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Original article

From Global Origins to Local Fields: First Comprehensive Profiling of *Nigella sativa L.* Nutritional and Fatty Acid Composition in Albanian Agroecological Conditions

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Abstract

Nigella sativa L. (black cumin) is a widely used medicinal and nutritional crop, yet its chemical characteristics under Albanian agroecological conditions remain unexplored. This study provides the first assessment of the fatty acid profile and macronutrient composition of *N. sativa* L. varieties cultivated in Tirana, with the aim of supporting breeding efforts, functional food development, and crop diversification. Eight varieties originating from different countries were grown at the Experimental Didactic Field of the Agricultural University of Tirana. Mature seeds were analyzed for fatty acids following derivatization to FAMEs using GCMS-QP2010 Ultra, while macronutrient concentrations (Na, K, Ca, Mg, P) were quantified using ICP-MS. The varieties exhibited significant inter-varietal variability. T7 showed the highest monounsaturated fatty acids (21.9%) and calcium concentration (2,012.31 mg kg^{-1}). T8 recorded the highest saturated fatty acids (17.2%) and sodium level (128.58 mg kg^{-1}), whereas T4 had the highest polyunsaturated fatty acids (63.0%). For minerals, T3 contained the greatest potassium (11,450.19 mg kg^{-1}) and magnesium (2,904.45 mg kg^{-1}), while T5 had the highest phosphorus content (9,309.01 mg kg^{-1}). These results highlight substantial nutritional diversity within *N. sativa* L. grown under Tirana conditions, identifying promising genotypes with superior fatty acid and mineral profiles. Such genotypes have strong potential for use in functional foods, nutraceutical production, and sustainable agricultural development.

Keywords: *Nigella Sativa*, Fatty Acid Composition, Macronutrients, Albania, Crop Diversification, Nutritional Quality, Functional Foods, Sustainable Agriculture.

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INTRODUCTION

Agricultural production systems worldwide are undergoing significant transformations in response to increasing demand for food security, environmental sustainability, and improved nutritional quality. Crop diversification has emerged as a key strategy for addressing these challenges, as the integration of underutilized or alternative species can strengthen ecological resilience, enhance dietary diversity, and generate new economic opportunities for farmers. In the context of sustainable agriculture, the introduction of high-value crops with recognized nutritional and functional properties is increasingly seen as an important pathway toward achieving both environmental and socio-economic benefits (Altieri, Agroecology: the science of sustainable agriculture, 2018); (Gliessman, 2022)

Among these promising species, *Nigella sativa* L., commonly known as black cumin, has gained considerable attention due to its combined medicinal, nutritional, and agronomic value. Cultivated for centuries across the Middle East, Asia, and parts of Southern Europe, (Hannan, 2021) N. sativa is traditionally valued for its aromatic seeds and therapeutic applications (Tembhurne, 2014) Recent scientific studies confirm that the seeds contain essential bioactive compounds, (Zielinska, 2021) including thymoquinone, unsaturated fatty acids, proteins, and minerals, supporting their classification as a functional food (Cheikh-Rouhou). Its fatty acid profile, characterized by high levels of linoleic acid (C18:2, ω-6) and oleic acid (C18:1, ω-9), is associated with positive effects on cardiovascular health, immune function, and metabolic balance. The presence of adequate macronutrients such as proteins, carbohydrates, and fats further supports its role in nutritionally balanced diets. (Atta, 2003) (Ramadan, 2007)

Growing consumer interest in natural products with health-promoting properties has increased the relevance of *N. sativa* in modern food systems. Seeds and cold-pressed oils derived from this crop are now widely used in dietary supplements, nutraceuticals, and functional foods, contributing both to human health and to value creation within agricultural supply chains. For countries aiming to strengthen their agri-food sectors through innovation, *N. sativa* offers opportunities to align agricultural production with contemporary trends in health, nutrition, and sustainability (Thompson G. D., 1998) (Yimer, 2019) (Hertel, 2011)

