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Research Article

Study on Correlation of Agromorphologic Properties in Some Camelina (*Camelina sativa* (L.) CRANTZ.) Genotypes

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Abstract: The correlation of agromorphological traits can be useful for breeders in the selection of plant genotypes. In this study, the rosette period (days), days of maturity, plant height (cm), 1000-seed weight (g), and seed yield (kg ha^{-1}) characteristics of 42 different Camelina genotypes that grown in Ankara (middle Anatolia) and Şanlıurfa (southeastern Anatolia), and their correlations with each other, were investigated. The accessions showed different results depending on the location in terms of the studied characters in both locations under rainfed conditions. The results showed that the highest seed yield was obtained from the PI 311735 accession (3151.8 kg ha^{-1}) in Ankara and the PI 650142 accession (3056.0 kg ha^{-1}) in Şanlıurfa. While the rosette period (days), days of maturity, plant height (cm), and 1000-seed weight (g), in Ankara were between 152.3 and 132.3 days, 274 and 247 days, 103.8 and 59.5 cm, and 1.50 and 0.84 g, while there were between 108.8 and 88.8 days, 202.1 and 180.1 days, 115.4 and 59.2 cm, and 1.40 and 0.50 g, in Şanlıurfa, respectively. Results showed significant differences among the genotypes in all of the studied parameters. Correlation analysis of the genotypes in both locations on the mentioned parameters was also performed. Since climate and environment affect each agromorphological parameter differently, it was observed that a genotypic correlation independent of the climate and environment could not be explained in the *Camelina sativa* genotypes.

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1. Introduction

The *Camelina sativa*, known as fake flax, German sesame, and Siberian oilseed, is distributed in the natural flora of the Mediterranean Basin and the Central Asian region (Kınay et al., 2019; Mcvay, 2008). The cultivation of false flax began in the Neolithic age and it was used as an oilseed crop during the Iron Age (Katar and Katar, 2017; Knorzer, 1978; Yilmaz et al., 2019). It was reported that it had been cultivated in a wide area up to southeast Europe and southwest Asia steppes during the Roman Empire (Knorzer, 1978). Today, in Canada (Downey, 1971; Robınson, 1987), Germany, Poland, and the former Soviet Union, it is cultivated in small quantities (Seehuber and Ambroth, 1984). False flax is known as an annual crop that can be sown both in winter and spring (Frohlıc and Rıce, 2005; Straton et al., 2007). Recently, its use as a biofuel raw material has been increasing steadily (Katar and Katar, 2017; Vollmann et al., 2007). *C. sativa* (L.) Crantz., *C. laxa* C. A. Mey, *C. rumelica*, *C. microcarpa* Andrz. ex DC., *C. hispida* Boiss., *C. anomala* Boiss. & Hausskn., and *C. Alpkoyensis* Yield are the 7 most widely known species of the genus Camelina Crantz (Mutlu, 2012). Of these species, only the *Camelina sativa* species has been cultured (Kurt and Seyis, 2008).

Although the cultivated form of the false flax (*C. sativa*) is annual, its wild forms are perennial. The plant height generally varies between 25 and 100 cm. Single stem development prevails in the plant, and the stem is round and covered with hairs. The leaves are lanceolate 5–8 cm long and the edges are straight. The flowers consist of 4 green leaves, 4 yellow or yellowish-white petals, 6 male organs, and one female organ. The camelina plant is mostly self-pollinated. The fruit is in the form of capsules with a diameter of 0.7–2.5 mm, and the color ranges from orange to brown. Each capsule contains 8–16 seeds. The 1000-seed weight varies between 0.8 and 1.8 g. While the seeds of the summer cultivars of the plant contain 42% oil, this rate is 45% for the winter cultivars (Katar and Katar, 2017; Kurt and Seyis, 2008; Yılmaz et al., 2019).

Camelina is highly adaptable to adverse extreme climatic conditions and marginal land sites, and both its synthetic chemical input and agricultural energy demand are low. In other words, the plant has a high tolerance to environmental stress factors. In addition, the use of synthetic chemical inputs in cultivation is limited due to the high competitiveness of the plant against weeds, and the tolerance of the plant to diseases and pests, which is an important feature (Kurt and Seyis, 2008).

