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Investigation of Seed Yield and Quality Traits of Some Soybean Genotypes Using a Biplot Technique in Çukurova, Türkiye

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ABSTRACT

This research was carried out in Çukurova/ Türkiye conditions in the 2018 and 2019 main crop growing seasons. Years have been considered as the environment. The research was carried out to investigate seed yield and quality characteristics, genotype, genotype × environment interactions (GGE), and the relationships between the characteristics and environment examined by multi-trait GGE Biplot analysis in 11 soybean genotypes. According to the results of the combined analysis of variance, the interaction of environment, genotype and environment × genotype was significant ($p < 0.05$) in all examined traits. According to the average results of both environments, the seed yield of the different genotypes varied between 4111 and 5536 kg/ha, and the oil, protein, palmitic acid, oleic acid, linoleic acid, and saturated fatty acid contents were 22.49-24.17%, 31.22-37.6%, 10,55-11.68%, 21.43-28.31%, 46,68-53,83%, and 14,45-16,44%, respectively. Genotype explained 86.60% of the total variation of the experiment in the multi-trait biplot. In terms of seed yield, the 'Atakisi' variety was the highest, followed by the 'KA-08-03-1' line. The 'KA-08-03-1' line had the highest protein and linoleic acid contents, whereas the 'Cinsoy' variety had the highest palmitic acid and saturated fatty acid contents. In conclusion, the interaction of genotype and the multi-trait biplot analysis method may be sufficient to evaluate cultivar candidates for selection.

Çukurova'da Bazı Soya Genotiplerinin Tohum Verimi ve Kalite Özelliklerinin Biplot Tekniği Kullanılarak Araştırılması

Araştırma Makalesi

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ÖZ

Bu araştırma, 2018 ve 2019 ana ürün yetiştirme sezonlarında Çukurova/Türkiye koşullarında yürütülmüştür. Yıllar çevre olarak kabul edilmiştir. Araştırma 11 soya fasulyesi genotipinde tohum verim ve kalite özellikleri, genotip, genotip × çevre etkileşimleri (GGE) ve özellikler ile çevre arasındaki ilişkilerin multi-trait GGE Biplot analizi ile incelenmesi amacıyla yapılmıştır. Birleştirilmiş varyans analizi sonuçlarına göre, incelenen tüm özelliklerde çevre, genotip ve çevre × genotip etkileşimi önemli bulunmuştur ($p < 0.05$). Her iki çevrenin ortalama sonuçlarına göre, farklı genotiplerin tane verimleri 4111 ile 5536 kg/ha arasında değişirken, yağ, protein, palmitik asit, oleik asit, linoleik asit ve doymuş yağ asidi içerikleri ise sırasıyla %22,49- 24,17, %31,22-37,6, %10,55-

11,68, %21,43-28,31, %46,68-53,83 ve %14,45-16,44 olarak tespit edilmiştir. Genotip, çoklu özellik biplotunda toplam varyasyonun %86,60'ını açıklamıştır. Tohum verimi açısından en yüksek 'Atakisi'' çeşidi bulunmuş ve daha sonra 'KA-08-03-1' hattı takip etmiştir. 'KA-08-03-1' hattı en yüksek protein ve linoleik asit içeriğine, 'Cinsoy' çeşidi en yüksek palmitik asit ve doymuş yağ asidi içeriğine sahip bulunmuştur. Sonuç olarak, genotip ve çok özellikli biplot analiz yönteminin etkileşimi, seleksiyon için çeşit adaylarını değerlendirmek için yeterli olabileceği gösterilmiştir.

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Introduction

Soybean (*Glycine max (L.) Merr.)* is one of the most important protein and oil crops, as well as one of the world's most important field crops in terms of growing area and productivity. The FAOSTAT record shows that between 1994 and 2019, the soybean harvest area expanded by 92%, while production increased by 145% (FAOSTAT, 2018). Because legumes have oilseed nutraceutical benefits, soybean continues to gain popularity as a food for human nutrition, as well as for use as animal feed. Soybean breeders' main objective is to increase soybean yield (Assefa et al., 2018; Wang et al., 2020).

The effect of genotype and environment interactions (GEIs) can be described by the stability of the studied trait. Regardless of whether the trait studied is seed yield or quality traits, the phenotypic stability of the trait is the ability of a genotype to perform consistently in a variety of environments. For this reason it is important to select high-performance and highly stable genotypes in breeding programmes and to provide plant breeders with superior and competitive varieties under different conditions (Ahmed et al., 2020; Angelini et al., 2022; Goksoy et al., 2019; Kocaturk et al., 2019; Mulugeta et al., 2022). Plant breeders aim to select varieties that perform well in different environments. However, the accurate selection of highly stable varieties can be difficult when a plant breeder has to consider the GEI of multiple traits in multiple environments. In the selection process, statistical modelling should be performed to predict and evaluate the genetic values of multiple traits (Gauch et al., 2008; Omrani et al., 2022; Yan, 2011).

