

Article

A Statistical Approach to Identify Appropriate Sampling Scheme Capable of Geographical Identification Analysis of the Protected Origin Pulse Crops in Greece

George Tsirogiannis ^{1,*}, Anastasios Zotos ^{2,*} , Eleni C. Mazarakioti ¹, Efthimios Kokkotos ¹,
Achilleas Kontogeorgos ³ , Angelos Patakas ¹  and Athanasios Ladavos ¹ 

¹ Department of Food Science and Technology, University of Patras, 30100 Agrinio, Greece

² Department of Sustainable Agriculture, University of Patras, 30100 Agrinio, Greece

³ Department of Agriculture, International Hellenic University, 57001 Thessaloniki, Greece

* Correspondence: gtsirogianni@upatras.gr (G.T.); azotos@upatras.gr (A.Z.); Tel.: +30-26410-74193 (A.Z.)

Abstract: In this study, we aimed to develop a sampling method that could be used in geographical discrimination studies of Protected Geographical Indication (PGI) dry beans (*Phaseolus vulgaris* L.) by considering the geoclimatic variability within the cultivation zone of the analyzed product. The Regional Unit of Kastoria in Greece, a major area of protected designation origin of pulse crops, was selected for detailed investigation. Meteorological data were collected from five weather stations in different subregions of Kastoria (Argos Orestiko, Kalochori, Lakkomata, Lithia, and Polykarpi), over a period of six years (2015 to 2020), along with data of soil texture. The collected data were analyzed in order to determine statistically significant differences among the subregions with regard to the aforementioned parameters. A seasonality pattern was observed for all subregions concerning the microclimate, which splits the data into two clusters. Moreover, a significant variation of the soil textures was revealed, frequently affecting farmers' decision regarding agronomic practices, leading to the unique stable-isotope ratios and multi-elemental composition. This study guides the dry bean sample collection and will enable the designation of the boundaries of protected origin regions and enable future sampling schemes for stable-isotope and multi-elemental analysis.

Keywords: geographical identification; meteorological conditions; soil texture; pulses; statistical analysis



Citation: Tsirogiannis, G.; Zotos, A.; Mazarakioti, E.C.; Kokkotos, E.; Kontogeorgos, A.; Patakas, A.; Ladavos, A. A Statistical Approach to Identify Appropriate Sampling Scheme Capable of Geographical Identification Analysis of the Protected Origin Pulse Crops in Greece. *Appl. Sci.* **2023**, *13*, 3623. <https://doi.org/10.3390/app13063623>

Academic Editor: Yosoon Choi

Received: 22 December 2022

Revised: 8 March 2023

Accepted: 9 March 2023

Published: 12 March 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

In recent decades, a growing interest in high-quality food products with a clear geographical origin has been observed. This tendency could be attributed to the need for foodstuffs with specific organoleptic qualities associated with particular regional areas and traditional farming production methods. An additional reason could be the consumers' uncertainty of the quality and safety of non-local products. According to the European Union (EU) Regulation 1151/2012, food products could be characterized by the following geographical indications: Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI). PGI emphasizes the relationship between the specific geographical area and the name of the product, where a certain quality or specific characteristics can be primarily attributed to its geographical origin.

Soil conditions have shown to play an important role in determining the geographical identity of food products, connecting them with distinct characteristics related to their growing area [1–6]. Although the concentration of mineral elements found in the surface layers of the soil can be significantly affected by applied agricultural practices, including irrigation and fertilization, the availability of most trace elements in the soil and their subsequent absorption by the plants is strongly affected by the soil mechanical properties [7,8]. Indeed, the soil is considered as a heterogeneous mixture of different organisms and mineral, organic and organo-mineral substances presented in three phases:

solid, liquid, gaseous. In this frame, trace metals and rare earth element (REEs) [9–11] occur in different species according to whether they are externally or internally bounded to various soil components or in the liquid phase. The solubility of elements, and thus their concentration in the soil solution, depends upon the solubility equilibrium. On the other hand, total levels of elements concentration are rarely indicative of plant availability because the latter depends on soil pH, organic matter content, adsorptive surfaces, and other physical, chemical, and biological conditions in the rhizosphere. Obviously, soil properties affect most of the chemical reactions and processes that occur in the rhizosphere and thus differences in soil properties could be used to accurately survey and map the geographic distribution of soil micronutrient contents and availability at scales ranging from global to sites within single production fields [12].

On the other hand, microclimatic conditions, mainly air temperature, relative humidity, solar radiation, and wind speed, are critical for agricultural production and also influence the geographical origin discrimination. As well as the availability of elements in the soil, differences in microclimatic parameters can seriously affect the stable isotope ratios of specific elements in plant tissues, which can be used for geographical production discrimination [13]. For instance, the stable isotopic ratios of $^{18}\text{O}/^{16}\text{O}$ and $^2\text{H}/^1\text{H}$, which are known to be greatly associated with the geographical origin of food products, depend on the regional climatic conditions and particularly total precipitation and seasonality [14–16].

Based on the assumption that the values of the isotopic and elemental profile/composition of food products are decisively influenced by the soil and microclimatic conditions of their cultivation area, the definition and the mapping of the existing geoclimatic variability within the total geographical area from which the samples are collected should be taken into consideration. Thus, the main objective of this study is to develop a sampling method to determine the geographical origin of PGI food products, considering the soil and microclimatic variability of the specific geographical areas, through the creation of sampling subregions within the wider cultivation zone of the examined product.

2. Materials and Methods

Though this study is based on data analysis and design of experiment, here we follow the usual terminology and structure of agronomy and food science where materials and methods follow the preamble.

2.1. Region of Interest

A major area of protected designation origin of pulse crops and in particular dry beans (*Phaseolus Vulgaris* L.) in Greece is the Regional Unit of Kastoria (Figure 1). It is located in the northwest of Greece, enclosed by the Pindos range, next to the lake Orestiada. This area was selected due to its intriguing geomorphological diversity. The altitude and the slope of the farming land, as well as the distance from the lake, vary significantly. The microclimate and soil texture are expected to vary among subregions influencing and providing special characteristics to the local production of beans [7,8,13,14].



Figure 1. Study Area of PGI beans products.

In particular, five individual subregions of the Regional Unit of Kastoria (Argos Orestiko, Kalochori, Lakkomata, Lithia, and Polykarpi) were selected for detailed investigation. Argos Orestiko ($40^{\circ}27' \text{ N}$, $21^{\circ}15' \text{ E}$) is the second largest city of the Regional Unit of Kastoria, located 8 km South of the city of Kastoria, at 660 m above sea level. Next to Argos Orestiko, the Lakkomata settlement ($40^{\circ}25' \text{ N}$, $21^{\circ}12' \text{ E}$) is found, in the southwest of the city of Kastoria, at an altitude of 660 m. In the east of Kastoria, at a distance of 28 km, the villages of Lithia ($40^{\circ}31' \text{ N}$, $21^{\circ}24' \text{ E}$) and Polykarpi ($40^{\circ}31' \text{ N}$, $21^{\circ}19' \text{ E}$) are located, at altitudes of 760 and 640 m, respectively. Finally, the village of Kalochori ($40^{\circ}29' \text{ N}$, $21^{\circ}08' \text{ E}$) is situated in the west of the city of Kastoria, at a distance of 14 km and an altitude of 721 m. The majority of dry bean production is carried out in the above-mentioned subregions, the special soil-climatic characteristics of which result in the special organoleptic characteristics of the final PGI products.