Albania, with its diverse agro-ecological zones ranging from coastal plains to mountainous areas, provides favorable conditions for the introduction and assessment of alternative crops such as *N. sativa*. (Shumka L. a., 2023) Despite this potential, limited scientific data exist on the nutritional composition of *N. sativa* grown under Albanian conditions. Most available studies originate from other regions and may not reflect the effects of local climate, soil characteristics, or cultivation practices on seed biochemical traits. Understanding how Albania’s agro-ecological conditions influence the fatty acid profile and macronutrient content of *N. sativa* is therefore essential for evaluating its suitability for crop diversification and its potential contribution to public health and food securit (Jonida Biturku, 2024) (Zolekar, 2015)

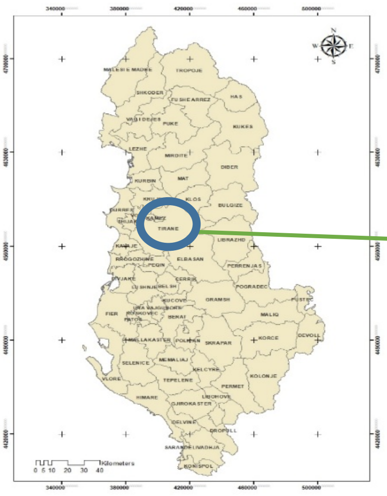
Integrating *N. sativa* into Albanian agriculture could offer multiple benefits. Agronomically, it represents a low-input crop capable of thriving under semi-arid conditions, thereby contributing to more resilient farming systems (Hufnagel, 2020). Nutritionally, its seed composition may help address dietary imbalances and expand access to functional foods. Socio-economically, promoting its cultivation and processing could support smallholder farmers and stimulate rural development through the creation of new value chains. These combined advantages underscore the importance of investigating the nutritional properties of this species within the Albanian context(Haque, 2022) (Fao, 2018) (Lampietti, 2009)

This study therefore aims to evaluate the fatty acid composition and macronutrient content of *Nigella sativa* cultivated in Albania. By characterizing its nutritional profile, the research provides insights into the potential role of *N. sativa* in promoting crop diversification, enhancing nutritional quality, and supporting sustainable agricultural development. Additionally, the findings contribute to the knowledge base required for integrating black cumin into functional food production and advancing agro-biodiversity in Albania(Shumka S. a., 2022) (Capacci, 2012)

MATERIAL and METHODS

Seeds collection

In August 2023, eight varieties of *Nigella sativa* L. were collected from the Didactic Experimental Field of the Agricultural University of Tirana (41.3998180, 19.7285460). Site location is shown in Figure.1. The plant materials represented a diverse geographic origin, including Egypt (Nabial MORSI.CO, sample no. 136), Saudi Arabia (Sifa International Manufacturing, Jeddah), Syria (Almnarco.com; Natural Dry Nuts & Herbs, code 353), and Turkey (Sakli Doğa, product no. 012). This wide range of origins reflects both regional and international diversity, providing a representative basis for evaluating the nutritional and biochemical characteristics of the species under Albanian agro-ecological conditions.



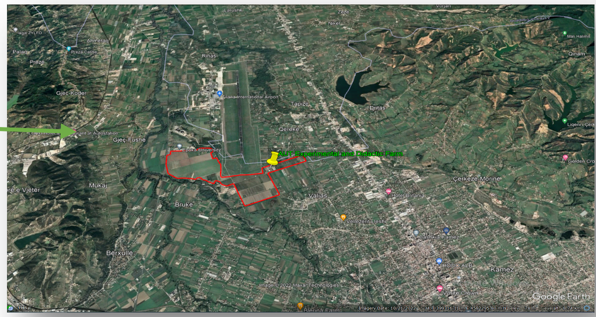


Figure 1a: Albania administrative map **Figure 1b**: Google Earth view with the field boundary (red) and site marker