Various statistical methodologies exist for the analysis of GEI interactions, from univariate statistics to multivariate methods (Crossa and Cornelius, 1997). One of the most widely used multivariate methods is the additive principal effects and multiplicative interaction (AMMI) model, which allows us to predict the stability of varieties and classify environments (Gauch, 1992; Gauch et al., 2008; Enyew et al., 2021; Erdemci, 2018). The model combines analysis of variance as an additive model with principal components (PC) as a multiplicative model that allows analysis of interactions.

In many plant breeding programmes, GEI has been conducted for a single trait (Pour-Aboughadareh et al., 2022; Sharma et al., 2022). However, when more than one feature is considered, selecting high-performance and stable cultivars becomes difficult, while the degree of accuracy in cultivar selection increases. In soybean breeding, only high-yielding varieties can be developed, but the evaluation of oil yield, protein content, and some quality criteria of soybean, which is an oil plant, will enable the development of yielding and high-quality soybean varieties. Yan (2001) developed the GGE biplot methodology as a tool that perfectly interprets GEI with graphics in multi-environmental experiments. This method has been used in many studies, and its advantages compared to other numerical methods have been reported. The GGE biplot is an interpretation model that visually answers important questions about genotype and environmental assessment (Yan and Tinker, 2006). Thus, multi-environment experiments with multiple features have been increasingly used in recent years (Abdelghany et al., 2021; Huanuqueño et al., 2022; Nardino et al., 2022; Zuffo et al., 2020).

The aim of this study was to visually evaluate the seed yield and some quality characteristics of some soybean varieties and advanced lines in Cukurova, Türkiye, during two seasons, with the multi-trait GGE biplot method and to determine which genotypes show high performance.

Materials and Methods

Materials

This research was carried out in the experimental area of the Eastern Mediterranean Agricultural Research Institute located at Adana in the 2018-2019 main crop-growing season. In this research, a total of 11 soybean genotypes, 6 pure soybean lines (‘S02-14-11,’ ‘KA-08-09-1,’ ‘KA-08-03-1,’ ‘KA-07-06-04,’ ‘S03-03-03-7,’ ‘CU04-01’) and 5 standard soybean varieties (‘ATAEM-7,’ ‘Cinsoy,’ ‘Blaze,’ ‘Atakisi’, ‘SA 88’), were used as research materials. Table 1 presents the monthly average temperature, minimum and maximum temperatures, and precipitation amounts for the 2018 and 2019 seasons and long term data of the experiment area.

Table 1. Climatic data of 2018 and 2019 and long term data.

	Measurement Period	April	May	June	July	August	September	October
Mean Temp.	2018	18.69	23.23	25.29	27.41	27.66	26.06	21.08
	2019	16	22.77	26	27.24	28.15	25.63	22.34
	Long term (1929-2020)	17.5	21.8	25.6	28.2	28.7	26.1	21.7
Mean Max. Temp. (°C)	2018	27.62	31.04	31.74	32.44	33.32	33.71	29.51
	2019	22.84	30.8	32.59	33.19	34.65	33.52	30.47
	Long term (1929-2020)	23.7	28.3	31.7	33.9	34.7	33.1	29.1
Mean Min. Temp. (°C)	2018	10.99	16.44	19.38	22.35	22.67	19.93	14.71
	2019	10.06	15.15	20	21.51	22.56	19.25	16.19
	Long term (1929-2020)	11.9	15.8	19.8	23	23.3	20.1	15.7
Mean Monthly Total Rainfall (mm)	2018	40.4	76.3	14	2.3	0.3	17	44.5
	2019	102.2	6.9	17.5	3.6	3.9	1	46
	Long term (1929-2020)	51.1	48.7	22.2	10.2	9.6	19.6	43.6

Methods

This research was carried out in a randomised complete block experimental design with four replications, with a total of 11 genotypes in both environments (years). In the experiment, each plot had a total cultivation area of $2.8 \times 5 = 14\ m^2$. The seeds were inoculated with *Rhizobium bredy japonicum* before sowing. Trial sowing was carried out at the end of April in both years with a sowing machine. Pure 6 kg/da nitrogen (N) fertiliser was applied per decare as the base fertiliser. According to the needs of the plant, irrigation was applied 4 times in the furrow. For the edge effect, 0.5 m was taken from the front and back of each plot, and the harvest was made with Hege over 5.6 m^2.

The seed yield, oil and protein ratio, palmitic acid, oleic acid, linoleic acid, and saturated fatty acid quality characteristics of the genotypes were investigated.

Oil and Protein Analyses

The crude protein content (calculated as N × 5.83) was determined on soybean samples by the standard Kjeldahl procedure and crude oil was extracted from aliquots with petroleum ether using a Soxhlet apparatus for 4 h (AOAC, 2005).

Fatty Acid Analysis

Fatty acid methylesters obtained by methylation of total lipids were analysed by the American Oil Chemists' Society according to the method described in the analysis methods of Ce1-62 (AOCS 2005).