2.2. Data Collection and Analysis

Meteorological data from the automatic weather stations, which have been installed by the Regional Unit of Kastoria to monitor relative humidity, air temperature, wind speed, rainfall and solar radiation, were collected (Figure 2). The data collection period spans a period of six years (2015–2020) to eliminate possible temporal variations. The following data were recorded hourly and the mean daily values were used: solar radiation (W/m^2), rainfall (mm), wind speed (km/h), relative humidity (%), air temperature ($^{\circ}\text{C}$) and reference evapotranspiration—ET_o (mm).

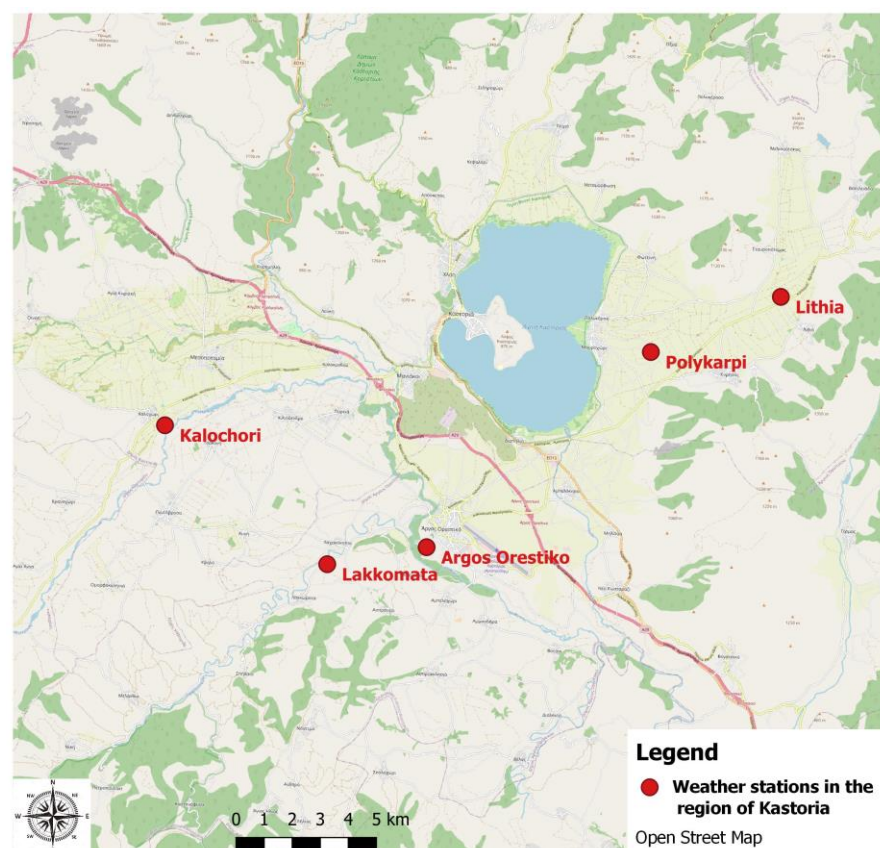


Figure 2. Distribution of the weather station in the region of Kastoria.

Additionally, a total of 364 soil samples were collected [17] from the whole area, distributed as follows: Argos Orestiko—45 samples; Kalochori—104 samples; Lakkomata—89 samples; Lithia—84 samples; and Polykarpi—42 samples. Soil samples were air dried, then crushed and sieved through a 2 mm sieve. Particle size distribution was assessed using Bouyoucos’s method [18]. The soil texture of samples was defined according to USDA particle-size classification diagram [19].

2.3. Statistical Analysis

The analysis is based on descriptive and hypothesis testing statistics of the meteorological and soil texture measurements. With descriptive statistics, we present an overview of the data distributions along with their interactions—pairwise and manifold-like.

The application of multiple statistical tests verified or proved wrong our hypothesis of the similarities among the subregions. Because all possible combinations of subregions were examined, a suitable significance level correction scheme was used. Technical details are given in the following sections.

3. Results and Discussion

3.1. Meteorological Factor

One of the common factors that has a major impact on the special characteristics of protected origin agricultural products such as dry beans is the microclimate of the cultivated area [20,21]. The analysis of the microclimate data allows us to answer the following research question: Is there any statistically significant difference among the subregions regarding the meteorological conditions? The answer to this question will guide the next steps of the detailed designation of the boundaries of protected origin regions and will determine the sampling schemes, as proposed in Section 3.3 for future stable isotope and multi-elemental analysis.

3.1.1. Descriptive Statistics and Topological Data Analysis of the Meteorological Factor

The distributions of the measurements for all subregions are shown in Figure 3. A kernel-based method was used for the computation of the distributions of major diagonal [22]. A good agreement between the distributions of all regions except Lakkomata with respect to the pyranometer (and thus reference evapotranspiration) was observed. This difference provoked a further investigation, and thus a topological data analysis was performed and the computed manifold was projected in the 2D embedding of Figure 4. The main idea of this method [23] is to preserve the topological information of the high dimensional space (i.e., 5D in this case: pyranometer, rainfall, wind speed, relative humidity, air temperature, reference evapotranspiration) and via a non-linear transformation to project the points into the xy -plane. In particular, it can be defined as a non-linear principal component analysis where the points that are similar/neighbors in the 5D space will be close to each other in 2D space, while the dissimilar ones are projected very far away. In Figure 4, a clear separation of Lakkomata can be seen, as well as a seasonality pattern for all subregions, which splits the data into two clusters, i.e., April–May (left cluster) and June–August (right cluster), while September is split between those two clusters. This shows a very strong indication of special microclimatic conditions of the Lakkomata subregion, which is investigated in the next section.