Figure 1. (a) Location of the experimental site within Albania; (b) satellite view of the Didactic Experimental Field, Agricultural University of Tirana (41.3998180, 19.7285460). The red polygon outlines the field area. *Note.* Maps were prepared in QGIS 3.34.12 (WGS84). Panel (b) imagery: Google Earth; Map data ©

Oil Extraction

15 grams of *N.sativa.L* seeds were ground into a fine powder and placed in a Soxhlet extractor with 150–200 mL of petroleum ether (boiling range 40–60°C). The solvent was cycled for 6–8 hours until clear, indicating complete extraction. The solvent-oil mixture was evaporated to recover the solvent, leaving crude oil as residue. The oil was collected and stored for further analysis. (Le, 2004)

Mineral Determination via ICP-MS

The concentrations of macroelements (Na, K, Ca, Mg, and P) in *Nigella sativa L.* seeds were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Sample preparation was carried out using a closed-vessel microwave-assisted acid digestion system (Berghof, Model MSW-4), following validated procedures for plant-based materials (Hoenig, 1998)

Approximately 200 mg of finely ground seed material was placed into Teflon digestion vessels. To each sample, 5 mL of concentrated nitric acid (65% HNO_3) and 1 mL of hydrogen peroxide (H_2O_2) were added. The digestion program consisted of the following steps:

- Temperature ramped to 160 °Cover 5 minutes and held for 5 minutes
- Increased to 190 °Cover 1 minute and held for 10 minutes
- The samples were cooled to 50 °C before handling

After digestion, the samples were brought to a final volume of 10 mL with ultrapure water. A 0.1 mL aliquot from each digest was further diluted with ultrapure water to the appropriate concentration for analysis.

Elemental quantification was performed using a Perkin Elmer NexION 350X ICP-MS instrument, operated in standard (STD) and kinetic energy discrimination (KED) mode with helium as the collision gas. The instrument was configured with a Mainhard concentric nebulizer and a glass cyclonic spray chamber. Operating parameters were as follows: plasma gas flow rate 18.0 L/min, auxiliary gas flow 1.2 L/min, nebulizer gas flow 0.74 L/min, RF power 1500 W, and sample uptake rate 1.0 mL/min. Each sample was analyzed in triplicate (n = 3).

Fatty acid methyl esters were prepared using the standard IUPAC method (Thompson M. a., 2002), *Standard Methods for the Analysis of Oils, Fats and Derivatives*. (Paquot, 1987)

Fatty Acid Composition Analysis

Fatty acid composition of *Nigella sativa* L. seed oil was determined after derivatization to fatty acid methyl esters (FAMEs), following the ISO 129661:2014 standard (ISO, 2014).

Approximately 0.1 g of cold-pressed oil was transferred into a 15 mL screw-capped plastic centrifuge tube. Ten milliliters of *n*-hexane were added, and the tube was sealed and shaken vigorously. Then, 0.5 mL of 2N methanolic potassium hydroxide (prepared by dissolving 11.2 g of KOH in methanol and diluting to 100 mL) was added, and the mixture was shaken again. The tubes were kept in a dark environment and left to stand for 1–2 hours until the upper phase became clear.

A 1 µL aliquot of the upper *n*-hexane layer was injected into a GCMS-QP2010 Ultra system (Shimadzu, Japan) for the analysis of FAMEs. The system was equipped with a TRCN-100 capillary column (100 m × 0.25 mm i.d., 0.20 µm film thickness). The temperature program was as follows: initial oven temperature at 140°C (held for 6 minutes), then increased to 240°C at a programmed rate and held at 240°C for 20 minutes. The detector (mass spectrometer) temperature was set at 260°C.

Peak identification and integration were performed from GC–MS outputs (FAMEs) using retention times and library matches. Raw peak lists were exported to Excel (Microsoft 365 v2508, built 19127.20192) for initial checks and then imported into RStudio (R 4.4.2) for statistical analysis and data visualization. A representative chromatogram and the full peak lists for each variety are provided in Supplementary Figures S1–S8 and Supplementary Tables S1–S8.

