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Characterization and Multivariate Assessment of Faba Bean (*Vicia faba* L.) Varieties Based on Mineral, Agro-Morphological and Technological Characteristics

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ABSTRACT

Faba bean (*Vicia faba* L.) is the oldest cultivated plant in the world, rich in protein, vitamins, minerals and antioxidant compounds. This study aimed to characterize some economically important faba bean cultivars based on agro-morphological, technological, and mineral properties using multivariate analysis methods. The research was carried out for two years in the trial land of Erciyes University Agricultural Research and Application Center located in the central campus of Erciyes University in 2021 and 2022. The trial was conducted using a randomized complete block design with three replications. The spacing was set at 50 cm between rows and 20 cm within rows, with 1 m spacing between plots and blocks, and a plot length of 4 m. The study determined significant positive correlations with plant height trait, wet volume, wet weight, dry weight, water absorption capacity, dry volume, 100-grain weight, and Na content of the grain. Based on the angle and correlation values of the axes in the same region with the Zn axis, Cu, protein ratio, Ca, P, cooking time, and S showed positive correlations, while the number of pods, Mn, and hydration coefficient showed negative correlations. Based on the angle and correlation values from the axes in the same region as the swelling index, water absorption index, Mn, hydration coefficient, the number of pods, Mg, and unite weight showed a positive correlation, while it showed a negative correlation with cooking time. The cluster analysis performed to define the genetic relationship between the varieties determined that 11 varieties were divided into 3 different clusters based on their morphological, technological, and mineral characteristics.

1. INTRODUCTION

Legume crops are widely cultivated throughout the world. Edible legumes are important plant groups in human diets due to their high protein content (Dhull et al., 2021). Faba bean (*Vicia faba* L.), which belongs to the *Fabaceae* family, is an annual plant that can grow to a height of 1-2 m, grows upright and unbranched. The stem is hollow and ridged. The flowers are found in short panicles in the leaf axils, typically containing 1 to 8 flowers in each panicle. It is divided into two subspecies, *V. faba ssp.* paucijuga and *V. faba ssp.* eufaba. The second subspecies consists of three botanical species in terms of seed size. These are; small-seeded species (*V. faba* minor), with a 1000-seed weight of less than about 500 g, found in the Ethiopian region and preferred by Northern European agriculture. Medium-seeded species (*V. faba* equina) in the Middle East and North Africa, and large-seeded species (*V. faba* major), with a 1000-seed weight of more than 1000 g, concentrated in Egypt (Duc, 1997). Faba bean is one of the oldest widely cultivated crops worldwide (Mínguez and Rubiales, 2021). Mediterranean countries, China, India, Afghanistan, Northern Europe, Ethiopia, Egypt, and North Africa are the primary producers of faba beans in the world (Rahate et al., 2020; Dhull et al., 2021). Faba bean is a versatile crop that contributes to various ecosystems and can be used for human nutrition, animal feed, and soil improvement. Faba bean is crucial in crop rotations due to its ability to fix atmospheric nitrogen symbiotically to increase the amount of available phosphorus and nitrogen-rich soil for the following crop (Köpke and Nemecek, 2010; Neugschwandtner et al., 2015). Faba bean grain plays an essential role in human nutrition as it contains 26.1% protein, 58.3% carbohydrate, and 25.0% dietary fiber. In addition, faba beans contain a wide variety of bioactive compounds (total phenolics, flavonoids, and antioxidants). Faba bean grain contains antinutrients such as lectins, trypsin inhibitors, saponins, phytic acids, tannins. Oligosaccharides are also present in faba bean grain. They may produce gas, leading to abdominal discomfort. Lectins can also be destroyed during normal cooking due to high heat or by germination, making faba beans suitable for human consumption (Singh et al., 2013; Labba et al., 2021; Dhull et al., 2021). In addition, broad beans are a promising source of plant-based protein with health benefits such as improved gut function and reduced risk of chronic diseases (Martineau-Côté et al., 2022). Faba beans are utilized in different ways around the world. They are consumed fresh or cooked and canned. They are also consumed as a breakfast food in the Middle East and Mediterranean Region, China, and Ethiopia. The most popular foods made from faba beans are Medamis (boiled faba beans), Falafel (deep-fried), Bissara (cotyledon puree), Hummus (faba bean puree), and Nabet soup prepared from boiled and germinated faba beans (Dhull et al., 2021; Singh et al., 2013).