Despite Camelina's many uses, there is a lack of deep scientific research on this plant in the world as well as in Turkey. Due to the importance of its oil for human health in recent years, the characterization and adaptation studies on this plant have been considered in many countries, especially in Germany. In this study, some morphological characteristics of 42 different Camelina genotypes were examined and their correlations were determined.

2. Material and Methods

2.1. Materials

The seeds of 42 camelina genotypes (*Camelina sativa* (L.) Crantz) in the study were obtained from the Seed Bank of the Agricultural Research Service of the United States Department of Agriculture (Table 1). Additionally, 3 standard genotypes [Line-1 (C1), PI 650149 (C2), and PI 650151 (C3)] were used in the trial. Field experiments were conducted during the 2014–2015 cropping season at the Research and Implementation Area of the Field Crops Agricultural Research Institute, in Ankara, and the GAP Agricultural Research Institute, in Şanlıurfa, Turkey.

The soil characteristics at the Şanlıurfa location were clayey and slightly alkaline, and there were no problems with regard to salinity. It was determined that the soil was very calcareous, the content of the organic matter was moderate, the available phosphorus content was low, and the available potassium content was high (sufficient). On the other hand, the soil structure at the Ankara location was clayey-loamy, high in potassium, poor in organic matter content, alkali with no problem of salinity, and enough phosphorus content.

In both locations, the precipitations were above the average for several years in March. Moreover, at the Ankara location, the minimum temperature decreased to –27,5 °C in January, which was below the average for the long-term mean (Table 2). Some of the plants were damaged from this cold temperature, but later vegetatively self-recovered in the following months.

Table 1. *Camelina sativa* (L.) Crantz. genotypes used in the research and their origins

Accession ID	Accession No.	Origin	Accession No.	Accession No.	Origin
Ames 31219	1	Georgia	PI 650147	22	Sweden
Ames 31220	2	Georgia	PI 650148	23	Germany
Ames 31224	3	Georgia	PI 650150	24	Denmark
Ames 31231	4	Georgia	PI 650152	25	Germany
Ames 31232	5	Georgia	PI 650153	26	Russia
Einfact	6	Germany	PI 650154	27	Russia
PI 258366	7	Russia	PI 650155	28	Poland
PI 258367	8	Russia	PI 650156	29	Russia
PI 304269	9	Sweden	PI 650157	30	Russia
PI 304270	10	Sweden	PI 650158	31	Poland
PI 304271	11	Sweden	PI 650159	32	Poland
PI 311735	12	Poland	PI 650160	33	Russia
PI 311736	13	Poland	PI 650161	34	Russia
PI 597833	14	Denmark	PI 650162	35	Poland
PI 633192	15	Germany	PI 650164	36	Austria
PI 633193	16	Germany	PI 650165	37	Russia
PI 633194	17	Germany	PI 650166	38	Russia
PI 650141	18	America	PI 650167	39	Poland
PI 650142	19	Denmark	PI 650168	40	America
PI 650144	20	Denmark	PI 652885	41	Slovenia
PI 650145	21	Germany	PI 652886	42	Slovenia

Table 2. Monthly average of meteorological data of the experimental farm during growing season

Location	Month	Temperature (°C)		Precipitation (mm)	
		Long-term mean	2015–2016	Long-term mean	2015–2016
Ankara	Oct	13.8	11.3	31.8	19.2
	Nov	7.8	4.4	34.2	20.0
	Dec	3.6	–2.9	42.0	33.8
	Jan	–1.4	–1.7	42.2	66.4
	Feb	0.8	5.0	4.5	18.6
	Mar	4.7	5.9	16.3	67.0
	April	9.5	11.9	12.8	11.9
	May	14.3	12.7	45.3	58.0
	June	22.8	19.0	1.2	8.4
Ş. Urfa	Oct	19.4	21.7	19.3	13.6
	Nov	12.0	14.0	18.2	28.1
	Dec	7.5	8.7	44.5	16.4
	Jan	5.6	4.7	46.7	22.0
	Feb	7.2	11.5	40.5	54.0
	Mar	11.2	13.6	39.7	65.4
	April	16.5	20.4	25.8	14.8
	May	22.5	23.2	18.7	1.0
	June	28.4	29.8	1.3	0.2

