

Evaluation of the Chemical Composition of *Nigella sativa* L. Seeds Grown in Different Locations

Farklı Lokasyonlarda Yetiştirilen Çörek Otu (*Nigella sativa* L.) Tohumlarının Kimyasal Kompozisyonlarının Değerlendirilmesi

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ABSTRACT

Nigella sativa L., commonly known as black cumin, holds a significant place among medicinal and aromatic plants due to its rich chemical composition and positive effects on health. This study was conducted to compare the chemical composition of black cumin seeds cultivated under different ecological conditions in Erzurum (Türkiye) and Budapest (Hungary) in 2018. The 'Çameli' variety was used in both locations. The seeds were analyzed for their protein, oil, ash, and mineral contents, as well as their fatty acid profiles. All chemical analyses were carried out in the laboratories of the Department of Field Crops, Faculty of Agriculture, Atatürk University. Seeds from Türkiye exhibited higher levels of protein (20.5%), oil (37.2%), linoleic acid (62.60%), magnesium (434.31 mg/100 g), and manganese (13.61 mg/100 g). Conversely, seeds from Hungary showed greater concentrations of oleic acid (23.03%), phosphorus (1007.26 mg/100 g), potassium (1113.19 mg/100 g), calcium, iron, copper, and zinc. Total ash content was also slightly higher in seeds from Türkiye. These findings demonstrate that ecological factors such as climate, soil structure, and altitude significantly influence the nutritional and biochemical properties of black cumin seeds. The study provides valuable insights for optimizing the cultivation of *Nigella sativa* based on regional environmental conditions and offers practical implications for improving seed quality in food, pharmaceutical, and industrial applications. In conclusion, ecological conditions play a decisive role in determining seed composition, and location-specific agricultural strategies should be considered to enhance both the quality and economic value of black cumin cultivation.

Keywords: Black cumin, Ecological conditions, Fatty acid, Mineral content, Seed quality

ÖZ

Çörek otu (*Nigella sativa* L.), zengin kimyasal bileşimi ve sağlık üzerindeki olumlu etkileri sayesinde tıbbi ve aromatik bitkiler arasında önemli bir yere sahiptir. Bu çalışma, 2018 yılında Türkiye'nin Erzurum ili ile Macaristan'ın Budapeşte kentinde, farklı ekolojik koşullar altında yetiştirilen çörek otu tohumlarının kimyasal bileşimlerini karşılaştırmak amacıyla yürütülmüştür. Her iki lokasyonda da 'Çameli' çeşidi kullanılmış; tohumların protein, yağ, kül ve mineral içerikleri ile yağ asidi profilleri analiz edilmiştir. Tüm kimyasal analizler, Atatürk Üniversitesi Ziraat Fakültesi Tarla Bitkileri Bölümü laboratuvarlarında gerçekleştirilmiştir. Türkiye'de yetiştirilen tohumlarda protein (%20,5), yağ (%37,2), linoleik asit (%62,60), magnezyum (434,31 mg/100 g) ve manganez (13,61 mg/100 g) değerleri daha yüksek bulunmuştur. Buna karşılık, Macaristan'da yetiştirilen tohumlar oleik asit (%23,03), fosfor (1007,26 mg/100 g), potasyum (1113,19 mg/100 g), kalsiyum, demir, bakır ve çinko açısından daha zengin bulunmuştur. Türkiye örneklerinde toplam kül oranı da daha yüksektir. Bu sonuçlar, iklim, toprak yapısı ve rakım gibi ekolojik faktörlerin çörek otu tohumlarının besin ve biyokimyasal özelliklerini belirlemede etkili olduğunu ortaya koymaktadır. Çalışma, *Nigella sativa*'nın bölgeye özgü ekolojik koşullara göre optimize edilerek yetiştirilmesine yönelik bilimsel bir temel sunmakta ve beslenme, farmasötik ve endüstriyel kullanım alanlarına katkı sağlamaktadır.