Faba bean, an essential legume, had 6,144,394 tons of dry bean production from 2,684,296 hectares and 1,642,153 tons of fresh bean production from 257,815 hectares in 2022. China is the leading country with the highest cultivation area in the world with 810,356 hectares of cultivation area. China is followed by Ethiopia and Australia (FAO, 2024). In Türkiye, 4,268 tons of faba beans were produced from 1.7554 hectare of land in 2023. Çanakkale, which has the highest production area in Türkiye, is at the top of the list with 444.9 hectare of land. Çanakkale is followed by Balıkesir and Kütahya provinces (TurkStat, 2024).

Multivariate analyses are used to characterize, evaluate, and classify genetic resources when assessing the heritability of various traits with morphological, agronomic, and physiological significance (Astaraki et al., 2020). Multivariate analysis methods such as cluster analysis and principal component analysis (PCA) are frequently used to reduce the dimensionality and visualization of variable datasets. PCA provides a detailed insight into the relationships of traits and is an effective method for identifying key characteristics of high importance for phenotypic characterization. Cluster analysis is used to determine the genetic diversity of genotypes based on trait similarities (Alam et al., 2024). These analyses are the most appropriate tools for selecting suitable parents for future breeding studies. In addition to these analyses, correlation analysis provides information about the relationship between the examined characters. It contributes to determining characters that have direct or indirect effects on the examined characters (Benlioglu and Ozkan, 2021). This study aimed to characterize some economically important faba bean varieties based on agro-morphological, technological, and mineral characteristics using multivariate analysis methods.

2. MATERIALS AND METHODS

Material

In the study, 11 registered faba bean (*Vicia faba* L.) varieties were used. The varieties were Emiralem, Eresen-87, Filiz-99, Gölyaka, Hilal, Kıtık-2003, Lara, Luz De Otono, Sakız, Salkım, and Sevil.

Experiment location

The experiment was conducted at Erciyes University Agricultural Research and Application Center (ERUTAM) Yıldırım Beyazıt Farm in the central campus of Erciyes University during the 2021 and 2022 growing season. The test site is located at an altitude of 1094 m above sea level, between 34° 56' and 36° 59' east longitude and 37° 45' and 38° 18' north latitude.

Climate Characteristics of the Experimental Area

Table 1 summarizes the climatic data on average, minimum and maximum temperatures, rainfall and average relative humidity values for the months covering the growing period in the 2021 and 2022 growing seasons. When table 1 is examined, it is observed that the temperatures in 2021, the first production year, were within the climatological normals, and the amount of rainfall in 2021 was lower than the average of many years. The rainfall in August was above the long-term average. The average relative humidity value was below the long-term average. In 2022, the second growing season, the temperature was around the long-term average. Considering the rainfall patterns in the second year, precipitation in April was below the long-term average, while rainfall in May and June exceeded the climatological normals. Relative humidity remained close to the long-term average.

Table 1 Climate data for Kayseri province for 2021, 2022, and long-term average

Climate data	April	May	June	July	August	September
			2021			
T_{avg}(°C)	10.7	15.9	18.8	23.8	21.9	16.9
T_{max}(°C)	16.8	23.6	25.8	31.8	30.7	24.2
T_{min}(°C)	4.5	7.4	12.1	14.6	13.5	10.4
RH_{avg}(%)	63.5	56.4	53.1	44.7	41.5	49.4
Rainfall (mm)	22.7	21.3	37.2	0.0	17.1	16.7
			2022			
T_{ort}(°C)	13.4	13.8	19.9	21.6	25.1	
T_{max}(°C)	29.7	32.3	34.9	36.3	37.2	
T_{min}(°C)	-4.8	1.0	9.0	7.6	13.6	
RH_{ort}(%)	46.0	60.7	54.5	46.9	40.9	
Rainfall (mm)	23.1	72.1	82.9	0.6	***	
			Long Term Average			
T_{avg}(°C)	10.6	15.0	19.0	22.2	22.0	17.3
T_{max}(°C)	17.7	22.5	26.8	30.6	30.7	26.5
T_{min}(°C)	3.1	6.8	9.7	11.9	11.4	7.3
RH_{avg}(%)	62.3	61.2	55.8	49.5	49.2	54.1
Rainfall (mm)	52.1	51.8	39.5	10.5	8.8	15.0

T_{avg}: Average Temperature T_{max}: Maximum temperature T_{min}: Minimum temperature RH_{avg}: Average relative humidity

Soil Characteristics of the Experimental Area

Table 2 Soil analysis results of the experimental area

Years	Clay (%)	Silt (%)	Sand (%)	Texture Class	pH	EC (Mmhos cm-1)	Organic Matter (%)	P_2O_5 (kg ha^{-1})	Lime (%)
2021	16.64	14.56	68.80	Sandy Loam	7.41	0.272	0.83	67.6	1.28
2022	14.56	9.78	75.66	Sandy Loam	7.97	0.184	0.77	61.7	1.60

Soil samples taken from the experimental field were analyzed in the laboratory of Erciyes University, Department of Soil Science and Plant Nutrition. Soil analysis results are given in Table 2. Based on the first-year soil analysis in Table 2, it was determined that the soil contained 16.64% clay, 14.58% silt, 68.80% sand, and the soil class was sandy loam. The soil was slightly alkaline, salt-free, low in organic matter content, medium in useful phosphorus, and calcareous. According to the soil analysis results in the second year of the experiment, the soil contained 14.56% clay, 9.78% silt, and 75.66% sand, and was classified as sandy loam. The soil was classified as medium alkaline, salt-free, low in organic matter, medium in useful phosphorus, and calcareous.

