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Morphological characterization of some Besni pepper (*Capsicum annuum* L.) genotypes in Kayseri conditions

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Abstract
The pepper genetic resources, which is a widely produced and consumed vegetable in Turkey and the world, are faced with some threats arising from the environmental conditions and agricultural activities. Therefore, it is very important to protect pepper genetic resources and include them in breeding programs. During the production adventure of pepper in Turkey, pepper genotypes known by the name of the regions were developed in different regions such as Demre, Uşak, Karaisalı, and Arapkir pepper. One of them, Besni Pepper, is grown in and around Besni district of Adıyaman province and makes significant contributions to the regional economy. In this study, 26 pepper genotypes collected from the villages of Besni and Gölbaşı districts, and three control varieties were characterized according to 42 morphological traits. Pepper genotypes showed significant variation in terms of the characteristics considered. Principal Component Analysis (PCA) was applied to the investigated traits. The PCA analysis yielded 10 principal components explaining 86% of the total variation. The eigen values of 10 PC's varied from 10,50 to 1,10. The first three PC's explain 51,20% of the total variance. The variation between genotypes is mostly due to fruit characteristics such as fruit shape, fruit size, and blossom end shape. While the genotypes were divided into 4 groups in the cluster analysis, the pepper varieties used as control were separated from all genotypes and formed a separate group.

Keywords
Capsicum annuum, Besni pepper, Morphological characterization, Variation

Introduction
Genetic resources are the unique resource for the development of high-yielding varieties that are resistant to biotic and abiotic stress conditions to ensure the sustainability of plant production. Local populations that have adapted to their ecology for years and have survived and sustained against certain biotic and abiotic stress factors are important resources for plant breeding. Turkey has unique resources in terms of landraces of cultivated crops, which are formed as a consequence of selection by local producers and still show great diversity. Seeds or other multiplication materials are always the most important element in plant production. The yield or product quality of a plant is directly related to the seed genetic makeup. Although the cultural practices applied in plant production are maintained at the optimum level, yield and quality cannot go beyond the genetic limits determined by the seed genetic potential. Therefore, it is possible to achieve a significant increase in yield and quality by introducing new and superior plant varieties into agricultural production by using genetic diversity. Local genotypes are important genetic resources because they have unique gene pools and serve as important resources of genetic diversity for plant breeding and conserving biodiversity (Arslan, 2010; Balkaya et al., 2010).

Local populations are rich genetic resources in this respect and constitute starting materials that can be used to develop new cultivars. The use of these local genotypes/landraces as new varieties that satisfy consumer demands becomes possible by developing them in breeding programs. Local varieties that are not registered and selected (bred) by the local people are characterized by their special adaptation to the

environmental conditions in the cultivated area, and they are closely related to the lifestyles, knowledge and traditional uses of the societies that selected them and continued to cultivation (Negri, 2007).

Biological diversity has indispensable roles and importance in meeting the basic needs of people, especially food and clothing. It is estimated that 20% of global biodiversity is lost due to continuous and misuse of natural resources as well as pollution caused by human activities. Loss of biodiversity in any population reduces their ability to overcome biotic and abiotic stress conditions causing a reduction in yield and quality of crop plants. Turkey, which has important plant biodiversity, has been faced with the loss of biological diversity due to various adverse factors (natural and mankind activities). For this reason, the collection, preservation, characterization, and use of plant genetic resources are of crucial importance in sustainable agriculture and the environment (Davis et al., 1988; Özhatay et al., 2009).