Statistical analysis

Microsoft Excel for Microsoft 365 v2508 (Build 19127.20192) was used for data management; statistical analyses and visualization of the data were produced in R 4.4.2 softare.

RESULTS and DISCUSSION

The concentrations of five macronutrients (Na, K, Ca, Mg, and P) in *Nigella sativa* seeds cultivated under Tirana agro-ecological conditions are presented in Table 1. Mean concentrations ranged from 121.96 mg kg^{-1} for sodium (Na) to 10,697.72 mg kg^{-1} for potassium (K). Calcium (Ca) and magnesium (Mg) were present at intermediate levels (1,946.84 mg kg^{-1} and 2,817.36 mg kg^{-1}, respectively), while phosphorus (P) reached 8,948.14 mg kg^{-1}.

The standard deviation (SD) values indicated different degrees of variability among nutrients. Calcium (54.60 mg kg^{-1}) and magnesium (69.62 mg kg^{-1}) showed the lowest variation across the eight studied varieties, suggesting stable accumulation patterns. In contrast, potassium (748.88 mg kg^{-1}) and phosphorus (391.63 mg kg^{-1}) displayed wider variation, reflecting differences in varietal uptake and storage capacity.

Table 1. Result of Macroelement concentrations per variety with mean and SD

Sample Id	Na (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	P (mg kg^{-1})
Tirane-1	127.04	10555.68	1832.35	2812.43	8929.8
Tirane-2	125.94	11166.95	1936.88	2790.81	9307.22
Tirane-3	116.82	11450.19	1983.13	2904.45	8934.27
Tirane-4	105.71	9074.34	1927.52	2750.55	8091.68
Tirane-5	122.19	10635.21	1987.46	2829.57	9309.01
Tirane-6	122.46	10787.63	1951.79	2887.89	9217.05
Tirane-7	126.95	11367.3	2012.31	2699.53	8858.91
Tirane-8	128.58	10544.45	1943.29	2863.66	8937.21
Mean	121.96	10697.72	1946.84	2817.36	8948.14
SD	7.08	700.51	51.08	65.12	366.33

This trend was further supported by the coefficient of variation (CV%), which normalizes variability relative to the mean. Magnesium (2.47%) and calcium (2.80%) exhibited the highest consistency across varieties, followed by phosphorus (4.38%). Sodium (6.21%) and potassium (7.00%) showed greater relative variation, indicating that these nutrients are more influenced by genetic diversity or agro-environmental factors. (Table 2) Overall, potassium and phosphorus were the dominant macronutrients in the seeds, whereas sodium was present at the lowest levels.

Table 2. Macroelement Summary with CV%

Macroelement	Mean concentration(mg kg^{-1})	Standard deviation	Coefficient of variation (%)
Na	121.96	7.57	6.21
K	10697.72	748.88	7
Ca	1946.84	54.6	2.8
Mg	2817.36	69.62	2.47
P	8948.14	391.63	4.38

Result of Fattyy acids composition

The fatty acid composition of *Nigella sativa* L. seeds cultivated under Tirana agro-ecological conditions is presented in Table 3. The results revealed that the oil was dominated by polyunsaturated fatty acids (PUFAs), with linoleic acid (C18:2n6c) being the most abundant, accounting for an average of 58.56% ± 0.40 of the total fatty acids. This finding aligns with previous studies reporting linoleic acid as the major component of *N. sativa* oil, confirming its classification as a PUFA-rich seed oil.

Oleic acid (C18:1n9c) represented the second most abundant fatty acid at 21.00% ± 0.59, indicating that *N. sativa* oil also contains a considerable proportion of monounsaturated fatty acids (MUFAs). Together, linoleic and oleic acids contributed to nearly 80% of the total fatty acids, suggesting a favorable balance of ω-6 and ω-9 fatty acids. This composition underlines the nutritional value of the oil, as both fatty acids are associated with cardiovascular protection and lipid metabolism regulation.