Method

The experiment was conducted in 2021 and 2022 with 3 replications according to the randomized complete block design. In the experiment, a 1 m distance was left between the plots and blocks. Plot lengths were 4 m, 6 rows in each plot, 50 cm between the rows, and 20 cm between plants in the same row. Before sowing, fertilization was made with DAP at a rate of 20 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5 and fertilizers were mixed with the soil. Stones and materials preventing emergence were removed from the area using a rake. The experiments were performed by sowing the faba bean seeds on April 29, 2021, in the first year, and May 13, 2022, in the second year. After sowing, sprinkler irrigation was used to ensure uniform plant emergence. After the plants reached a height of about 30 cm, mechanical control was carried out with a hand hoe for weed control and hilling. After the hilling process, a drip irrigation system was installed by placing one drip irrigation pipe in each row. In the experiment, the varieties that reached harvest maturity were removed 1 row from the edges of the parcel, 0.5 m from the beginning and end of the parcel. Ten sample plants were taken from the remaining part to represent the parcel, measurements were made, and data were recorded.

Characteristics Analyzed

Morphological Characteristics

Plant height, first pod height, number of main branches, number of pods, number of grains per pod, and number of grains per plant were determined on 10 plants selected from each plot. When the moisture content of the seeds became constant, seed yield was calculated by converting the yield obtained from the plot into hectare. Grain protein content was determined according to Kjeldahl method.

Technological Characteristics

Fresh weight, dry weight, fresh volume, swelling index, swelling capacity, water absorption index, water absorption capacity, cooking time, hydration coefficient, and bulk density characteristics were determined according to Ozaktan and Doymaz (2022).

Mineral Content

Macronutrients (Ca, Mg, K, P, S, Na) and micronutrients (Zn, Mn, Fe, Cu) were determined using the Agilent 5800 VDV model ICP-OES. 0.5 g of ground grain underwent acid digestion in a microwave digestion unit by adding 10 ml of Nitric Perchloric acid. Mineral compositions of the samples were determined in ICP-OES spectrometer.

Statistical Analysis

Multivariate analysis methods were used to determine the relationship between the studied characteristics. The effects of the varieties on agronomic traits, technological properties and grain mineral compositions were analyzed using the JMP Pro 17 statistical package program. Significant means were compared using Tukey's test ($p<0,05$) PCA, and correlation analyses were performed using two-year averages of the analyzed characters. R^2 (Coefficient of Determination) is the model's accuracy rate decision coefficient. A high value of this coefficient indicates that the prediction relationship is good. RMSE (Root Mean Square Error) is a measure of error, so low results are inversely proportional to performance, and a measure that shows high performance (Wang and Xu, 2004). When the R^2 value approaches 1 and the RMSE value approaches 0, it indicates that the data received is successful. Evaluating these two criteria together provides comprehensive information about both the accuracy of the model and the error size (Gultepe, 2019).

3. RESULTS AND DISCUSSION

The analysis of variance table for morphological parameters, technological parameters and mineral matter contents are given in Table 3. The effect of each examined parameter on the source of varietal variation was found statistically significant. In addition, the effects of plant height, grain protein content, grain dry weight, grain wet weight and volume, water uptake capacity, hydration coefficient, swelling capacity and water uptake index values on year*variety variation source were found statistically insignificant (Table 3).