2.2. Methods

The materials were examined in augmented trial designs in 6 blocks. The materials were sown with 15- and 10-cm inter- and intra-row spacings, respectively. The row length was 5 m. All of the genotypes were examined for their rosette period (days), days to maturity, plant height (cm), 1000-seed weight (g), and seed yield (g) (Katar et al., 2012). No irrigation or fertilization was applied during the vegetation period. Weeds were controlled mechanically by hand-hoeing.

The materials were sown in early October 2015 with 15 cm between the rows, 10 cm spacing between plants of intra-row, and a row length of 5 m. Harvesting took place in Ankara in mid-June and in Şanlıurfa in mid-May 2016.

2.3. Observations and measurements

Rosette period (days): This is the number of days between the date when half of the plants in the plot completed emerging from the soil surface and the date when half of the plants in the same plot exhibited a shift in their stem elongation from horizontal to vertical.

Plant height (cm): In 20 randomly selected plants in each plot, the distance from the ground to the top point of the plant was measured with a ruler. The average of the values obtained from the 20 plants was considered as the plant height value of the genotype.

Days to maturity (days): This was determined as the number of days from the date when half of the plants in each plot emerged until the plants reached harvesting maturity.

Seed yield (kg ha^{-1}): The seeds in the plot were harvested and weighed, and then calculated as kg ha $^{-1}$.

The 1000-seed weight: 100 seeds with 4 replications from each plot were collected and weighed. The average values obtained were multiplied by 10 and the 1000-seed weights were determined.

2.3. Statistical analyses

Analysis of variance (ANOVA) was performed with JMP Pro11 (SAS Institute Inc., Cary, NC), while correlation analysis was performed using the XLSTAT program (Add in soft, Paris, France). The mean values of the properties were compared using the Duncan multiple range test (P<0.05).

3. Results and Discussion

Variance analysis, correlation analysis, and grouping of the values obtained in the study were examined (Tables 3 and 4). At the Ankara and Şanlıurfa locations, statistically significant differences were observed between the rosette periods, days to maturity, plant heights, 1000-seed weights, and seed yields. It was concluded that the rosette period in Ankara varied between 132.3 and 152.3 days, while, in Şanlıurfa varied between 88.8 and 108.8 days. Similarly, significant differences were determined between the locations in the number of days to maturity. These values were recorded between 274-247 days in Ankara, and 202.1-180.1 days in Şanlıurfa, respectively. Depending on the location, significant differences were observed in the plant heights. These values varied between 103.8-59.5 cm in Ankara, and 59.2-115.4 cm in Şanlıurfa. The variation in the plant heights was determined in different genotypes in both locations. These findings were coherent with those reported by Katar et al. (2012) (85.29 cm) and Arslan et al. (2014) (52.7 cm and 116.4 cm).

Table 3. Analysis of variance of augmented block design for five quantitative traits in 45 genotypes of *Camelina sativa*

Location	Variation Source	D.F.	Mean square				
			Rosette period	Days to maturity	Plant height (cm)	1000-seed weight (g)	Seed yield (kg ha^{-1})
Ankara	Block	5	19.193**	20.305**	12.460**	0.012**	38130.6**
	Genotype	44	15.428**	14.609**	119.298**	0.010**	460170.1**
	Error	10	0.861	0.805	0.130	0.001	1332.0
	C. V. (%)		0.640	1.900	4.600	2.420	2.2
Şanlıurfa	Block	5	2.305**	2.305**	2.074	0.010	22520.4**
	Genotype	44	17.822**	25.378**	198.716**	0.052**	443080.1**
	Error	10	0.222	0.222	13.139	0.009	3020.0
	C.V. (%)		0.490	0.250	4.430	8.430	4.1

