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Original Article

Elemental Characterization of Termiye: Mineral Composition of Debitterized Lupin Seeds Cultivated at Different Locations

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ABSTRACT

The utilization of marginal lands for agricultural production without input use is crucial for sustainable agriculture, the creation of new food sources, and regional development. The aim of this study was to highlight the value of termiye in terms of location-based mineral nutrition. This study used seed of lupin (*Lupinus albus* L.) as the material, grown without inputs and processed into termiye, a traditional snack. The debittered lupin seeds (termiye) were obtained from growers in five locations: Deşdiğin, Konakkale, Ketenli, Başköy, and Akçalar. Termiye seeds were analyzed separately for mineral composition using ICP-OES. According to the general average locations, macroelement contents were found to be 4398 mg kg^{-1} P, 3900 mg kg^{-1} Ca, 2332 mg kg^{-1} S, 846 mg kg^{-1} Mg, 782 mg kg^{-1} Na, and 135 mg kg^{-1} K. Microelements were determined as 1228.23 mg kg^{-1} Mn, 42.98 mg kg^{-1} Zn, 37.22 mg kg^{-1} Fe, 27.32 mg kg^{-1} B, 7.57 mg kg^{-1} Cu, and 0.68 mg kg^{-1} Mo. The Ca/P ratio ranged from 0.62 to 1.26, the Na/K ratio from 3.83 to 8.13, and the K/(Ca+Mg) ratio from 0.02 to 0.04. According to the results, the rich mineral content of termiye, known in a limited area as a traditional food, has been revealed according to locations. Although the Deşdiğin location stands out, it has been determined that termiye has high macro and micro nutrient contents in all locations. The ratios of elements to each other in termiye grains in all locations are also in the appropriate range in terms of nutrition. It was understood that lupin plant can be grown and used as termiye in all locations.

Key words: *Lupinus albus* L., macronutrient, micronutrient, Ca/P ratio, Na/K ratio, K/Ca+Mg ratio

Termiye'nin Elemental Karakterizasyonu: Farklı Lokasyonlarda Yetiştirilen Tatlandırılmış Lüpen Tohumlarının Mineral Bileşimi

ÖZ

Sürdürülebilir tarım, yeni gıda kaynaklarının oluşturulması ve bölgesel kalkınma için, marjinal alanları girdi kullanmadan tarımsal üretime kazandırmak oldukça önemlidir. Bu çalışmada materyal olarak marjinal alanlarda tarımı yapılan lüpen (*Lupinus albus* L.) bitkisinin geleneksel yöntemle çerez haline getirilmiş ve termiye adıyla bilinen taneleri kullanılmıştır. Çalışmada termiyenin lokasyon bazlı mineral beslenme açısından değerinin ortaya konulması amaçlanmıştır. Termiyeler, lüpen yetiştiriciliğinin en fazla yapıldığı Konya'daki beş farklı lokasyonda (Deşdiğin, Konakkale, Ketenli, Başköy, Akçalar) üretim yapan yetiştiricilerden temin edilmiş ve her bir lokasyon için termiyelerdeki mineral madde kompozisyonları ICP-OES ile tespit edilmiştir. Lokasyon genel ortalamasına göre makroelement içerikleri; 4398 mg kg^{-1} P, 3900 mg kg^{-1} Ca, 2332 mg kg^{-1} S, 846 mg kg^{-1} Mg, 782 mg kg^{-1} Na ve 135 mg kg^{-1} K şeklinde elde edilmiştir. Mikroelement içerikleri de ; 1228.23 mg kg^{-1} Mn, 42.98 mg kg^{-1} Zn, 37.22 mg kg^{-1} Fe, 27.32 mg kg^{-1} B, 7.57 mg kg^{-1} Cu ve 0.68 mg kg^{-1} Mo olarak tespit edilmiştir. Termiyelerdeki Ca/P oranı 0.62-1.26, Na/K oranı 3.83-8.13 ve K/(Ca+Mg) oranı 0.02-0.04 aralığında değerler almıştır. Sonuçlara göre geleneksel bir gıda olarak sınırlı bir alanda tanınan termiyenin zengin mineral içeriği lokasyonlara göre ortaya konulmuştur. Deşdiğin lokasyonu öne çıksa da tüm lokasyonlarda termiyenin makro ve mikro besin içeriklerinin yüksek olduğu tespit edilmiştir. Termiyelerin tüm lokasyonlarda elementlerin birbirlerine oranları da besleme açısından uygun aralıkta yer almıştır. Tüm lokasyonlarda lüpen bitkisinin yetiştirilebileceği ve termiye olarak kullanılabileceği anlaşılmıştır. Termiyenin beslenmeye ve sürdürülebilir tarıma sağlayacağı katkılar göz önüne alındığında daha geniş alanlarda üretim yapılabilmesi için çalışmalara ihtiyaç olduğu ifade edilebilir.

Anahtar kelimeler: *Lupinus albus* L., makro besin elementleri, mikro besin elementleri, Ca/P oranı, Na/K oranı K/Ca+Mg oranı

INTRODUCTION

Marginal agricultural lands are areas where modern agricultural techniques cannot be used due to limiting factors resulting from soil characteristics, geographical and/or topographical structure, and where agriculture is carried out using traditional methods (Demirel and Şenol, 2019). The inclusion of such areas in agricultural production and/or their more active use in production is of great importance for sustainable agriculture.

Another strategically important issue for countries is ensuring that basic nutritional needs are met at sufficient, reliable, and nutritious levels (Koç and Uzmay, 2015). Achieving food security requires protecting food resources, integrating alternative crops into production, and/or assessing their potential for utilization. Legumes, recognized as the primary source of plant-based protein worldwide, are considered indispensable for both food security and sustainable agricultural practices. The Food and Agriculture Organization of the United Nations (FAO) has stated that leguminous plants, including lupin, possess significant nutritional value due to their high protein, fiber, and mineral content, emphasizing the lupin plant's particular importance for its nutritional and functional properties within this group (Poteras et al., 2024).