Table 3. Analysis of variance table for morphological parameters, technological parameters and mineral contents

Source of Variation	Degree of Freedom	Plant Height (cm)	Number of Main Branches (branch plant^{-1})	First Pod Height (cm)	Number of Pods (pod plant^{-1})	Number of Seeds Per Plant (seeds plant^{-1})	Number of Seeds Per Pod (seeds pod^{-1})	Seed Yield (kg ha^{-1})	100 Seed Weight (g)	Seed Proteın Rate (%)	
		Morphological parameters F values									
Year	1	1.235	1264.800**	220.253**	35.805*	53.083*	27.169*	183.417*	11.785*	26.401*	
Rep. (Block)	4	0.939	5.358*	4.877*	0.819	1.506	3.307*	2.545	2.036	0.991	
Cultivars	10	10.463**	14.748**	2.616*	14.697**	6.335**	6.515**	73.211**	24.560*	6.860**	
Year*Cultivars	10	0.471	13.459**	2.690*	2.370*	2.299*	7.357**	10.731**	3.615*	0.862	
		Technological parameters F values									
		Dry Weight (g)	Dry Volume (ml)	Fresh Weight (g)	Fresh Volume (ml)	Cooking Time (min.)	Water Absorption Capacity (g seed^{-1})	Swelling Index (%)	Hydration Coefficient (g seed^{-1})	Swelling Capacity (ml seed^{-1})	Water Absorption index (%)	Unıt Weight (g ml^{-1})
Year	1	25.450*	118.478*	83.433*	52.494*	2.784	16.040*	12.855*	0.545	1.486	2.141	245.226**
Rep. (Block)	4	1.400	0.790	0.285	0.722	1.480	0.545	1.533	2.819*	1.094	2.085	0.240
Cultivars	10	15.088**	16.525**	16.334**	24.548**	21.483**	15.843**	18.007**	11.837**	27.003**	18.607**	3.884**
Year*Cultivars	10	1.396	2.262*	1.608	1.692	2.938*	1.619	2.091*	1.107	1.330	1.215	3.090*
		Mineral Contents F values									
		B (ppm)	Ca (ppm)	Cu (ppm)	Fe (ppm)	K (ppm)	Mg (ppm)	Mn (ppm)	Na (ppm)	P (ppm)	S (ppm)	Zn (ppm)
Year	1	974.301**	1133.640**	11.828*	166.271*	29912.950**	768.921**	106.447*	2670.667**	475.110**	4814.714**	41.452*
Rep. (Block)	4	2.636*	1.485	7.335*	0.286	0.174	1.814	0.615	3.422*	1.592	1.334	1.786
Cultivars	10	8.860**	20.573**	74.155**	58.498**	2.505*	8.872**	6.865**	29.905**	6.873**	17.326**	79.858**
Year*Cultivars	10	4.053*	37.319**	65.380**	25.839**	5.617**	5.823**	6.160**	42.523**	16.533**	25.391**	23.249**

While the number of pods per plant varied between 6.95 and 20 pod plant^{-1}, grain yield varied between 1790 and 4690 kg ha^{-1}. Filiz-99 variety had the highest values in terms of both the number of pods per plant (18.18 pod plant^{-1}) and grain yield (4472.5 kg ha^{-1}), and R^2 values were recorded as 0.812 and 0.950, respectively. Kebede et al. (2022) reported the number of pods per plant to be between 8.9 and 22.7, and Oncan Sumer and Erten (2022) observed it to be between 14.6 and 16.2. When the total number of grains per plant was analyzed, the values varied between 18.75 and 56.45 seeds plant^{-1} and the highest average number of grains per plant was the Hilal variety with 43.65 seeds plant^{-1}, and the R^2 value was 0.672. In addition, the Hilal variety was in the same statistical group as the Filiz-99 variety in terms of grain yield. The number of grains per plant was reported by Ton (2021) as 15.9-20.1 seeds plant^{-1}, Soysal et al. (2020) as 18.8-25.6 seeds plant^{-1}, and by Karakoy et al. (2017) as 1.2-40.4 seeds plant^{-1}. The minimum number of grains in pods was recorded as 1.7 seeds pod^{-1} and the maximum as 3.4 seeds pod^{-1}. In terms of mean values, the Sevil variety had the highest value at 2.98 seeds pod^{-1}. RMSE and R^2 values were 0.26 and 0.672, respectively. In the literature, Abdel-aziz and Ismail (2023) found the number of grains per pod to range from 3.8 to 4.1 seeds pod^{-1} in the control group, while Dewangan et al. (2022) reported a range of 2.22 to 4.89 seeds pod^{-1}. The 100-grain weight varied between 80.07 and 132.48 g, and the R^2 value was 0.897. The Eresen-87 variety had the highest average 100-grain weight. 100-grain weight was recorded as 108.8 - 110.9 g by Oncan Sumer and Erten (2022), 120.3 - 142.6 g by Ton (2021), and 47.93 - 193.37 g by F. Sheikh et al. (2015). Grain protein ratio values varied between 20.98% and 29.88%. The Lara variety had the lowest average grain yield with 1964.2 kg ha^{-1}, while the average grain protein value was 28.19%. RMSE and R^2 values were 1.21 and 0.727, respectively. In the literature, the grain protein ratio was reported as 23.5 - 28.4% by Segers et al. (2022), and 25.71- 31.15% by Zulkadir et al. (2022). When comparing the values obtained from the examined morphological parameters with those in the literature, it is seen that the study's results are compatible with the literature.