Among the saturated fatty acids (SFAs), palmitic acid (C16:0) was predominant, averaging 12.26% ± 0.37, followed by stearic acid (C18:0) at 3.01% ± 0.12. Minor amounts of lauric (C12:0), myristic (C14:0), pentadecanoic (C15:0), heptadecanoic (C17:0), and arachidic (C20:0) acids were also detected, each contributing less than 1% of the total composition. The relatively low SFA content is nutritionally beneficial, as it supports the production of heart-healthy oils with reduced risks of hypercholesterolemia.

Other minor unsaturated fatty acids included palmitoleic acid (C16:1, 0.21% ± 0.02), cis-11-eicosenoic acid (C20:1n9, 0.20% ± 0.02), and cis-13,16-docosadienoic acid (C22:2n6, 0.07% ± 0.02). Importantly, the oil also contained essential fatty acids such as alpha-linolenic acid (C18:3n6, 0.37% ± 0.06) and cis-11,14,17 eicosatrienoic acid (C20:3n3, 0.06% ± 0.01), although in small quantities. Furthermore, cis-8,11,14-eicosatrienoic acid (C20:3n6) was present at a notable level (3.47% ± 0.07), adding to the PUFA content.

Overall, the fatty acid profile of *N. sativa* seeds cultivated in Tirana demonstrates a favorable nutritional composition, characterized by high levels of PUFAs and MUFAs and comparatively low levels of SFAs. This composition underscores the potential of *N. sativa* as a functional food source with significant health-promoting properties, particularly in the context of cardiovascular health. Moreover, the relatively stable standard deviation (SD) values across fatty acids suggest consistency among the studied varieties, supporting its suitability as a reliable crop for functional oil production in Albanian agro-ecological conditions.

Table 3. Fatty acid composition of *Nigella sativa* L. seed oil cultivated in Tirana (mean ± SD, % of total fatty acids).

FAs	Nomeclature	Content (%) *
C12:0	Lauric acid	0.06 ± 0.02
C14:0	Myristic acid	0.23 ± 0.06
C15:0	Pentadecanoic acid	0.04 ± 0.01
C16:0	Palmitic acid	12.26 ± 0.37
C16:1	Palmitoleic acid	0.21 ± 0.02
C17:0	Heptadecanoic acid	0.09 ± 0.01
C18:0	Stearic acid	3.01 ± 0.12
C18:1n9c	Oleic acid	21.00 ± 0.59
C18:2n6c	Linoleic acid (LA)	58.56 ± 0.40
C18:3n6	γ-Linolenic acid (GLA)	0.37 ± 0.06
C20:1n9	Cis-11-eicosenoic acid	0.20 ± 0.02
C20:0	Arachidic acid	0.37 ± 0.02
C20:3n6	Eicosatrienoic acid (n-6)	3.47 ± 0.07
C20:3n3	Eicosatrienoic acid (n-3)	0.06 ± 0.01
C22:2n6	Docosadienoic acid	0.07 ± 0.02
ΣSFA	Saturated fatty acids	16.06 ± 0.49
ΣMUFA	Monounsaturated fatty acids	21.41 ± 0.58
ΣPUFA	Polyunsaturated fatty acids	62.53 ± 0.33
ΣUFA	Total unsaturated fatty acids	83.94 ± 0.49

**Note.* Values are expressed as mean ± SD (% of total fatty acids) based on three independent analytical replicates (n = 3). Abbreviations: SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA = unsaturated fatty acids

The ΣUFA value observed in this study (83.94%) is consistent with reports from other regions where *Nigella sativa* oils are typically dominated by unsaturated fatty acids. Studies from Egypt, Turkey, and Saudi Arabia generally report ΣUFA in the ~80–88% range, with linoleic (C18:2n6c) and oleic (C18:1n9c) acids as the major contributors and SFAs at ~12–20% (Ahmad, 2013) (Kiralan, 2017). More recent Mediterranean datasets also place ΣUFA near the mid-80% mark (Telci, 2023). Thus, the Tirana-grown material aligns well with the international profile, suggesting that Albania's agro-ecological conditions support a fatty-acid pattern comparable to leading production areas.