Lupin (*Lupinus albus* L.), known in Türkiye by various names such as acı bakla, termiye, tirmis, delice bakla, and kurt baklası, is a legume that can be cultivated on marginal agricultural lands where other legumes cannot grown without the need for agricultural inputs (Yorgancılar et al., 2020; Elma et al., 2021). The name *Lupinus* is derived from the Latin word lupus (wolf). *L. albus* L. belongs to the family *Leguminosae* and is the most widely cultivated species of the genus *Lupinus*, which comprises more than 200 species and originates from the Mediterranean region (Erbaş et al., 2005; Yorgancılar et al., 2009b; Sezer et al., 2023). Lupin, which is also present in the natural flora of the Mediterranean Basin, is well adapted to acidic and sandy soils (Valente et al., 2024). It is cultivated across the Mediterranean, Australia, and Latin America, with approximately 18% of global production occurring in Europe (Caramona et al., 2024). However, its tolerance to high lime content and elevated soil pH levels is relatively low. For this reason, lupin cultivation in Türkiye has been primarily confined to the Lakes Region (Akşehir, Beyşehir, Eğirdir, and Doğanhisar), where the soil has lower lime content and pH values (Hakkı et al., 2007; Aydın and Yorgancılar, 2015). In terms of its botanical characteristics, *L. albus* L. exhibits all the soil-improving effects of other leguminous crops, including a deep root system, nitrogen fixation through *Rhizobium*, and an increase in soil organic matter (Lermi and Palta, 2018). With a symbiotic nitrogen fixation capacity ranging from approximately 50 to 200 kg ha^{-1}, it serves as a sustainable alternative to industrial fertilizers (Caramona et al., 2024).

Lupin seeds contain two to three times more protein (33–47%) than cereals and are also rich in vitamins and minerals (Aydın and Yorgancılar, 2015; Yorgancılar et al., 2009a). They have higher iron, zinc, copper, and manganese content compared to other legumes, making them a valuable source of micronutrients (Trugo et al., 1993). The starch content of lupin seeds (5%) is significantly lower than that of other legumes (50%) (Duarte et al., 2022). In addition, the seeds contain omega-3 and omega-6 fatty acids, antioxidants, and a high fiber content. These properties make lupin a valuable crop for both human and animal nutrition (Yorgancılar et al., 2020; Sezer et al., 2023; Güloğlu, 2023). Lupin is widely used in Mediterranean countries, where it is processed into various food products (Yorgancılar et al., 2020). In different countries, lupin is used as a raw material alternative to soy in products such as bread, biscuits, cakes, pasta, confectionery, and soy sauce. It is also utilized as a source of high-quality vegetable oil rich in antioxidants, gluten-free flour, an emulsifier, a dairy alternative, and a snack (Mülayim and Acar, 2008; Yorgancılar and Bilgiçli, 2014; Özcan et al., 2021; Baltacıoğlu and Tarım Özcan, 2024). It is estimated that approximately 2 million tons of lupin seeds are produced annually in European countries, while around 500,000 tons of lupin-derived products are consumed. Additionally, the global lupin seed market is expected to grow by approximately 5% by 2029 (Caramona et al., 2024).

Minerals are essential for organisms to perform metabolic activities. In particular, inadequate intake of micronutrients leads to serious global health issues, commonly referred to as hidden hunger (Khazaei and Vandenberg, 2020; Nadeem, 2021). The Food and Agriculture Organization (FAO) has reported that more than 2 billion people worldwide suffer from severe health issues related to micronutrient deficiencies and has emphasized the risk of this number increasing. According to the World Health Organization (WHO), the most common micronutrient deficiencies worldwide are iron, iodine, and zinc (Anonymous, 2025a; Weffort and

Lamounier, 2024). For this reason, the WHO has long regarded the enrichment of agricultural products with protein, vitamins, calcium, magnesium, iron, zinc, copper, selenium, and iodine, or the consumption of foods containing these nutrients, as a priority issue (Orman and Ok, 2016). Similar to the global situation, widespread nutritional issues related to micronutrients have also been identified in Türkiye (Eyüpoğlu et al., 1995).

The aim of this study was to determine the mineral nutritional value of termiye, a traditionally known yet underrecognized food, and to introduce it to a wider audience. The material used consisted of seeds from the lupin plant (*L. albus* L.), which is cultivated in marginal areas of Türkiye and traditionally processed into a snack known as termiye. The study analyzed the mineral composition of termiye seeds from five different locations where production is most concentrated. The mineral composition across different locations, the distribution rates of minerals within the seeds, and the amounts of minerals consumed in the snack were interpreted using literature data.

MATERIALS AND METHODS

Materials

The seeds of the lupin (*L. albus* L.) plant, traditionally processed to remove alkaloids (debittered) and consumed as a regional snack known as termiye, were used as the material (Figure 1).

Figure 1. Appearance of termiye: whole seed (left), cotyledons and seed coat (testa) (right)

The region where lupin is most widely cultivated includes the rural neighborhoods of the Doğanhisar and Seydişehir districts in Konya province. Therefore, the study material was obtained from local producers in five different locations (Deşdiğin, Konakkale, Ketenli, Başköy, and Akçalar) who grow lupin and sell it as termiye in local markets (Table 1).

Table 1. Locations and coordinates of lupin cultivation areas

Province	District	Neighborhood	Coordinates
Konya	Doğanhisar (38.142371°N, 31.686279°E)	Deşdiğin	38.054245°N, 31.634553°E
		Konakkale	38.019212°N, 31.682440°E
		Başköy	38.140682°N, 31.757124°E
	Seydişehir (37.424495°N, 31.848346°E)	Akçalar	37.523744°N, 31.843805°E
		Ketenli	37.522652°N, 32.057311°E

* The coordinate information was obtained from Google Maps

L. albus L. is an annual herbaceous legume with white flowers arranged in a raceme, podded fruits, and white seeds. The plant can reach a height of approximately 120 cm and has a taproot system (Bayram, 2023). Each raceme contains 3–7 flowers, from which 3–7 fruits develop. Each fruit contains 3–7 seeds (Balcıoğlu and Orak, 2020).

Since low-alkaloid and regionally adapted sweet varieties of *L. albus* L. have not been developed in Türkiye, termiye, a snack consumed after a series of processing steps, is obtained from the mature, dry seeds of the lupin plant. In the traditional method known as debittering, lupin seeds are boiled in hot water (60–70°C) for 1–2 hours and then placed in sacks. They are then soaked in drinking water in special pools for 2–4 days, with the water being changed at least 4–5 times. In rural areas, debittering is typically carried out by placing the boiled seeds in sacks and soaking them in running water for 2–4 days. This process dissolves the bitter alkaloids in the water and removes them from the seeds. The result of this debittering process is termiye, a lupin snack product (Yorgancılar et al., 2009a; Baltacıoğlu and Tarım Özcan, 2024).

