çok tercih edilen iç mekan süs bitkilerinden Cylcamen (sklamen) en iyi örneklerden biridir. İç mekan süs bitkilerinde birçok bitki çeşidi tohum yerine çeliklerle üretilirken, tohum ise daha çok ıslah amaçlı çalışmalarda kullanılmaktadır.

4.1.Tohumla üretim

İç mekan süs bitkilerinde, sklamen, kasımpatı, kadife çiçeği, papatya gibi bir kısım bitkiler ticari olarak tohumla üretilir. Bu bitkilerin tohumları, hazırlanan harca ekilerek, tohumdan fide elde edilir.

Begonya, gül, kaktüs çeşitleri, afrika menekşesi gibi diğer bir kısım bitkiler ise ticari olarak gövde, yaprak ve sürgün çelikleriyle fide elde edilir. Bu bitkilerde tohumlar genellikle bilimsel çalışmalarda veya ıslah çalışmalarında kullanılmaktadır.

İç ve dış pazara üretim yapan firmalarda tohum ekim harcı olarak sadece torf veya 2:1 oranda torf + perlit karışımı kullanılmaktadır. Bilimsel çalışma yapan veya hobi olarak üretim yapan üreticiler, diğer katı ortamlarıda kullanmaktadır. Özellikle bilimsel çalışmalarda yeni organik ve inorganik maddelerde üretime katmak amacıyla, tohum ekim harcı olarak denenmektedir.

Büyük çapta üretim yapan, iç ve dış pazara ürün gönderen firmalar tohum ekim harcı için önceden istenen oranda besin katkılı, steril edilmiş torf ve perlit sipariş verilerek temin etmektedirler. Alınan torf ve perlit tohum ekimi yapılacak tüplere, viyollere %100 torf veya torf ve perlit karışımı şeklinde doldurulur. Doldurulan viyol ve tüplere tohum ekimi yapılır. Yapılan tohum ekiminden sonra hazırlanan besin çözeltisiyle yağmurlam sulama veya sisleme şeklinde sulama yapılır. Çimlenen tohumlar, fide durumuna geldiğinde, asıl saksılarına alınarak üretim sürecine devam edilir.

4.2. Sporla üretim

Paşa kılıcı gibi çiçeksiz süs bitkiler sporlar ile üretilir. Spor, tek hücreden oluşmuş nemli ortamlarda yaşayan ve yaprakların alt yüzeyinde meydana gelen oluşumlardır. Spor kesesi içinde yer alan bu sporlar kesenin olgunlaşıp patlaması ile etrafa yayılarak uygun ortam bulunca çimlenerek gelişmeye başlar. Sporlar özel ortamlarda çimlendirilir. Bu amaçla 1:1 oranında torf ve perlit karışımı gibi steril edilmiş hafif ortamlar kullanılmaktadır (Demirbaş 2010).

4.3. Soğanla üretim

Lale ve sümbül gibi kesme çiçek olan ve iç mekan süs bitkisi olarakta evleri süsleyen bitkilerin üretiminde kullanılır.

Süs bitkilerinde lale ve sümbül gibi soğanlı bitkilerin soğanlarının direk veya katı ortam kültüründe dikilmesi şeklinde yapılır. Özellikle sadece torf veya 2:1 oranında torf ve perlit karışımının doldurulduğu tüplere soğan dikimi yapılır. Soğan dikimi yapılırken, embriyonun bulunduğu sivri olan uç kısım, tüpün üst kısmına ve soğanın kılcal köklerin oluşacağı kısım ise

tüpün alt kısmına gelecek şekilede dikilir (Demirbaş, 2010; Kazaz, 2017; Faust and Dole, 2021).

4.4. Çelikle üretim

Bitkilerin sürgün ve yapraklarından alınan çelikler kullanılır. Katı ortamlardan özellikle sadece perlit kullanılarak köklendirme yapılmaktadır. Köklendirme küvetlerine, saksılara ve tüplere perlit doldurularak köklendirme yapılır. Köklendirme amacıyla alınan çelikler, boğum kısmından kök oluşumunu teşvik etme amacıyla, köklendirme hormonuna (IBA (indol-3-bütirik asit)) batırılıp üretim parseline 3 - 5 cm aralıklarla dikimi yapılır. Çeliklerin üst kısmında ise tek yapraklı, 2-3 sürgün gözlü çelikler olmalıdır (Doldur, 2008; Kazaz, 2017; Faust and Dole, 2021, Kabay, 2023; Şenol, 2023; Kabay 2025).

Afrika menekşesinden alınan yaprak çelikleri ve paşa kılıcı, katüs gibi bitkilerin yapraksı ve sukulent gövdeden alınan parçalar torf, perlit veya torf ile perlit karışımı ile elde edilen harca yerleşirilerek üretilir. Afrika menekşesi gibi yapraklı çelikler sap kısmından 1-2 cm kadar hazırlanan harca batırılarak dikim işemi yapılır. Sukulent gövdeli kaktüs ve paşa kılıcı gibi bitkiler ise kesilen kısımları, hazırlanan harca 1 cm batırılarak dikim işlemi yapılır. Dikim işlemi bittikten sonra hazırlanan cesin çözeltisi ile sulama işlemi yapılır.

Begonya ve gül gibi bitkilerde üretim, sıklıkla gövde çeliklerinin köklendirilmesiyle gerçekleştirilir. Bu amaçla alınan çeliklerin alt kısımları, yaklaşık 2–3 cm derinliğe kadar hazırlanmış ortama yerleştirilir. Özellikle %100 perlit kullanımı, bu tür bitkilerde kök oluşumunu teşvik ettiği için yaygın olarak tercih edilmektedir. Çeliklerin üst kısımlarnda ise yapraklar koparılır veya sadece 1-2 yaprak bırakılarak perlit ortamına köklendirme amaçlı dikilir. Köklendirme amacıyla dikilen çelikler, besin çözeltisiyle sulanarak sürekli nemli tutulur.

4.5. Daldırma yöntemiyle üretim

Katı ortamlardan, daldırma ile üretim için en çok kullanılan ortam, torf ve torf ile perlit karışımı kullanılır. Torf veya torf ile perlit karışımının doldurulduğu torbalar, kasalar, tüpler veya saksılar daldırma ortamı olarak kullanılır. Daldırılan bitkilerin kısımları (sürgünler), ana bitkiden ayrılmadan ortama daldırılır. Daldırılan sürgünlerin daldırılan kısım ile uç kısım arası 10-20 cm olmalıdır (Doldur, 2008; Kazaz, 2017; Faust and Dole, 2021, Kabay, 2023; Şenol, 2023; Kabay 2025).

Begonya ve gül gibi bitkilerde üretim, daldırma yöntemiylede gerçekleştirilebilir. Üretim için seçilen sürgünlerin boğum bölgeleri hafifçe yaralanarak, torf, perlit veya torf–perlit karışımından oluşan köklendirme ortamına daldırılır ve bu sayede kök oluşumu teşvik edilir.

İç mekanda da kullanılan, kesme çiçek olarak yetiştirilen karanfil gibi bitkilerde, sürgün boğumlarında oluşan filizler, ana sürgünden koparılmadan bağlantı noktasından itibaren hazırlanmış köklendirme ortamına daldırılır. Köklenen filizler, fide olarak üretime hazır hale gelir. Daldırılan sürgün ve filizler, kök oluşumu tamamlanıncaya kadar besin çözeltisi ile sulanarak ortamın sürekli nemli kalması sağlanır.

4.6. Doku kültürü ile üretim

Doku kültüründe bitkilerin değişik organlarından alınan çok küçük parçacıklar steril olan besin jelleri gibi özel ortamlarda çimlendirilip köklendirilmesiyle uygulanan bir çoğaltma yöntemidir. Doku kültürüyle üretilen fideler, steril bitki olduğu için, hassas çalışmalarda ve üretimlerde kullanıldığı gibi ıslah çalışmalarında da çok tercih edilmektedir (Demirbaş 2010).

Doku kültüründe kullanılan bitki kısmına göre meristem, kallus (yara dokusu), anter, polen, embriyo, hücre ve protoplazma kültürü olarak adlandırılır.

Tablo 3. İç mekan süs bitkilerinde doku kültürü yapılan bitki kısımlarından bazıları (Demirbaş 2010)

Bitki Kısımları	İç Mekan Süs Bitkileri
Tohum, Embriyo	Atatürk Çiçeği, Orkide
Çiçek sapı	Çarkıfelek, Begonya, Orkide
Meristem, Sürgün ucu	Orkide, Açelya, Karanfil, Krizantem
Koltukalti tomurcuk	Bromeliadlar, Orkide, Dracena
Yaprak parçaları	Begonya, Crassulali
Yaprak sapı	Begonya, Afrika Menekşesi
Rizom parçaları	Eğreltiler
Soğan pullan, Soğan tablası	Zambak, Lale
Yumru dokusu	Tavşan Kulağı

5. Üretim

İç mekân süs bitkilerinin fideleri, katı ortamla doldurulmuş saksılara aktarılarak üretim sürecine devam edilir. Özellikle büyük ölçekli pazarlara yönelik saksılı süs bitkisi üretiminde, genellikle torf tercih edilmektedir. Üretici firmalar, kullandıkları torfu belirli fiziksel özelliklere ve besin içeriğine göre özel olarak sipariş ederek temin etmektedir.

Katı ortam kullanılarak saksılarda yapılan yetiştiricilikte, tüm iç mekân süs bitkilerinin üretimi gerçekleştirilebilir. Sulama işlemi ise genellikle hazırlanan besin çözeltisi ile birlikte damla sulama yöntemiyle uygulanmaktadır (Demişbaş 2010; Kabay 2025).

Su kültüründe, kök gelişimini tamamlamış ve fide aşamasına ulaşmış iç mekân süs bitkilerinin yetiştiriciliği yapılmaktadır. Bu yöntemde, genellikle deliksiz saksılar kullanılarak bitkiler durgun su kültüründe geliştirilir; besin çözeltisi ise 7–10 gün aralıklarla yenilenir. Durgun su kültürünün yanı sıra, zaman ayarlı olarak besin çözeltisinin dolaşımını sağlayan fasılalı akış sistemleri de üretim amacıyla kullanılmaktadır (Demişbaş 2010; Kabay 2025)..

Katı ortam veya su kültüründe yapılan yetiştiriciliklerde, bitkilerin direk ışık alan veya almayan türlere göre konumlara konulmalıdır. Bunun yanında iç mekan süs bitkilerinin bulunduğu ortamın nem, ışık ve sıcaklık istekleri ve sulama şekilleri, bitkilere göre değişim göstermektedir. Bitkilerin bulunduğu saksılar çok sık olmamalı, hava sirkülasyonun olacağı kadar mesafe olmalıdır.