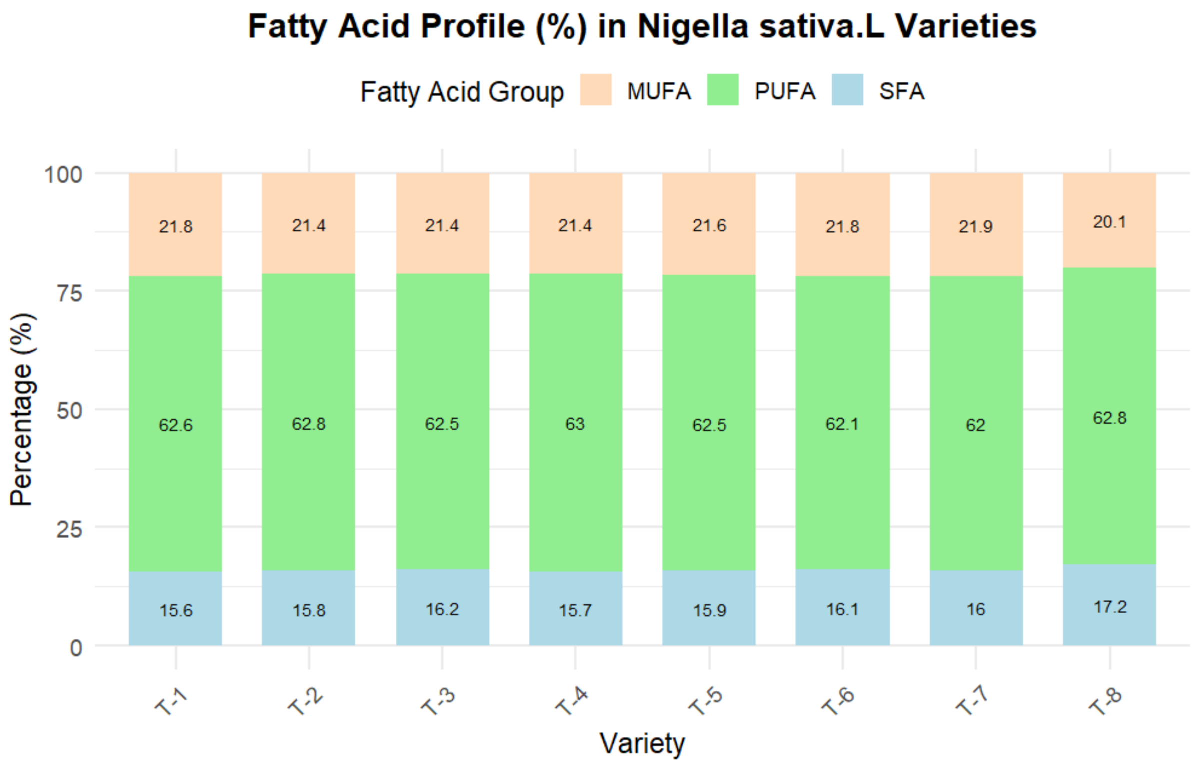


Figure 1. Grouped fatty-acid composition of eight *Nigella sativa L.* varieties cultivated in Tirana. Bars show ΣSFA, ΣMUFA, and ΣPUFA per variety

Note. Grouped data and visualization were produced in the RStudio environment (R 4.4.2, ggplot2); values shown are mean ± SD (*n* = 3).