Statistical Analyses

Analysis of variance (ANOVA) was performed separately for each environment, followed by a combined analysis of variance according to the statistical model described in Equation (1):

$$Y_{ijk} = \mu + G_i + E_j + GE_{ij} + \varepsilon_{ijk} \tag{1}$$

where Y_{ijk} represents the ith genotype in the jth environment and the kth block; μ is the overall mean; G_i is the effect of the ith genotype; E_j is the effect of the jth environment; GE_{ij} is the effect of the interaction of the ith genotype with the jth environment; and ε_{ijk} is the effect of experimental error.

Analysis of variance and the comparison of the averages of the traits were conducted with the Duncan comparison test in IBM SPSS Statistics Version 25 (IBM, 2020).

This study researched genotype-environment (year)–trait 3-way data to be used from all possible perspectives (Yan and Kang, 2003). First, to examine the relationships among traits in all environments, trait associations were made using a trait association by environment biplot. Then, the relationships among the traits and the trait profiles of the genotypes were evaluated (Yan, 2011). Genotype × environment and trait data were analysed using GGE biplot Pattern Explorer software (GGE-biplot, 2009), and the results were presented visually.

Results and Discussion

Table 1 shows the average precipitation amount and minimum and maximum temperatures in the 2018 and 2019 growing seasons. The temperatures were higher than the average of the long term data, but the amount of precipitation decreased. These changes, which can be measured in climate data, were evaluated as environmental factors causing variations in yield and quality characteristics of soybean genotypes between years. In this study, soybean seed yield, oil and protein ratio, palmitic acid, oleic acid, linoleic acid and saturated fatty acid properties were investigated. The variance analyses of the data obtained from the research are shown in Table 2. Differences between genotypes were significant ($p < 0.05$) in the ANOVA performed in separate years for soybean seed yield, oil and protein ratio, palmitic acid, oleic acid, linoleic acid and saturated fatty acid characteristics (Table 2). In the combined analysis of variance, the environment was important in terms of grain yield and quality characteristics, except for palmitic acid ($p < 0.05$). In the combined analysis of variance, genotype and genotype × environment interactions were significant for all seed yield and quality characteristics ($p < 0.05$). The examined variables were grouped with the DUNCAN's multiple range mean comparison test, and the results are shown in Table 3.

Seed yield (5391 kg/ha), palmitic acid (11.26%) and linoleic acid (51.06%) had a higher average in Env_1. The oil ratio (23.74%), protein ratio (37.86%), oleic acid (25.60%), and saturated fatty acid (15.50%) had a higher average in Env_2 (Table 3). Seed yield averages of genotypes for Env_1 showed that KA-08-09-01 (6358 kg/ha) and KA-08-03-01 (6013 kg/ha) had the highest performance, while Cinsoy (4454 kg/ha) had the lowest. For Env_2, KA-08-03-01 (5060 kg/ha), SA88 (4834 kg/ha) and Atakisi (4715 kg/ha) had the highest seed yield, while SO2-14-11 (3281 kg/ha) had the lowest.

Table 2. Combined analyses of variance table for yield and quality traits in Env_1 and Env_2.

			Seed Yield			Oil (%)			Protein (%)			Palmitic acid (%)		
Source	**DF**	**DF(Com.)**	**Env_1**	**Env_2**	**Com.**	**Env_1**	**Env_2**	**Com.**	**Env_1**	**Env_2**	**Com.**	**Env_1**	**Env_2**	**Com.**
Environment	-	1	-	-	31881920.73***	-	-	31.63**	-	-	1113.64**	-	-	0.08NS
Environment x Genotype	-	10	-	-	1392426.93***	-	-	1.93**	-	-	19.32**	-	-	0.16*
Genotype	10	10	1204485.37**	1488266.11**	1300324.55***	3.56*	0.83**	2.46**	4.56*	41.57**	26.80**	0.53**	0.69**	1.05**
Replicate	3	-	9996.20NS	238819.90NS	-	2.27NS	0.31NS	-	1.46NS	5.47**	-	0.06NS	0.01NS	-
Error	30	66	116890.67	50581.53	294024.46	1.417	0.119	0.816	2.134	0.593	1.554	0.093	0.071	0.078

			Oleic acid (%)			Linoleic acid (%)			Saturated fatty acid (%)		
Source	**DF**	**DF(Com.)**	**Env_1**	**Env_2**	**Com.**	**Env_1**	**Env_2**	**Com.**	**Env_1**	**Env_2**	**Com.**
Environment	-	1	-	-	47.53**	-	-	31.94**	-	-	1.51**
Environment x	-	10	-	-	7.13**	-	-	7.97**	-	-	0.6**

Genotype											
Genotype	10	10	17.11**	31.68**	41.66**	16.02**	32.07**	40.11**	1.37**	1.81**	2.55**
Replicate	3	-	0.30NS	2.26NS	-	0.67NS	2.69NS	-	0.12NS	0.09NS	-
Error	30	66	2.148	1.232	1.653	1.73	1.705	1.714	0.148	0.224	0.178

Env_1: 2018; Env_2:2019; Com.: Combined;*, ** significant at $p < 0.05$ and $p < 0.01$ level of probability, respectively; NS: not significant

Table 3. Mean values of the genotypes and varieties and Duncan grouping.