Anahtar Kelimeler: Çörek otu, Ekolojik koşullar, Yağ asidi, Mineral içerik, Tohum kalitesi

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Introduction

Nigella sativa L., commonly referred to as black cumin, is a herbaceous annual plant from the Ranunculaceae family, predominantly found in regions of Southwest Asia. It has a longstanding history in ethnomedicine, where it has been employed across cultures for its wide-ranging therapeutic applications. This species typically attains a height between 30 and 60 cm, with finely divided, feathery foliage and flowers that are white or light blue in color. The plant produces a sizable fruit capsule that encloses numerous tiny black seeds. These seeds are predominantly recognized for their medicinal value and are widely used in various traditional healing systems (Kinki, 2020; Randhawa & Alghamdi, 2002; Sarwar et al., 2025).

Black cumin is renowned for its wide range of health benefits, including anti-inflammatory (Shaheen et al., 2022), antioxidant (Albakry et al., 2022), and antimicrobial (Biswas et al., 2023) activities. Traditionally, it has been used to treat various health conditions such as asthma, coughs, allergies, digestive disorders, and skin diseases. In recent years, the oil extracted from black cumin seeds has attracted growing scientific interest due to its potential therapeutic applications (Chatterjee et al., 2025; Pandey et al., 2025).

The seeds of black cumin are recognized for their rich chemical composition, containing significant amounts of ash, protein, oil, fatty acids, and minerals, all of which contribute to their nutritional and medicinal value. Black cumin seeds predominantly consist of fixed oils (32-40%), essential oils (0.4-0.45%), proteins (16-19.9%), minerals (1.7-3.7%), carbohydrates (30.0-33.9%), fiber, water, alkaloids, coumarins, saponins, and amino acids (Randhawa & Al-Ghamdi, 2002).

The seeds have a rich chemical composition, containing significant amounts of ash, protein, oil, fatty acids, and minerals. Black cumin oil is particularly rich in unsaturated fatty acids, mainly linoleic and oleic acids, as well as essential fatty acids like omega-6 and omega-3, which are important for maintaining immune system balance and managing chronic diseases (Darakeh et al., 2021; Terzi et al., 2010). In terms of mineral composition, black cumin seeds are rich in macroelements such as potassium, calcium, phosphorus, and magnesium, which are crucial for physiological functions. They also provide important micronutrients including iron, zinc, copper, and manganese, supporting enzymatic activities and immune responses (Ulus et al., 2018).

Ecological factors such as climate and soil conditions play a crucial role in the cultivation of medicinal plants, influencing not only yield but also quality, including the

synthesis of active compounds and essential oils (Yaşar, 2005). Black cumin is often grown under dry farming conditions, which may lead to reduced seed yield and quality. Variations in ecological conditions can thus result in significant differences in the chemical composition and nutritional quality of black cumin seeds (Can et al., 2021).

This study was conducted to investigate the differences in fatty acid composition, macro and micronutrient content, protein, oil and ash content of black cumin seeds cultivated under the distinct ecological conditions of Türkiye (Erzurum) and Hungary (Budapest).

Methods

Site and Experiment Description

Field experiments were conducted in 2018 under two distinct ecological conditions. The first trial was established at the Plant Production Application and Research Center of Atatürk University in Erzurum, Türkiye (L₁), located at 39°55'59.9"N, 41°14'10.6"E, at an altitude of 1787 meters above sea level. The second trial was conducted at the Experimental Station of the Hungarian University of Agriculture and Life Sciences (MATE), in Budapest, Hungary (L₂), situated at 47°23'38"N, 19°08'15"E, with an elevation of 108 meters above sea level. The 'Çameli' cultivar of black cumin (*Nigella sativa* L.), registered in Türkiye, was selected as the plant material for both experimental sites.