Methods

The ready-to-eat fresh termiye was prepared in two different forms as the material: whole seeds and the inner part (cotyledons), which are consumed after the removal of the seed coat. Since termiye is generally preferred without the seed coat, both whole seed and cotyledon analyses were conducted to determine the overall nutritional value. The seed coat was manually removed, and the kernels were separated. The prepared samples were dried in an oven (Sanyo) at 70°C. After drying, each material was separately ground into flour using a laboratory mill (Retsch ZM-100).

The whole seeds and cotyledons from each location were analyzed separately. To determine the mineral content, 0.2 g of each ground material was weighed and digested in a microwave system (MarsExpress, CEM Corp., USA) at high temperature (210°C) and pressure (200 PSI) using 5 mL of concentrated nitric acid (HNO_3) and 2 mL of hydrogen peroxide (H_2O_2, 30% w/v). The digested samples were diluted to 25 mL with deionized water, filtered through filter paper (Whatman No. 42), and analyzed for mineral content using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) (Agilent 5110). The determined values were multiplied by the dilution factor (final volume/weight of the initial sample) to obtain the macro- and micronutrient contents in mg kg^{-1}.

In interpreting the mineral contents of termiye from different locations, the percentage changes relative to the overall average for each analyzed element were used. For this purpose, the variations in the elemental contents of the seed parts compared to the average were calculated. The percentage change was determined using the following formulas:

% Change (whole seed): Location grain mineral value/location average grain mineral value)*100 (Eq. 1).

% Change (cotyledone): Location cotyledone mineral value/location average cotyledone mineral value)*100 (Eq. 2).

The percentage differences in the values of each sample compared to the average were calculated as follows:

% Difference: % change - 100 (Eq. 3). Here, a negative (−) value indicates a decrease, while a positive (+) value indicates an increase compared to the location average.

The analyses and measurements were conducted using a factorial experimental design in a randomized complete block design with three independent replications. Excel 2016 software was used to calculate the mean values and standard deviations for each measurement. The obtained results were analyzed using the MSTAT-C software package. A variance analysis was performed according to the factorial experimental design in a randomized complete block design, and differences between groups were determined using the least significant difference (LSD) test based on the results of the F-test.

RESULTS AND DISCUSSION

The primary factor determining the elemental content of plant products is the plant's genetic potential; however, the expression of this potential is influenced by climatic and environmental conditions.

The traditional snack termiye from five different locations was analyzed in both its whole seed form with the shell and its edible cotyledon after shell removal. The mineral contents of all samples were determined on a dry weight basis.

Macronutrients

Macronutrients are essential for an organism to properly perform its metabolic activities (Abdo et al., 2022). Calcium (Ca) is the most abundant structural mineral and plays a crucial role in metabolic processes. Potassium (K) is essential for cell membrane functions. Magnesium (Mg) acts as a cofactor in enzymatic reactions. Phosphorus (P) is vital for maintaining basic cellular functions. Sodium (Na) is necessary for normal cell function, water regulation, and electrolyte balance (Benayad and Aboussaleh, 2021). Sulfur (S) is a biologically important mineral due to its incorporation into various molecules such as amino acids, proteins, enzymes, and vitamins, as well as its role in physiological pathways (Hewlings and Kalman, 2019).

In this study, statistically significant differences were found among the amounts of macronutrients in termiye ($p < 0.01$). Among the analyzed macronutrients, phosphorus (P), calcium (Ca), and sulfur (S) were present in higher amounts compared to the others. The macronutrients in termiye were ranked from highest to lowest as follows: P (4398 mg kg^{-1}), Ca (3900 mg kg^{-1}), S (2332 mg kg^{-1}), Mg (846 mg kg^{-1}), Na (782 mg kg^{-1}), and K (135 mg kg^{-1}) (Table 2). Yorgancılar et al. (2009a) determined the P content in dehulled termiye (cotyledone) as 5613 mg kg^{-1}, K as 231 mg kg^{-1}, Ca as 3793 mg kg^{-1}, Mg as 817 mg kg^{-1}, and Na as 665 mg kg^{-1}. Abdo et al. (2022), in their analysis of termiye milk obtained from dehulled termiye, reported the macronutrient contents as 3325 mg P kg^{-1}, 1875 mg Ca kg^{-1}, 1630 mg K kg^{-1}, and 1161 mg Mg kg^{-1}. In another study on termiye, Balcıoğlu and Orak (2020) determined the average P content as 0.24%, K content as 0.85%, Ca content as 0.23%, and Mg content as 0.13%. Panasiewicz (2022) reported that the average seed content of *L. albus*, when grown using traditional methods, contains 4.8 mg g^{-1} P, 1.8 mg g^{-1} Mg, 0.10 mg g^{-1} Na, 11.98 mg g^{-1} K, and 0.15 mg g^{-1} Ca. In all these studies, researchers have emphasized that *L. albus* seeds contain high levels of macronutrients and serve as a nutrient-rich alternative food source. The results obtained in this study also confirm the presence of high macronutrient levels and support the findings in the literature.

The locations showed significant differences in elemental content ($p < 0.01$). When the general mean values of macronutrient contents across the locations were ranked, it was found that Ketenli (2188 mg kg^{-1}), Konakkale (2160 mg kg^{-1}), and Deşdiğin (2126 mg kg^{-1}) had similar results. In terms of macronutrient content, Başköy (1963 mg kg^{-1}) had lower values, while Akçalar (1890 mg kg^{-1}) had the lowest macronutrient content (Table 2).

It is known that the mineral content of plant seeds varies depending on genotype, location, and agricultural practices (Panasiewicz, 2022). In a study conducted in Australia, it was determined that *L. albus* seeds obtained from 33 different locations exhibited variations based on location; however, all examined locations had seeds rich in P, K, Ca, Mg, S, and Na (Hung et al., 1998). Since the materials used in this study were sourced from the L. albus population in the region and traditional methods were applied in both cultivation and the subsequent debittering process, the differences in elemental content can be considered location-dependent. The fact that the differences between locations were statistically significant further supports this finding.