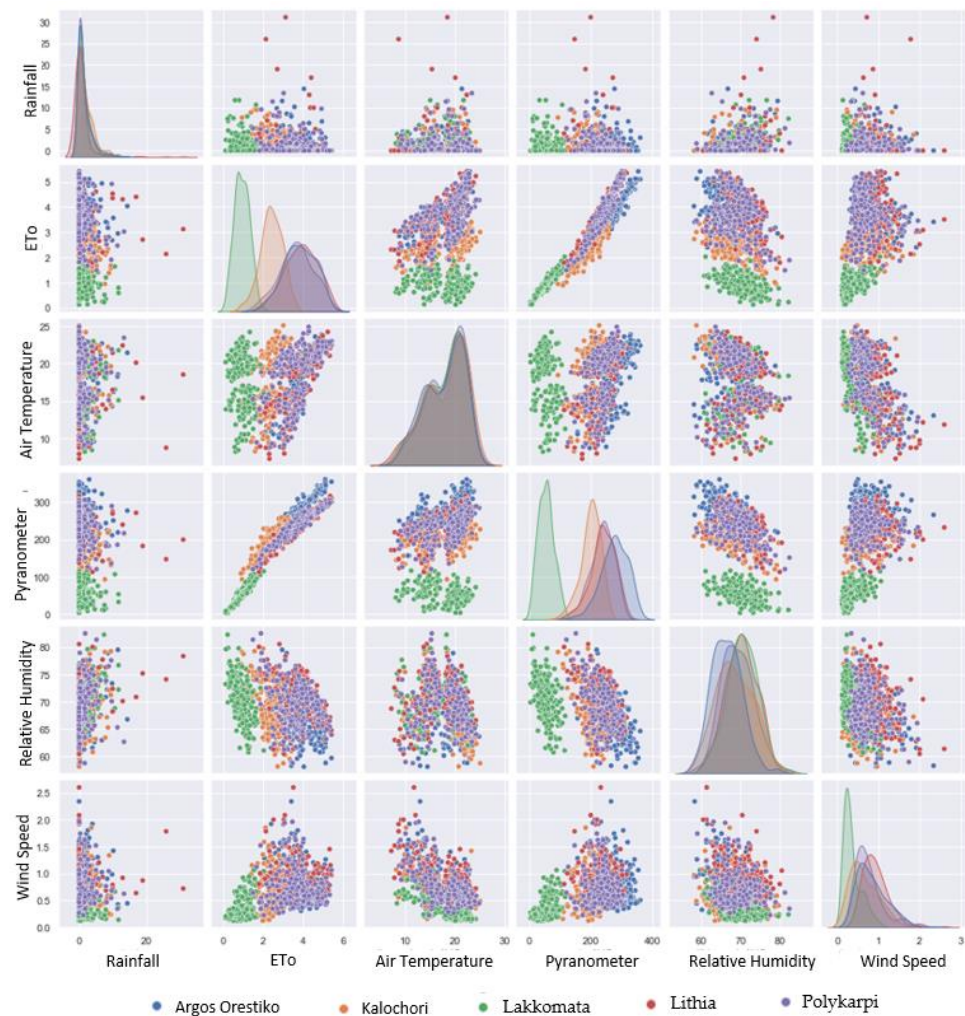


Figure 3. Pairwise plots of wind speed (km/h), relative humidity (%), pyranometer (W/m^2), air temperature ($^{\circ}\text{C}$), ETo (mm) and rainfall (mm) from Kastoria.

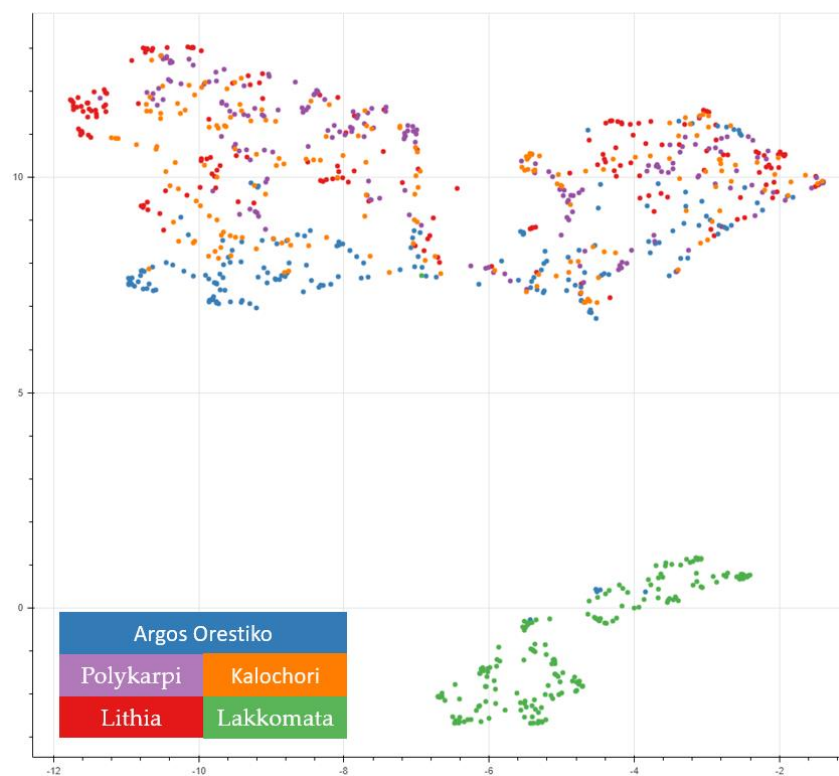


Figure 4. Topological data analysis of meteorological data from Kastoria.

3.1.2. Statistical Analysis and Hypothesis Testing of the Meteorological Factor

Although the descriptive statistical analysis of the previous section concludes that the region of Lakkomata was different, all possible pairs of subregions have been compared for completeness reasons. Since the initial set of data were five-dimensional, Root Sum Square (RSS) was used as a single metric and the hypothetical distribution of this statistic was estimated using resampling and Monte Carlo simulations ([22], ch. 9). The null hypothesis H_0 states that there is no difference between the two regions regarding the RSS mean value. Specifically, the point-to-point difference with respect to the simulated population was computed, and the corresponding probability was estimated. In the case of a common situation, i.e., very central location at the distribution obtained by the Monte Carlo simulation, H_0 is not rejected, while a rare/unlike value leads to the rejection of H_0 .

An interesting pattern was revealed when all pairs of Kastoria subregions were compared, which is in agreement with the observations of the topological data analysis of the previous section. For instance, when Lithia was compared with the RSS distribution of Argos Orestiko, it was observed that the obtained value of Lithia corresponded to a very common/central value of the distribution (Figure 5), and thus, no statistically significant difference could be concluded. On the contrary, if the RSS values of Lithia, Kalochoi, Argos Orestiko, and Polykarpi with the distribution of Lakkomata are compared, their values are out of scale (Figure 6). Extremely rare values correspond to nearly zero probability. From a statistical point of view, this leads to a clear rejection of H_0 for all subregions. After visiting the region of Lakkomata and in particular the location of the meteorological station, local farmers helped the research team to investigate if the orientation of this region is such that could be shadowed by neighboring hills/mountains. It was concluded that this is not the case, and from ad hoc measurements of the pyranometer, it revealed that the sensor drifted significantly. When the pyranometer's indicators were removed from the dataset, no statistically significant difference was found.

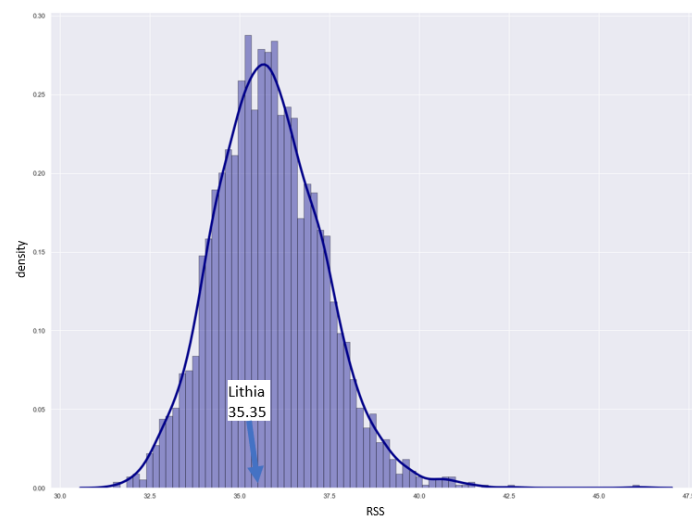


Figure 5. RSS distribution of meteorological data from Argos Orestiko vs. Lithia.

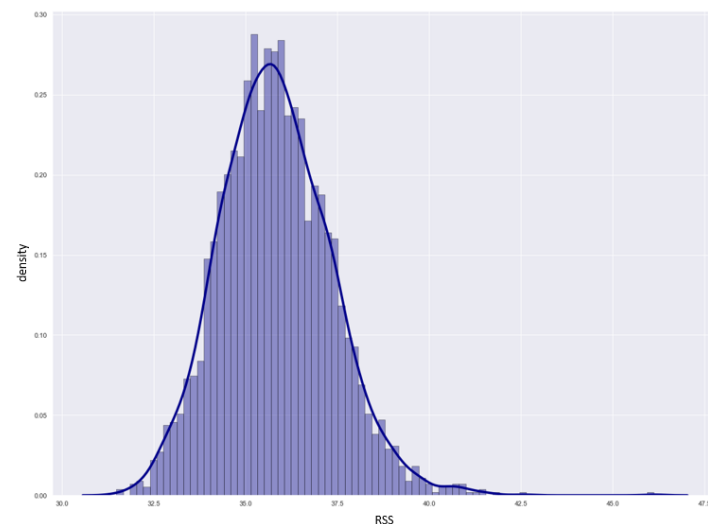


Figure 6. RSS distribution of meteorological data from Lakkomata. The RSS values of all other subregions are out of scale: Kalochori 102.13, Lithia 158.09, Argos Orestiko 168.51 and Polykarpi 146.69.