6. Besin Çözeltisi Hazırlanışı

Topraksız tarımda besin çözeltisi hazırlanırken, besin elementi kaynaklarının kimyasal formülü çok önemlidir. Hazırlanan besin çözeltisinin EC ve pH değeri, kullanılan suyun EC değerine ve kimyasal bileşimlere göre değişmektedir.

Süs bitkisi üretimi için hazırlanan besin çözeltisinde kullanılan suyun EC değeri sıfır veya sıfıra yakın olmalıdır. Saf su cihazlarında üretilen su, sıfır veya sıfıra yakın bir EC' ye sahiptir. Ancak saf su dışındaki kullanılan ve herhangi bir kaynaktan kullanılan suyun EC değeri, suyun tuzluluğuna ve bünyesinde bulundurduğu bileşenlere göre artış gösterebilmektedir. Bu nedenle hazırlanan besin çözeltisinin EC değeri ve pH değeri, üretim yapılan bitkilerin istediği değerlere yakın olmalıdır. Genel olarak topraksız tarımda hazırlanan besin çözeltisinin EC değeri 1.5 - 2.5 mS/cm ve pH değeri ise 5.5 - 6.5 arasında olmalıdır(Sevgican, 1999; Waiba ve ark., 2020; Arumugam ve ark., 2021; Hazar ve Bakır, 2013; Kahraman 2014).

Besin çözeltisi hazırlanırken, bitkinin ihtiyaç duyduğu besin elementlerinin bulunması gerekir. Süs bitkilerinin üretim sürecinde, besin çözeltisi hazırlanırken, bitki için mutlak gerekli makro ve mikro besin elementleri vardır. Makro besin elementleri azot (N), fosfor (P), potasyum (K), kalsiyum (Ca), magnezyum (Mg) ve kükürt (S). bu elementleri, kimyasal kaynaklar kullanılarak belli oranlarda su içine katılarak hazırlanır. Karbon (C), hidrojen (H) ve

oksijen (O) makro elementini bitkiler CO_2 ve H_2O' dan alırlar. Mikro elementler ise bor (B), klor (Cl), bakır (Cu), demir (Fe), mangan (Mn), molibden (Mo) ve Çinko (Zn). Mikro besin elementi besin çözeltisi, kimyasal kaynaklardan gerekli miktarda suya karıştırılarak elde edilir (Sevgican, 1999; Toprak ve Gül, 2013; Waiba ve ark., 2020; Arumugam ve ark., 2021).

Topraksız tarımda bitki üretiminin yapıldığı besin çözeltilerinin örnek reçeteleri Tablo 1, 2 ve 3'te verilmiştir.

Tablo 4. Hoagland besin çözeltisi (Johnson, 1980; Sevgican, 1999)

Stok konsantrasyon	5 litre suya
Potasyumnitrat (KNO_3)	252.88 g
Potasyumdihidrojenfosfat (KN_2PO_4)	144.12 g
Magnezyumsülfat ($MgSO_4$-$7H_2O$)	252.88 g
Borikasit (H_3Bo_3)	1428.57 mg
Mangansülfat ($MnSO_4$-H_2O)	740.74 mg
Çinkosülfat ($ZnSO_4$-$7H_2O$)	105.82 mg
Bakırsülfat ($CuSO_4$-$5H_20$)	26.45 mg
Molibasit (MoO_3-$2H_2O$)	13.22 mg

Tablo 5. Sebzelarin tümü için ortak besin çözeltisi (Benoit, 1992; Sevgican, 1999)

Besin elementi	Konsantrasyon ppm
Azot	150
Fosfor	55
Potasyum	175
Kalsiyum	105
Magnezyum	90
Kükürt	125
Bor	0.008
Demir	1.0
Mangan	0.36
Çinko	0.046
Bakır	0.026
Molibden	0.001

Tablo 6. Topraksız tarımda tüm bitkiler için besin çözeltisi (Anonim, 2025)

Besin Maddesi	100 Litre Suya Miktar
Kalsiyum Nitrat ($Ca(NO_3)_2$)	1.2 g
Potasyum Nitrat (KNO_3)	0.5 g
Monopotasyum Fosfat (KH_2PO_4)	0.3 g
Magnezyum Sülfat ($MgSO_4$)	0.5 g
Potasyum Sülfat (K_2SO_4)	0.3 g
Demir Şelatı (Fe-EDDHA)	4 mg
Borik Asit (H_3BO_3)	0.3 mg
Çinko Sülfat ($ZnSO_4$)	0.1 mg
Manganez Sülfat ($MnSO_4$)	0.5 mg
Bakır Sülfat ($CuSO_4$)	0.05 mg
Sodyum Molibdat (Na_2MoO_4)	0.02 mg

Süs bitkileri için hazırlanacak besin çözeltilerinde kalsiyumnitrat ($Ca(NO_3)_2$) ile Sülfat İçeren kimyasallar ($MgSO_4$, K_2SO_4) ayrı hazırlanmalıdır. Fosfat içeren kimyasallar (KH_2PO_4) ile Kalsiyumnitrat ($Ca(NO_3)_2$) doğrudan karıştırılmamalıdır. Demir Şelatı (Fe-EDDHA, Fe-DTPA) ile Fosfatlı kimyasallar (KH_2PO_4) çökelme oluşturabileceğinden ayrı tutulmalıdır. Bakır ($CuSO_4$) ile demir (Fe) çökelme riski taşır, ayrı verilmelidir (Sevgican, 1999; Toprak ve Gül, 2013; Waiba ve ark., 2020; Arumugam ve ark., 2021; Anonim, 2025).

Topraksız bitki üretim amacıyla hazır olarak satılan A ve B çözeltisi isimli besin çözeltileride vardır. Bu çözeltiler ise 1 litre suya ne kadar verileceği çözelti üstünde yazılıdır. Satın alınan A ve B çözeltileri bitkiye verileceği zaman karıştırılmalıdır. Önceden hazırlanan

besin çözeltilerinde, kimyasal tepkimeler nedeniyle çökelme meydana gelmektedir. Çökelmenin olması ise besin çözeltisinin yarayışlılığını azaltacağı için bitkide besin elementi eksikliği görülmeye başlar.

7. Sonuç

Son yıllarda iç mekân süs bitkisi üretiminde topraksız tarım uygulamaları artış göstermektedir. Topraksız üretim sistemlerinde, bitki türüne özel olarak hazırlanabilen besin çözeltileri, bitkinin ihtiyaç duyduğu makro ve mikro besin elementlerini dengeli şekilde sağlayarak, yüksek verim ve kaliteli ürün elde edilmesine olanak tanımaktadır. pH ve EC değerlerinin hassas biçimde ayarlanabilmesi, özellikle iç mekân koşullarında üretim yapan işletmeler için büyük bir avantajdır.

Topraksız tarım sayesinde iç mekân süs bitkileri, saksı, kasa, balya ya da su kültürü gibi farklı sistemlerde yetiştirilebilmektedir. Bu üretim sistemleri, küçük ölçekli üreticiden büyük sera işletmelerine kadar geniş bir kitleye, üretim kolaylığı sağlamaktadır.

Topraksız tarımın iç mekân süs bitkileri sektörüne entegre edilmesi, yalnızca üretim miktarını artırmakla kalmamış; aynı zamanda bitki sağlığını, estetik değerini ve pazarlanabilirliğini de iyileştirerek iç ve dış ticarete katkı sağlamıştır. Türkiye'nin farklı iklim bölgelerinde uygulanabilirliği sayesinde, bu sistemin ülke genelinde yaygınlaşması mümkündür.

Sonuç olarak, topraksız tarım sistemleri, iç mekân süs bitkileri üretiminde yüksek verim, hijyenik üretim, kaynak verimliliği ve sürdürülebilirlik gibi temel avantajlar sağlamaktadır. Üretimde ve bilimsel çalışmalarda farklı substrat kombinasyonları, otomasyon sistemleri ve üretilen bitkiye özel besin çözeltisi reçeteleri üzerine araştırmalar yapılması, bu alandaki gelişimi daha da hızlandıracaktır.

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Hava Yolu Kargo Operasyonlarında İş Güvenliği Risklerinin Değerlendirilmesi

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Anahtar Kelimeler
İş Güvenliği,
Sivil Havacılık,
Kargo Operasyonları

Özet: Gelişen küreselleşme ve teknolojik gelişmeler doğrultusunda, sivil havacılık sektörü özellikle kargo taşımacılığı alanında kritik bir rol üstlenmektedir. Ancak, operasyonların karmaşıklığı, insan faktörleri ve süreç eksiklikleri gibi unsurlar, iş güvenliği risklerini artırmakta ve sektörde kazalara neden olabilmektedir. Bu çalışma, hava yolu kargo operasyonlarında mevcut iş güvenliği risklerini detaylı bir şekilde analiz ederek, insan faktörleri, süreç hataları ve çevresel koşulların bu riskler üzerindeki etkisini ortaya koymaktadır. Çalışmada, özellikle çok kriterli karar verme yöntemlerinden ARAS ve CIMAS gibi stratejik değerlendirme teknikleri kullanılarak, risk faktörlerinin ve çözüm önerilerinin etkinliği sistematik biçimde ölçülmüştür. Ayrıca, uzman görüşleri ve literatür verileri ışığında, sektörün özgün ihtiyaçlarına uygun risk yönetim modeli geliştirilmiştir. Analizler sonucunda, yükleme, boşaltma ve bakım süreçlerindeki olumsuz olayların çoğunlukla personel hatalarına dayandığı ve denetimlerin, eğitimlerin güçlendirilmesiyle risklerin önemli ölçüde azaltılabileceği ortaya çıkmıştır. Çalışma, bütünsel risk yönetim yaklaşımıyla, sektörde kalıcı ve sürdürülebilir güvenlik kültürünün yaygınlaştırılmasını hedeflemektedir. Bulgular, personel eğitimleri, teknolojik inovasyonlar ve risk odaklı uygulamaların sektör genelinde benimsenmesine yönelik özgün ve pratik rehberlik sağlar niteliktedir. Bu bağlamda, çalışma hem akademik hem de sektörel uygulamalar açısından yeni ve değerli bir katkı sunmaktadır.