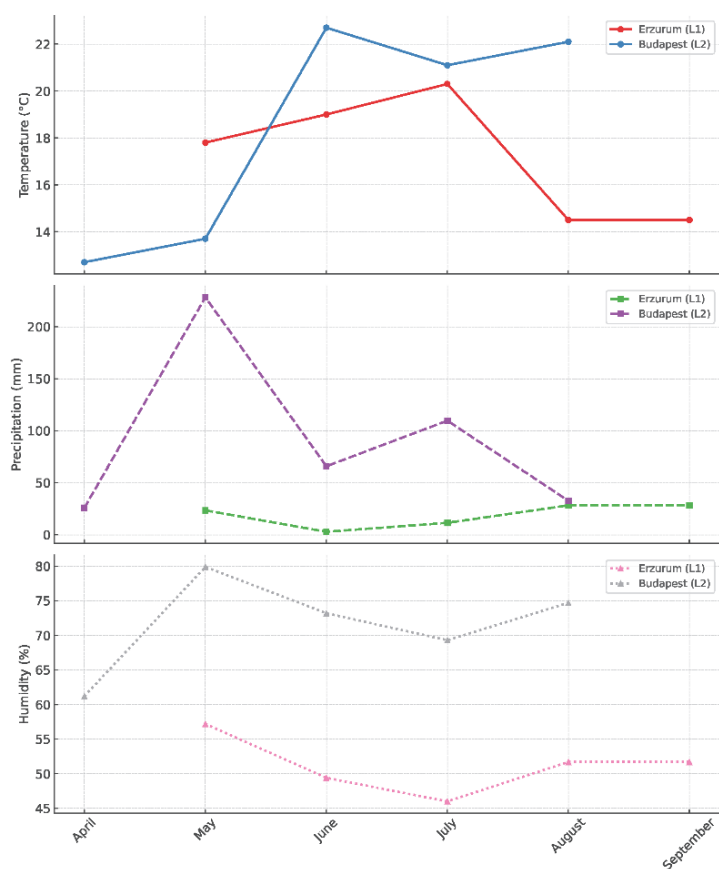
Significant climatic differences were observed between the two locations during the growing season. The total precipitation at L₂ was markedly higher, particularly in May (228.4 mm) and July (109.8 mm), compared to L₁. In contrast, L₁ exhibited substantially lower rainfall, with a sharp decline in July (3 mm). In terms of temperature, values at L₂ increased earlier in the season, reaching 12.7 °C in April and peaking at 22.7 °C in June. At L₁, however, the temperature rose more gradually, starting from 11.9 °C in May and reaching 20.3 °C in August. This difference is likely attributable to the higher elevation of L₁, which is situated at 1787 meters above sea level. Relative humidity was also consistently higher at L₂ throughout the season. These data indicate that the two locations differ substantially in terms of climatic conditions, as detailed in Figure 1.

The physical and chemical properties of the soils at the two experimental locations used in this study showed distinct differences. The experimental field in Erzurum (L₁) is classified as clay-loam in texture, with 35.78% clay, 29.50% silt, and 34.72% sand. The soil has a slightly alkaline pH of 7.56. Organic matter content is 1.01%, and calcium carbonate (CaCO₃) content is 1.14%. Available phosphorus and potassium contents are 4.41 kg P₂O₅/da and 171 kg K₂O/da, respectively. The experimental site in Budapest (L₂) has a slightly acidic pH of 6.49 and low salinity (0.039%). The

humus content is 1.17%. The phosphorus (P_2O_5) content is significantly higher at 291 mg/kg, whereas the potassium (K_2O) level is lower at 36.7 mg/kg. Additionally, concentrations of NO_3-N (1.24 mg/kg), Ca (0.489%), Mg (53 mg/kg), Fe (109 mg/kg), Mn (37.8 mg/kg), Zn (1.73 mg/kg), and Cu (3.47 mg/kg) were also recorded at this site. The lime ($CaCO_3$) content at L_2 is below 1%. While the L_1 soil offers structural advantages due to its higher potassium content and clay-loam texture, the L_2 soil is richer in available phosphorus and micronutrients, reflecting a more nutrient-dense profile.