**Indicate significance at the 1% levels.

The 1000-seed weights ranged between 0.84-1.50 g in Ankara, and 0.50-1.40 g in Şanlıurfa. These findings were similar to the findings of Vollmann et al. (2007) (0.96–1.21 g). The seed yields ranged from 168.4 kg ha $^{-1}$ (PI 650141) to 3151.8 kg ha^{-1} (PI 311735) in Ankara, and from 205.6 (PI 650160) to 3056.0 (PI 650142) kg ha^{-1} in Şanlıurfa (Table 4). Kurt and Gore (2020) reported that the PI 650142 accession was highly tolerant against environmental stresses. The seed yield findings showed a wide variation, which was similar to the findings by Arslan et al. (2014) (1066.1–4198.2 kg ha^{-1}) and Katar et al. (1845.4 kg ha^{-1}). As is known, many factors are effective on the growth and development of plants (Katar and Katar, 2017). These factors are generally divided into two groups, intrinsic and extrinsic factors (Janına, 2003). Intrinsic factors are controlled by the genetic makeup of the plants (Franz, 1993). Therefore, the growth and development performances of plants with various inherited characteristics differ due to the effect of their genes. On the other hand, extrinsic factors are defined as environmental factors that affect the growth and development vigor of plants (Smykal et al., 2011). This shows that the genetic makeup of the plants, as well as the environmental conditions, are also effective on the growth and development of plants (Reddy et al., 2013). In addition, changing the response of varieties/genotypes from one environment to another, especially in the yield and yield components defined as genotype by environment interactions (GEIs) (Goksoy et al., 2019). Considering the studied characters, the accessions were included in different groups at different locations. It was indicated that the GEIs played a significant role in the studied characters. This may have been attributed to the fact that the accessions responded differently to various environmental conditions. As with other agromorphological features, the accession data showed large differences in the traits between both locations. The rosette period lasted longer in all of the genotypes since Ankara has a cold climate. While genotype 13 had the longest rosette period in Ankara (152.3 days), genotype 38 showed the longest rosette duration in Şanlıurfa (108.8 days). The days to maturity were longer in the Ankara location due to its colder climate. While genotype 39 showed the longest days to maturity in Ankara at 274 days, genotype 38 showed 202.1 days in Şanlıurfa (Table 4).

Table 4. Agromorphologic values and groups of the *Camelina sativa* genotypes created from the Ankara and Şanlıurfa corrected data