Evaluation of Occupational Safety Risks in Air Cargo Operations

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Abstract: With the ongoing globalization and technological advancements, the civil aviation sector, particularly air cargo transportation, has gained critical importance. However, the increasing complexity of operations, coupled with human factors and process deficiencies, elevates occupational safety risks and may lead to accidents within the industry. This study systematically analyzes the current occupational safety risks associated with air cargo operations, highlighting the impacts of human factors, procedural shortcomings, and environmental conditions on risk levels. Employing multi-criteria decision-making methods such as the ARAS and CIMAS techniques, the effectiveness of risk factors and proposed solutions were quantitatively and qualitatively assessed. Furthermore, a comprehensive risk management model tailored to the sector's specific needs was developed based on expert opinions and literature review. The findings indicate that a majority of adverse events during loading, unloading, and maintenance processes stem from personnel errors, and that strengthening safety protocols, training, and supervisory mechanisms can significantly mitigate these risks. The novelty of this work lies in the integration and application of an holistic risk management approach, fostering the dissemination of a sustainable safety culture within the industry. The results provide practical and scholarly guidance for the adoption of personnel training, technological innovations, and risk-oriented practices across the sector. Consequently, this research makes a valuable contribution both academically and practically, establishing a robust framework for enhancing safety and operational reliability in air cargo transportation.

1. Giriş

İnsanlar, tarih boyunca çeşitli sebepler için yer değiştirme ihtiyacı hissetmişlerdir. Sanayileşme dönemiyle birlikte motorlu araçlar icat edilmiş ve modern anlamda seyahat kavramı bu dönemde kullanılmaya başlanmıştır. İlk olarak karayolu, ardından demiryolu ve daha sonrasında denizyolu ile gerçekleştirilen toplu seyahatler ulusal ve uluslararası bir ekonomik faaliyet olarak sistemdeki yerini almıştır. Tüm bunları, özellikle İkinci Dünya Savaşı'nın ardından yeniden canlanan sanayileşme çabalarıyla ve askeri uçakların sivil hava taşımacılığında kullanılmaya başlamasıyla, hava yolu taşımacılığı dördüncü ve son bir ulaşım aracı olarak tamamlandığı görülmektedir. (Akın, 2021)

Sivil havacılığın temel amacı, insanları ve yükleri güvenli, hızlı ve ekonomik bir biçimde bir noktadan başka bir noktaya taşımaktır. Bu çerçevede, sivil havacılık, uluslararası ve ulusal düzeyde hava trafiğinin düzenlenmesi, havaalanlarının işletilmesi, hava yollarının yönetimi ve hava güvenliğinin sağlanması gibi pek çok önemli unsuru kapsar. (Balık, 2015).

Kargo taşımacılığı, sadece ürünlerin fiziksel olarak taşınması değil, aynı zamanda bu süreçteki lojistik yönetimi, ambalajlama, etiketleme ve takip sistemlerini de içinde barındırmaktadır. Kargo taşımacılığında, modern teknolojiye gelen yeniliklerle birlikte dijital çözümler ve otomasyon sistemleri kullanılmakta, bu da süreçlerin daha verimli ve hızlı bir şekilde yönetilmesine olanak tanımaktadır. Kargo takip sistemleri sayesinde gönderilen kargoların anlık olarak nerede oldukları takip edilebilmekte ve bunun sayesinde hem gönderen hem de kargoyu alacak kişiler için büyük bir güvence sağlamaktadır. (Balık, 2015).

İş Sağlığı ve Güvenliği (İSG), herhangi bir işyerinde personelin mesai süresi içerisinde sağlığının korunması ve/veya emniyetli bir şekilde işleri sürdürebilmesi için oluşturulan sistemler bütünüdür. (Yılmaz ve Polat, 2023).

Sivil havacılıkta İSG' nin önemi, çalışanların karşılaştığı farklı risklerden ortaya çıkmaktadır. Bu riskler içerisinde fiziksel tehlikeler (örneğin, yüksek gürültü düzeyleri, ağır yüklerin taşınması), kimyasal tehlikeler (yakıtlar, yağlar ve diğer kimyasallar), psikolojik stres (vardiyalı çalışma, yoğun iş temposu) ve ergonomik tehlikeler (uzun süreli oturumlar, tekrarlayan hareketler) bulunmaktadır (Yılmaz ve Polat, 2023).

Havacılık alanı, uçuş ve yer güvenliğinden ödün vermeden, sıfır kaza kırım amacına erişmek için uçak bakım kuruluşlarına ve bu kuruluşlarda görev yapan bakım çalışanına gereksinim duymaktadır. Faaliyet alanı nedeniyle, en ufak güvensiz bir durumda ve/veya muhtemel bir uçak kazasında insanların tümü ya da çoğunluğu için hayatlarını kaybetme riski taşıdığı gibi havacılık işletmesi ve yapısında bulunan uçak bakım işletmeleri de önemli bir itibar kaybı ve finansal zarara yaşayacaklardır. Havacılık alanı özellikle birçok sektörde hata ve kazaların başlıca nedeni insan etkenleridir. Havacılık sektöründe eskiden insan etkenlerinin kök nedenleri için yapılan araştırmalar özellikle havayolu çalışanları (pilot, kabin personeli vb.) üzerinde inceleme yaparken, günümüzde uçak bakım şirketlerinde bakım hataları üzerine daha fazla odaklanılmaktadır (Kocamış ve Apak, 2024).

6331 sayılı iş sağlığı ve güvenliği kanunu ülkemizde 2012 yılında yürürlüğe girmiştir. Bu sayede iş sağlığı ve güvenliği ile ilgili önlemler almak ve alınan önlemler ile yaşanabilecek iş kazaların önüne geçilmesi amaçlanmıştır. Risk değerlendirmesi proaktif bir yaklaşım olarak 2013 yılında benimsenmiştir. Tehlikelerin riske dönüşme olasılığını hesaplayarak gerekli önleyici ve koruyucu önlemler alınarak kazaların yaşanmadan önlenmesi amaçlanmıştır. Risk analizinin temel prensibi, iş kazaları meydana gelmeden ortamda var olan tehlikelerin zarar verme potansiyelinin hesaplanmasına dayanmaktadır. Tehlikelerin riske dönüşme olasılığını hesaplayarak gerekli önleyici ve koruyucu önlemler alınarak kazaların yaşanmadan önlenmesi

amaçlanmıştır. Risk analizinin temel prensibi, iş kazaları meydana gelmeden ortamda var olan tehlikelerin zarar verme potansiyelinin hesaplanmasına dayanmaktadır (Barut, 2024).

2. Materyal ve Yöntem

2.1. CİMAS yöntemi

Criteria importance assessment (CIMAS) yöntemi kriter ağırlıklarını hesaplamak için kullanılır (Sun, 2025). Yöntemde uzmanların değerlendirmesini kullanarak bir karar verme sürecinde kriterlerin önemi belirlenir. Uzman bilgisi ve deneyimi ile ilgili önemli bir husus, bu yöntemin uzmanların söz konusu alanda geçirdikleri yıllardaki deneyimlerini dikkate almasıdır (Bošković ve ark., 2023).

CIMAS yöntemi 11 adımdan oluşmaktadır. Bu adımlar aşağıdaki gibidir (Bouraima ve ark., 2023):

Adım 1: Kriter tanımı değerlendirmesi: İlk adım, önemi değerlendirmek için kriterleri belirlemektir. Bu kriterler, literatür taraması veya uzman danışmanlığı yoluyla belirlenebilir (Bouraima ve ark., 2023).

Adım 2: Uzman sayısı değerlendirmesi: Karar verici, alandaki uzmanların sayısını değerlendirir ve onların deneyim süresi hakkında veri toplar (Bouraima ve ark., 2023).

Adım 3: Uzman deneyimi değerlendirmesi: Uzmanlar, alanlarındaki deneyimlerini yıl bazında detaylandırır ve karar verici, bu deneyimin önemini belirler (Bouraima ve ark., 2023).

Adım 4: Uzman önem derecesi hesaplaması: Tipik bir senaryoda, uzmanın önemi şu şekilde hesaplanabilir (Denklem (2.1.1) (Bouraima ve ark., 2023)):

$$w^{E_i} = \frac{E_i}{\sum_{i=1}^{q} E_i}, i = 1,2, \dots, q. \quad (2.1.1)$$

Adım 5: Girdi veri matrisi formülasyonu: Bu adım sırasında, bir girdi karar verme matrisi oluşturulur (bkz: denklem (1)) (Bouraima ve ark., 2023).

Adım 6: Girdi veri matrisi normalizasyonu: Girdi veri matrisinin oluşturulmasının ardından, 6. adım veri normalizasyonunu içerir. Bu süreçte, normalizasyon tekniği Denklem (2.1.2)'yi uygulayarak gerçekleştirilir (Bouraima ve ark., 2023).

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{q} x_{ij}}, i = 1,2, \dots, q; j = 1,2, \dots, p. \quad (2.1.2)$$

Adım 7: Uzman ağırlık matrisi hesaplaması: Normalleştirilmiş girdi verileri, adım 4'te uzmanlara atanan ağırlıklarla çarpılır. Hesaplama, Denklem (2.1.3) kullanılarak gerçekleştirilir (Bouraima ve ark., 2023).

$$\widehat{x_{ij}^{*}} = x_{ij}^{*} \cdot W^{E_i}, i = 1,2, \dots, q; j = 1,2, \dots, p, \quad (2.1.3)$$

Adım 8: Her kriterin maksimum ve minimum değerinin hesaplanması: Her kriterin maksimum $\left(\mathrm{R_{j\,max}}\right)$ ve minimum $\left(\mathrm{R_{j\,min}}\right)$ değeri, Denklem (2.1.4) ve (2.1.5) kullanılarak değerlendirilir (Bouraima ve ark., 2023).

$$R_{j\,max} = \underset{i}{max}.\left[\widehat{x_{ij}^{*}}\right], j = 1,2, \dots, p, \quad (2.1.4)$$

$$R_{j\,min} = \underset{i}{min}.\left[\widehat{x_{ij}^{*}}\right], j = 1,2, \dots, p, \quad (2.1.5)$$

Adım 9: Minimum ve maksimum fark değerlerinin hesaplanması: Önceki adımdaki elde edilen minimum ve maksimum değerler arasındaki fark $\mathrm{B_j}$, Denklem (2.1.6) kullanılarak hesaplanır (Bouraima ve ark., 2023).

$$B_j = R_{j\,max} - R_{j\,min}, j = 1,2,\dots,p. \quad (2.1.6)$$

Adım 10: Son sıralama formülü uygulaması yapılır. (Denklem (2.1.7)) (Bouraima ve ark., 2023).

$$L_j = \frac{B_j}{\sum_{j=1}^{p} B_j}, j = 1,2,\dots,p. \quad (2.1.7)$$

Adım 11: Güvenilirlik endeksi (RI) kontrolü: CIMAS gibi öznel yöntemler kullanılırken, uzman yanıtlarının güvenilirliği çok önemlidir. Tutarsızlık oranlarını ölçen Analitik Hiyerarşi Süreci (AHP) yöntemi aksine, CIMAS güvenilirliği değerlendirmek için alternatif bir yaklaşım kullanmaktadır. Bu iki yaklaşım içerir. İlk tur sonuçlarından habersiz olan uzmanların kriterlere %0-100 ölçeğine yüzdelik önem atadığı mülakat turu. İkinci tur görüşmelerden elde edilen yanıtlar olarak P_j, kapağını kullandığımızı varsayalım ve L_j ise daha önceki elde edilen CIMAS ağırlıklarını ifade eder. Bu durumda, güvenirlik endeksi (RI) denklem (2.1.8) aracılığıyla hesaplanabilir (Bouraima ve ark., 2023).

$$RI = \frac{\sum_{j=1}^{n} |F_j * 100 - P_j|}{100}. \quad (2.1.8)$$

2.2. Küresel bulanık kümeler

Bulanık kümeler, dilbilimsel tabanlı yapıları nedeniyle uzman değerlendirmelerinde kullanılmaktadır (Kara ve ark., 2024a).