Figure 1.

Climate Parameter Comparison Between Erzurum (L_1) and Budapest (L_2)



Black cumin (*Nigella sativa* L.) was sown on April 1 at the L_2 location and on May 3 at the L_1 location. Sowing was carried out using a plot drill with 30 cm row spacing at a seeding rate of 20 kg seed ha^{-1} , and seedlings were subsequently thinned by hand to ensure uniform plant distribution. Nitrogen (as ammonium sulfate) and phosphorus (as triple superphosphate) fertilizers were applied to all plots at both locations at rates of 70 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1} , respectively, and incorporated into the seedbed prior to sowing. Irrigation was applied four times at the L_1 location and twice at the L_2 location to avoid water stress during critical growth stages. Weed control was performed manually through hand-hoeing during the growing period.

Harvesting was conducted on July 25 at the L_2 location and on September 1 at the L_1 location, when approximately 50% of the capsules had turned from green to brown, indicating physiological maturity. At both locations, harvesting was carried out manually by pulling the mature plants from the soil along with their roots.

Seeds obtained from the L_2 location were shipped to the L_1 site, and to ensure comparability and sample homogeneity, quality analyses of seed samples from both locations were conducted in the same laboratory. All analyses were performed at the Eastern Anatolia High Technology Application and Research Center (DAYTAM).

Seed Quality Analysis

The protein content of the seed samples was assessed using the Kjeldahl method, employing an automated analyzer in accordance with AOAC (2000) Official Method 979.06. For each analysis, 1.0 g of the sample was digested with concentrated sulfuric acid (12 mL) in the presence of catalyst mixtures ($CuSO_4 \cdot 5H_2O$ and K_2SO_4) at 420 °C for 60 minutes. The ammonia released during digestion was distilled and trapped in a boric acid solution, followed by automatic titration with 0.2 N HCl.

The total nitrogen (%) was calculated using the following equation:

$$\text{Nitrogen (\%)} = \frac{(V_s - V_b) \times N_{HCl} \times 14.01}{\text{Sample weight}} \times 100 \quad (1)$$

In this formula, V_s refers to the amount of acid required to neutralize the digested sample, whereas V_b indicates the volume used in the blank determination. The term N_{HCl} stands for the concentration (normality) of the hydrochloric acid solution. The constant 14.01 represents the atomic weight of nitrogen. To estimate the crude protein level, the calculated nitrogen percentage was multiplied by a standard factor of 6.25, following the equation:

$$\text{Crude protein} = \text{Nitrogen (\%)} \times 6.25 \quad (2)$$

Crude fat content was determined following the AOAC (2000) Official Method 920.39 using the Soxhlet extraction technique. Approximately 2.0 g of the sample (W_1) was wrapped in fat-free cotton and placed in an extraction thimble. A pre-weighed extraction flask (W_2) was filled with 50 mL of diethyl ether, and the system was run for 4 hours. The solvent was evaporated, and the flask was dried in an oven at 70 °C for 30 minutes, cooled in a desiccator, and then weighed again (W_3). Crude fat content was calculated using the following formula:

$$\text{Crude fat (\%)} = \frac{(W_3 - W_2)}{(W_1)} \times 100 \quad (3)$$

Ash content was measured according to AOAC (2000) Official Method 923.03. A pre-weighed crucible (W_1) was filled with 5.0 g of the sample (W_2) and initially charred on

a hot plate. The sample was then transferred to a muffle furnace at 550 °C and incinerated for 5 hours, until a constant white-gray ash color was observed. After cooling in a desiccator, the crucible and its contents were weighed again (W3). The ash content was determined as:

$$\text{Ash (\%)} = \frac{(W_3 - W_1)}{(W_2)} \times 100 \quad (4)$$

The concentrations of macroelements and microelements were determined following wet digestion of dried and finely milled samples. Sample digestion was conducted using microwave-assisted incineration (Speedwave MWS-2, Berghof, Germany) according to the U.S. EPA Method 3052 (USEPA, 1997). Elemental analysis was subsequently performed using inductively coupled plasma mass spectrometry (ICP-MS) with an Agilent 7800 system (Agilent Technologies, Santa Clara, CA, USA).