Figure 2, which presents the technological characteristics, shows that the minimum and maximum values for dry weight were 98.06 - 157.34 g, for dry volume 97 - 158 ml, and for fresh weight 172.98 - 314.5 g. The Eresen-87 variety had the highest average value in these three characteristics. The Luz De Otono variety had the lowest average values for dry weight (101.4 g) and dry volume (102.3 ml), while the Hilal variety recorded the lowest average for wet weight (186.9 g). The fresh volume values varied between 144 and 294 ml, and the Filiz-99 variety had the highest average at 282.7 ml. Various factors such as seed differences, location, variety characteristics, environmental factors, soil properties, and storage conditions also affect cooking quality of chickpeas (Wang et al., 2017). Cooking times of desi chickpea varies between 55 – 200 minutes (Williams et al., 1983) and cooking times of kabuli chickpeas vary between 33–72 minutes (Ozer et al., 2010). Consumers demand legumes with shorter cooking times (Ozaktan, 2021). When evaluating the cooking times, the average cooking time varied between 32 and 42 minutes, with the Gölyaka variety exhibiting the shortest average cooking time, recorded at 33 minutes. Conversely, the Hilal variety showed the longest average cooking time, recorded at 40.8 minutes. RMSE and R^2 values were recorded as 1.10 and 0.911, respectively. Water absorption capacity values varied between 0.612 and 1.573 g seed^{-1}, with an RMSE value of 0.11 and an R^2 value of 0.835. The Eresen-87 genotype recorded the highest mean value of 1.419 g seed^{-1}. While the swelling index values varied between 1.262% and 2.283% and unit weight values ranged from 0.958 to 1.149 g ml^{-1}. RMSE and R^2 values for swelling index and unit weight parameters were 0.11-0.03 and 0.867-0.704, respectively. When the mean values of hydration capacity and water absorption index were analyzed, the Gölyaka genotype had the highest values, with 2.151g seed^{-1} and 1.159%, respectively. R^2 values were recorded as 0.742 and 0.704, respectively. The swelling capacity values varied between 0.31 and 1.5 ml seed^{-1}, and the highest value was obtained from the Salkım (1.45 ml seed^{-1}) genotype. RMSE and R^2 values were 0.11 and 0.912, respectively. In the literature, Cilesiz et al. (2023) determined the swelling capacity to range from 0.45 to 1.72 ml seed^{-1}. They reported that the hydration capacity values varied between 0.59 and 2.07 g seed^{-1} and that the swelling index varied between 1.30% and 5.35%.

Figure 1. Data on morphological parameters of faba bean varieties (Min value, Max value, Range, CV, RMSE, R^2)

In Figure 3, which analyzes the mineral matter contents of faba bean grains, the boron contents of the genotypes varied between 12.37 ppm (Luz de Otono) and 14.93 ppm (Hilal). The R^2 value was recorded as 0.744. Ca content values varied between 1267 ppm (Lara) and 1617 ppm (Gölyaka), with an R^2 value of 0.896 and an RMSE value of 37.89. The highest mean value of Cu content was obtained from the Lara genotype with 17.5 ppm, while the lowest mean value was obtained from the Eresen-87 genotype with 12.6 ppm. RMSE and R^2 values were 0.29 and 0.966, respectively. Fe content values varied between 34.0 and 49.8 ppm, with the highest average value observed in the Kıtık 2003 genotype and the lowest in the Gölyaka genotype. The R^2 value was recorded as 0.971. When the average content amounts of potassium (10193-11742 ppm) and mg (1399-1761 ppm) were analyzed, the highest amount was obtained from the Sakız genotype. R^2 values were 0.551 and 0.774, respectively. Mn contents varied between 12.7 and 14.9 ppm, and the R^2 value was recorded as 0.770. Na contents varied between 297.2 and 387.3 ppm, and the R^2 value was recorded as 0.923. While the highest average Mn content was obtained from the Eresen-87 genotype, the highest average Na content was obtained from the Salkım genotype. Phosphorus content values varied between 6320.1 and 7639.6 ppm, and the R^2 value was recorded as 0.773. Sulfur content values varied between 1303.5 and 1584.6 ppm, and the R^2 value was recorded as 0.892. Zn content values varied between 47.4 and 78.7 ppm, and the R^2 value was recorded as 0.969. In addition, while the highest average values for P and Zn were obtained from the Lara variety, the lowest average content for S and Zn was obtained from the Eresen-87 genotype. When the literature was examined, Karakoy et al. (2018) reported that phosphorus in faba bean grain ranged from 1000 to 9900 ppm, potassium from 9400 to 56000 ppm, copper from 8,13 to 34,23 ppm, and zinc from 28,42 to 64,33 ppm. Khazaei and Vandenberg (2020) reported that boron content in the chemical composition of faba bean skin ranged from 10.35 to 12.32 ppm, sodium content from 21.85 to 163.74 ppm, magnesium content from 1232 to 1478 ppm, iron content from 48.57 to 52.54 ppm, and manganese content from 13.38 to 15.87 ppm. Baloch et al. (2014) reported that the amount of potassium in faba bean grain varied between 4500 and 19300 ppm, the amount of iron between 29.7 and 96.3 ppm, the amount of copper between 10.3 and 33 ppm, and the amount of zinc between 10.4 and 49.3 ppm. As a result of the literature evaluation, it was found that the results obtained from the study were compatible with the literatures.