Bulanık kümelerin Zadeh (1965) tarafından tanıtılması bir ilgi dalgası yaratmış ve çeşitli bilimsel alanlarda yaygın olarak benimsenmesine yol açmıştır (Rahim ve ark., 2025).

Bu yeni model, her derece için farklı terim seviyeleri sunmaktadır (Rahim ve ark., 2025).

p: Üyelik dereceleri (ϑ) için terim seviyesi,

q: Nötr üyelik dereceleri (η) için terim seviyesi,

r: Üyelik dışı dereceleri (φ) için terim seviyesi,

p, q, r-Küresel Bulanık Kümeler SFS (Spherical Fuzzy Set) koşulu aşağıdaki gibi ifade edilebilir.(Rahim ve ark., 2025):

$(\vartheta_T^U(\alpha))^p + (\eta\_T\text{^}U\ (\alpha))^q + (\varphi_T^U(\alpha))^r \ll 1,$

Burada belirtilen p, q ve r herhangi bir pozitif tam sayıdır.

Bu esneklik, üyeliğin, tarafsız üyeliğin ve üye olmamanın belirli özelliklerini daha iyi yakalanabileceğini daha özel bir yaklaşıma olanak tanır. Sonuç olarak, $IV_{(p,q,r)}$SFSs, bulanık bilgiyi temsil etmek için daha uyarlanabilir ve hassas bir çerçeve sunarak, daha geniş bir karar verme senaryosunu etkili bir şekilde modelleme ve çözme yeteneğini artırır. (Rahim ve ark., 2025). Başlangıçta Aralık Değerli Resim Bulanık Kümeleri IVPiFS (Interval-Valued Picture Fuzzy Sets), üyelik, tarafsız üyelik ve üyelik dışı değerlerin toplamının birden küçük veya eşit olması gereken p = q = r = 1 sabit terim seviyelerini kullanır. Bu, karesel değerlere aynı kısıtlamayı uygulayarak p = q = r = 2 ile interval-valued spherical fuzzy set IVSFS' ye dönüşür. Bir sonraki ilerleme, t terim seviyesinin birden büyük veya eşit bir değişken olduğu ve daha fazla esneklik sağlayan Interval-Valued Spherical Fuzzy Sets IV(t)SFS'lerdir. En uyarlanabilir model olan IV(p,q,r) SFSs, her derece için farklı terim seviyelerine izin vererek üyelik, tarafsız üyelik ve üye olmama derecelerine farklı önem seviyeleri atayarak karar vermeye özel bir yaklaşım sağlar (Rahim ve ark., 2025).

Tablo 1. Dilsel değişkenler ve aralık değerli p, q, r-küresel bulanık sayılar arasındaki korelasyon (Rahim ve ark., 2025).

Dilsel Değişkenler	$IV_{(p,q,r)}$spherical fuzzy numbers
Kesinlikle	([0.85, 0.90], [0.05, 0.10], [0.00, 0.10])
Neredeyse kesinlikle	([0.80, 0.84], [0.11, 0.20], [0.11, 0.15])
Büyük ihtimalle	([0.75, 0.80] ,[0.15, 0.25] ,[0.20, 0.30])
Muhtemelen	([0.65, 0.70] ,[0.26, 0.30] ,[0.31, 0.40])
Belki olabilir	([0.55, 0.65] ,[0.31, 0.35] ,[0.41, 0.45])
Belki olabilir	([0.45, 0.54] ,[0.36, 0.40] ,[0.46, 0.55])
Pek muhtemel değil	([0.40, 0.44] ,[0.41, 0.43] ,[0.56, 0.65])
İhtimal dışı	([0.30, 0.39] ,[0.44, 0.46] ,[0.66, 0.75])
Şüpheli bir şekilde	([0.20, 0.29] ,[0.47, 0.50] ,[0.76, 0.80])
Neredeyse hiç	([0.10, 0.19] ,[0.51, 0.53] ,[0.81, 0.85])
Asla	([0.0.5, 0.09] ,[0.54, 0.57] ,[0.86, 0.95])

2.2.1. Aralık değerli küresel bulanık kümelerin tanımları

D ve $\widetilde{\mathfrak{V}}$ sembolü, Denklem (2.2.1.1)'de ifade edildiği gibi IVSF setleri D setinin kapsayıcı çerçevesi içinde işlev görmektedir (Kara ve Ark., 2024b):

$$\widetilde{\mathfrak{V}} = \left\{ \mathfrak{d}, \begin{pmatrix} \left(\beta^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}), \beta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})\right), \\ \left(\gamma^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}), \gamma^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})\right), \\ \left(\delta^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}), \delta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})\right), \end{pmatrix} \mathfrak{d} \in \mathrm{D} \right\}, \qquad (2.2.1.1)$$

burada $0 \leq \beta^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}) \leq \beta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}) \leq 1, 0 \leq \gamma^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}) \leq \gamma^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}) \leq 1$ ve $0 \leq \delta^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}) \leq \delta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d}) \leq 1$. Söz konusu bağlam dahilinde fonksiyonları $\beta^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})$, $\gamma^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})$ ve $\delta^{\mathrm{L}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})$soyut olarak yorumlanabilir alt üyelik derecesini temsil eden kavramlar, alt derece ve tereddüt derecesi sırasıyla daha düşüktür. Bu fonksiyonları $\beta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})$, $\gamma^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})$ ve $\delta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})$ soyut olarak yorumlanabilir sırasıyla üst üyelik derecesini, üst üye olmama derecesini ve üst tereddüt derecesini temsil eden kavramlardır. Bu fonksiyonlar resmi olarak tanımlanırken eşitsizliğinin $0 \leq \left(\beta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})\right)^2 + \left(\gamma^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})\right)^2 + \left(\delta^{\mathrm{U}}_{\widetilde{\mathfrak{V}}}(\mathfrak{d})\right)^2 \leq 1$ D kümesinin üyesi olan tüm $\mathfrak{d}$ elemanları için geçerlidir (Kara ve ark., 2024b).

$\widetilde{\mathfrak{V}}_1 \oplus \widetilde{\mathfrak{V}}_2$= (Kara ve ark., 2024b).

$$\left\{ \left(\begin{array}{c} \left(\begin{pmatrix} \left(\left(\beta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 + \left(\beta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 - \left(\beta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 \left(\beta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 \right)^{1/2}, \\ \left(\left(\beta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 + \left(\beta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 - \left(\beta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 \left(\beta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2 \right)^{1/2} \end{pmatrix}, \\ \left(\left(\left(\gamma^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right) \left(\gamma^{L}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right) \right), \left(\left(\gamma^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right) \left(\gamma^{U}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right) \right) \right), \\ \left(\begin{pmatrix} \left(\begin{pmatrix} \left(1-\left(\beta^{L}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right)^2\right)\left(\left(\delta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2\right) + \\ \left(1-\left(\beta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2\right)\left(\left(\delta^{L}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right)^2\right) - \\ \left(\left(\delta^{L}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2\right)\left(\left(\delta^{L}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right)^2\right) \end{pmatrix}^{1/2}, \\ \left(\begin{pmatrix} \left(1-\left(\beta^{U}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right)^2\right)\left(\left(\delta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2\right) + \\ \left(1-\left(\beta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2\right)\left(\left(\delta^{U}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right)^2\right) - \\ \left(\left(\delta^{U}_{\widetilde{\mathfrak{V}}_1}(\mathfrak{d})\right)^2\right)\left(\left(\delta^{U}_{\widetilde{\mathfrak{V}}_2}(\mathfrak{d})\right)^2\right) \end{pmatrix}^{1/2} \end{pmatrix} \end{array} \right) \mathfrak{d} \in D \right\} \qquad (2.2.1.2)$$

Bir boş olmayan $\mathcal{Y}$ kümesi için, bir $\alpha \in$ Y elemanı için (IVSFS) S şu şekilde ifade edilir (Rahim ve ark., 2025):

$$S = \{\alpha, ([\vartheta_S^L(\alpha), \vartheta_S^U(a)], [\eta_S^L(\alpha), \eta_S^U(\alpha)] \cdot [\varphi_S^L(\alpha), \varphi_S^U(a)]) \mid \alpha \in Y\}, \qquad (2.2.1.1.1)$$

Burada $[\vartheta_S^L(\alpha), \vartheta_S^U(a)] \subseteq [0,1]$,$[\eta_S^L(a), \eta_S^L(a)] \subseteq [0,1]$ ve $[\varphi_S^L(a), \varphi_S^U(a) \subseteq [0,1]$ ve bu bileşenler sırasıyla üyelik, nötr (tarafsız) üye olmama derecelerini temsil eder, öyle ki $0 \leqslant \vartheta_S^L(\alpha) \leqslant \vartheta_S^U(a) \leqslant 1{,}0 \leqslant \eta_S^L(\alpha) \leqslant \eta_S^U(\alpha) \leqslant 1{,}0 \leqslant \varphi_S^L(\alpha) \leqslant \varphi_S^U(a) \leqslant 1$ ve $\left(\vartheta_S^U(a)\right)^2 + \left(\eta_S^U(\alpha)\right)^2 + \left(\varphi_S^U(a)\right)^2 \leqslant 1$, Eğer $\vartheta_S^L(\alpha) = \vartheta_S^U(a), \eta_S^L(\alpha) = \eta_S^U(\alpha)$ ve $\varphi_S^L(\alpha), \varphi_S^U(a)$**ise** IVSFS S, SFS'ye indirgenir.Bir aralık değerli küresel bulanık sayı IVSFNs (Interval-Valued Spherical Fuzzy Number) $([\vartheta_S^L, \vartheta_S^U], [\eta_S^L, \eta_S^U] \cdot [\varphi_S^L, \varphi_S^U])$ olarak gösterilebilir,öyle ki $0 \leqslant \vartheta_S^L \leqslant \vartheta_S^U \leqslant 1{,}0 \leqslant \eta_S^L \leqslant \eta_S^U \leqslant 1{,}0 \leqslant \varphi_S^L \leqslant \varphi_S^U \leqslant 1$ and $\left(\vartheta_S^U\right)^2 + \left(\eta_S^U\right)^2 + \left(\varphi_S^U\right)^2 \leqslant 1$ (Rahim ve ark., 2025).