Across the eight Tirana-grown varieties, T-4 exhibited the greatest proportion of polyunsaturated fatty acids (ΣPUFA = 63%), consistent with a linoleic-acid–rich profile of recognized cardioprotective value. Overall unsaturation was highest in T-1 (ΣUFA = 84.39%), which also showed the lowest saturated fraction (ΣSFA = 15.6%), indicating a favorable lipid balance. For monounsaturates, T-7 exhibited the highest nutritional value, as indicated by its superior ΣMUFA content (21.9%) and oleic-type signature. Collectively, these results suggest that T-4 is optimal when prioritizing PUFA-driven functionality, T-1 provides the most advantageous overall balance of high UFA and low SFA, and T-7 is most suitable where a MUFA-rich composition is desired.

CONCLUSION

This study provides an integrated assessment of the macroelement concentration and the fatty-acid composition (% of total FAs) of *Nigella sativa* L. seeds from eight Tirana-grown varieties under Albanian agro-ecological conditions. At the macroelement level, potassium (K) and phosphorus (P) were predominant (means ≈ 10,697.72 mg kg^{-1} and 8,948.14 mg kg^{-1}, respectively), whereas sodium (Na) was lowest (≈ 121.96 mg kg^{-1}). Variability across varieties was modest: calcium (Ca) and magnesium (Mg) were most consistent (CV ≈ 2.80% and 2.47%), while phosphorus and potassium showed moderate dispersion (CV ≈ 4.38% and 7.00%). These results indicate reliable mineral accumulation patterns across the material, with K and P dominating the elemental composition of the seeds.

The lipid fraction was nutritionally favorable, being dominated by unsaturated fatty acids: ΣUFA = 83.94% (comprising ΣPUFA = 62.53% and ΣMUFA = 21.41%), alongside ΣSFA = 16.06%. Linoleic (C18:2n6c) and oleic (C18:1n9c) acids were the principal constituents, whereas palmitic (C16:0) and stearic (C18:0) were the main saturated acids. Variety-level contrasts highlighted complementary strengths: T-4 maximized ΣPUFA (62.96%); T-1 combined the highest overall unsaturation with the lowest SFA (ΣUFA 84.39%, ΣSFA 15.61%); and T-7 led in ΣMUFA (21.94%). Thus, T-4 is preferable where PUFA-driven functionality is prioritized, T-1 offers the most balanced "high-UFA/low-SFA" profile, and T-7 is optimal when a MUFA-forward composition is desired.

From a food-and-nutrition perspective, the high UFA content supports positioning Albanian *N. sativa* as a functional ingredient with potential cardiometabolic benefits. Given the PUFA-rich nature of the oils, supply-chain practices should address oxidative stability (cool, dark storage; minimal oxygen exposure; and consideration of natural antioxidants). Agronomically, the macroelement results and the consistent fatty-acid patterns across varieties suggest *N. sativa* can be reliably integrated into local crop-diversification strategies with limited risk of compositional drift.

In summary, *N. sativa* cultivated in Tirana exhibits (i) a stable macroelement concentation (mg kg^{-1}) dominated by K and P, and (ii) a UFA-rich fatty-acid profile suitable for functional food applications. Future work should extend to multi-location/season trials, quantify antioxidant capacity and oxidative stability under practical storage/processing conditions, and dissect genotype-by-environment interactions to guide varietal selection and breeding for targeted nutritional profiles.

Additional Declaration

The abstract of this study was presented at the VII International Conference on Agricultural, Biological and Life Science.

Author Contributions

In this study, the contribution of the authors was equal; both authors contributed equally to the development of the research idea, data analysis, writing and proofreading stages. The contribution rates are first author (60%) and second author (40%).

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Responsible Artificial Intelligence Statement

In this study, artificial intelligence tools were used for minor language editing. All data handling, statistical analyses, and visualizations were conducted by the authors in R (4.4.2) and excel; AI tools did not perform original analyses, did not contribute scientific judgment, and did not generate novel results. No sensitive or personal identifiable information was provided to AI systems.

Conflicts of Interest

The authors declare that there are no conflicts of interest related to the publication of this study.

Ethics Approval

This study does not require ethics committee approval as it does not involve any direct application on human or animal subjects.

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