Genotype No.	Rosette period		Days to maturity		Plant height (cm)		1000-seed weight (g)		Seed yield (kg ha^{-1})	
	Ankara	Şanlıurfa	Ankara	Şanlıurfa	Ankara	Şanlıurfa	Ankara	Şanlıurfa	Ankara	Şanlıurfa
1	144.3de	101.8d	253f-ı	195.1d	65.3z	82.4m-q	1.03r-u	0.5h	366.6v	2700.4b
2	138.3gh	101.8d	247ı	195.1d	90.6h	69.4t-v	0.99uv	0.5h	808.6s	1339.2k-m
3	135.3jk	100.8e	252g-ı	194.1e	60.8e	59.2y	0.87y	0.5h	2881.2b	568.8v-y
4	136.3ıj	99.8f	268a-c	193.1f	77.1t	89ı-m	1.07n-s	0.6gh	1249.8n-p	872.1p-t
5	134.3kl	92.8m	260c-h	184.1o	77.3t	71.4s-u	1.5a	0.9de	906.6s	1250.1l-n
6	138.3gh	92.8m	264a-e	184.1o	78.1rs	92.4e-j	1.19c-g	1cd	2754.6b	1331.7k-m
7	137.3hı	90.8n	263b-f	182.1p	89.1ı	84.7k-o	1.13h-m	0.7fg	1302.6m-o	695.7t-w
8	138.3gh	92.8m	264a-e	184.1o	85.5j	90.4h-l	1.1k-p	0.7fg	2094.6ef	992.5op
9	134.3kl	102.8c	260c-h	196.1c	83.4k	83l-p	1.23b-d	1cd	1396.2lm	1545.2g-j
10	139.3g	98.8g	248ı	192.1g	75.1u	102.4cd	1.06o-t	0.6gh	2109ef	937.2o-s
11	143.3ef	94.8k	252g-ı	186.1m	78.6r	92.4e-j	1.06o-t	0.9de	1152p-r	1392.4ı-l
12	144.3de	88.8o	253f-ı	180.1q	74.3v	77.8o-s	1.14g-l	1cd	3151.8a	1241.2l-n
13	152.3a	94.8k	261b-g	188.1k	99.5d	99.4c-e	1.02s-v	0.5h	1105.8qr	688.4t-w
14	146.3c	94.8k	255d-ı	186.1m	81.4lm	69.8t-v	1.08m-r	0.9de	1356.6l-n	608.4u-x
15	145.3cd	94.8k	254e-ı	186.1m	78.7qr	74.8r-u	1.14g-l	1cd	373v	687.2t-w
16	143.3ef	101.8d	252g-ı	195.1d	59.5f	72.8s-u	1.01t-v	0.6gh	518.2tu	1103.2no
17	142.3f	94.8k	251g-ı	188.1k	73.2y	68.8uv	1.15f-k	1cd	425.8uv	408y
18	142.3f	94.8k	251g-ı	186.1m	65.5a	80.8n-r	1.16e-j	1.2b	168.4w	1503.2g-k
19	133.3lm	100.8e	250hı	194.1e	76.8t	60.6y	1.14g-l	1.2b	1409.2lm	3056a
20	134.3kl	93.8l	251ghı	185.1n	80.1op	91.6g-k	0.97v	1cd	564.4t	767.2s-v
21	133.3lm	100.8e	250hı	194.1e	63.2bc	60.6y	1.01t-v	1cd	1369.8l-n	1872.8ef
22	137.3hı	100.8e	254e-ı	194.1e	75.2u	111.9ab	1.19c-g	1.4a	795.6s	885.6p-t
23	136.3ıj	104.8b	253f-ı	198.1b	63.6b	94.6e-ı	1.06o-t	1.1bc	2214.6de	1928.8de
24	133.3lm	100.8e	250hı	194.1e	79.4pq	96.9d-h	1.21c-e	1.4a	2214.6de	469.6xy
25	133.3lm	93.8l	250hı	187.1l	102.6b	99.2c-f	0.84y	0.5h	2082.6fg	1376.8j-l
26	136.3ıj	98.8g	253f-ı	192.1g	62.3d	91.9f-k	1.06o-t	1cd	2478.6c	981.6o-r
27	138.3gh	96.8ı	255d-ı	190.1ı	73.7vy	93.6e-ı	1.04q-u	1cd	2143ef	2088.8d
28	134.3kl	102.8c	266a-c	196.1c	101c	86j-n	1.19c-g	0.8ef	776.8s	1375.2j-l
29	135.3jk	100.8e	267a-c	194.1e	76.7t	98.4c-g	1.21c-e	0.8ef	244c	1368.8j-l
30	139.3g	97.8h	271ab	191.1h	96.3e	95de-ı	1.09l-q	0.7fg	2321.2d	789.6q-u
31	139.3g	95.8j	271ab	187.1l	100.2d	72s-u	1.19c-g	1cd	1384lm	1591.2g-ı
32	134.3kl	93.8l	266a-c	185.1n	77.4st	105.4bc	1.28b	1.1bc	1958.2gh	565.6w-y
33	133.3lm	90.8n	265a-d	182.1p	88.9ı	90.4h-l	1.05p-t	0.6gh	2816.2b	205.6z
34	136.3ıj	95.8j	268a-c	189.1j	91.8g	74.4r-u	1.18d-h	1cd	1702.6jk	972.9o-q
35	135.3jk	95.8j	267a-c	189.1j	78.2r	75.4q-u	1.24bc	0.9de	1815ıj	784.1r-u
36	135.3jk	95.8j	267a-c	189.1j	82.1l	76.7p-t	1.11j-o	0.8ef	2123ef	1678.5fg
37	132.3m	92.8m	264a-e	184.1o	80.5no	115.4a	1.21cde	1cd	1065r	896.1p-s
38	135.3jk	108.8a	261b-g	202.1a	81.1mn	63.7vy	1.2c-f	0.9de	1216.8o-q	1656.1gh
39	148.3b	99.8f	274a	193.1f	103.8a	90h-l	1.09l-q	0.8ef	2470.8c	1316.9k-m
40	138.3gh	102.8c	264a-e	196.1c	93.1f	70t-v	1.12ı-n	0.8ef	1870.2hı	1474.1h-k
41	139.3g	90.8n	265a-d	182.1p	72z	96.4d-ı	1.16e-j	0.9de	1025.4r	1594.1gh
42	137.3hı	92.8m	263b-f	184.1o	62.8cd	92.4e-j	1.17e-ı	0.9de	1467.6l	1650.1gh
C1	142.50c-f	97.0cd	263.17e-g	190.0bc	83.80fı	85.53d-g	1.111ı-l	1.077a-d	1679.5k	1269.2lm
C2	143.83cd	96.0de	265.00cd	189.0c	78.03k-n	86.75d-f	1.140e-k	1.117a-c	1824.4ı	1215.3mn
C3	144.33cd	93.5fh	260..33hı	184.5f	79.05j-m	73.40k-p	1.188c-k	1.150a-c	2136.5ef	2243.8c