$\alpha = ([\vartheta_S^L, \vartheta_S^U], [\eta_S^L, \eta_S^U] \cdot [\varphi_S^L, \varphi_S^U])$, $\alpha_1 = \left([\vartheta_{S_1}^L, \vartheta_{S_1}^U], [\eta_{S_1}^L, \eta_{S_1}^U] \cdot [\varphi_{S_1}^L, \varphi_{S_1}^U]\right)$ ve $\alpha_2 = \left([\vartheta_{S_2}^L, \vartheta_{S_2}^U], [\eta_{S_2}^L, \eta_{S_2}^U] \cdot [\varphi_{S_2}^L, \varphi_{S_2}^U]\right)$ herhangi üç IVSFN ise

$$1.\alpha_1 \bigcup \alpha_2 \begin{pmatrix} [\max(\vartheta_{S_1}^L, \vartheta_{S_2}^L), \max(\vartheta_{S_1}^U, \vartheta_{S_2}^U)], \\ [\min(\eta_{S_1}^L, \eta_{S_2}^L), \min(\eta_{S_1}^U, \eta_{S_2}^U)], \\ [\min(\varphi_{S_1}^L, \varphi_{S_2}^L), \min(\varphi_{S_1}^U, \varphi_{S_2}^U)] \end{pmatrix}$$

$$2.\alpha_1 \bigcap \alpha_2 \begin{pmatrix} [\min(\vartheta_{S_1}^L, \vartheta_{S_2}^L), \min(\vartheta_{S_1}^U, \vartheta_{S_2}^U)], \\ [\max(\eta_{S_1}^L, \eta_{S_2}^L), \max(\eta_{S_1}^U, \eta_{S_2}^U)], \\ [\min(\varphi_{S_1}^L, \varphi_{S_2}^L), \min(\varphi_{S_1}^U, \varphi_{S_2}^U)] \end{pmatrix}$$

$$3.\alpha_1 \oplus \alpha_2 =$$

$$\begin{pmatrix} \left[\left(\left(\vartheta_{S_1}^L\right)^2 + \left(\vartheta_{S_2}^L\right)^2 - \left(\vartheta_{S_1}^L\right)^2\left(\vartheta_{S_2}^L\right)^2\right)^{\frac{1}{2}}, \left(\left(\vartheta_{S_1}^U\right)^2 + \left(\vartheta_{S_2}^U\right)^2 - \left(\vartheta_{S_1}^L\right)^2\left(\vartheta_{S_2}^U\right)^2\right)^{\frac{1}{2}}\right], \\ [\eta_{S_1}^U \eta_{S_2}^U, \eta_{S_1}^L \eta_{S_2}^L], \\ \left[\left(\left(1 - \left(\vartheta_{S_1}^L\right)^2\right)\left(\varphi_{S_1}^L\right)^2 + \left(1 - \left(\vartheta_{S_1}^L\right)^2\right)\left(\varphi_{S_2}^L\right)^2 - \left(\varphi_{S_1}^L\right)^2\left(\varphi_{S_2}^L\right)^2\right)^{\frac{1}{2}}, \right. \\ \left. \left(\left(1 - \left(\vartheta_{S_2}^U\right)^2\right)\left(\varphi_{S_1}^U\right)^2 + \left(1 - \left(\varphi_{S_1}^U\right)^2\right)\left(\varphi_{S_2}^U\right)^2 - \left(\varphi_{S_1}^U\right)^2\left(\varphi_{S_2}^U\right)^2\right)^{\frac{1}{2}}\right] \end{pmatrix}$$

$$4.\ \alpha_1 \otimes \alpha_2 =$$

$$\begin{pmatrix} [\vartheta_{S_1}^L \vartheta_{S_2}^L, \vartheta_{S_1}^U \vartheta_{S_2}^U], \left[\left(\left(\eta_{S_1}^L\right)^2 + \left(\eta_{S_2}^L\right)^2 - \left(\eta_{S_1}^L\right)^2\left(\eta_{S_2}^L\right)^2\right)^{\frac{1}{2}}, \left(\begin{matrix}\left(\eta_{S_1}^U\right)^2 + \left(\eta_{S_2}^U\right)^2 -, \\ \left(\eta_{S_1}^L\right)^2\left(\eta_{S_2}^U\right)^2\end{matrix}\right)^2\right]^{\frac{1}{2}}, \\ \left[\left(\left(1 - \left(\eta_{S_2}^L\right)^2\right)\left(\varphi_{S_1}^L\right)^2 + \left(1 - \left(\eta_{S_1}^L\right)^2\right)\left(\varphi_{S_2}^L\right)^2 - \left(\varphi_{S_1}^L\right)^2\left(\varphi_{S_2}^L\right)^2\right)^{\frac{1}{2}}, \right. \\ \left. \left(\left(1 - \left(\eta_{S_2}^U\right)^2\right)\left(\varphi_{S_1}^U\right)^2 + \left(1 - \left(\eta_{S_1}^U\right)^2\right)\left(\varphi_{S_2}^U\right)^2 - \left(\varphi_{S_1}^U\right)^2\left(\varphi_{S_2}^U\right)^2\right)^{\frac{1}{2}}\right] \end{pmatrix}$$

$$5.\ \omega\alpha =$$

$$\left(\left[\left(1-\left(1-\left(\vartheta_S^L\right)^2\right)^\omega\right)^{\frac{1}{2}},\left(1-\left(1-\left(\vartheta_S^U\right)^2\right)^\omega\right)^{\frac{1}{2}}\right],\left[\left(\eta_S^L\right)^\omega\left(\eta_S^U\right)^\omega\right],\left[\left(\left(\left(1-\left(\vartheta_S^L\right)^2\right)^\omega-\left(1-\left(\vartheta_S^L\right)^2-\left(\varphi_S^L\right)^2\right)^\omega\right)^{\frac{1}{2}},\right]\left[\left(\left(\left(1-\left(\vartheta_S^U\right)^2\right)^\omega-\left(1-\left(\vartheta_S^U\right)^2-\left(\varphi_S^U\right)^2\right)^\omega\right)^{\frac{1}{2}}\right]\right)$$

6. $\alpha^\omega =$

$$\left(\left[\left(\vartheta_S^L\right)^\omega,\left(\vartheta_S^U\right)^\omega\right],\left[\left(1-\left(1-\left(\eta_S^L\right)^2\right)^\omega\right)^{\frac{1}{2}},\left(1-\left(1-\left(\eta_S^U\right)^2\right)^\omega\right)^{\frac{1}{2}}\right],\left[\left(\left(1-\left(\eta_S^L\right)^2\right)^\omega-\left(1-\left(\eta_S^L\right)^2-\left(\varphi_S^L\right)^2\right)^\omega\right)^{\frac{1}{2}},\left(\begin{array}{c}\left(1-\left(\eta_S^U\right)^2\right)^\omega-,\\ \left(1-\left(\eta_S^U\right)^2-\left(\varphi_S^U\right)^2\right)^\omega\end{array}\right)^{\frac{1}{2}}\right]\right)$$

$\alpha = \left([\vartheta_S^L,\vartheta_S^U],[\eta_S^L,\eta_S^U]\cdot[\varphi_S^L,\varphi_S^U]\right)$ bir IVSFS olsun, o zaman α için puan ve doğruluk fonksiyonu aşağıdaki gibi tanımlanabilir (Rahim ve ark., 2025):

$$S_{co}(\alpha)=\frac{\left(\vartheta_S^L\right)^2+\left(\vartheta_S^U\right)^2-\left(\eta_S^L\right)^2-\left(\eta_S^U\right)^2-\left(\frac{\varphi_S^L}{2}\right)^2+\left(\frac{\varphi_S^U}{2}\right)^2}{2}$$

$$A_{cc}(\alpha)=\left(\vartheta_S^L\right)^2+\left(\vartheta_S^U\right)^2-\left(\eta_S^L\right)^2-\left(\eta_S^U\right)^2-\left(\varphi_S^L\right)^2+\left(\varphi_S^U\right)^2$$

Burada $-1 \leqslant S_{co} \leqslant 1$ and $0 \leqslant A_{cc}(\alpha) \leqslant 1$.

2.2.2.Aralık değerli t-küresel bulanık kümeler (Interval-Valued t-Spherical fuzzy Sets)

Boş olmayan herhangi bir Y kümesi için, bir $\alpha \in Y$ elemanı için aralık değerli bir T küresel bulanık küme (IV(t)SFS) T aşağıdaki gibi tanımlanabilir (Rahim ve ark., 2025).

$$T=\left\{\alpha,\left(\left[\vartheta_T^L(\alpha),\vartheta_T^U(\alpha)\right],\left[\eta_T^L(\alpha),\eta_T^U(\alpha)\right],\left[\varphi_T^L(\alpha),\varphi_T^U(\alpha)\right]\right)|\alpha\in Y\right\},$$

Burada $\left[\vartheta_T^L(\alpha),\vartheta_T^U(\alpha)\right]\subseteq[0,1],\left[\eta_T^L(\alpha),\eta_T^U(\alpha)\right]\subseteq[0,1]$ ve $\left[\varphi_T^L(\alpha),\varphi_T^U(\alpha)\right]\subseteq[0,1]$ sırasıyla T'deki α elemanının üyelik, tarafsız üyelik ve üye olmama derecelerini temsil eder. öyle ki tüm $0 \leqslant \vartheta_T^L(\alpha \leqslant) \leqslant \vartheta_T^U(\alpha \leqslant) \leqslant 1,0 \leqslant \eta_T^L(\alpha) \leqslant \eta_T^U(\alpha) \leqslant 1,0 \leqslant \varphi_T^L(\alpha) \leqslant \varphi_T^U(\alpha) \leqslant 1$ ve $\left(\vartheta_T^U(\alpha)\right)^t+\left(\eta_T^U(\alpha)\right)^t+\left(\varphi_T^U(\alpha)\right)^t \leqslant$ tüm t için $\geqslant 1$. Eğer $\vartheta_T^L(\alpha)=\vartheta_T^U(\alpha),\eta_T^L(\alpha)=\eta_T^U(\alpha)$ ve $\varphi_T^L(\alpha),\varphi_T^U(\alpha)$ ise IVSFS S t-SFS'ye indirgenir. Bir aralık değerli t-küresel bulanık sayı $IV_{(t)}SFNs=\left[\vartheta_T^L,\vartheta_T^U\right],\left[\eta_T^L,\eta_T^U\right],\left[\varphi_T^L,\varphi_T^U\right]$ ile gösterilebilir, öyle ki $0 \leqslant \left(\vartheta_T^U\right)^t+\left(\eta_T^U\right)^t+\left(\varphi_T^U\right)^t \leqslant 1,0 \leqslant \eta_T^L \leqslant \eta_T^U \leqslant 1,0\varphi_T^L\varphi_T^U \leqslant 1$ ve $\left(\vartheta_T^U\right)^t+\left(\eta_T^U\right)^t+\left(\varphi_T^U\right)^t \leqslant 1$ burada $t \geqslant 1$. Reddetme derecesi aşağıdaki gibi tanımlanır.

$$\pi(a)=\left(\left[\sqrt[t]{1-\left(\vartheta_T^U(\alpha)\right)^t-\left(\eta_T^U(\alpha)\right)^t-\left(\varphi_T^U(\alpha)\right)^t},\ \sqrt[t]{1-\left(\vartheta_T^L(\alpha)\right)^t+\left(\eta_T^L(\alpha)\right)^t+\left(\varphi_T^L(\alpha)\right)^t}\right]\right).$$

$\prod=\left(\left[\vartheta_T^L,\vartheta_T^U\right],\left[\eta_T^L,\eta_T^U\right],\left[\varphi_T^L,\varphi_T^U\right]\right)$, (Rahim ve ark., 2025).