Fatty acid composition in oil extracts was determined after transforming the fatty acids into methyl esters (FAMES) through a reaction with 2 N KOH in methanol, according to IUPAC Method 2.301 (Dieffenbacher & Pocklington, 1992). The resulting methyl esters were analyzed using a gas chromatograph (GC 7890A, Agilent Technologies, USA) equipped with a 5975C mass selective detector and a BPX90 capillary column (100 m × 0.25 mm ID, 0.25 µm film thickness). The injector temperature was set at 250 °C. The oven temperature was planned to increase from 120 °C (held for 1 minute) to 250 °C at a rate of 5 °C per minute, followed by another 1-minute hold. Helium was used as the carrier gas at 1 mL/min with a 1:10 split. Identification was achieved by comparing the retention times to a certified standard (Supelco 37 Component FAME Mix, Bellefonte, PA, USA).

Data Analysis

Statistical analyses and data visualizations in this study were performed using RStudio (version 2025.05.0+496) developed by Posit Software. Descriptive statistics, including means and standard deviations, were calculated for all measured parameters, such as protein, oil, and ash content, fatty acid composition, and mineral concentrations. To determine whether the differences between the two cultivation locations (Türkiye and Hungary) were statistically significant, independent sample t-tests were conducted. A significance threshold of $p < .05$ was applied for all comparisons. Additionally, a radar chart was constructed using the “fmsb” package in R to visually compare the compositional attributes of black cumin seeds grown in the two different ecological environments.

Results

The chemical composition of black cumin seeds cultivated in Türkiye and Hungary is presented in Table 1. Seeds grown in Türkiye exhibited higher protein (20.5%) and fatty oil (37.2%) contents compared to those cultivated in Hungary, which recorded protein and oil levels of 17.8% and 33.7%, respectively. Additionally, the ash content was slightly higher in seeds from Türkiye (3.1%) than those from Hungary (2.7%). The differences between the two locations were found to be statistically significant ($p < .05$).

Table 1.

Chemical composition (%) of black cumin seeds grown in different ecological conditions (Türkiye and Hungary).

	Black cumin (%)		
	Türkiye	Hungary	<i>p</i>
Protein content (%)	20.5 ± 0.3	17.8 ± 0.4	<.05
Oil content (%)	37.2 ± 0.5	33.7 ± 0.6	<.05
Ash content (%)	3.1 ± 0.1	2.7 ± 0.1	<.05

Values are presented as mean ± standard deviation (n:3). Differences between groups were analyzed using t-tests ($p < .05$).

The fatty acid profiles of black cumin seeds grown in Türkiye and Hungary are shown in Table 2. Linoleic acid (C18:2) and oleic acid (C18:1n9) were the major fatty acids identified in the seeds. Seeds from the Türkiye location had a higher linoleic acid content (62.60%) compared to those from Hungary (58.39%), while oleic acid content was higher in seeds from the Hungary location (23.03%) than in those from Türkiye (18.91%).

In terms of saturated fatty acids (SFA), seeds from Hungary showed slightly higher levels (14.42%) compared to those from Türkiye (13.80%). For monounsaturated fatty acids (MFA), seeds from Hungary again recorded higher values (23.56%) compared to Türkiye (19.43%). However, seeds grown in Türkiye exhibited a higher proportion of polyunsaturated fatty acids (PuFA) (66.43%) than those grown in Hungary (61.60%). The total unsaturated fatty acid (UFA) content was comparable between the two locations, with values of 85.84% and 85.16% for Türkiye and Hungary, respectively.