3.1.3. Statistical Conclusions on the Meteorological Factor

Based on the statistical analysis of meteorological data of the Kastoria subregion, no significant difference was observed. The lack of significant differences regarding microclimatic data measurements suggests a non-determinate role of these parameters as factors differentiating isotopic and multi-elemental footprint values in the final product.

3.2. Soil Texture Factor

Another critical factor that is expected to influence the special characteristics of the protected origin dry beans of the regional unit of Kastoria is the soil texture. Based on this, a considerable amount of soil samples coming from these subregions were analyzed to answer the following research question: Is there any statistically significant difference among the subregions regarding the soil texture measurements?

3.2.1. Descriptive Statistics of the Soil Texture Factor

In general, low values of clay and medium values of sand were observed. The exact percentages (%) are: Silty Loam (SiL)—34.6; Loam (L)—34.2; Sandy Loam (SL)—15.1; Silty Clay Loam (SiCL)—8.2; Clay Loam (CL)—7.1; Silty Clay (SiC)—0.5; and Loamy Sand (LS)—0.3 Figure 7.

In Figure 8, local patterns are depicted; for example, in the Lakkomata subregion, lower values of Clay and higher values of Sand were shown. These observed patterns are a strong indication of differences between subregions and are statistically examined in the next section.

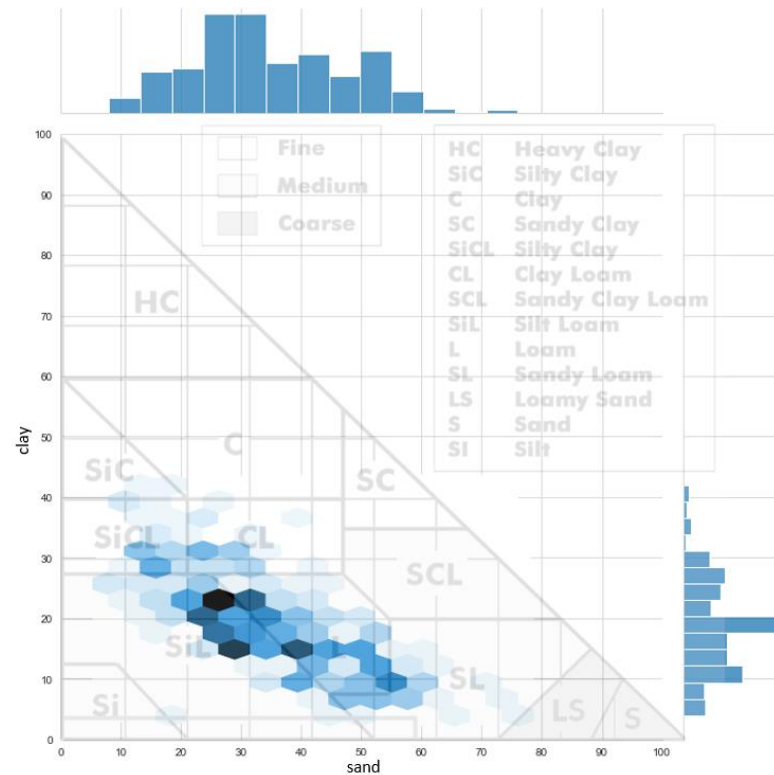


Figure 7. Distribution of soil samples on texture triangle (Kastoria).

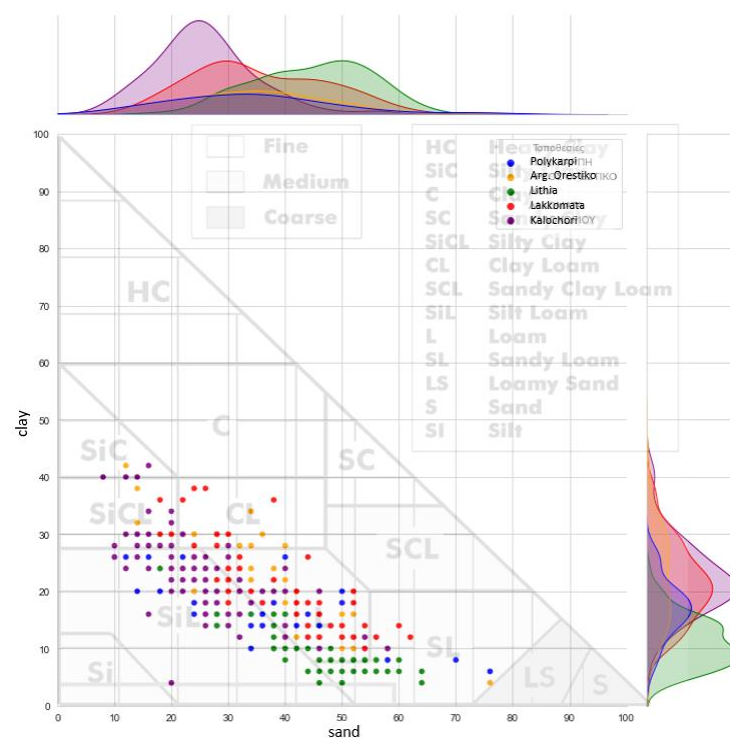


Figure 8. Distribution of soil samples on texture triangle (different colors correspond to major subregions of Kastoria).

3.2.2. Statistical Analysis and Hypothesis Testing of the Soil Texture Factor

We employed two types of statistical hypothesis tests. The first one is based on categorical data and their corresponding frequencies of soil texture classes, while the second one is based on the numerical values of Sand and Clay, which represent the two major factors of soil texture properties.

The rationale behind this approach is twofold; it is focused on the finest detail of soil texture classes and observed coarser differences based on numerical values. For the former approach, a Freeman–Halton exact test was applied with significance $\alpha = 1 \times 10^{-3}$ [24], and a significance level correction scheme based on the methodology described by Sidak [25]. The latter approach is based on Hotelling’s T-squared test [26] in combination with a similar significance level correction.

Inference based on categorical data:

The null hypothesis (H_0) is: There is no correlation of mechanical class frequency (i.e., columns of contingency table), with the subregion (i.e., rows of contingency table).

By applying the Freeman–Halton exact test on all combinations of subregions, and considering the significance level correction scheme, statistically significant results (i.e., rejection of H_0) were observed, as shown in Figure 9. Note: A conservative significance level of $\alpha = 1 \times 10^{-3}$ was chosen, due to the abrupt boundaries of mechanical classes. The full data of the contingency tables and p -values are given in Appendix A (Figure A1 and Table A1).



Figure 9. Statistically significant results of soil texture (categorical data; soil texture classes).

Inference based on numerical data:

The null hypothesis (H_0) is: There is no difference between the mean values of Sand and Clay measurements in the two subregions.

Data normality and covariance matrix equality are two prerequisites of this test. Both of them are verified by using Henze–Zirkler [27] and Bartlett’s test [28], respectively. Afterwards, the application of Hotelling’s T-squared test provided the following statistically significant results in Figure 10. The full data and p -values are given in Appendix B (Tables A2–A5).



Figure 10. Statistically significant results of soil texture (numerical data; Clay and Sand).

3.2.3. Statistical Conclusions on the Soil Texture Factor

In the Kastoria region, based on the statistical analysis of soil texture, a statistically significant difference was observed among the subregions of Argos Orestiko, Kalochori, Lakkomata, Lithia and Polykarpi. Focusing on the numerical values of Clay and Sand, differences among the subregions of Lithia, Argos Orestiko, and Polykarpi were found. However, based on the detailed information from the soil texture classes, we concluded that all subregions are different. This is very strong evidence that the subregions of Kastoria have dissimilar soil textures and this may influence the spatio-temporal application of the various cultivation practices such as irrigation and fertilization, consequently affecting the stable-isotope ratios and multi-elemental composition.