$\prod_1=\left(\left[\vartheta_{T_1}^L,\vartheta_{T_1}^U\right],\left[\eta_{T_1}^L,\eta_{T_1}^U\right],\left[\varphi_{T_1}^L,\varphi_{T_1}^U\right]\right)$ ve $\prod_2=\left(\left[\vartheta_{T_1}^L,\vartheta_{T_1}^U\right],\left[\eta_{T_1}^L,\eta_{T_1}^U\right],\left[\varphi_{T_1}^L,\varphi_{T_1}^U\right]\right)$
Herhangi üç $IV_{(t)}SFNs$' dir, o zaman

1. $\prod_1\oplus\prod_2=\left(\left[\left(\left(\vartheta_{T_1}^L\right)^t+\left(\vartheta_{T_2}^L\right)^t-\left(\vartheta_{T_1}^U\right)^t\left(\vartheta_{T_2}^L\right)^t\right)^{\frac{1}{t}},\left(\left(\vartheta_{T_1}^U\right)^t+\left(\vartheta_{T_2}^U\right)^t-\left(\vartheta_{T_1}^L\right)^t\left(\vartheta_{T_2}^U\right)^t\right)^{\frac{1}{t}}\right],\left[\eta_{T_1}^L\eta_{T_2}^L,\eta_{T_1}^U\eta_{T_2}^U\right],\left[\varphi_{T_1}^L\varphi_{T_2}^L,\varphi_{T_1}^U\varphi_{T_2}^U\right]\right)(t\geqslant 1),$
2. $\prod_1\otimes\prod_2=$
$$\left(\begin{array}{c}=\left[\vartheta_{T_1}^L\vartheta\eta_{T_2}^L,\vartheta_{T_1}^U\vartheta_{T_2}^U\right],\left[\eta_{T_1}^L\eta_{T_2}^L,\eta_{T_1}^U\eta_{T_2}^U\right],\\ \left[\left(\left(\varphi_{T_1}^L\right)^t+\left(\varphi_{T_2}^L\right)^t-\left(\varphi_{T_1}^L\right)^t\left(\varphi_{T_2}^L\right)^t\right)^{\frac{1}{t}},\left(\left(\varphi_{T_1}^U\right)^t+\left(\varphi_{T_2}^U\right)^t-\left(\varphi_{T_1}^L\right)^t\left(\varphi_{T_2}^U\right)^t\right)^{\frac{1}{t}}\right]\end{array}\right)(t\geqslant 1),$$

3. $\omega\prod=\left(\begin{array}{c}\left[\left(1-\left(1-\left(\vartheta_T^L\right)^t\right)^\omega\right)^{\frac{1}{t}},\left(1-\left(1-\left(\vartheta_T^U\right)^t\right)^\omega\right)^{\frac{1}{t}}\right],\\ \left[\left(\eta_T^L\right)^\omega,\left(\eta_T^U\right)^\omega\right],\left[\left(\varphi_T^L\right)^\omega,\left(\varphi_T^U\right)^\omega\right]\end{array}\right)$

4. $\prod^\omega=\left(\begin{array}{c}\left[\left(\vartheta_T^L\right)^\omega,\left(\vartheta_T^U\right)^\omega\right],\left[\left(\eta_T^L\right)^\omega,\left(\eta_T^U\right)^\omega\right],\\ \left[\left(1-\left(1-\left(\varphi_T^L\right)^t\right)^\omega\right)^{\frac{1}{t}},\left(1-\left(1-\left(\varphi_T^L\right)^t\right)^\omega\right)^{\frac{1}{t}}\right]\end{array}\right).$

$\prod=\left(\left[\vartheta_T^L,\vartheta_T^U\right],\left[\eta_T^L,\eta_T^U\right],\left[\varphi_T^L,\varphi_T^U\right]\right)$bir IVSFS olsun, o zaman için puan fonksiyonu aşağıdaki gibi tanımlanabilir (Rahim ve ark., 2025):

$$S_{co}(\Pi)=\frac{\left(\vartheta_T^L\right)^t\left(1-\left(\eta_T^L\right)^t-\left(\varphi_T^L\right)^t\right)+\left(\varphi_T^U\right)^2\left(1-\left(\eta_T^U\right)^t-\left(\varphi_T^U\right)^2\right)^t}{3}$$

2.2.3.Aralık Değerli p, q, r-Küresel Bulanık Kümeler (Interval-Valued p, q, r-spherical fuzzy sets)

Bu bölümde $IV_{(p,q,r)}$ SFS fikri açıklanmaktadır. $IV_{(p,q,r)}$ SFSs için temel işlemsel yasaları tanımlamakta ve özelliklerini incelemektedir. Bu işlemsel yasalara dayanarak bir dizi toplama operatörü önerilmiştir (Rahim ve ark., 2025).

Boş olmayan herhangi bir Y kümesi için, bir $\alpha\in$ Y elemanı için bir aralık değerli (interval-valued) p,q,r-küresel bulanık küme $\left(IV_{(p,q,r)}SFS\right)\mathcal{E}$ aşağıdaki gibi tanımlanabilir (Rahim ve ark., 2025):

$$\mathcal{E} = \left\{\alpha, \left(\left[\vartheta_{\mathcal{E}}^{L}(\alpha), \vartheta_{\mathcal{E}}^{U}(\alpha)\right], \left[\eta_{\mathcal{E}}^{L}(\alpha), \eta_{\mathcal{E}}^{U}(\alpha)\right], \left[\varphi_{\mathcal{E}}^{L}(\alpha), \varphi_{\mathcal{E}}^{U}(\alpha)\right]\right) | \alpha \in Y\right\} \qquad (2.2.3.1.1)$$

Denklem(6)'da $\left[\vartheta_{\mathcal{E}}^{L}(\alpha), \vartheta_{\mathcal{E}}^{U}(\alpha)\right] \subseteq [0,1], \left[\eta_{\mathcal{E}}^{L}(\alpha), \eta_{\mathcal{E}}^{U}(\alpha)\right] \subseteq [0,1]$ ve $\left[\varphi_{\mathcal{E}}^{L}(\alpha), \varphi_{\mathcal{E}}^{U}(\alpha)\right] \subseteq [0,1]$ sırasıyla Y'deki α elemanının üyelik, nötr üyelik ve üyelik dışı derecelerini temsil eder, öyle ki $0 \leqslant \vartheta_{\mathcal{E}}^{L}(\alpha) \leqslant \vartheta_{\mathcal{E}}^{U}(\alpha) \leqslant 1{,}0 \leqslant \eta_{\mathcal{E}}^{L}(\alpha) \leqslant \eta_{\mathcal{E}}^{U}(\alpha) \leqslant 1{,}0 \leqslant \varphi_{\mathcal{E}}^{L}(\alpha) \leqslant \varphi_{\mathcal{E}}^{U}(\alpha) \leqslant 1$ ve $\left(\vartheta_{\mathcal{E}}^{U}(\alpha)\right)^{p} + \left(\eta_{\mathcal{E}}^{U}(\alpha)\right)^{r} + \left(\varphi_{\mathcal{E}}^{U}(\alpha)\right)^{q} \leqslant 1$ tüm p için, q $\geqslant$ 1 olduğunda $r = LCM_{(p,q)}$. Eğer $\vartheta_{\mathcal{E}}^{L}(\alpha) = \vartheta_{\mathcal{E}}^{U}(\alpha), \eta_{\mathcal{E}}^{L}(\alpha) = \eta_{\mathcal{E}}^{U}(\alpha)$ ve $\varphi_{\mathcal{E}}^{L}(\alpha), \varphi_{\mathcal{E}}^{U}(\alpha)$ ise $IV_{(p,q,r)}SFS\ \mathcal{E}$' ye indirgenir. Bir aralık değerli t-küresel bulanık sayı $IV_{(t)}SFNs\ \mathcal{E} = \left(\left[\vartheta_{\mathcal{E}}^{L}, \vartheta_{\mathcal{E}}^{U}\right], \left[\eta_{\mathcal{E}}^{L}, \eta_{\mathcal{E}}^{U}\right], \left[\varphi_{\mathcal{E}}^{L}, \varphi_{\mathcal{E}}^{U}\right]\right)$ şeklinde gösterilebilir, öyle ki $0 \leqslant \vartheta_{\mathcal{E}}^{L} \leqslant \vartheta_{\mathcal{E}}^{U} \leqslant 1{,}0 \leqslant \eta_{\mathcal{E}}^{L} \leqslant \eta_{\mathcal{E}}^{U} \leqslant 1{,}0 \leqslant \varphi_{\mathcal{E}}^{L} \leqslant \varphi_{\mathcal{E}}^{U} \leqslant 1$ ve $\left(\vartheta_{\mathcal{E}}^{U}\right)^{p} + \left(\eta_{\mathcal{E}}^{U}\right)^{r} + \left(\varphi_{\mathcal{E}}^{U}\right)^{q} \geqslant 1$ tüm p, q $\geqslant$1 için burada $r = LCM_{(p,q)}$ (Rahim ve ark., 2025).

2.3. ARAS Yöntemi

Çalışmada ayrıca ARAS yönteminden yararlanılmıştır. ARAS yöntemine göre bir araştırmada ihtimal dahilinde bir alternatifin göreli etkinliğini saptamakta kullanılan fayda fonksiyonu, kriterlerin ağırlık ve değerlerinin göreli etkileri ile doğrudan orantılıdır. ARAS yöntemi seçeneğin performansını saptamaya yardımcı olur ve her seçeneğin ideal seçeneğe göre oransal benzerliğini açığa çıkarır. Mesela bir kriterin optimal puanın 10 olduğunu, ama bu kritere göre değerlendirmede alternatifler içindeki en yüksek puanın 9 olduğunu varsayalım. Bu durumda kriterin optimallik puanı farklı çok kriterli karar verme yöntemlerinde olduğu gibi 1.0 değil 0.9'dur. Böylece ARAS yöntemi oransal derecelendirme hedefine en yakın yöntem olarak tanımlanmaktadır. (Yıldırım ve ark., 2019).