	Seed Yield (kg/ha)			Oil (%)			Protein (%)			Palmitic acid (%)		
Genotype	**Env_1**	**Env_2**	**Combined**	**Env_1**	**Env_2**	**Combined**	**Env_1**	**Env_2**	**Combined**	**Env_1**	**Env_2**	**Combined**
S02-14-11	5314c-e	3281d	4298cd	24.46a	23.88b-d	24.17a	30.03ab	38.48d	34.25de	11.30a-c	11.13bc	11.21b-d
KA-08-09-1	6358a	3507b-d	4932b	21.66bc	23.84b-d	22.75c	31.50ab	37.34e	34.42cd	11.72a	11.64a	11.68a
KA-08-03-1	6013ab	5060a	5536a	21.16c	23.83b-d	22.49c	32.52a	42.72a	37.62a	11.38a-c	11.18bc	11.28b-d
KA-07-06-04	5828bc	3935a-d	4881bc	23.56ab	24.52a	24.04ab	31.21a-c	41.53b	36.37b	11.24a-c	11.03cd	11.13cd
S03-03-03-7	5179de	3902a-d	4540b-d	22.48bc	23.68b-d	23.08bc	28.79c	37.18e	32.98ef	11.57ab	11.47ab	11.52ab
ÇU-04-01	4776ef	3445cd	4111d	21.95bc	23.93bc	22.94c	29.32ab	38.61cd	33.97d-f	11.55ab	11.47ab	11.51ab
SA 88	5208de	4834a	5021ab	22.48b c	23.55cd	23.02c	30.61a-c	39.54cd	35.08b-d	10.74d	10.70de	10.72e
ATAEM-7	5076de	4617ab	4847bc	22.83a-c	22.76e	22.79c	31.69ab	39.74c	35.71bc	11.12b-d	10.88cd	10.99d
CİNSOY	44548f	4491a-c	4472b-d	23.15ab	23.58cd	23.36a-c	30.53a-c	34.93f	32.73f	11.67a	11.53ab	11.60a
BLAZE	5621b-d	4272a-d	4946b	22.51bc	24.23ab	23.37a-c	31.07a-c	31.38g	31.22g	10.98cd	11.76a	11.37a-c
ATAKİSİ	5474c-d	4715a	5094ab	21.72bc	23.35d	22.53c	30.92a-c	35.00f	32.96ef	10.65d	10.45e	10.55e
Mean	5391A	4188	4789	22.54B	23.74A	23.14	30.74B	37.86A	34.3	11.26NS	11.2NS	11.23
CV	4.34	5.19	11.32	20.67	20.35	3.89	18.09	15.64	3.64	28.94	28.83	2.49
	Oleic acid (%)			**Linoleic asid (%)**			**Saturated fatty acid (%)**					
Genotype	**Env_1**	**Env_2**	**Combined**	**Env_1**	**Env_2**	**Combined**	**Env_1**	**Env_2**	**Combined**			
S02-14-11	26.57ab	30.06a	28.31a	49.18c	45.70f	47.44f	15.19cd	15.26-e	15.22cd			

KA-08-09-1	24.59b-d	27.72bc	26.15b	50.17bc	47.42ef	48.80e	15.61bc	15.88a-c	15.75b
KA-08-03-1	21.61e	21.25h	21.43e	53.42a	54.24a	53.83a	15.05cd	14.88de	14.97de
KA-07-06-04	24.47b-d	24.65d-f	24.56c	50.65bc	51.44bc	51.05cd	15.82b	15.47b-d	15.64bc
S03-03-03-7	28.10a	29.15ab	28.63a	47.11d	46.25f	46.68f	15.24bd	15.54bd	15.39b-d
ÇU-04-01	23.86c-e	22.01gh	22.94d	50.13bc	52.12b	51.13cd	16.43a	16.45a	16.44a
SA 88	23.27de	23.51fg	23.39cd	52.07ab	52.28ab	52.17bc	14.62de	14.77de	14.70ef
ATAEM-7	21.53e	25.61de	23.57cd	53.77a	49.99cd	51.88b-d	15.02cd	15.19c-e	15.10de
CİNSOY	22.59de	26.11cd	24.35cd	52.02ab	49.04de	50.53d	15.56bc	16.10ab	15.83b
BLAZE	25.87bc	27.32c	26.59b	50.24bc	47.69ef	48.96e	14.73de	16.53a	15.63bc
ATAKİSİ	22.96de	24.23ef	23.59cd	52.94a	52.28ab	52.61ab	14.40e	14.51e	14.45f
Mean	24.13B	25.6A	24.86	51.06A	49.86B	50.46	15.24B	15.5A	15.37
CV	19.85	19.22	5.19	14.26	14.5	2.6	24.93	24.57	2.73

Genotypes are grouped in lowercase letters for each trait. Genotype averages are grouped in capital letters on the same line in terms of Env_1 and Env_2.