The mineral composition of black cumin seeds cultivated under different ecological conditions is summarized in Table 3. Magnesium (434.31 mg 100 g⁻¹) and manganese (13.61 mg 100 g⁻¹) levels were notably higher in the Türkiye location compared to Hungary (345.39 mg 100 g⁻¹ and 4.78 mg

Table 2.

Fatty acid composition (%) of black cumin seeds grown in different ecological conditions.

Fatty acids	L1	L2	p
Butyric acid (4:0)	0.02 ± 0.00	0.02 ± 0.00	ns
Capric acid (10:0)	0.05 ± 0.00	0.05 ± 0.00	ns
Myristic acid (14:0)	0.15 ± 0.01	0.13 ± 0.02	ns
Palmitic acid (16:0)	10.40 ± 0.04	11.47 ± 0.01	<.05
Palmitoleic acid (16:1)	0.17 ± 0.01	0.19 ± 0.02	ns
Stearic acid (18:0)	3.02 ± 0.02	2.60 ± 0.01	<.05
Oleic acid (18:1n9)	18.91 ± 0.05	23.03 ± 0.06	<.05
Linoleic acid (18:2)	62.60 ± 0.58	58.39 ± 0.21	<.05
Linolenic acid (18:3)	0.29 ± 0.01	0.32 ± 0.01	<.05
Arachidic acid (20:0)	0.16 ± 0.01	0.15 ± 0.01	ns
Eicosenoic acid (20:1)	0.35 ± 0.01	0.34 ± 0.02	ns
Eicosadienoic acid (20:2)	3.54 ± 0.28	2.89 ± 0.11	<.05
Total	99.64 ± 0.37	99.52 ± 0.23	ns
SFAs	13.80 ± 0.05	14.42 ± 0.01	<.05
MFAs	19.43 ± 0.04	23.56 ± 0.07	<.05
PuFAs	66.43 ± 0.31	61.60 ± 0.27	<.05
Total UFAs	85.84 ± 0.32	85.16 ± 0.25	ns

SFA (Saturated Fatty Acids), MFA (Monounsaturated Fatty Acids), PuFA (Polyunsaturated Fatty Acids), and UFA (Total Unsaturated Fatty Acids) refer to the respective classes of fatty acids identified in the seed oil samples. Values are expressed as mean ± standard deviation. Statistical differences were determined using independent sample t-tests ($p < .05$). NS: Not Significant.

Table 3.

Mg, P, Ca, K, Mn, Fe, Cu, Zn contents of black cumin. Values were expressed on a mg 100g⁻¹ dry weight basis.

Nutritions	Black cumin (mg 100g ⁻¹)		
	L1	L2	p
Magnesium (Mg)	434.31 ± 5.12	345.39 ± 6.23	<.05
Phosphor (P)	816.10 ± 8.87	1007.26 ± 10.24	<.05
Potassium (K)	1001.27 ± 12.35	1113.19 ± 15.24	<.05
Calcium (Ca)	155.97 ± 4.36	200.02 ± 7.85	<.05
Manganese (Mn)	13.61 ± 1.02	4.78 ± 0.85	<.05
Iron (Fe)	1.43 ± 0.62	16.22 ± 1.23	<.05
Copper (Cu)	1.43 ± 0.42	1.58 ± 0.51	ns
Zinc (Zn)	5.04 ± 0.83	18.64 ± 1.20	<.05

Values are expressed as mean ± standard deviation (n = 3). Statistical comparisons between Türkiye and Hungary were performed using independent sample t-tests. Differences were considered statistically significant at $p < .05$. ns: Not significant.