When the interaction between location, seed part, and element content was analyzed ($p < 0.01$), Konakkale was identified as the location with the highest P content, with 4254 mg kg^{-1} in the whole seed and 5330 mg kg^{-1} in the cotyledon. In terms of Ca, Ketenli stood out in both the whole seed (5241 mg kg^{-1}) and the cotyledon (3874 mg kg^{-1}). Regarding S, Başköy had the highest content in the whole seed (2209 mg kg^{-1}), while Ketenli had the highest sulphur content in the cotyledon (3226 mg kg^{-1}) (Table 2).

Table 2. Macronutrient contents (mg kg^{-1}) in termiye collected from different locations*

Location	Macronutrients (mg kg^{-1}) Calcium (Ca)		Potassium (K)		Magnesium (Mg)		Phosphorus (P)		Sulfur (S)		Sodium (Na)		General av..
	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	
Deşdiğin	4308±116,74	2988±46,98	220±65,34	143±90,52	950±8,79	809±16,94	4209±16,67	4685±96,39	2173±50,73	2606±38,85	1302±83,56	1116±54,60	**2126**
Konakkale	5062±93,76	3765±24,98	131±8,34	116±2,63	900±9,62	795±8,47	4254±73,98	5330±65,03	2014±14,82	2257±14,74	688±45,18	608±21,02	**2160**
Başköy	3861±84,19	2914±52,03	169±2,38	171±11,64	956±16,62	878±8,39	3893±50,48	4669±83,13	2209±34,51	2499±28,32	649±46,47	686±29,16	**1963**
Akçalar	4129±134,80	2854±60,14	95±18,96	79±7,87	841±13,05	713±17,54	3671±34,82	4386±121,05	2121±4,43	2443±50,26	696±42,29	652±60,23	**1890**
Ketenli	5241±27,49	3874±30,11	109±2,63	116±23,38	866±1,89	750±4,26	4157±78,70	4722±47,32	1773±9,32	3226±756,98	687±38,61	732±69,06	**2188**
Location av.	**4520**	**3279**	**145**	**125**	**903**	**789**	**4037**	**4758**	**2058**	**2606**	**804**	**759**	
General av.	**3900**		**135**		**846**		**4398**		**2332**		**782**		

* All values for whole seed and cotyledon were determined on a dry weight basis per kilogram. ± represents the standard deviation of the replicate means.

For the other macronutrients, Deşdiğin had the highest K content in the whole seed (220 mg kg^{-1}), while Başköy had the highest K content in the cotyledon (171 mg kg^{-1}). For Mg, Başköy ranked first in both the whole seed (956 mg kg^{-1}) and the cotyledon (878 mg kg^{-1}). Similarly, Deşdiğin had the highest Na content in both the whole seed (1302 mg kg^{-1}) and the cotyledon (1116 mg kg^{-1}) (Table 2).

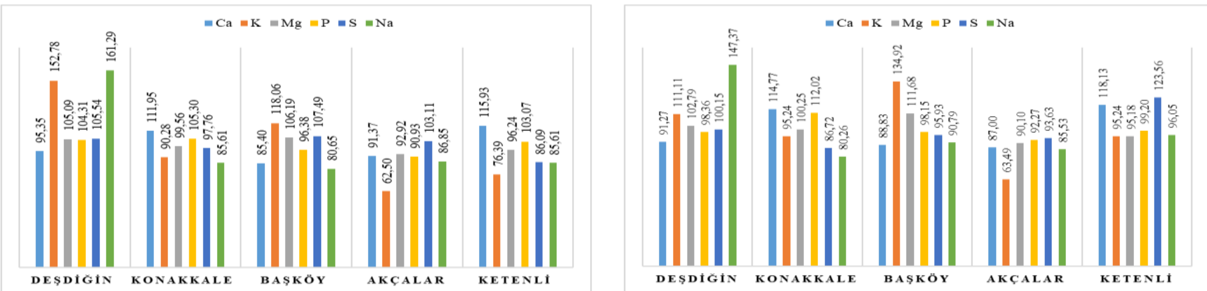


Figure 2. Percentage changes in macronutrient contents relative to the average (%) (Left: whole seed, Right: cotyledon)

When examining the variations in macronutrient contents relative to the location averages in the whole seed, it was determined that K and Na were higher in Deşdiğin; Ca and P in Konakkale; K and S in Başköy; S and Mg in Akçalar; and Ca and P in Ketenli. Among the variations observed in the consumed inner part (cotyledons), Na and P were prominent in Deşdiğin; Ca and P in Konakkale; K and Mg in Başköy; S and P in Akçalar; and Ca and S in Ketenli (Figure 2).

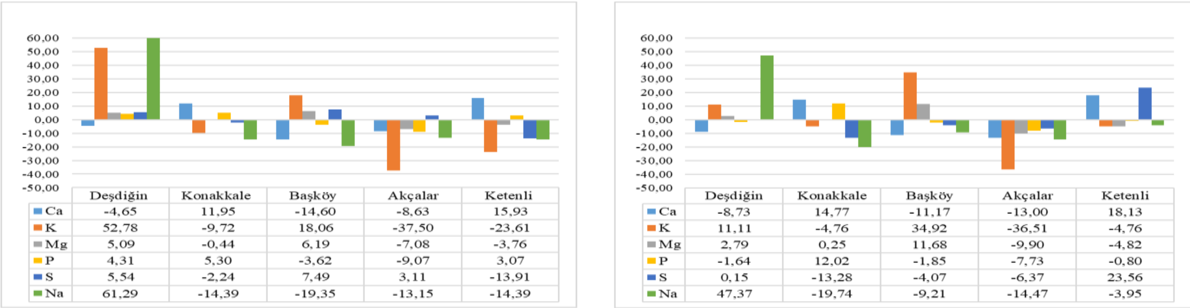


Figure 3. Percentage differences in macronutrient contents relative to the overall average (%) (Left: whole seed, Right: cotyledon)

According to the differences in variation relative to the location averages in the whole seed, decreases were observed Ca in Deşdiğin; P, Mg, S, and Na in Konakkale; Ca, P, and Na in Başköy; Ca, K, Mg, P, and Na in Akçalar; and K, Mg, S, and Na in Ketenli. In the cotyledons, decreases were detected in Ca and P in Deşdiğin; K, S, and Na in Konakkale; Ca, P, S, and Na in Başköy; Ca, K, Mg, P, S, and Na in Akçalar; and K, Mg, P, and Na in Ketenli (Figure 3).