3.3. Proposed Sampling Schemes

The main goal of the investigation of the differences between the two critical factors, microclimate and soil texture, is to consider possible variability contributors of protected origin dry beans in Greece. The statistical analysis revealed that even though the microclimate is a critical factor, no significant differences were observed in the region of Kastoria. On the contrary, the soil texture in Kastoria should be taken into consideration when local crops are studied. Thus, soil texture statistical analysis enables and directs the sampling scheme of the collection of dry beans. Using the proposed sampling schemes, all possible variability of the yearly production could be captured.

The first sampling scheme focuses on the different soil texture classes and treats subregions as equivalent/identical ones. Thus, the collection of five samples from each soil texture classes was proposed (i.e., LS, SL, L, SiL, CL, SiCL, and SiC) independently of the subregion (five samples were proposed for robust averaging). A random selection was performed.

The second sampling scheme fulfills two objectives simultaneously: the complete coverage of soil texture classes and subregions. In particular, the collection of five samples per subgroup combination is proposed (e.g., five from Polykarpi-SiL, five from Polykarpi-L, and Polykarpi-SL. A total of 120 samples are distributed in the following subregions: Polykarpi: SiL-L-SL; Argos Orestiko: SiL-L-SL-SiCL-CL-SiC-LS; Lithia: SiL-L-SL; Lakkomata: SiL-L-SL-SiCL-CL; Kalochori: SiL-L-SL-SiCL-CL-SiC. A random selection was performed.

4. Conclusions and Future Work

Even though initially the intense geographical profile of the subregions appeared to be an interesting and promising microclimate regulator, in our study this was not confirmed. It was shown that all subregions share a common microclimate. The statistical analysis showed that only the soil texture is a significant factor and, thus, a potential discriminant component for the *Phaseolus vulgaris* L. dry beans PGI of Kastoria. For these reasons, soil texture classes of different subregions have been included in the proposed sampling schemes, as an expected main contributor of the variability of stable isotope ratios and multi-elemental analysis, for the determination of the geographical origin. Based on the proposed schemes, samples of dry beans were collected and are currently being analyzed for designation and an accurate geographical identification of the Kastoria region. The results will be presented in a future paper.

Author Contributions: Conceptualization, G.T., A.Z., A.P. and A.L.; methodology, G.T., A.Z., A.P. and A.K.; validation, G.T., A.Z., E.C.M., E.K., A.P., A.L. and A.K.; investigation, G.T. and A.Z.; resources, A.P., A.L. and A.K.; data curation, G.T., A.Z., E.C.M. and E.K.; writing—original draft preparation, G.T. and A.Z.; writing—review and editing, G.T., A.Z., E.C.M., E.K., A.P., A.K. and A.L.; visualization, G.T. and A.Z.; supervision, A.P. and A.L.; project administration, A.P.; funding acquisition, A.P. and A.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been financed by the Public Investment Programme/General Secretariat for Research and Innovation, under the call “YPOERGO 3, code 2018SE01300000: project title: ‘Elaboration and implementation of methodology for authenticity and geographical origin assessment of agricultural products’”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: Soil data comes from the Institute of Soil and Water Resources (SWRI), a research unit of the Hellenic Agricultural Organisation “DEMETER”, which were collected to create the soil map of Western Macedonia.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

	SiL	L	SL	SiCL	CL	SiC	LS
Polykarpi	23	15	4	0	0	0	0
Argos Orestiko	7	19	2	6	9	1	1
	SiL	L	SL	SiCL	CL	SiC	LS
Polykarpi	23	15	4	0	0	0	0
Lithia	24	24	36	0	0	0	0
	SiL	L	SL	SiCL	CL	SiC	LS
Polykarpi	23	15	4	0	0	0	0
Lakkomata	12	46	11	7	13	0	0
	SiL	L	SL	SiCL	CL	SiC	LS
Polykarpi	23	15	4	0	0	0	0
Kalochori	60	20	2	17	4	1	0
	SiL	L	SL	SiCL	CL	SiC	LS
Lithia	24	24	36	0	0	0	0
Argos Orestiko	7	19	2	6	9	1	1
	SiL	L	SL	SiCL	CL	SiC	LS
Lithia	24	24	36	0	0	0	0
Lakkomata	12	46	11	7	13	0	0
	SiL	L	SL	SiCL	CL	SiC	LS
Lithia	24	24	36	0	0	0	0
Kalochori	60	20	2	17	4	1	0
	SiL	L	SL	SiCL	CL	SiC	LS
Lakkomata	12	46	11	7	13	0	0
Argos Orestiko	7	19	2	6	9	1	1
	SiL	L	SL	SiCL	CL	SiC	LS
Lakkomata	12	46	11	7	13	0	0
Kalochori	60	20	2	17	4	1	0
	SiL	L	SL	SiCL	CL	SiC	LS
Kalochori	60	20	2	17	4	1	0
Argos Orestiko	7	19	2	6	9	1	1

Figure A1. Contingency tables of Kastoria region.

Table A1. *p*-values of Freeman-Halton exact test based on the above contingency tables.

Polykarpi vs. Argos Orestiko	$8.306559111725096 \times 10^{-6}$
Polykarpi vs. Lithia	0.0002053205823589391
Polykarpi vs. Lakkomata	$3.6336856485210914 \times 10^{-6}$
Polykarpi vs. Kalochori	0.0015215140410542742
Argos Orestiko vs. Lithia	$5.044428484837929 \times 10^{-11}$
Argos Orestiko vs. Lakkomata	0.22004126416018469
Argos Orestiko vs. Kalochori	$1.3230744173263569 \times 10^{-6}$
Lithia vs. Lakkomata	$4.658235373877026 \times 10^{-10}$
Lithia vs. Kalochori	$4.682843816824416 \times 10^{-6}$
Lakkomata vs. Kalochori	$1.2315974377714092 \times 10^{-12}$

Appendix B

Table A2. Soil texture measurements of Kastoria Region.

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
SL	70	8	22	POLYKARPI
L	40	22	38	ARGOS ORESTIKO
CL	40	28	32	ARGOS ORESTIKO
SL	50	8	42	LITHIA
L	40	12	48	LITHIA
L	38	16	46	LITHIA
SL	54	6	40	LITHIA
L	50	14	36	LITHIA
SL	56	6	38	LITHIA
SiL	30	16	54	LITHIA
L	44	14	42	LITHIA
L	40	14	46	LITHIA
SL	52	6	42	LITHIA
SL	46	6	48	LITHIA
SL	46	4	50	LITHIA
SL	46	8	46	LITHIA
L	46	10	44	LITHIA
L	40	12	48	LITHIA
SL	64	4	32	LITHIA
CL	24	28	48	ARGOS ORESTIKO
L	50	12	38	ARGOS ORESTIKO
L	42	12	46	ARGOS ORESTIKO
SiCL	14	30	56	ARGOS ORESTIKO
LS	76	4	20	ARGOS ORESTIKO
SiL	18	20	62	POLYKARPI
SiL	30	16	54	POLYKARPI
L	44	16	40	POLYKARPI
L	42	14	44	POLYKARPI
SiL	34	10	56	LITHIA
SiL	30	14	56	LITHIA
L	46	10	44	LITHIA
SiL	30	14	56	LITHIA
SL	48	6	46	LITHIA
SiL	26	18	56	ARGOS ORESTIKO
SiL	26	16	58	ARGOS ORESTIKO

Table A2. Cont.