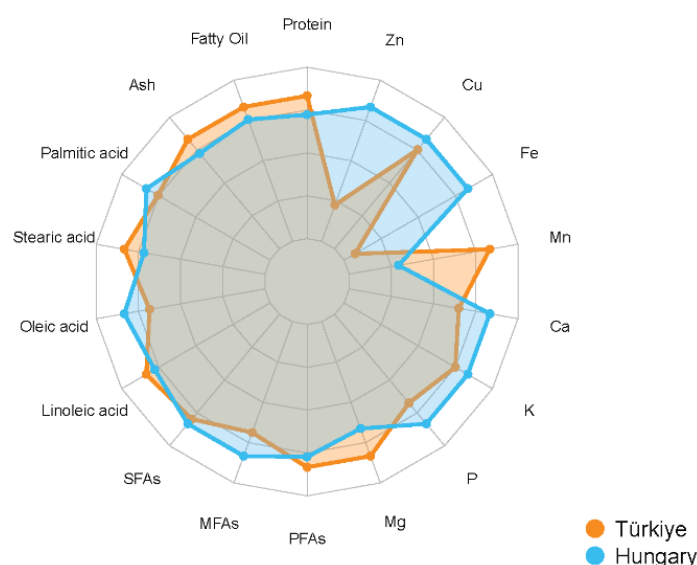
100 g⁻¹, respectively). Conversely, seeds cultivated in Hungary exhibited higher concentrations of phosphorus (1007.26 mg 100 g⁻¹), potassium (1113.19 mg 100 g⁻¹), calcium (200.02 mg 100 g⁻¹), iron (16.22 mg 100 g⁻¹), copper (1.58 mg 100 g⁻¹), and zinc (18.64 mg 100 g⁻¹) compared to those from Türkiye.

These results demonstrate that environmental conditions, particularly soil and climate differences, substantially influence the accumulation of macro- and micronutrients in black cumin seeds.

The comparison of black cumin composition between Türkiye and Hungary, including major minerals, fatty acids, and general proximate values, is illustrated in Figure 2. The radar chart clearly highlights the differences in nutrient profiles between the two countries.

Figure 2.

Radar chart comparing the black cumin composition between Türkiye and Hungary.



Significant differences were observed between black cumin seeds cultivated in Türkiye and Hungary, particularly in terms of protein, fatty oil, fatty acid composition, and mineral contents. Seeds grown in Türkiye exhibited higher protein, fatty oil, linoleic acid, magnesium, and manganese levels, while those cultivated under Hungarian conditions had greater concentrations of oleic acid, phosphorus, potassium, calcium, iron, copper, and zinc.

These discrepancies are likely due to variations in ecological factors such as temperature regimes, precipitation patterns, soil nutrient availability, and agronomic practices. Climatic differences, especially temperature and rainfall distribution, may have influenced the metabolic pathways responsible for fatty acid biosynthesis and nutrient accumulation, ultimately leading to distinct seed quality profiles between the two locations.

Discussion

The present study demonstrated that black cumin seeds cultivated under the ecological conditions of Türkiye had higher levels of oil (37.2%), protein (20.5%), and ash (3.1%) compared to those cultivated in Hungary, which showed corresponding values of 33.7%, 17.8%, and 2.7%. These differences highlight the significant influence of environmental variables, such as climate, soil composition, and cultivation practices, on seed composition (Kabir et al., 2019; Tura et al., 2023).

The oil content observed in seeds from Türkiye aligns closely with previous reports. Al-Jassir (1992) recorded an oil content of 38.2%, while Oubannin et al. (2022) reported a similar value of 37.83%. Conversely, Khalid et al. (2019) reported a lower oil range of 30.74%–34.41%, and Kabir et al. (2019) documented a notably higher value of 45.4%. Such discrepancies are likely attributable to genotypic variation and local environmental conditions, which play a crucial role in oil biosynthesis.

Protein content in seeds from Türkiye (20.5%) was also slightly higher than in those from Hungary (17.8%). These values are consistent with those reported by Mamun and Absar (2018), Albakry et al. (2022), Oubannin et al. (2022), and Sultan et al. (2009), who found protein levels ranging between 18.09% and 22.08%. However, significantly higher protein values have been recorded in seeds from Ethiopia and Syria (26.1% and 25.8%, respectively), suggesting that geographical location, storage conditions, and genetic differences are major contributing factors (Mariod et al., 2012).