The variation detected in seed yield between years can be explained by the fact that the minimum, maximum and average temperatures in April and May of 2018 were higher than in 2019 and the average of long term data, and the monthly average of precipitation was more regular. In the combined ANOVA, the KA-08-03-01 genotype had the highest mean values in terms of seed yield, protein ratio and linoleic acid concentration.

The SO2-14-11 genotype was one of the highest valued genotypes in Env_1 (24.46% and 30.03%) and 2019 (23.88% and 38.48%) in terms of the oil and protein ratio, respectively. However, the increase in the average oil and protein ratio in 2019, due to the difference in climatic conditions, was significantly different from Env_1 ($p < 0.05$). Significant differences were determined in the seed yield, oil and protein ratio, and fatty acid composition of the genotypes according to year.

Significant differences in seed yield, protein ratio and fatty acid composition between genotypes under different environmental conditions have also been reported in other studies (Abdelghany et al., 2021; Assefa et al., 2018; Wu et al., 2017). In these studies, researchers explained the inconsistent responses of genotypes with environmental factors, such as different climates, temperature and sunshine duration.

Multi-traits GGE Biplot Analysis Results

In the multi-traits biplot technique, PC1 (59.30%) and PC2 (27.30%) were explained the 86.60% of the total variation. According to the research results, the seed yield was higher in the first year than in the second year, depending on the environmental factors of the growing seasons. Seed yield, palmitic acid, and linoleic acid were higher in Env_1 compared to Env_2. Oil ratio, protein ratio, oleic acid and saturated fatty acid were higher in Env_2 than in Env_1.

Biplot graphs of the investigated features are given in Figures 1-4. Although 11 soybean genotypes were used in the study, 7 cultivars above the general average were identified in all biplot graphics obtained by the GGE-biplot Version 5.2. (2009) software. The biplot in Figure 1 presents data for seven traits, including yield, oil and protein ratio, palmitic acid, oleic acid, linoleic acid and saturated fatty acid, of 11 soybean varieties in Cukurova soybean performance trials. One of the most important issues in soybean cultivation is evaluating grain yield together with quality characteristics (Abdelghany et al., 2021).

If there is an acute angle between the characteristics in the GGE Biplot graphics, it is positively correlated. If there is an obtuse angle, it is negatively correlated. If it is at a right angle or close to a right angle, there is no relationship between the characteristics or independent characteristics (Yan, 2011).

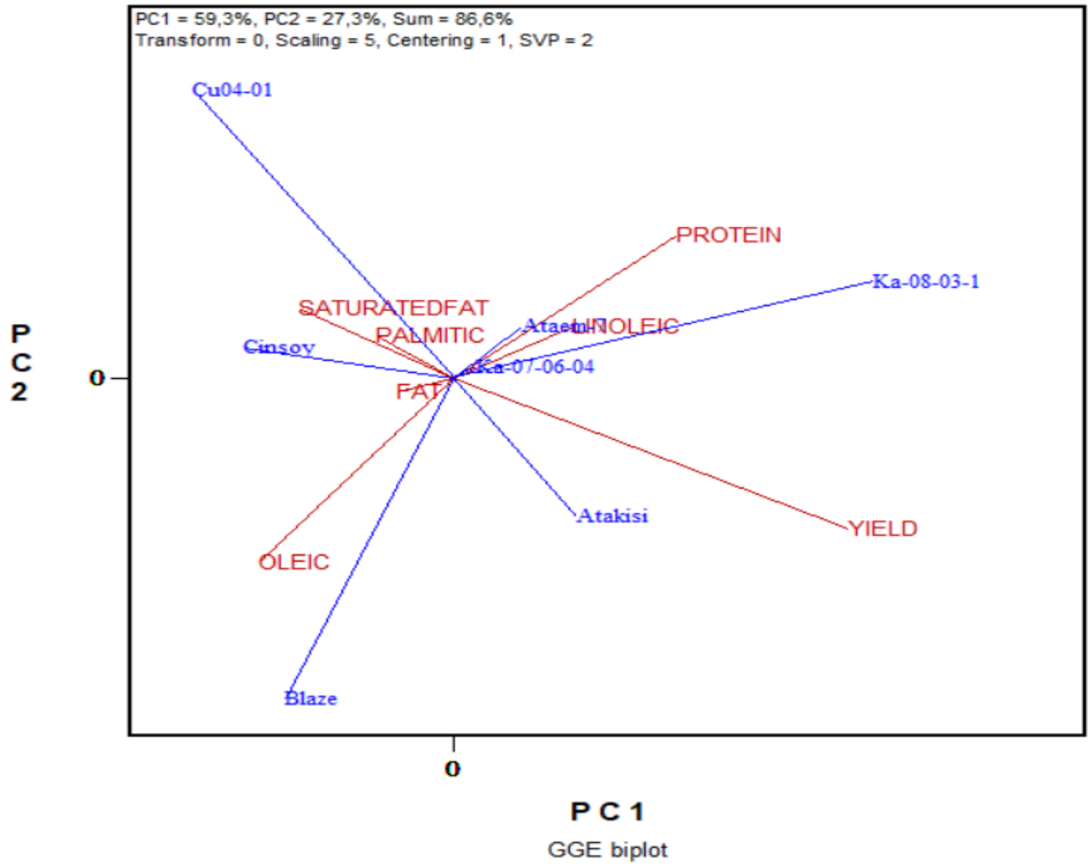

Figure 1. GGE biplot for genotype, trait and inter-trait relationships.