When the correlations of the plant properties with each other were studied, significant differences were observed among the locations. Although there was a positive correlation between the rosette period and the days to maturity in Şanlıurfa, there was no correlation between these parameters in Ankara. A positive correlation was observed between the days to maturity with plant height and 1000-seed weight in Ankara. Additionally, there was a positive correlation between the seed yield and the rosette period in Şanlıurfa (Table 5).

Table 5. Pearson's correlation coefficient analysis for the different plant characteristics of the 42 Camelina genotypes

Location		Rosette period	Days to maturity	Plant height (cm)	1000-seed weight (g)	Seed yield (kg ha^{-1})
Ankara	Rosette period	**1**				
	Days to maturity	–0.002	**1**			
	Plant height (cm)	0.090	**0.487****	**1**		
	1000-seed weight (g)	–0.154	**0.404****	0.018	**1**	
	Seed yield (kg ha^{-1})	–0.161	0.253	0.093	–0.118	**1**
Şanlıurfa	Rosette period	**1**				
	Days to maturity	**0.992****	**1**			
	Plant height (cm)	–0.235	–0.220	**1**		
	1000–seed weight (g)	–0.030	–0.061	0.079	**1**	
	Seed yield (kg ha^{-1})	**0.304***	0.285	–0.259	0.131	**1**

Values in bold are different than 0 with a significance level of 5% (*P < 0.05) and 1% (**P < 0.01).

The first two PCAs were used to draw a graph in order to see the pattern of variation between the locations The PCA-based correlation matrix for the first two principal components accounted for 57.237% and 67.098% of the variation in Ankara and Şanlıurfa, respectively (Table 6).

Table 6. Eigenvectors, eigenvalues, and individual and cumulative percentages of variation explained by the first five principal components (PC) after assessing morphological properties in *Camelina sativa* accessions

	PCA1		PCA2		PCA3		PCA4		PCA5	
	Ankara	**Ş. Urfa**	**Ankara**	**Ş. Urfa**	**Ankara**	**Ş. Urfa**	**Ankara**	**Ş. Urfa**	**Ankara**	**Ş. Urfa**
Rosette period	–0.085	0.630	0.742	–0.114	–0.315	0.283	–0.572	–0.087	–0.123	–0.709
Days to maturity	0.697	0.625	0.046	–0.148	–0.064	0.292	–0.158	–0.076	0.694	0.705
Plant height (cm)	0.526	–0.299	0.451	–0.040	0.022	0.787	0.584	0.539	–0.422	–0.011
1000–seed weight (g)	0.391	–0.028	–0.492	0.844	–0.537	0.324	–0.297	–0.425	–0.478	0.022
Seed yield (kg ha^{-1})	0.277	0.350	–0.047	0.500	0.780	–0.333	–0.466	0.718	–0.310	0.009
Eigenvalue	1.695	2.266	1.167	1.089	1.128	0.977	0.697	0.661	0.313	0.007
Variability (%)	33.898	45.327	23.339	21.770	22.561	19.532	13.938	13.221	6.264	0.149
Cumulative (%)	33.898	45.327	57.237	67.098	79.798	86.629	93.736	99.851	100.000	100.000

When the correlations of the plant properties of the same genotypes were examined for both locations together via biplot analysis, large differences were observed between the locations (Figure 1).