Figure 2. Data on technological parameters of faba bean varieties (Min value, Max value, Range, CV, RMSE, R^2)

When the scatterplot matrix for the overview of correlations and fit lines is examined, blue circles indicate the positive correlation between the examined parameters, red circles denote the negative correlation, and the circle's diameter represents the strength of the relationship. In addition, Figure 5 shows the scatter plot of varieties and fit lines in terms of the examined parameters. Furthermore, in the biplot (Figure 4), formed from the mean values of all examined parameters, the colored circles formed by the groups formed in the dendrogram (Figure 6) are also given on the biplot. Both the axis lengths and angles from the biplot analysis and the scatter of varieties from the dendrogram are presented together in Figure 4. In this context, a long axis length and a narrow angle between the other axis define a highly positive relationship between the axes, while the opposite indicates a negative relationship (Okumus et al., 2023).

Based on the angle values and correlation values of the axes in the same region with the plant height axis, wet volume (r=0.795), wet weight (r=0.758), dry weight (0.742), water absorption capacity (r=0. 637), dry volume (r=0.636), swelling capacity (r=0.669), 100 grain weight (r=0.624) and Na (r=0.521), while it showed a positive relationship between the number of grains in the pod (r=0.649) and Fe (r=0.629).

Based on the angle and correlation values of the axes in the same region as the Zn axis, Cu (r=0.902) showed a positive correlation with protein ratio (r=0.595), Ca (r=0.592), P (r=0.572), cooking time (r=0.443), and S (r=0.391), while it showed a negative correlation with the number of pods (r=-0.833), Mn (r=-0.775), and hydration coefficient (r=-0.743).

Based on the angle and correlation values of the axes in the same region as the swelling index, water absorption index (r=987), Mn (r=463), hydration coefficient (r=0.744), number of pods (r=0.471), Mg (r=0.457), and unite weight (r=455) showed a positive correlation, while cooking time (r=-0.762) showed a negative correlation.

According to the literature, Erten and Oncan Sumer (2023) reported that there is a negative correlation between seed yield and protein content in the seed, Baloch et al. (2014) reported a significant positive correlation between K content and Mn, Fe, Cu, and Zn, as well as a strong positive correlation between the Zn content of grain and P, K, Fe, Mn, and Cu. Ozaktan and Doymaz (2022) reported significant positive correlations between Fe and first pod height, seed yield, number of pods per plant, number of seeds per plant, and plant height, as well as notable positive correlations between the amount of zinc in grain and the number of main branches and grain protein content.