Thus, in Figure 1, protein and linoleic acid; saturated fatty acid and palmitic acid; and oil ratio and oleic acid were positively correlated. Palmitic acid and saturated fatty acid by seed yield; oil and protein; and protein and oleic acid were negatively correlated. However, the seed yield and protein, seed yield, and oleic acid features were independent. In addition, in 7 genotypes, protein and linoleic acid; palmitic acid, saturated fatty acid, and oil ratio; and oil ratio and oleic acid were positively correlated.

In some studies conducted in terms of seed yield, protein, oil content, and fatty acid composition in soybean, a negative relationship was reported between seed yield and protein content (Mello Filho et al., 2004). However, there is a positive relationship between seed yield and protein ratio in some studies (Johnson et al., 1955). In addition, Whaley and Eskandari (2019) identified high seed yielding and high protein varieties for different locations with the GGE biplot approach.

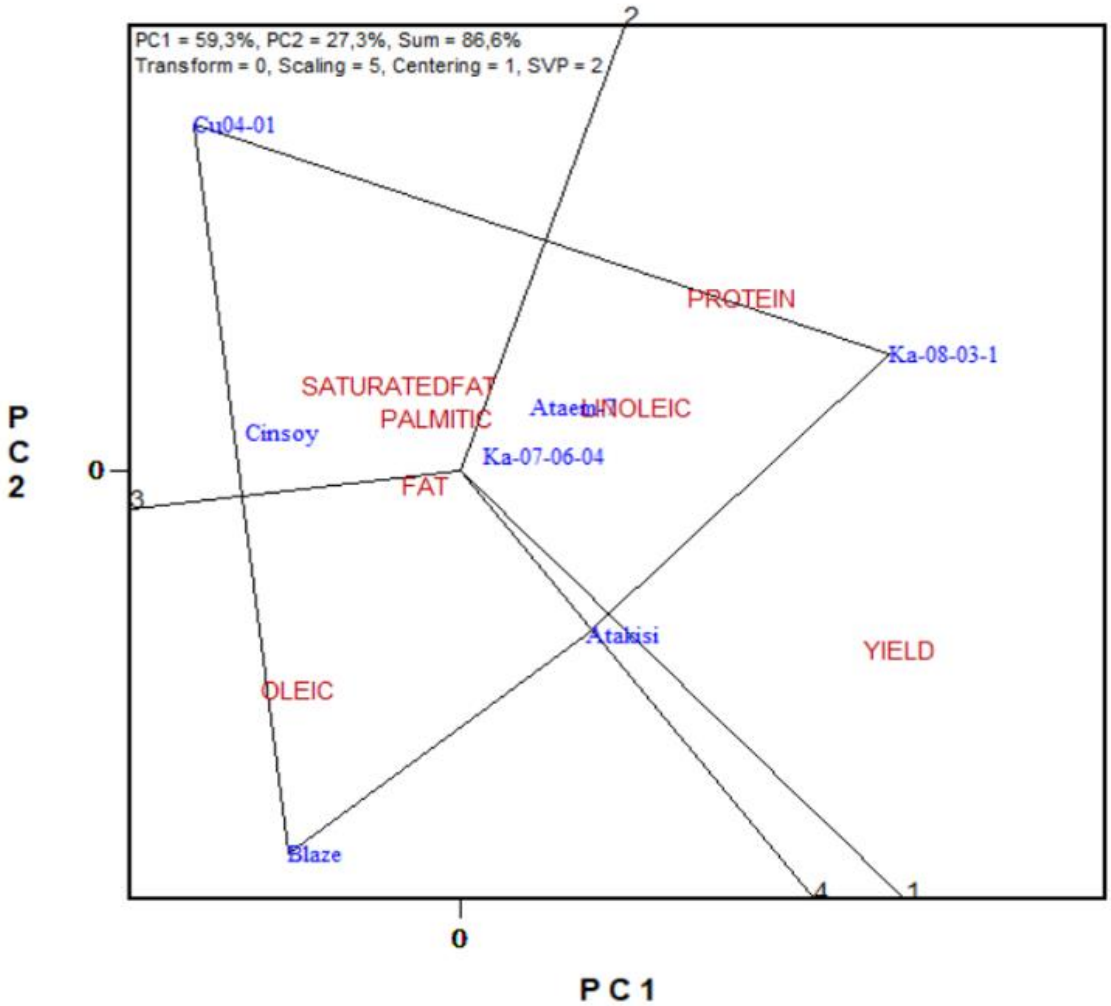

Figure 2. Genotype × characteristic biplot graph of the grouping of examined characteristics in soybean cultivars.