ARAS yöntemi 4 adımdan oluşmaktadır. Bu adımlar aşağıdaki gibidir (Yıldırım ve ark., 2019);

Adım 1: Karar matrisi oluşturulması.

Adım 2: Normalize karar matrisi oluşturulması.

Adım 3: Ağırlıklı normalize karar matrisi oluşturulması.

Adım 4: Optimal fonksiyon değerinin hesaplanması.

3. Bulgular ve Tartışma

Tablo 2. Uzmanlara ait demografik veriler

	Yaş	İGU Çalışma Yılı	Toplam Çalışma Yılı	Sertifika Sayısı
Uzman 1	50	15	22	9
Uzman 2	45	13	20	11
Uzman 3	44	12	20	14
Uzman 4	37	10	14	6
Uzman 5	36	5	16	1

Tablo 2 kargo bölümündeki iş güvenliği risklerini değerlendiren uzmanların demografik verilerini içermektedir.

Yaş Dağılımı: Uzmanların yaş aralıkları 36 ile 50 arasında değişmekte olup, ortalama yaşın 43 civarında olduğu görülmektedir. Bu, sektördeki deneyimli profesyonellerin değerlendirme sürecine katkıda bulunduğunu ve yer alan uzmanların belirli bir bilgi ve deneyim seviyesine sahip olduğunu göstermektedir.

İş Güvenliği Uzmanlığı (İGU) Çalışma Yılı: Uzmanların, iş güvenliği alanında ortalama olarak 10-15 yıl arasında tecrübeleri bulunmaktadır. Bu, uzmanların sektörde uzun bir süre geçirdiğini ve dolayısıyla risk değerlendirmelerinde sağlam bir bilgi birikimi sunduklarını göstermektedir.

Toplam Çalışma Yılı: Uzmanların sektördeki toplam çalışma yılları 14 ile 22 yıl arasında değişmektedir. Bu, uzmanların yalnızca iş güvenliği değil, aynı zamanda sektördeki çeşitli süreçler hakkında derin bilgi sahibi olduklarını gösterir.

Sertifika Sayısı: Uzmanların sahip olduğu sertifika sayısı değişkenlik göstermekte olup, bu da uzmanların farklı konularda ne kadar eğitim aldığını ve kendilerini geliştirdiklerini göstermektedir.

Tablo 3.1'de sunulan demografik veriler, iş güvenliği alanında yüksek düzeyde deneyime ve bilgiye sahip uzmanlardan oluşan bir ekibin risk değerlendirmesi sürecine katkı sağladığını ortaya koymaktadır. Bu durum, araştırmanın güvenilirliğini artırmakta ve elde edilen verilerin değerlendirilmesinde dikkate alınması gereken önemli bir unsurdur. Uzmanların tecrübeleri, önerilen modelin uygulanabilirliği ve etkinliği açısından önemli bir dayanak sunmaktadır.

Tablo 3. Merkezileştirilmiş demografik veriler

	Yaş	İGU Çalışma Yılı	Toplam Çalışma Yılı	Sertifika Sayısı
Uzman 1	7,6	4	3,6	0,8
Uzman 2	2,6	2	1,6	2,8
Uzman 3	1,6	1	1,6	5,8
Uzman 4	-5,4	-1	-4,4	-2,2
Uzman 5	-6,4	-6	-2,4	-7,2

Tablo 4. Normalize edilmiş demografik veriler

	Yaş	İGU Çalışma Yılı	Toplam Çalışma Yılı	Sertifika Sayısı
Uzman 1	0,64883839	0,52522573	0,54772256	0,08048436
Uzman 2	0,22197103	0,26261287	0,24343225	0,28169527
Uzman 3	0,13659756	0,13130643	0,24343225	0,58351164
Uzman 4	-0,4610167	-0,1313064	-0,6694387	-0,221332
Uzman 5	-0,5463902	-0,7878386	-0,3651484	-0,7243593

Tablo 5. Kovaryans Matrisi

	Yaş	İGU Çalışma Yılı	Toplam Çalışma Yılı	Sertifika Sayısı
Yaş	0,2	0,18160339	0,1901613	0,13845528
İGU Çalışma Yılı	0,18160339	0,2	0,15183005	0,15852172
Toplam Çalışma Yılı	0,1901613	0,15183005	0,2	0,13347384
Sertifika Sayısı	0,13845528	0,15852172	0,13347384	0,2

Tablo 6. Uzmanların İzdüşümleri ve Ağırlık Değerleri

	iz düşüm	Uzman ağırlıkları
Uzman 1	49,107455	0,240145
Uzman 2	45,377898	0,221907
Uzman 3	45,723756	0,223598
Uzman 4	34,333705	0,167899
Uzman 5	29,947785	0,146451

Tablo 7. Uzman Değerlendirme Matrisi

Kriterler	Uzman 1	Uzman 2	Uzman 3	Uzman 4	Uzman 5
Fiziksel	10	7	11	10	10
Kimyasal	8	6	9	8	8
Biyolojik	7	5	8	7	7
Psikososyal	6	4	7	6	6
Ergonomik	9	9	10	9	9

Tablo 8. Bulanık Girdi Veri Matrisi

MM2	F						K							B						P						E				
UUzman 1	00,8	00,84	00,11	00,2	00,11	00,05	00,65	00,7	00,26	00,3	00,31	00,4	00,55	00,65	00,31	00,35	00,41	00,45	00,45	00,54	0,36	00,4	00,46	00,55	00,75	00,8	00,15	00,25	00,2	00,3
UUzman 2	00,6	00,65	00,31	00,35	00,41	00,45	00,45	00,54	00,36	00,4	00,46	00,55	00,4	00,44	00,41	00,43	00,56	00,65	00,3	0,39	00,44	00,5	00,66	00,75	00,75	00,8	00,15	00,25	00,2	00,3
UUzman 3	00,9	00,9	00,05	00,1	00	00,1	00,75	00,8	00,15	00,25	00,2	00,3	00,65	00,7	00,26	00,3	00,31	00,4	00,55	0,65	00,31	00,4	00,41	00,45	00,8	00,8	00,11	00,2	00,1	00,1
UUzman 4	00,8	00,84	00,11	00,2	00,11	00,05	00,65	00,7	00,26	00,3	00,31	00,4	00,55	00,65	00,31	00,35	00,41	00,45	00,45	0,54	00,36	00,4	00,46	00,55	00,75	00,8	00,15	00,25	00,2	00,3
UUzman 5	00,8	00,84	00,11	00,2	00,11	00,05	00,65	00,7	00,26	00,3	00,31	00,4	00,55	00,65	00,31	00,35	00,41	00,45	00,45	0,54	00,36	00,4	00,46	00,55	00,75	00,8	00,15	00,25	00,2	00,3

Tablo 9. Durağanlaştırılmış Girdi Veri Matrisi

M3	F	K	B	P	E
Uzman 1	0,3021839	0,136017	0,085528	0,037851	0,240141
Uzman 2	0,0855277	0,037851	0,017289	0,007013	0,240141
Uzman 3	0,3926573	0,240141	0,136017	0,085528	0,302184
Uzman 4	0,3021839	0,136017	0,085528	0,037851	0,240141
Uzman 5	0,3021839	0,136017	0,085528	0,037851	0,240141

Tablo 10. Normalleştirilmiş Matris

M4	F	K	B	P	E
Uzman 1	0,2182248	0,198263	0,20866	0,18366	0,190173
Uzman 2	0,0617646	0,055174	0,04218	0,034027	0,190173
Uzman 3	0,283561	0,350037	0,331838	0,414992	0,239307
Uzman 4	0,2182248	0,198263	0,20866	0,18366	0,190173
Uzman 5	0,2182248	0,198263	0,20866	0,18366	0,190173

Tablo 11. Uzman Ağırlıklı Normalize Matris

M5	F	K	B	P	E
Uzman 1	0,0524057	0,0476119	0,0501088	0,0441052	0,0456692
Uzman 2	0,0137060	0,0122434	0,0093601	0,0075508	0,0422008
Uzman 3	0,0634038	0,0782678	0,0741984	0,0927915	0,0535086
Uzman 4	0,0366397	0,0332881	0,0350338	0,0308364	0,0319298
Uzman 5	0,0319592	0,0290357	0,0305585	0,0268972	0,0278510

Tablo 12. Maksimum Değer ile Minimum Değer Arası Fark

B	0,0496978	0,0660244	0,0648383	0,0852408	0,0256576
L	0,1705138	0,226531	0,222461	0,292462	0,088032

Tablo 13. İkinci Defa Uzman Değerlendirmesi

Kriterler	Uzman 1	Uzman 2	Uzman 3	Uzman 4	Uzman 5
Fiziksel	25	22	24	23	2
Kimyasal	20	23	28	23	13
Biyolojik	20	20	21	20	13
Psikososyal	22	24	22	21	60
Ergonomik	13	11	5	13	12

Tablo 14. Kriter Ağırlıkları ve Güvenilirlik Testi

	L	AV		RI
f	0,1705138	19,2	2,148616	0,093984
k	0,2265308	21,4	1,253075	
b	0,2224613	18,8	3,446129	
p	0,2924624	29,8	0,553755	
e	0,0880317	10,8	1,996834	

Tablo 15. Puanlama Uzman 1

Alternatifler	Fiziksel	Kimyasal	Biyolojik	Psikososyal	Ergonomik
Teknolojik iyileştirmeler	10	7	5	3	8
Esnek Taşıma Çözümleri	9	8	7	4	9
Sektörel Eğitim ve Bilinçlendirme Programları	6	5	4	5	6
Uluslararası İş Birlikleri	4	6	5	4	5

Tablo 16. Puanlama Uzman 2

Alternatifler	Fiziksel	Kimyasal	Biyolojik	Psikososyal	Ergonomik
Teknolojik iyileştirmeler	9	9	8	4	7
Esnek Taşıma Çözümleri	10	9	6	4	11
Sektörel Eğitim ve Bilinçlendirme Programları	6	7	5	2	8
Uluslararası İş Birlikleri	6	5	4	3	7

Tablo 17. Puanlama Uzman 3

Alternatifler	Fiziksel	Kimyasal	Biyolojik	Psikososyal	Ergonomik
Teknolojik iyileştirmeler	7	9	4	2	9
Esnek Taşıma Çözümleri	6	8	6	5	10
Sektörel Eğitim ve Bilinçlendirme Programları	3	4	2	1	6
Uluslararası İş Birlikleri	5	6	4	2	8