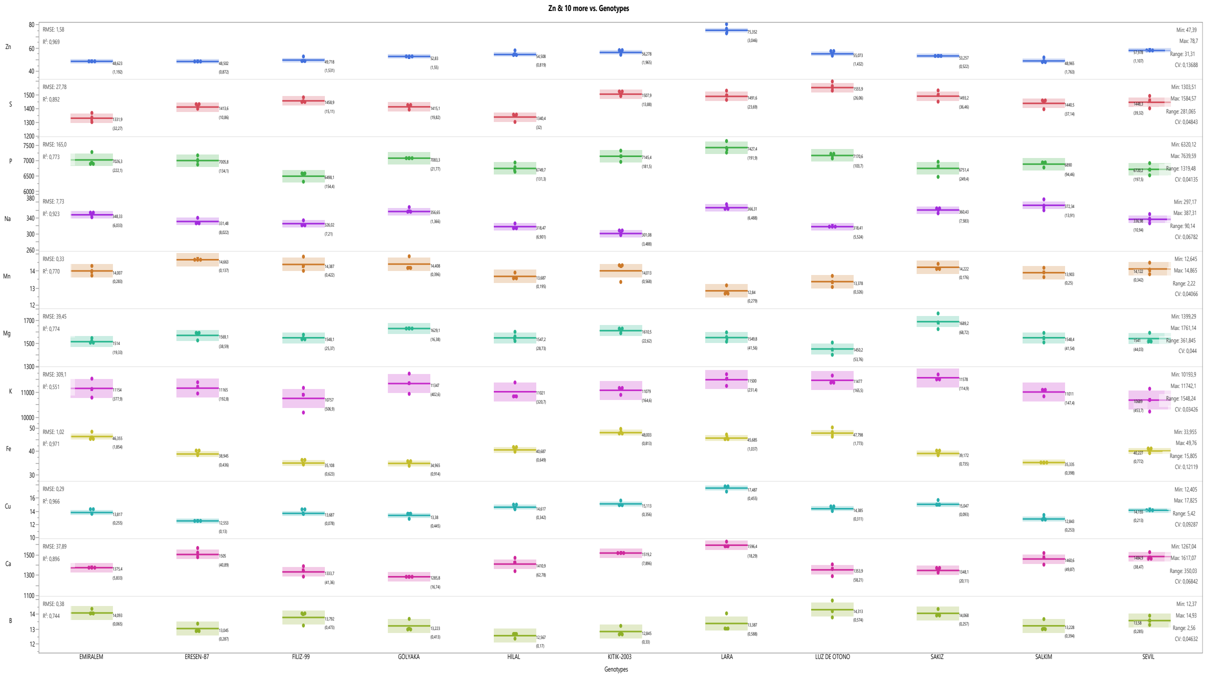

Figure 3. Data on mineral contents of faba bean varieties (Min value, Max value, Range, CV, RMSE, R^2)