In Figure 2, a biplot graph was obtained according to the averages of the genotypes, consisting of four sections. In the first part, KA-08-03-1, ATAEM-7, and KA-07-06-04 lines and varieties came forward in terms of protein, linoleic acid, and yield characteristics. In the second part, the CU04-01 line and Cinsoy cultivars came forward due to their saturated fatty acid and palmitic acid properties. In the third section, the Blaze variety attracted attention in terms of the oil ratio and oleic acid properties. Finally, the Atakisi variety was included in the fourth section in terms of seed yield.

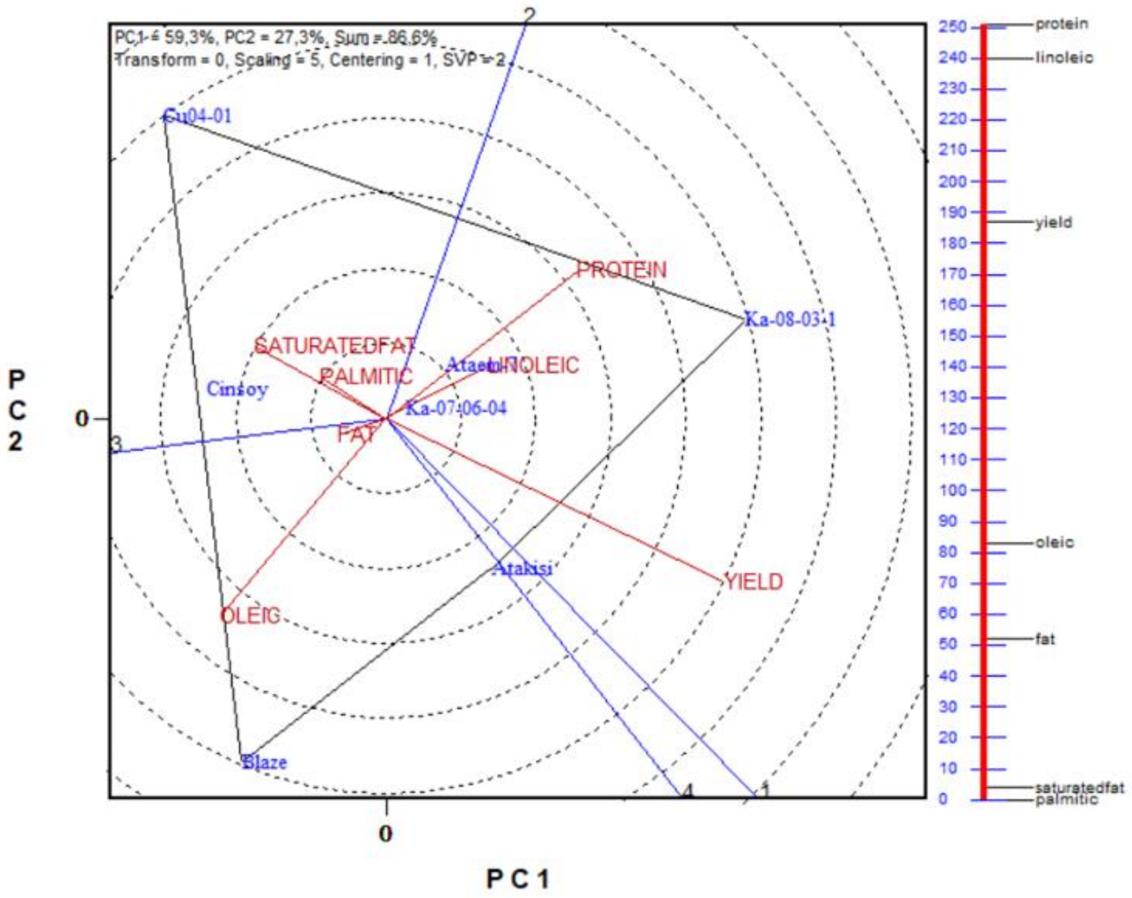

Figure 3. Stability of genotypes relative to the multi-trait mean.

Figure 3 shows the stability of the genotypes relative to the average of the examined traits. While the Atakisi variety had the highest seed yield, it was followed by the KA-08-03-1 line. The KA-08-03-1 line was also observed to be the highest in terms of protein and linoleic acid concentrations. Cinsoy had the highest palmitic acid and saturated fatty acid contents. KA-07-06-04 was the most stable line in terms of all characteristics. In general, if a feature is not found in the circle where the genotype is located, it is possible to say that the genotype is weak in terms of that feature (Yan, 2001).