The highest decrease was observed in K content in the Akçalar location, with a reduction of 37.50% in the whole seed and 36.51% in the cotyledon. Among the differences caused by an increase, the highest difference in the whole seed was recorded for Na in Deşdiğin, with a 61.29% increase. The highest difference in the cotyledon was observed for K in Başköy, with a 34.92% increase.

A study on *L. albus* and *L. angustifolius* seeds emphasized that most of the nutrients accumulate in the cotyledons and that L. albus seeds and processed foods derived from them could be a valuable source of nutrition due to their high protein and mineral content (Hung et al., 1998). Another study on termiye reported proportional differences in elemental content between the cotyledon and the seed coat, indicating that some elements are more concentrated in the seed coat, while others are more abundant in the cotyledon (Yorgancılar et al., 2009; Yorgancılar and Bilgiçli, 2014). Abdo et al. (2022) emphasized in their study that nutrient accumulation is higher in the seed endosperm. In this study, no statistically significant differences in mineral content were found between the different termiye parts. However, when evaluating the interaction between location, seed part, and element, statistically significant differences were observed.

Considering all the factors examined for macronutrients, including content, seed part, variation, and variation differences, Deşdiğin was identified as the most prominent location.

Micronutrients

One of the most fundamental indicators of nutritional value is a product's mineral content. Plants are known to be a good source of essential minerals for humans. Therefore, a rich mineral composition is a highly valuable attribute in terms of food quality (Khazaei and Vandenberg, 2020). Micronutrients are essential for the formation and proper functioning of various metabolic processes (Abdo et al., 2022). Deficiency or toxic levels of these elements can significantly impact human and animal health, just as they do in plants (Aygün et al., 2018).

Iron (Fe) plays a key role in several metabolic processes, including oxygen transport, DNA synthesis, and electron transfer. Zinc (Zn) is essential for protein, lipid, and nucleic acid metabolism. Copper (Cu) acts as a fundamental catalyst in many metabolic reactions. Manganese (Mn) is involved in the synthesis and activation of various enzymes and in the regulation of glucose and lipid metabolism (Benayad and Aboussaleh, 2021). Boron (B) is involved in cellular transport mechanisms, bone regeneration, and the regulation of oxidative stress (Nielsen and Eckhert, 2020).

In this study, termiye was found to contain high levels of Mn, Zn, Fe, and B. Additionally, significant differences ($p < 0.01$) were observed in the amounts of micronutrients among the analyzed termiye samples. Among the micronutrients, the highest value was recorded for Mn at 1228.23 mg kg^{-1}, followed by Zn at 42.98 mg kg^{-1}, Fe at 37.22 mg kg^{-1}, B at 27.32 mg kg^{-1}, Cu at 7.57 mg kg^{-1}, and molybdenum (Mo) at 0.68 mg kg^{-1}, in decreasing order (Table 3). Abdo et al. (2022) emphasized that termiye milk obtained from dehulled termiye contained high levels of Fe at 17.14 mg kg^{-1} and Zn at 13.86 mg kg^{-1}, highlighting that termiye is a mineral-rich material, especially in terms of Fe and Zn. In another study, termiye seeds were found to contain an average of 53.15 mg kg^{-1} Fe, 4.16 mg kg^{-1} Cu, 31.30 mg kg^{-1} Zn, and 1094 mg kg^{-1} Mn (Balcıoğlu and Orak, 2020).

The general location averages for micronutrient contents ($p < 0.01$) were as follows: 272.17 mg kg^{-1} in Deşdiğin, 238.05 mg kg^{-1} in Konakkale, 211 mg kg^{-1} in Ketenli, 204.96 mg kg^{-1} in Başköy, and 193.63 mg kg^{-1} in Akçalar. Based on micronutrient contents, Başköy had lower values compared to other locations, while Akçalar was identified as the location with the weakest micronutrient content (Table 3). Naadem (2021) stated that variations in mineral content can occur depending on location, which may be attributed to genotypic differences and/or environmental changes associated with location. A study reported that the environment has a strong influence on most elements, and this interaction becomes more pronounced for certain elements depending on genotypic characteristics (Khazaei and Vandenberg, 2020).

The Mn content varied between 978.77 mg kg^{-1} and 1516 mg kg^{-1} ($p < 0.01$). The highest Mn value was obtained from the cotyledon of Deşdiğin (1516 mg kg^{-1}), while the lowest value was recorded in the whole seed of Akçalar (978.77 mg kg^{-1}). The Zn content ranged from 36.50 mg kg^{-1} to 51.91 mg kg^{-1}. The highest Zn content was obtained from the cotyledon in Konakkale (51.91 mg kg^{-1}), while the whole seed from Deşdiğin (44.47 mg kg^{-1}) had higher values compared to other locations. Fe content varied between 27.23 mg kg^{-1} and 45.67 mg kg^{-1}. In terms of Fe content, Deşdiğin stood out with the highest values in both the whole seed (45.67 mg kg^{-1}) and the cotyledon (38.38 mg kg^{-1}) compared to other locations. B content ranged from 20.40 mg kg^{-1} to 39.33 mg kg^{-1}. Deşdiğin had the highest B content among all locations, with 39.33 mg kg^{-1} in the whole seed and 33.22 mg kg^{-1} in the cotyledon (Table 3).

Table 3. Microelement contents (mg kg^{-1}) in termiye collected from different locations*

Location	Micronutrients (mg kg^{-1})*												General av.
	Boron (B)		Copper (Cu)		Iron (Fe)		Manganese (Mn)		Zinc (Zn)		Molybdenum (Mo)		
	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	
Deşdiğin	39.33±3.05	33.22±2.22	7.90±0.34	8.81±0.17	38.38±2.23	45.67±0.58	1483.12±4.32	1516.31±27.96	44.47±1.31	46.96±0.87	1.05±0.14	0.85±0.03	**272.17**
Konakkale	32.71±1.10	26.95±0.90	6.51±0.10	7.52±0.09	37.37±1.14	43.82±0.69	1123.76±1.59	1483.34±15.15	41.73±0.12	51.91±0.39	0.48±0.11	0.44±0.06	**238.05**
Başköy	26.80±0.28	26.02±1.64	8.05±0.14	8.97±0.19	27.23±0.47	33.32±1.05	1061.15±24.06	1186.08±27.96	36.69±0.47	43.94±1.24	0.53±0.06	0.68±0.12	**204.96**
Akçalar	24.45±0.58	21.87±1.57	6.85±0.04	7.57±0.11	30.23±0.53	39.31±0.30	978.77±8.73	1133.45±32.10	36.50±0.47	42.94±1.08	0.87±0.05	0.69±0.04	**193.63**
Ketenli	21.45±0.31	20.40±1.02	6.36±0.09	7.18±0.07	37.21±1.61	39.68±1.04	1136.26±16.47	1180.05±7.74	39.72±0.79	44.91±1.36	0.47±0.14	0.73±0.61	**211**
Location av.	**28.95**	**25.69**	**7.13**	**8.01**	**34.08**	**40.36**	**1156.61**	**1299.85**	**39.82**	**46.13**	**0.68**	**0.68**	
General av.	**27.32**		**7.57**		**37.22**		**1228.23**		**42.98**		**0.68**		

* All values for whole seed and cotyledon were determined on a dry weight basis per kilogram. ± represents the standard deviation of the replicate means.