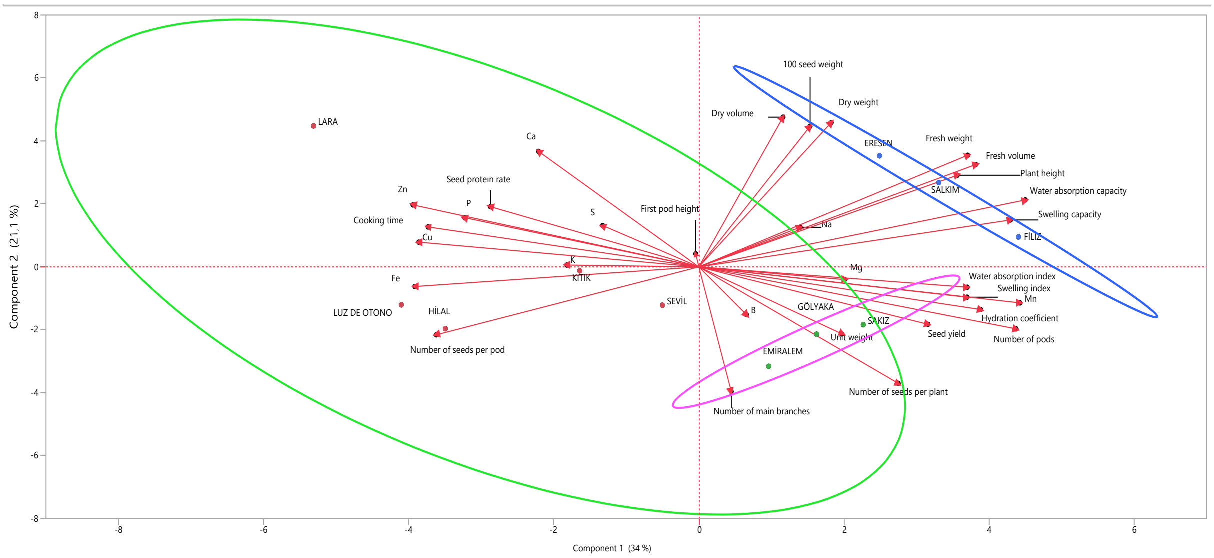

Figure 4. Biplot analysis on the examined parameters and clustering of varieties

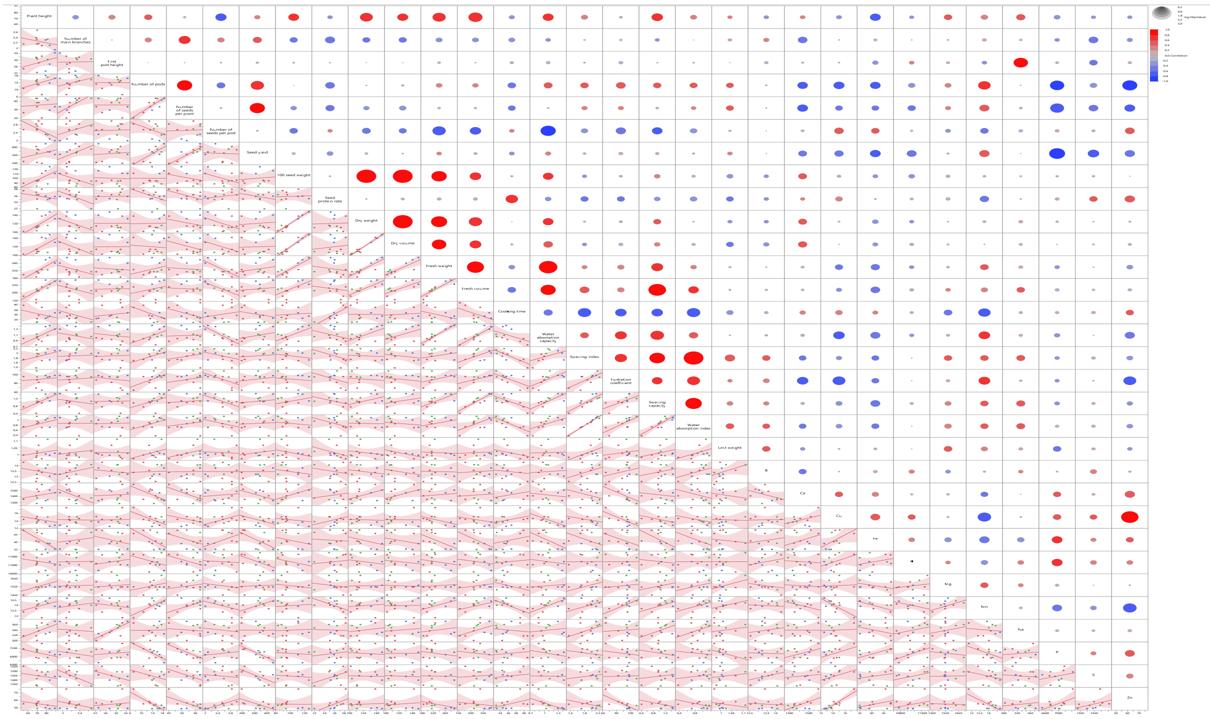

Figure 5. Scatterplot matrix for an overview of correlations and fit lines

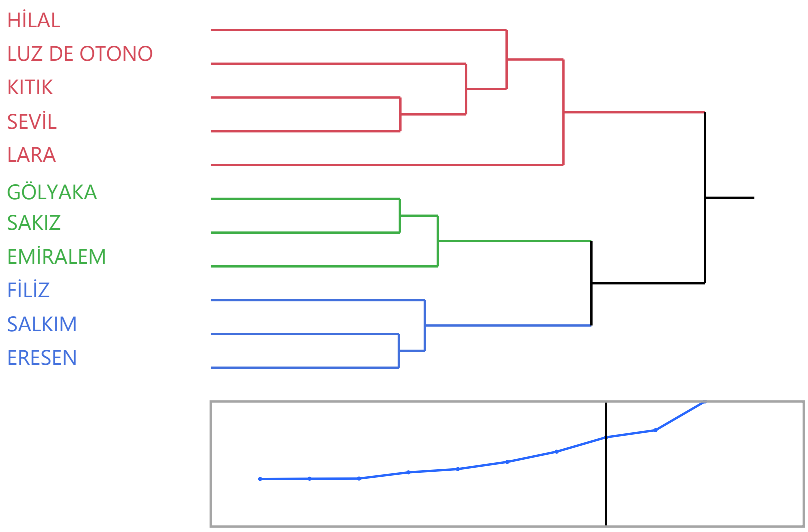

Figure 6. Dendrogram for 11 varieties of faba bean based on the examined parameters

4. CONCLUSION

The study which characterized morphological, technological, and mineral contents of faba bean varieties using multivariate statistical analysis methods, identified a wide variation among the faba bean varieties. The correlation analysis performed to determine the relationship between the traits revealed significant positive correlations with plant height trait, wet volume, wet weight, dry weight, water absorption capacity, dry volume, 100-grain weight, and Na content of grain. Significant positive correlations were determined between Zn content and Cu, grain protein content and Ca, and P and S contents, while negative correlations were determined between pod number and hydration coefficient. A significant positive correlation was determined between the swelling index trait and water uptake index, Mn content, hydration coefficient, number of pods per plant, and grain Mg content, while a negative correlation was determined with cooking time. The cluster analysis performed to identify the genetic relationship between the varieties determined that 11 varieties were divided into 3 different clusters based on their morphological, technological, and mineral characteristics.

For similar ecological conditions, Filiz 99 variety with the highest grain yield, Gölyaka variety with the shortest cooking time and Lara variety with the highest protein content and zinc content in the grain can be recommended.

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