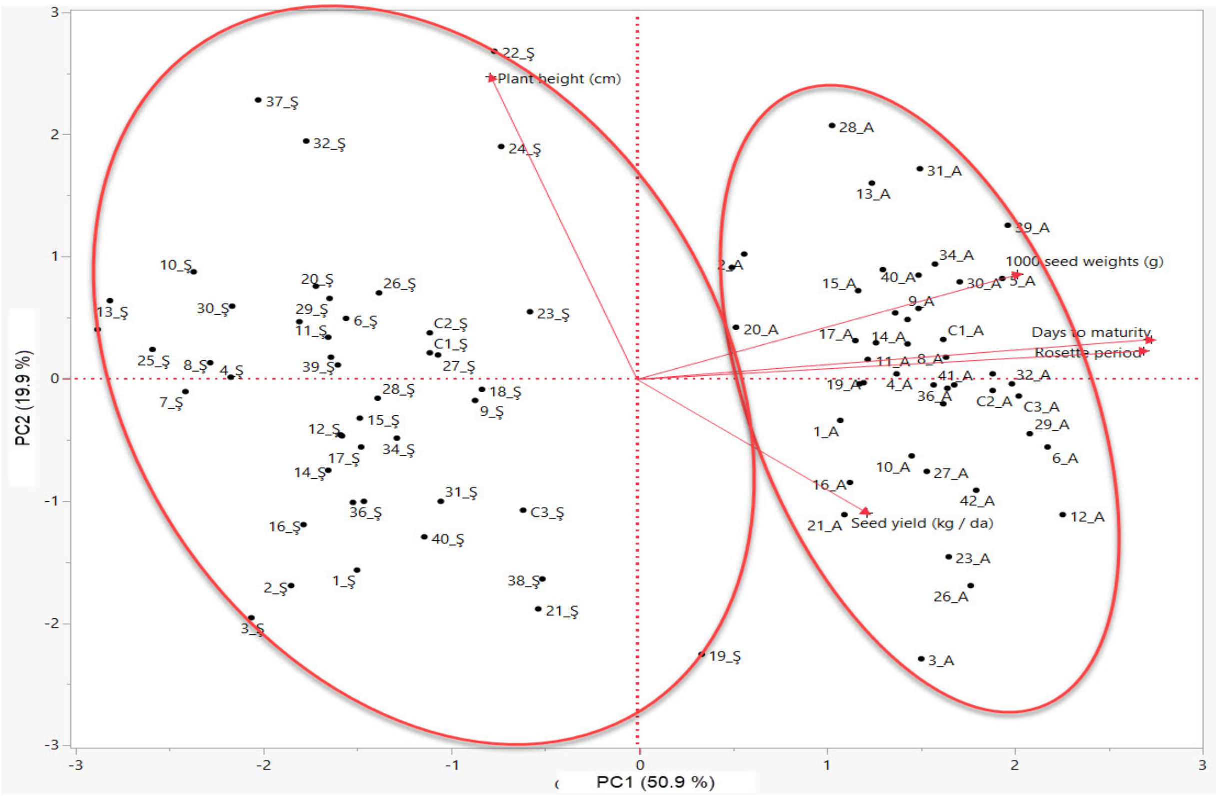

Figure 1. Biplot diagram of the agromorphological properties of the *C. sativa* genotypes in Ankara and Şanlıurfa.

Conclusion

It was observed that plant parameters were significantly affected by climate. Therefore, it can be suggested that a relationship cannot be established between genotypes based on agromorphological characters.

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