When examining the variations in micronutrient contents, in the whole seed, Deşdiğin showed greater changes in Mo and B; Konakkale in B and Fe; Başköy in Cu and B; Akçalar in Mo and Cu; and Ketenli in Fe and Zn compared to the location averages. In the consumed inner part (cotyledons), the most pronounced changes were observed in B and Mo in Deşdiğin; Mn and Zn in Konakkale; Cu and Mo in Başköy; Mo and Fe in Akçalar; and Mo and Fe in Ketenli (Figure 4).

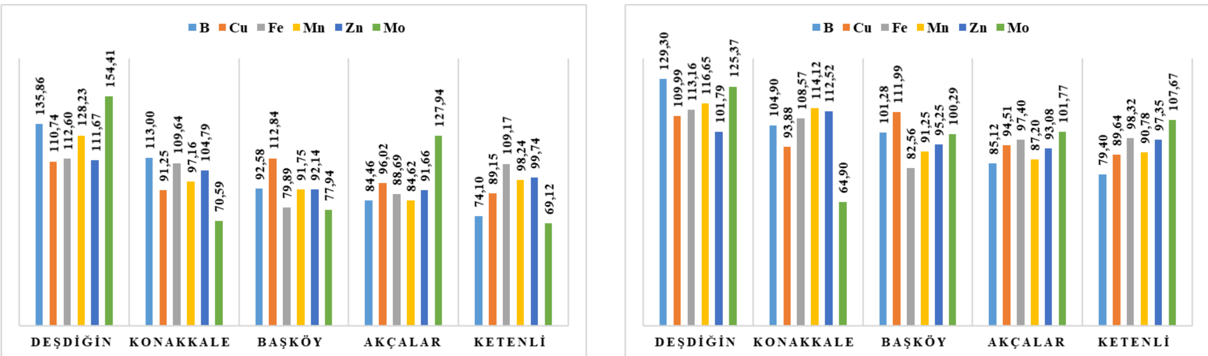
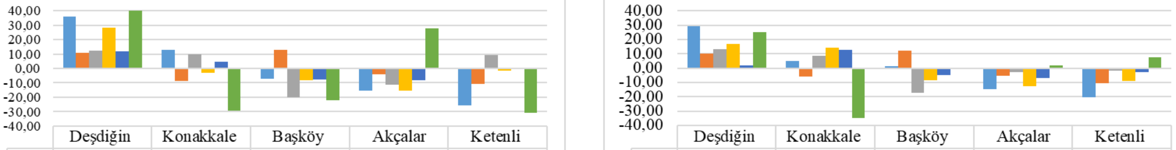


Figure 4. Percentage changes in micronutrient contents relative to the average (%) (Left: whole seed, right: Cotyledon)

According to the differences in variation relative to the location averages in the whole seed, a decrease was observed in Mo, Cu, and Mn in Konakkale; Mo, Fe, Mn, Zn, and B in Başköy; B, Mn, Fe, Zn, and Cu in Akçalar; and Mo, B, Cu, Mn, and Zn in Ketenli. In the cotyledon, a decrease compared to the average was observed for Mo and Cu in Konakkale; Fe and Zn in Başköy; B, Mn, Zn, Cu, and Fe in Akçalar; and B, Cu, Mn, Zn, and Fe in Ketenli (Figure 5). The highest decrease in B content was observed in Ketenli for the whole seed (30.88%) and in Konakkale for the cotyledon (35.10%). When evaluating the differences due to an increase, all the values in

Deşdiğin showed an upward trend. The highest increase in the whole seed was recorded for Mo in Deşdiğin at 54.41%, while the highest increase in the cotyledon was also recorded in Deşdiğin for B at 29.30%.



	Deşdiğin	Konakkale	Başköy	Akçalar	Ketenli
B	35,86	13,00	-7,42	-15,54	-25,90
Cu	10,74	-8,75	12,84	-3,98	-10,85
Fe	12,60	9,64	-20,11	-11,31	9,17
Mn	28,23	-2,84	-8,25	-15,38	-1,76
Zn	11,67	4,79	-7,86	-8,34	-0,26
Mo	54,41	-29,41	-22,06	27,94	-30,88

	Deşdiğin	Konakkale	Başköy	Akçalar	Ketenli
B	29,30	4,90	1,28	-14,88	-20,60
Cu	9,99	-6,12	11,99	-5,49	-10,36
Fe	13,16	8,57	-17,44	-2,60	-1,68
Mn	16,65	14,12	-8,75	-12,80	-9,22
Zn	1,79	12,52	-4,75	-6,92	-2,65
Mo	25,37	-35,10	0,29	1,77	7,67

Figure 5. Differences in micronutrient contents relative to the general average (%) (Left: whole seed, right: Cotyledon)

Bhardwaj et al. (1998) conducted a study to determine the environmental effects on the seed composition of L. albus and found significant variation between states. They emphasized that these variations could affect the nutritional value of the product and should be taken into account. In this study, significant differences were observed between the locations, with Deşdiğin standing out. In this respect, the results obtained align with the literature. Duarte et al. (2022) stated that *L. albus* is rich in minerals and that the bioavailability of these minerals is considerably high. Hung et al. (1998) determined that *L. albus* seeds contain micronutrients such as Fe, Zn, Cu, Mo, B, and Mn, making them a highly nutritious material for both human and animal nutrition. In this study, termiye was found to be rich in micronutrients at all locations, similar to its macroelement composition, with Deşdiğin standing out more than the others. Yorgancılar et al. (2009a) also showed that termiye from Deşdiğin has a high micronutrient content.