Tablo 18. Puanlama Uzman 4

Alternatifler	Fiziksel	Kimyasal	Biyolojik	Psikososyal	Ergonomik
Teknolojik iyileştirmeler	6	7	4	1	8
Esnek Taşıma Çözümleri	9	8	6	3	9
Sektörel Eğitim ve Bilinçlendirme Programları	6	4	3	2	7
Uluslararası İş Birlikleri	5	6	5	2	7

Tablo 19. Puanlama Uzman 5

Alternatifler	Fiziksel	Kimyasal	Biyolojik	Psikososyal	Ergonomik
Teknolojik iyileştirmeler	8	8	5	3	8
Esnek Taşıma Çözümleri	9	8	6	4	10
Sektörel Eğitim ve Bilinçlendirme Programları	5	5	4	3	7
Uluslararası İş Birlikleri	5	6	5	3	7

Tablo 20. Bulanık Karar Matrisi

	F						K						B						P						E			
T	00,7	00,75	00,21	00,28	00,34	00,4	00,68	00,74	00,22	00,29	00,33	00,39	00,48	00,53	00,38	00,41	00,58	00,67	00,22	00,3	00,48	00,51	00,78	00,85	00,66	00,72	0,24	00,3	00,32	00,39
E	00,73	00,78	00,17	00,26	00,3	00,37	00,68	00,73	00,23	00,29	00,29	00,38	00,48	00,57	00,35	00,39	00,45	00,53	00,32	00,39	00,44	00,46	00,67	00,74	00,8	00,84	00,1	00,19	00,16	00,23
S	00,42	00,5	00,39	00,42	00,59	00,65	00,43	00,51	00,4	00,42	00,59	00,67	00,31	00,37	00,45	00,47	00,71	00,77	00,28	00,32	00,48	00,51	00,79	00,86	00,55	00,62	00,32	00,36	00,42	00,49
U	00,4	00,46	00,41	00,43	00,57	00,66	00,44	00,52	00,37	00,41	00,49	00,58	00,37	00,42	00,42	00,44	00,61	00,7	00,23	00,31	00,48	00,5	00,77	00,81	00,56	00,63	00,32	00,36	00,45	00,51

Tablo 21. Durağanlaştırılmış Karar Matrisi

	F	K	B	P	E
T	-0,1	-0,11	-0,25	-0,27	-0,11
E	-0,07	-0,1	-0,2	-0,26	0,06
S	-0,25	-0,25	-0,27	-0,29	-0,18
U	-0,24	-0,21	-0,25	-0,27	-0,19

Tablo 22. Optimal Karar Matrisi

	F	K	B	P	E
Opt	-0,25	-0,25	-0,27	-0,29	-0,19
T	-0,1	-0,11	-0,25	-0,27	-0,11
E	-0,07	-0,1	-0,2	-0,26	0,06
S	-0,25	-0,25	-0,27	-0,29	-0,18
U	-0,24	-0,21	-0,25	-0,27	-0,19

Tablo 23. Normalize Karar Matrisi

	F	K	B	P	E
opt	0,27	0,27	0,22	0,21	0,31
T	0,11	0,11	0,2	0,2	0,18
E	0,08	0,1	0,16	0,19	-0,1
S	0,27	0,27	0,22	0,21	0,3
U	0,27	0,23	0,2	0,19	0,31

Tablo 24. Ağırlıklandırılmış Normalize Karar Matrisi ve Satır Toplamları

	F	K	B	P	E	S
opt	0,05	0,06	0,05	0,06	0,03	0,25
Teknolojik İyileştirmeler	0,02	0,03	0,04	0,06	0,02	0,16
Esnek Taşıma Çözümleri	0,01	0,02	0,04	0,06	-0,01	0,12
Sektörel Eğitim ve Bilinçlendirme Programları	0,05	0,06	0,05	0,06	0,03	0,24
Uluslararası İş Birlikleri	0,05	0,05	0,05	0,06	0,03	0,23

Tablo 25. Alternatiflerin Sıralanması

	K Değerleri	Sıralama
Teknolojik iyileştirmeler	0,67	3
Esnek Taşıma Çözümleri	0,48	4
Sektörel Eğitim ve Bilinçlendirme Programları	0,99	1
Uluslararası İş Birlikleri	0,93	2

Bu çalışmada elde edilen bulgular, kargo sektöründe iş sağlığı ve güvenliğinin artırılması amacıyla önerilen alternatiflerin etkinliğini ortaya koymaktadır. Tablo 3.24'te görüldüğü üzere, farklı risk önleme stratejileri arasında yapılan değerlendirme sonucunda, "Sektörel Eğitim ve Bilinçlendirme Programları" en yüksek puanı alarak, kargo operasyonları için en etkili strateji olarak belirlenmiştir. Bu sonuç, personelin eğitimi ve güvenlik bilincinin artırılmasının, iş güvenliği risklerini minimize etmede kritik bir rol oynadığını göstermektedir.

4. Sonuçlar

Bu çalışmada hava yolu kargo operasyonlarında yaşanan mevcut iş güvenliği riskleri değerlendirilerek, insan faktörleri, süreç eksiklikleri ve çevresel koşulların, kargo operasyonları içerisinde iş kazalarınaa ve verimsizliklere etkilerinin bulunduğu gözlenmiştir. Çalışmada gerçekleştirilen analiz ile yükleme, boşaltma ve bakım süreçlerindeki yaşanan birçok olumsuz olayın personel hatalarından kaynaklandığı ortaya çıkmakta ve çalışan eğitimlerinin ve denetlemelerinin güçlendirilmesi gerektiği anlaşılmaktadır. Ayrıca, araştırma, sıkı güvenlik protokollerine ve düzenlemelere uyulmasının önemini göstermiştir. Bu protokollerin tutarlılıkla uygulanması, risklerin önemli ölçüde azaltılmasına katkı sağlayabilir. Bu çalışmada önerilen risk değerlendirme ve yönetim modeli, kargo operasyonları içindeki güvenlik uygulamalarının sürekli izlenmesini ve sistematik risk değerlendirme süreçlerinin entegrasyonunu vurgulayan bütünsel bir yaklaşım olup mevcut endüstri standartlarıyla uyumlu olmanın yanı sıra, operasyonel performansı artıran bir güvenlik kültürünü de teşvik etmektedir.

Çalışmada elde edilen bulgular, kargo operasyonlarında iş güvenliğinin artırılması amacıyla önerilen alternatiflerin etkinliğini ortaya koymaktadır. Birbirinden farklı risk önleme stratejilerinin değerlendirmesi sonucunda, "Sektörel Eğitim ve Bilinçlendirme Programları" en yüksek puanı alarak, kargo operasyonları için en etkili strateji olarak belirlenmiştir. Bu sonuç, personel eğitimlerinin ve çalışanlarda güvenlik bilinci artırılmasının iş güvenliği risklerini en aza indirmede kritik bir rol oynadığını göstermektedir. Bulgularda ikinci en yüksek puan, "Uluslararası İş Birlikleri" alternatifidir. Bu bulgu, kargo taşıma süreçlerinde uluslararası standartların ve iş birliğinin önemini vurgulamaktadır. Ayrıca, bu iş birlikleri sayesinde global iyi uygulama örneklerinin paylaşılması, sektör genelinde risklerin daha etkili bir şekilde yönetilmesine yardımcı olabilir. "Teknolojik İyileştirmeler" ve "Esnek Taşıma Çözümleri" alternatifleri ise sırasıyla üçüncü ve dördüncü en yüksek puanları almıştır. Bu durum, teknolojinin kargo operasyonları üzerindeki olumlu etkilerini ve esnek yaklaşımların süreç verimliliğini artırabileceğini ortaya koymaktadır.

Kargo operasyon süreçlerine dair daha kapsamlı araştırmalara ve uygulamalara bir temel oluşturabilmek ve bu sektördeki iş güvenliği risklerini azaltmak amacıyla önerilen bu modelin

uygulanması, eğitim, iş birliği ve teknolojik inovasyon gibi unsurları kapsamaktadır. Bu stratejilerin bütünleşmiş bir şekilde hayata geçirilmesi, sektördeki iş kazalarını ve sağlık sorunlarını minimize etmek için kritik bir adım olacaktır.

Kargo operatörlerinin insan faktörlerine odaklanan ve güvenlik protokollerine uyumun kritik önemi üzerine kapsamlı eğitim programları geliştirmesi hayati önem taşımaktadır. Düzenli eğitimler, acil durumlar sırasında sağlıklı karar alma ve tepki verme becerilerini geliştirmek için simülasyonlar ve senaryo tabanlı uygulamaları içermelidir.

Kargo operasyonları için özel olarak tasarlanmış işlem prosedürlerinin belirlenmesi ve sıkı bir şekilde uygulanması, süreçleri standartlaştırarak değişkenliği azaltabilir ve hata riskini en aza indirebilir. Bu prosedürlerin, süreçte olan operasyonlardan alınan geri bildirimlerle iyileştirilmesi ve güncellenmesi önerilmektedir.

Periyodik güvenlik denetimlerinin yapılması, mevcut uygulamalardaki iyileştirme alanlarını tanımlamak ve güvenlik düzenlemelerine uyumu sağlamak için önemlidir. Bu denetimlerin, yer ekipleri, bakım personeli ve yönetim de dahil olmak üzere tüm paydaşların katılımıyla gerçekleştirilmesi, güvenlik konusuna yönelik iş birliği anlayışını güçlendirecektir.

Otomatik takip sistemleri ve gerçek zamanlı güvenlik izleme araçları gibi gelişmiş teknolojilerin kargo operasyonlarının verimliliğini artırmak ve daha iyi risk yönetimi sağlamak amacıyla entegrasyonu önemlidir. Veri analitiğinin sürece dahil edilmesi güvenlik olaylarına ilişkin kalıpların ve trendlerin belirlenmesine yardımcı olabilir, bu sayede proaktif önlemler alınabilir.

Tüm çalışanların güvenlik standartlarının korunması ve geliştirilmesinde sorumluluk hissetmesini sağlayacak olan güvenlik odaklı bir kültürün kurum içinde; tanıma programları, açık iletişim kanalları ve düzenli takım toplantılarında teşvik edilmesi son derece önemlidir. Yapılan bu önerilerin hayata geçirilmesiyle, sivil havacılık kargo operasyonları iş güvenliği çerçevesini önemli ölçüde güçlendirebilir ve sonuçta daha güvenli ve verimli bir operasyonel ortam sağlanabilir. Gelecek araştırmalar için bu müdahalelerin güvenlik sonuçları ve operasyonel verimlilik üzerindeki uzun dönemli etkilerini değerlendiren derinlemesine çalışmalara odaklanılmasının faydalı olacağı düşünülmektedir.

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