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
SiCL	12	30	58	ARGOS ORESTIKO
CL	30	30	40	ARGOS ORESTIKO
L	40	14	46	ARGOS ORESTIKO
L	50	18	32	LAKKOMATA
CL	22	30	48	LAKKOMATA
L	30	22	48	LAKKOMATA
L	40	16	44	LAKKOMATA
L	46	14	40	LAKKOMATA
SiCL	18	28	54	LAKKOMATA
L	38	22	40	LAKKOMATA
L	32	22	46	LAKKOMATA
L	32	24	44	LAKKOMATA
CL	28	30	42	LAKKOMATA
L	30	24	46	LAKKOMATA
CL	30	30	40	LAKKOMATA
SiL	34	16	50	LITHIA
L	40	16	44	KALOCHORI
SiL	20	22	58	KALOCHORI
SiL	24	22	54	KALOCHORI
SiL	28	20	52	KALOCHORI
SiL	26	20	54	KALOCHORI
SiL	16	24	60	KALOCHORI
SiL	24	26	50	KALOCHORI
SiCL	16	30	54	KALOCHORI
SiCL	20	32	48	KALOCHORI
SiCL	12	40	48	KALOCHORI
SiCL	16	34	50	KALOCHORI
CL	22	30	48	KALOCHORI
L	38	18	44	ARGOS ORESTIKO
L	32	22	46	KALOCHORI
L	28	24	48	KALOCHORI
L	46	16	38	ARGOS ORESTIKO
L	50	16	34	ARGOS ORESTIKO
SiL	26	24	50	ARGOS ORESTIKO
SiC	12	42	46	ARGOS ORESTIKO
L	38	20	42	ARGOS ORESTIKO
L	30	24	46	LAKKOMATA
L	46	20	34	LAKKOMATA
CL	24	28	48	LAKKOMATA
SiL	22	24	54	LAKKOMATA
SiCL	18	30	52	LAKKOMATA
SL	52	12	36	LAKKOMATA
SiL	24	24	52	LAKKOMATA
SiCL	18	36	46	LAKKOMATA
L	30	22	48	LAKKOMATA
CL	24	30	46	LAKKOMATA
SiCL	16	28	56	LAKKOMATA
SL	52	12	36	LAKKOMATA
L	40	16	44	LAKKOMATA
L	38	18	44	LAKKOMATA
SL	54	10	36	LAKKOMATA
L	30	24	46	LAKKOMATA
L	34	18	48	LAKKOMATA
SiL	26	22	52	LAKKOMATA
L	34	18	48	LAKKOMATA
SL	54	10	36	LAKKOMATA
L	42	16	42	LAKKOMATA

Table A2. Cont.

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
CL	30	28	42	ARGOS ORESTIKO
CL	34	28	38	ARGOS ORESTIKO
SiL	24	22	54	KALOCHORI
SiL	20	24	56	KALOCHORI
SiCL	20	28	52	KALOCHORI
L	36	20	44	KALOCHORI
SiC	16	42	42	KALOCHORI
L	36	20	44	KALOCHORI
L	40	24	36	KALOCHORI
SiL	20	4	76	KALOCHORI
SiL	24	24	52	KALOCHORI
SiCL	16	34	50	KALOCHORI
SiL	14	26	60	KALOCHORI
SiCL	14	28	58	KALOCHORI
SiCL	10	28	62	KALOCHORI
SiL	22	24	54	KALOCHORI
L	38	16	46	ARGOS ORESTIKO
SL	52	8	40	LITHIA
L	44	10	46	LITHIA
SiL	30	14	56	LITHIA
SL	56	8	36	LITHIA
SiL	30	18	52	LITHIA
SL	56	8	36	LITHIA
L	38	14	48	LITHIA
SL	64	6	30	LITHIA
SiL	38	10	52	LITHIA
SiL	30	14	56	LITHIA
SL	48	6	46	LITHIA
SiL	40	10	50	POLYKARPI
SiL	34	14	52	POLYKARPI
SL	44	6	50	LITHIA
SL	54	8	38	LITHIA
SiL	30	20	50	LITHIA
SL	54	6	40	LITHIA
SL	60	6	34	LITHIA
SL	50	4	46	LITHIA
SL	50	6	44	LITHIA
SiL	36	14	50	LITHIA
SiL	38	10	52	LITHIA
SiL	40	10	50	LITHIA
L	50	12	38	LITHIA
SL	60	8	32	LITHIA
L	50	14	36	LITHIA
SL	54	10	36	LITHIA
SL	58	6	36	LITHIA
SL	54	8	38	LITHIA
L	38	20	42	LITHIA
L	50	12	38	LITHIA
L	48	14	38	LITHIA
SL	58	10	32	LITHIA
SL	54	12	34	LITHIA
L	46	14	40	LITHIA
SL	52	10	38	LITHIA
SL	56	8	36	LITHIA
L	40	14	46	LITHIA

Table A2. Cont.

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
SiL	24	20	56	LITHIA
SL	58	8	34	LITHIA
SL	56	12	32	LITHIA
SL	54	10	36	LITHIA
L	50	14	36	LITHIA
L	46	20	34	LITHIA
SiL	26	16	58	POLYKARPI
SL	58	8	34	POLYKARPI
SiL	28	16	56	POLYKARPI
SiL	34	10	56	POLYKARPI
SiL	18	24	58	POLYKARPI
L	34	20	46	POLYKARPI
SiL	10	26	64	POLYKARPI
SiL	34	16	50	POLYKARPI
L	46	14	40	POLYKARPI
SiL	12	26	62	POLYKARPI
SiL	22	26	52	POLYKARPI
SiL	26	20	54	POLYKARPI
SiL	22	20	58	POLYKARPI
SiL	18	20	62	POLYKARPI
L	34	18	48	POLYKARPI
L	40	26	34	POLYKARPI
SiL	26	20	54	KALOCHORI
CL	30	28	42	KALOCHORI
SiL	22	20	58	KALOCHORI
SiL	22	20	58	KALOCHORI
SiL	22	22	56	KALOCHORI
SiL	30	20	50	KALOCHORI
SiL	30	16	54	KALOCHORI
SiL	32	16	52	KALOCHORI
SiL	28	20	52	KALOCHORI
SiL	20	22	58	KALOCHORI
SiL	24	20	56	KALOCHORI
SiL	22	20	58	KALOCHORI
CL	24	38	38	LAKKOMATA
CL	22	36	42	LAKKOMATA
CL	28	30	42	LAKKOMATA
SiCL	14	30	56	LAKKOMATA
SL	54	10	36	POLYKARPI
SiL	40	10	50	LITHIA
L	42	10	48	LITHIA
SL	58	10	32	LITHIA
SiL	38	10	52	LITHIA
SiL	30	18	52	LITHIA
SiL	30	16	54	LITHIA
SiL	40	8	52	LITHIA
SL	52	8	40	LITHIA
SiCL	14	40	46	KALOCHORI
SiCL	14	30	56	KALOCHORI
SL	54	12	34	KALOCHORI
L	40	14	46	KALOCHORI
L	44	12	44	POLYKARPI
L	36	16	48	POLYKARPI
L	36	18	46	POLYKARPI
SiL	28	16	56	LITHIA
SiCL	14	38	48	ARGOS ORESTIKO

Table A2. Cont.