Another notable aspect of this study is the exceptionally high manganese (Mn) content in Termiye. Mn was found in remarkably high amounts in all locations and in both parts of the termiye. The Mn content was determined to be 1156.61 mg kg^{-1} in the whole seed and 1299.85 mg kg^{-1} in the cotyledon. This result has been reported by several researchers and serves as evidence that *L. albus* absorbs Mn from the soil at a high rate (Trugo et al., 1993; Yorgancılar et al., 2009a; Hung et al., 1998). Considering that these values were determined on a dry weight basis and that termiye is transformed into a snack containing approximately 70% water (Yorgancılar et al., 2009a), along with the fact that the seed coat is removed before consumption, it is assumed that the high Mn content does not pose a nutritional concern. In some Latin American countries, lupin flour has been added to foods in specific proportions and has been reported to cause no adverse effects in children or adults. However, since unprocessed dry seeds are used in animal feed, it is emphasized that caution should be exercised regarding Mn intake during consumption (Trugo et al., 1993; Hung et al., 1998).

Ratios of Selected Minerals in Termiye

The mineral richness of a food is an important criterion for both human and animal nutrition. Another factor determining food quality is the ratio of these minerals to each other.

Particularly in animal nutrition, these ratios are carefully considered in addition to the nutrient content of the feed to maintain animal health. Knowing the concentration of nutrients in feed and their ratios to each other is crucial for animal health (Yılmaz, 2022). In high-quality feed, the reported nutrient contents are as follows: calcium 0.27–0.50%, phosphorus 0.15–0.27%, potassium 0.30–0.80%, magnesium 0.10–0.20%, sodium 0.16–0.22%, iron 4–15%, copper 4–5%, zinc 20–40%, and manganese 7–10% (Aydın et al., 1997; Doğrusöz et al., 2020).

The ratios of the elements to each other were determined using the values from Table 2 and Table 3, and the obtained values are presented in Table 4.

Table 4. Ratios of selected essential mineral nutrients to each other

Location	Elemental Rations											
	Ca/P		Na/K		Ca/Mg		K/Ca+Mg		Fe/Zn		Zn/Cu	
	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone	seed	cotyledone
Deşdiğin	1.02	0.64	5.91	8.00	4.54	3.69	0.04	0.04	0.86	1.44	5.63	4.55
Konakkale	0.99	0.62	3.82	4.06	4.02	3.31	0.04	0.04	0.74	0.48	4.56	6.50
Başköy	1.13	0.65	7.78	8.13	4.92	4.01	0.02	0.02	0.83	0.35	5.33	7.88
Akçalar	1.19	0.71	5.31	5.08	5.62	4.76	0.02	0.03	0.90	0.76	6.41	7.05
Ketenli	1.26	0.82	6.27	6.08	6.02	5.16	0.02	0.03	0.94	0.72	6.25	6.43
General av.	1.14	0.70	5.64	5.95	5.16	4.30	0.03	0.03	0.87	0.54	5.75	7.15

In termiye, the average Ca/P ratio across locations was determined as 1.14 in the whole seed and 0.70 in the cotyledon. The Ca/P values varied within a range of 0.62–1.26. The lowest ratio was found in the cotyledon of Konakkale, while the highest value was observed in the whole seed of Ketenli. It has been stated that when Ca or P levels are insufficient, the nutritional value of foods decreases. For healthy physiological function, the Ca/P ratio should be between 2:1 and 1:2 (Işıl and Balkan, 2022). Additionally, it has been emphasized that the calcium-to-phosphorus (Ca/P) ratio plays a crucial role in ruminant body metabolism and rumen microbial health and that this ratio should be either 2:1 or 1:1 (Aygün et al., 2018). It has been reported that animals fed on diets with a Ca/P ratio exceeding these values are at risk of parturient paresis (milk fever) (Gülümser et al., 2020). As shown in Table 4, the ratios at all locations fall within the ranges reported in the literature. A ratio closer to 1 indicates a more balanced proportion of the two elements.

In termiye, the average Na/K ratio among the locations was found to be 5.64 in the whole seed and 5.95 in the cotyledon. Among the locations, the lowest Na/K ratio was found in the whole seed from Konakkale, while the highest ratio was observed in the cotyledon from Başköy. The values obtained varied within a range of 3.83–8.13. The balance between K and Na is known to be crucial. It has been stated that high K content can lead to electrolyte imbalance in animals and, due to its antagonistic effect, may cause Na deficiency, thereby increasing the risk of grass tetany (Yılmaz, 2022). A similar interaction has also been emphasized for the K+Na / Ca+Mg ratio (Aygün et al., 2018). It has been reported that the K/Na ratio in feeds should be, on average, 5:1, with a maximum of 10:1 (Aydın et al., 1997). The values obtained from the locations fall within the specified range.

Based on the overall averages of the locations, it was determined that the K/(Ca+Mg) ratio in termiye, both in the whole seed and the consumed cotyledon, remained within the recommended limits at all locations (Table 4).

Tetany is a metabolic disorder observed in ruminants, caused by magnesium deficiency in the blood, which results from an imbalance in the mineral composition of feeds (Yılmaz, 2022). The risk of grass tetany increases with a higher K/(Ca+Mg) ratio in the feed. To eliminate the risk of this disease, it is recommended that the K/(Ca+Mg) ratio be below 2.2 (Çaçan and Kökten, 2024). The values obtained from different locations and seed parts were found to be quite close to this threshold.

In termiye, the average Fe/Zn ratio across locations was calculated as 0.87 in the whole seed and 0.57 in the cotyledon. The Fe/Zn ratios obtained from different locations ranged between 0.35 and 1.44. The lowest ratio was recorded in the cotyledon from Başköy, while the highest value was found in the cotyledon from Deşdiğin.

For the Zn/Cu ratio, the average across all locations was 5.75 in the whole seed and 7.15 in the cotyledon. The lowest Zn/Cu ratio was found in the cotyledon from Deşdiğin, whereas the highest value was recorded in the cotyledon from Başköy (Table 4).

There is an antagonistic relationship between Fe, Zn, and Cu. Due to their similar physicochemical structures and shared transport systems, these minerals compete for absorption, resulting in reduced bioavailability (Baydaş et al., 1990; Doguer et al., 2019; İnce and Çağındı, 2020). Therefore, in addition to their presence, the proportional relationship between these minerals is also important (Watabe et al., 1965; Kebede et al., 2021). In termiye, the ratios of mineral elements to each other were found to be within reasonable limits.