In terms of ash content, the values identified in this study (3.1% for Türkiye, 2.7% for Hungary) are generally lower than those reported in earlier studies, such as Mamun and Absar (2018) (4.69%), Sultan et al. (2009) (4.20%), and Khalid et al. (2019) (4.28%–4.72%). A significantly higher ash content of 7.39% was recorded by Kabir et al. (2019), while Albakry et al. (2022) reported a value of 3.02%, which is comparable to our findings. These variations likely stem from soil mineral availability, fertilization, and processing methods.

Regarding mineral composition, potassium (K), phosphorus (P), magnesium (Mg), and calcium (Ca) emerged as the dominant elements in both regions. Seeds from Hungary contained higher levels of potassium (1113.19 mg/100 g) and phosphorus (1007.26 mg/100 g), while those from Türkiye had higher magnesium (434.31 mg/100 g) content. Previous studies support these findings, identifying K, P, Ca, and Mg as the principal minerals in black cumin seeds (Albakry et al., 2022; Haron & Shahar, 2014; Kabir et al., 2019). The minor discrepancies across studies can be explained by differences in soil composition, pH, and the plant's nutrient uptake efficiency (Izgi, 2020). Nonetheless,

potassium appears to be consistently the dominant mineral.

Fatty acid analysis revealed linoleic acid (C18:2), oleic acid (C18:1n9), and palmitic acid (C16:0) as the major components in both cultivation locations. Seeds grown in Türkiye exhibited higher linoleic acid content (62.60%) but lower oleic (18.91%) and palmitic (10.40%) acid levels compared to Hungary (58.39%, 23.03%, and 11.47%, respectively). Although the fatty acid profiles were generally consistent between the two sites, the quantitative differences underscore the effect of cultivation site on oil quality, as previously emphasized by Salaheldin et al. (2020).

Comparable fatty acid compositions have been reported by Tulukcu (2011), who identified linoleic acid values between 54.32%–70.81%, oleic acid between 15.17%–24.15%, and palmitic acid between 8.2%–13.3%. Similar trends were noted in the studies by Işık et al. (2011), Demirbolat and Kartal (2019), and Kaskoos (2011), further confirming the findings of the present study. These results indicate that although genetic factors provide a baseline composition, environmental conditions such as temperature and soil type significantly influence fatty acid biosynthesis.

Conclusion and Recommendations

This study presents a comparative evaluation of the effects of different ecological conditions specifically Erzurum (Türkiye) and Budapest (Hungary) on the chemical and nutritional composition of black cumin (*Nigella sativa* L.) seeds. The findings reveal that environmental factors such as climate, altitude, and soil characteristics significantly influence key seed quality traits, including protein, oil, ash content, fatty acid profiles, and mineral composition.

Seeds cultivated in Türkiye were found to contain higher levels of protein, oil, linoleic acid, magnesium, and manganese, while those grown in Hungary exhibited greater concentrations of oleic acid, phosphorus, potassium, calcium, iron, copper, and zinc. These differences reflect the complex interplay between environmental variables and plant metabolic processes, underscoring the importance of ecological adaptation in the cultivation of medicinal plants.

The results of this study are consistent with prior literature while also providing new and original insights into how ecological diversity affects the phytochemical and nutritional profiles of black cumin seeds. These findings suggest that region-specific agricultural strategies can be developed to optimize seed quality for nutritional, pharmaceutical, or industrial applications.

In conclusion, this research highlights the decisive role of ecological factors in shaping the quality characteristics of black cumin seeds. It provides a scientific foundation and practical roadmap for stakeholders seeking to enhance the quality and economic value of *Nigella sativa* cultivation.

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