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
SiCL	14	32	54	ARGOS ORESTIKO
CL	34	34	32	ARGOS ORESTIKO
SiCL	20	30	50	ARGOS ORESTIKO
L	38	24	38	ARGOS ORESTIKO
CL	24	30	46	ARGOS ORESTIKO
SL	52	16	32	ARGOS ORESTIKO
SL	52	10	38	ARGOS ORESTIKO
L	40	12	48	ARGOS ORESTIKO
SiL	28	22	50	LAKKOMATA
L	32	20	48	ARGOS ORESTIKO
SiL	30	16	54	ARGOS ORESTIKO
CL	32	28	40	ARGOS ORESTIKO
L	44	18	38	LAKKOMATA
SL	54	10	36	LAKKOMATA
SiL	24	24	52	LAKKOMATA
SiL	30	18	52	LAKKOMATA
L	34	20	46	LAKKOMATA
L	32	24	44	LAKKOMATA
L	30	22	48	LAKKOMATA
L	38	22	40	LAKKOMATA
L	40	20	40	LAKKOMATA
CL	22	30	48	LAKKOMATA
SL	52	20	28	LAKKOMATA
L	50	12	38	ARGOS ORESTIKO
SiL	20	24	56	LAKKOMATA
L	30	22	48	LAKKOMATA
L	44	18	38	LAKKOMATA
SL	54	14	32	LAKKOMATA
L	42	18	40	LAKKOMATA
SiL	24	26	50	LAKKOMATA
CL	38	36	26	LAKKOMATA
L	44	26	30	LAKKOMATA
SiCL	20	30	50	LAKKOMATA
L	30	24	46	LAKKOMATA
CL	26	38	36	LAKKOMATA
L	38	18	44	LAKKOMATA
SiL	30	20	50	LAKKOMATA
SiL	30	20	50	LAKKOMATA
L	32	20	48	LAKKOMATA
L	46	18	36	LAKKOMATA
L	32	20	48	LAKKOMATA
SiL	26	22	52	KALOCHORI
CL	22	30	48	KALOCHORI
SiL	26	24	50	KALOCHORI
SiCL	16	28	56	KALOCHORI
SiL	26	24	50	ARGOS ORESTIKO
L	34	22	44	ARGOS ORESTIKO
SiL	14	20	66	POLYKARPI
L	50	18	32	POLYKARPI
SL	48	8	44	LITHIA
L	48	10	42	LITHIA
SiL	24	18	58	KALOCHORI
SiL	26	18	56	KALOCHORI
SiL	20	20	60	KALOCHORI
SiL	30	14	56	KALOCHORI
SiL	26	18	56	KALOCHORI

Table A2. Cont.

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
SiL	24	18	58	KALOCHORI
SiL	28	14	58	KALOCHORI
SiL	26	22	52	KALOCHORI
SiL	26	16	58	KALOCHORI
SiL	26	14	60	KALOCHORI
SiL	30	16	54	KALOCHORI
SiL	24	22	54	KALOCHORI
SiL	24	20	56	KALOCHORI
L	40	20	40	KALOCHORI
L	38	20	42	KALOCHORI
SiL	26	24	50	KALOCHORI
L	32	22	46	KALOCHORI
SiL	28	20	52	KALOCHORI
L	46	20	34	KALOCHORI
L	36	18	46	KALOCHORI
SiL	22	24	54	KALOCHORI
SiL	26	20	54	KALOCHORI
SiL	26	22	52	KALOCHORI
SiL	30	16	54	KALOCHORI
SiCL	20	28	52	KALOCHORI
SiCL	8	40	52	KALOCHORI
SiL	12	24	64	KALOCHORI
SiL	32	12	56	KALOCHORI
SiL	16	16	68	KALOCHORI
SiL	10	26	64	KALOCHORI
L	34	18	48	KALOCHORI
L	34	18	48	KALOCHORI
SiCL	20	28	52	KALOCHORI
L	30	26	44	KALOCHORI
SiL	20	26	54	KALOCHORI
SL	58	10	32	KALOCHORI
SiL	32	16	52	KALOCHORI
L	40	12	48	KALOCHORI
SiL	20	24	56	KALOCHORI
SiL	28	18	54	KALOCHORI
SiL	30	20	50	KALOCHORI
L	26	26	48	KALOCHORI
L	36	20	44	KALOCHORI
L	32	20	48	KALOCHORI
SL	76	6	18	POLYKARPI
L	50	20	30	POLYKARPI
L	50	10	40	ARGOS ORESTIKO
L	38	16	46	ARGOS ORESTIKO
SL	48	8	44	LITHIA
L	38	14	48	LITHIA
SiL	28	18	54	POLYKARPI
SiL	24	18	58	POLYKARPI
SiL	24	16	60	POLYKARPI
L	38	18	44	POLYKARPI
L	48	14	38	POLYKARPI
SiL	28	14	58	POLYKARPI
L	36	18	46	POLYKARPI
SiL	26	20	54	POLYKARPI
L	36	16	48	POLYKARPI
SiL	16	26	58	POLYKARPI
SiL	34	16	50	LITHIA
SL	50	8	42	LITHIA

Table A2. *Cont.*

Mechanical Class	Sand (%)	Clay (%)	Silt (%)	Sub-Region
SiL	28	14	58	LITHIA
L	40	16	44	LITHIA
SiL	18	24	58	LITHIA
L	38	16	46	LITHIA
L	42	20	38	LAKKOMATA
SL	60	14	26	LAKKOMATA
L	32	26	42	LAKKOMATA
SiL	24	24	52	LAKKOMATA
SiCL	18	28	54	LAKKOMATA
CL	28	30	42	LAKKOMATA
SL	52	18	30	LAKKOMATA
L	46	16	38	LAKKOMATA
SL	62	12	26	LAKKOMATA
L	50	12	38	LAKKOMATA
L	48	14	38	LAKKOMATA
SL	56	12	32	LAKKOMATA
L	44	14	42	LAKKOMATA
L	44	12	44	LAKKOMATA
L	46	12	42	LAKKOMATA
L	44	14	42	LAKKOMATA
L	36	18	46	LAKKOMATA
L	46	12	42	LAKKOMATA
L	34	20	46	LAKKOMATA
SiL	30	20	50	LAKKOMATA
L	46	10	44	KALOCHORI
L	34	24	42	ARGOS ORESTIKO
L	50	14	36	ARGOS ORESTIKO
L	40	18	42	ARGOS ORESTIKO
SiL	24	20	56	ARGOS ORESTIKO
SiL	24	24	52	ARGOS ORESTIKO
SiCL	18	28	54	ARGOS ORESTIKO
SiL	26	16	58	KALOCHORI
SiL	36	14	50	KALOCHORI
SiL	26	20	54	KALOCHORI
SiL	28	18	54	KALOCHORI
SiCL	20	34	46	KALOCHORI
SiL	24	24	52	KALOCHORI
SiCL	18	28	54	KALOCHORI
CL	22	30	48	KALOCHORI
SiCL	12	30	58	KALOCHORI
L	30	22	48	LAKKOMATA
CL	28	28	44	LAKKOMATA
L	50	14	36	LAKKOMATA
SiL	36	14	50	POLYKARPI
SiL	26	24	50	KALOCHORI
SiL	24	26	50	KALOCHORI
SiL	38	12	50	LITHIA
CL	36	30	34	ARGOS ORESTIKO

Table A3. *p*-values of Henze-Zirkler test.

Polykarpi	0.666272771407832	0.16031658465601523
Lithia	1.0284853302716628	0.029673729263590087
Lakkomata	1.9559287379273946	0.0001111020613499396
Argos Orestiko	0.35109431068311686	0.7722480057196142
Kalochori	1.610375954176091	0.0009399490740980984

Table A4. *p*-values of Bartlett's test.

Polykarpi vs. Argos Orestiko	0.01938135940700507
Polykarpi vs. Lithia	0.00045249555393457185
Argos Orestiko vs. Lithia	0.988532912979268

Table A5. *p*-values of Hotteling's test.