Humans can obtain essential minerals from both plant-based and animal-based food sources. Due to the synergistic and antagonistic interactions among minerals, the region where food sources are obtained and the growing conditions significantly influence the mineral composition of food (Njira and Nabwami, 2015). Additionally, dietary habits, geographical and economic accessibility, and daily mineral intake through diet affect both the amount of minerals consumed and their relative ratios (Quintaes et al., 2015). Furthermore, factors such as age, gender, metabolic needs, and other physiological conditions significantly influence mineral intake (Anonymous, 2025b).

Due to these reasons, studies evaluating the ratios of minerals obtained from food in humans are quite limited and are usually conducted to examine specific conditions. For instance, a study in the United States on infant formulas reported that the Ca/P ratio in breast milk is approximately 2:1. Based on this, it was recommended that the ratio in supplementary foods produced for infants should be within the 1:1 to 2:1 range (Loughrill et al., 2017).

A study on vitamin D metabolism stated that an adequate Ca/P ratio of approximately 2:1 in the diet is essential for optimal bone development, and this value is close to that found in breast milk (Schneider, 1930). In a study evaluating the relationship between magnesium metabolism and the Ca:P range, Pinotti et al. (2021) recommended an optimal dietary Ca/Mg ratio of 2:1 or approximately 3:1 for both animals and humans.

According to El-Said and El-Sikaily (2013), hypertension (high blood pressure) in individuals can be managed through the K/Na balance in the diet. They emphasized that K content should be higher than Na to effectively regulate blood pressure. Minerals perform similar functions in human and animal metabolism.

Based on reference values and scientific data, it can be confidently stated that the elemental ratios in termiye (*L. albus*) are suitable for human consumption. However, as pointed out by Zang et al. (2021), determining the ideal mineral ratio for a healthy human population is quite challenging. Therefore, most studies focus on analyzing the mineral content of foods and the extent to which they contribute to daily nutritional requirements.

Nutritional Value of Termiye Snack

Foods are the primary source of minerals, and their mineral richness is highly valuable in terms of nutrition (Abdo et al., 2022). The daily recommended or adequate intake of minerals through food may vary depending on several factors, such as health status, age, gender, and physical activity level (Benayad and Aboussaleh, 2021). For macronutrients, the average daily intake amounts for an adult individual are determined as follows: 1000 mg for Ca, 4.7 g for K, 700 mg for P, approximately 370 mg for Mg, and 1.5 g for Na (Anonymous, 2025c; Benayad and Aboussaleh, 2021).

Daily nutrient intakes, calculated while considering the influence of various factors, are defined as average intakes that can meet the nutrient requirements of a healthy individual. However, due to physiological differences, the requirements for microelements differ between adult men and women. For a healthy adult woman, the recommended daily intakes are 18 mg for Fe, 8 mg for Zn, 1.8 mg for Mn, 900 µg for Cu, and 55 µg for selenium (Se). In contrast, for an adult man, the corresponding recommended intakes are 8 mg for Fe, 11 mg for Zn, 2.3 mg for Mn, 900 µg for Cu, and 55 µg for Se (Benayad and Aboussaleh, 2021).

In the lupin plant, the seed coat (testa) constitutes approximately 25% of the seed weight and is reported to contain a high amount of dietary fiber, along with low levels of protein, lipids, minerals, and phytochemicals such as polyphenols (Malekipoor et al., 2022). In one study, the seed coat was found to constitute approximately 20% of the seed (Yorgancılar et al., 2009a).

Elements accumulate or integrate into the seed coat and cotyledons at different rates. While genotype influences this distribution, environmental factors can also play a role. Due to the difficulty of breaking down its high-fiber structure, consumers prefer to remove the seed coat when consuming termiye. This preference leads to differences in mineral composition between the whole seed and the cotyledons, which may result in some element loss.

When lupin seeds are processed into termiye, they absorb water. With a moisture content of approximately 70% in the processed form, Yorgancılar et al. (2009a) found that about 400 g of termiye must be consumed to reach the mineral content calculated on a dry weight basis. It is estimated that consuming the inner part remaining after removing the seed coat can provide approximately 22–60% of the daily mineral requirement.

Similar nutritional results were obtained from all locations where termiye was sourced. In this respect, products grown in all locations can be safely consumed. The high dietary fiber content, low glycemic index, and rich mineral composition make termiye a suitable option for consumption as a healthy snack.

CONCLUSION

Plants are essential sources of minerals. The mineral content of food is a crucial criterion for both human and animal nutrition. Particularly in developing countries, legumes are frequently preferred in nutritional programs due to their affordability as a protein source. Additionally, they hold significant nutritional importance as they are especially rich in essential micronutrients.

Lupin (*L. albus* L.) is a leguminous plant that can be cultivated in marginal areas with minimal input use, without causing adverse environmental effects. Due to its high protein content and balanced ratios of macro- and micronutrients in its seed structure, it is not only a valuable food or food ingredient for human consumption but also an alternative feed source for animal nutrition. Lupin has significant potential for combating mineral deficiencies, aligning with one of the United Nations' 2030 Sustainable Development Goals.

Termiye, traditionally consumed as a snack, is obtained through a series of processes from the seeds of the lupin plant. In this study, termiye was found to have a rich content of macro- and micronutrients across all locations. Considering that health issues related to microelement deficiencies affect almost everyone today, incorporating termiye into diets as a mineral source can be recommended.

In terms of the examined parameters, the Deşdiğin location stands out. Based on the results obtained, Deşdiğin can be recommended as the primary location for cultivation. The Başköy and Ketenli locations recorded lower values for most parameters. However, since termiye obtained from these locations still has a rich mineral content compared to other legumes, its cultivation can be effectively carried out in Başköy and Ketenli, which are classified as mountain villages. This would provide a significant advantage for both rural development in the region and the utilization of agricultural land. In locations where lupin cultivation is practiced, there is potential for obtaining organic and high value-added products from termiye.

Establishing cooperatives or regional brands can be recommended. Since soil pH is the primary limiting factor for lupin cultivation, further research is needed on breeding lime-tolerant genotypes and developing sweet varieties with reduced alkaloid content.

Declaration of Interests

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

Author Contributions

Emine Atalay: Investigation; methodology; project administration; software; writing— original draft; writing—review and editing).

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