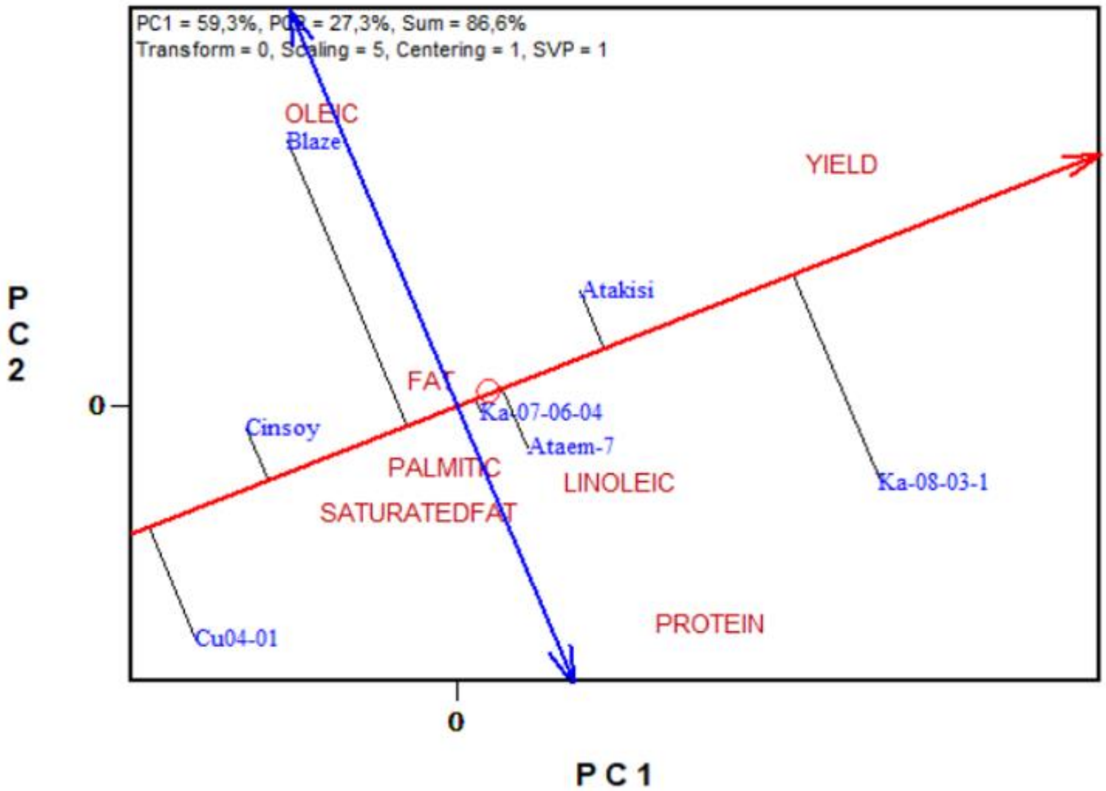

Figure 4. Ranking genotypes according to stability.

A stability line was formed over the average seed yields of all properties examined in the study. The biplot method that ranks genotypes according to this stability line is shown in Figure 4, which shows a model that ranks genotypes according to stability (horizontal) and mean (vertical) baseline curves for all traits in multi-feature studies. In Figure 4, the KA-07-06-04 line and the ATAEM-7 variety, which are above the vertical curve and close to the horizontal curve, were selected as the most stable genotypes in terms of all traits. Although Blaze had the weakest stability, it stood out due to its high oleic acid content. CU04-01 and Cinsoy can be selected in negative selection because they are below the curve (vertical curve) but perform well in terms of saturated fat and palmitic acid concentration. The multi-trait biplot technique can be used easily in selection because it makes it easy to interpret the relationships visually.

In this study, some lines were found to be superior to standard cultivars in terms of the examined traits. According to biplot analysis, KA-07-06-04, KA-08-03-1, CU04-01, ATAEM-7, Cinsoy, Atakisi and Blaze genotypes can be used as a parent or candidate variety in breeding programmes due to their stability and some outstanding features.

Conclusion

This study was carried out in a soybean breeding programme in Cukurova, Türkiye, for two years. Soybean lines developed for the Mediterranean region were compared with standard varieties in terms of both yield and quality characteristics using the multi-trait GGE Biplot technique. To obtain the most accurate results expected from GEI and, accordingly, GGE Biplot analyses, studies need to be conducted in more environments. In studies using only two-year results, it is difficult to obtain accurate results regarding the stability of genotypes or which genotypes are adapted to good conditions or bad conditions in terms of the trait. However, within the scope of the breeding programme carried out with this study, candidate lines and parent varieties that could be transferred to the next generation were determined using the multi-featured GGE Biplot technique. Thus, the usability of the multi-trait GGE biplot technique in breeding programmes has been demonstrated.

KA-07-06-04, KA-08-03-1, and CU04-01 lines were determined as cultivar candidates among the tested genotypes because of their high seed yield and quality characteristics in soybean breeding programmes. ATAEM-7, Cinsoy, Atakisi and Blaze were selected as parents for use in soybean breeding programmes. As a result, the evaluation using a multi-trait biplot analysis method in different environmental conditions can be sufficient for the determination of cultivar candidates.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author’s Contributions

The contribution of the authors is equal.

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