Polykarpi vs. Lithia	$3.4544010000000000 \times 10^{-9}$
Argos Orestiko vs. Lithia	$2.8390020000000000 \times 10^{-17}$

References

- Oda, H.; Kawasaki, A.; Hirata, T. Determination of the Geographic Origin of Brown-Rice with Isotope Ratios of $^{11}\text{B}/^{10}\text{B}$ and $^{87}\text{Sr}/^{86}\text{Sr}$. *Anal. Sci.* **2002**, *17*, i1627–i1630. [\[CrossRef\]](#)
- Kawasaki, A.; Oda, H.; Hirata, T. Determination of strontium isotope ratio of brown rice for estimating its provenance. *Soil Sci. Plant Nutr.* **2002**, *48*, 635–640. [\[CrossRef\]](#)
- Chung, I.-M.; Kim, J.-K.; Prabakaran, M.; Yang, J.-H.; Kim, S.-H. Authenticity of rice (*Oryza sativa* L.) geographical origin based on analysis of C, N, O and S stable isotope ratios: A preliminary case report in Korea, China and Philippine. *J. Sci. Food Agric.* **2016**, *96*, 2433–2439. [\[CrossRef\]](#) [\[PubMed\]](#)
- Barbaste, M.; Robinson, K.; Guilfoyle, S.; Medina, B.; Lobinski, R. Precise determination of the strontium isotope ratios in wine by inductively coupled plasma sector field multicollector mass spectrometry (ICP-SF-MC-MS). *J. Anal. At. Spectrom.* **2002**, *17*, 135–137. [\[CrossRef\]](#)
- Swoboda, S.; Brunner, M.; Boulyga, S.F.; Galler, P.; Horacek, M.; Prohaska, T. Identification of Marchfeld asparagus using Sr isotope ratio measurements by MC-ICP-MS. *Anal. Bioanal. Chem.* **2008**, *390*, 487–494. [\[CrossRef\]](#)
- Bong, Y.-S.; Shin, W.-J.; Gautam, M.K.; Jeong, Y.-J.; Lee, A.-R.; Jang, C.-S.; Lim, Y.-P.; Chung, G.-S.; Lee, K.-S. Determining the geographical origin of Chinese cabbages using multielement composition and strontium isotope ratio analyses. *Food Chem.* **2012**, *135*, 2666–2674. [\[CrossRef\]](#)
- Zhao, H.; Guo, B.; Wei, Y.; Zhang, B. Multi-element composition of wheat grain and provenance soil and their potentialities as fingerprints of geographical origin. *J. Cereal Sci.* **2013**, *57*, 391–397. [\[CrossRef\]](#)
- Laursen, K.H.; Schjoerring, J.K.; Olesen, J.E.; Askegaard, M.; Halekoh, U.; Husted, S. Multielemental Fingerprinting as a Tool for Authentication of Organic Wheat, Barley, Faba Bean, and Potato. *J. Agric. Food Chem.* **2011**, *59*, 4385–4396. [\[CrossRef\]](#)
- Danezis, G.P.; Georgiou, C.A. Elemental metabolomics: Food elemental assessment could reveal geographical origin. *Curr. Opin. Food Sci.* **2022**, *44*, 100812. [\[CrossRef\]](#)
- Zhao, H.; Yang, Q. The suitability of rare earth elements for geographical traceability of tea leaves. *J. Sci. Food Agric.* **2019**, *99*, 6509–6514. [\[CrossRef\]](#)
- Magdas, D.A.; Feher, I.; Cristea, G.; Voica, C.; Tabaran, A.; Mihaie, M.; Cordea, D.V.; Băltesanu, V.A.; Dan, S.D. Geographical origin and species differentiation of Transylvanian cheese. Comparative study of isotopic and elemental profiling vs. DNA results. *Food Chem.* **2019**, *277*, 307–313. [\[CrossRef\]](#) [\[PubMed\]](#)
- White, J.G.; Zasoski, R.J. Mapping soil micronutrients. *Field Crops Res.* **1999**, *60*, 11–26. [\[CrossRef\]](#)
- Chiocchini, F.; Portarena, S.; Ciolfi, M.; Brugnoli, E.; Lauteri, M. Isoscapes of carbon and oxygen stable isotope compositions in tracing authenticity and geographical origin of Italian extra-virgin olive oils. *Food Chem.* **2016**, *202*, 291–301. [\[CrossRef\]](#)
- Greenough, J.D.; Fryer, B.J.; Mallory-Greenough, L. Trace element geochemistry of Nova Scotia (Canada) maple syrup. *Can. J. Earth Sci.* **2010**, *47*, 1093–1110. [\[CrossRef\]](#)
- Vinci, G.; Preti, R.; Tieri, A.; Vieri, S. Authenticity and quality of animal origin food investigated by stable-isotope ratio analysis. *J. Sci. Food Agric.* **2013**, *93*, 439–448. [\[CrossRef\]](#) [\[PubMed\]](#)
- Maione, C.; Araujo, E.M.; dos Santos-Araujo, S.N.; Boim, A.G.F.; Barbosa, R.M.; Alleoni, L.R.F. Determining the geographical origin of lettuce with data mining applied to micronutrients and soil properties. *Sci. Agric.* **2021**, *79*. [\[CrossRef\]](#)
- Sabbe, W.E.; Marx, D.B. Soil Sampling: Spatial and Temporal Variability. In *Soil Testing: Sampling, Correlation, Calibration, and Interpretation*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 1987; pp. 1–14. ISBN 978-0-89118-916-9.
- Bouyoucos, G.J. Hydrometer Method Improved for Making Particle Size Analyses of Soils. *Agron. J.* **1962**, *54*, 464–465. [\[CrossRef\]](#)
- Soil Survey Manual (Hardcover) | Hooked. Available online: <https://www.hookedlansing.com/book/9780160937439> (accessed on 5 March 2023).
- Magkos, F.; Arvaniti, F.; Zampelas, A. Organic food: Nutritious food or food for thought? A review of the evidence. *Int. J. Food Sci. Nutr.* **2003**, *54*, 357–371. [\[CrossRef\]](#)
- Young, K.L.; Woo, M.; Edlund, S.A. Influence of Local Topography, Soils, and Vegetation on Microclimate and Hydrology at a High Arctic Site, Ellesmere Island, Canada. *Arct. Alp. Res.* **1997**, *29*, 270–284. [\[CrossRef\]](#)

22. Bruce, P.; Bruce, A.; Gedeck, P. *Practical Statistics for Data Scientists: 50+ Essential Concepts Using R and Python*; O'Reilly Media, Inc.: Newton, MA, USA, 2020; ISBN 978-1-4920-7291-1.
23. McInnes, L.; Healy, J.; Melville, J. UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction. *arXiv* **2020**. [[CrossRef](#)]
24. Freeman, G.H.; Halton, J.H. Note on an exact treatment of contingency, goodness of fit and other problems of significance. *Biometrika* **1951**, *38*, 141–149. [[CrossRef](#)] [[PubMed](#)]
25. Sidak, Z. Rectangular Confidence Regions for the Means of Multivariate Normal Distributions. *J. Am. Stat. Assoc.* **1967**, *62*, 626–633. [[CrossRef](#)]
26. Hotelling, H. The Generalization of Student's Ratio. *Ann. Math. Stat.* **1931**, *2*, 360–378. [[CrossRef](#)]
27. Henze, N.; Zirkler, B. A class of invariant consistent tests for multivariate normality. *Commun. Stat.-Theory Methods* **1990**, *19*, 3595–3617. [[CrossRef](#)]
28. Bartlett, M.S.; Fowler, R.H. Properties of sufficiency and statistical tests. *Proc. R. Soc. Lond. Ser.-Math. Phys. Sci.* **1937**, *160*, 268–282. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.