Turkey, which has very different climate and soil characteristics due to its location, is located at the intersection of the Near East, the Mediterranean, and European gene centers, which are among the eight main plant genetic diversity centers. It is in the region where the Euro-Siberian, Mediterranean, and Iran-Turan plant geographical regions are located. Anatolia includes regions such as Mesopotamia (fertile-crescent) where agriculture was first practiced in the world. Therefore, Anatolia has become the diversity center and micro gene center of many cultivated plant species (Karagöz et al., 2020). According to Harlan, there are 5 micro-gene centers in Turkey where more than 100 species show wide variation (Demir, 1990). Moreover, a high degree of plant endemism has occurred, and 4.080 of the 12.476 plant species recorded in Turkey are endemic (Davis, 1965-1985; Davis et al., 1988; Güner et al., 2000; Vural, 2003; Erik and Tarıkahya, 2004; Özhatay and Kültür, 2006; Özhatay et al., 2009). However, these plant genetic resources are in danger of being lost by genetic erosion for some reasons. It is very important to protect the diversity for the sustainability of plant production, especially for the plant genetic resources of the cultivated species (Tan and İnal, 2003). Diversity in plant genetic resources is gradually decreasing due to reasons such as forest fire, erosion, increased land openings, replacing local varieties with bred modern varieties, urbanization, road construction, changes in agricultural systems and plant protection methods (intensive use of pesticides), and continuous supply of bulbous plants from nature. Countries that are aware of this danger faced in plant genetic resources have started studies on the collection, characterization, and preservation of resources (Tan, 1992). For example, in Bulgaria (Vesselinov et al., 1982), Peru (Gomez and Cuartero, 1984), Spain (Eshbaugh, 1988), Taiwan (Wang et al., 2000), Brazil (do Rêgo et al., 2011), Argentina (Occhiuto et al., 2014), Uganda (Nsabiyera et al., 2013) and Eritrea (Saleh et al., 2016), studies on collection and characterization of pepper germplasm have been carried out. Similarly, collection and characterization studies of local pepper genotypes in Turkey were carried out by Keleş (2007), Binbir and Baş (2010), Karağaç and Balkaya (2010), Bozokalfa and Eşiyok (2010), Baysal (2013), Çürük et al. (2015), Keleş et al. (2016), Başak (2019), Taş and Balkaya (2021) and Altuntaş (2021).

Pepper, an important member of the Solanaceae family, originated from America has a very wide distribution in the world (Vural et al., 2000). Pepper is a major vegetable species that was brought to Spain from the Americas with the travel of Columbus in the 1400s. In later times, it was reported that the pepper was increasingly distributed in the African and Asian continents by the Spanish and Portuguese merchants through trade and exploration routes. Pepper is extensively consumed as a spice or fresh vegetable in many parts of the world. Besides giving taste and color to the food, the fruit of the pepper is an important source of vitamins and minerals for humans. However, pepper juice and extracts are used in the cosmetic industry and pharmacology (Pernezny et al., 2003). Peppers have been classified according to different approaches by researchers. For the taxonomic classification in this genus, several alternative approaches such as geographical, ethnobotanical crossability, numerical taxonomy, cytogenetics, and biochemical data have been used (Pickersgill, 1991; Nicolai et al., 2013). The number of species belonging to the Capsicum genus, which was 38, has been updated to 43 with the addition of 5 new species identified by taxonomists (Barboza et al., 2019). Five of them were domesticated through prominent events at different locations in America (Heiser and Smith, 1953; Nicolai et al., 2013; Olmstead et al., 2008). According to), These are *Capsicum annum* L., *C. frutescens* L., *C. chinense* Jacq., *C. baccatum* L, and *C. pubescens* R&P (Samos and Kundt, 1984). *C. annuum* is the most common and economically important species of Capsicum in the world. It is a diploid and self-fertile crop with 24 chromosomes (Gyulai et al., 2000). However, two classifications are generally accepted as *C. annum* and *C. frutescens* groups. Plants belonging to the *C. annuum* species are known as monoecious and produce a single flower from each branching point. *C. frutescens*, on the other hand, is known as a perennial and forms more than one flower in bunches (Purseglove, 1974). Although Turkey's pepper production varies every year, it maintains its place in the top three along with China and Mexico (Fao, 2020). Peppers are grown in both protected (tunnels and greenhouse) cultivation and open field conditions in Turkey. According to the data of 2020 in Turkey; 2.625.669 tons of fresh pepper (long pointed, capia, bell, charleston) and 26.000 tons of dry pepper were produced (Tuik, 2020).

As stated above, plant germplasm may undergo genetic erosion due to different reasons, and the collection, characterization, and evaluation of them are important issues in the sustainability of plant production. In the previous researches, some of which were cited above, in Turkey, studies were carried out on pepper genotypes collected from different regions of Turkey. However, it has been determined that no studies have been carried out on the local pepper genotype known as Besni Pepper. Therefore, 26 Besni Pepper genotypes cultivated for many years in a restricted area in Turkey, were collected and morphologically characterized for 42 traits.

Materials and Methods

Plant materials

In this study, 29 pepper genotypes were used as plant material. 20 of them were collected from different villages of Besni district and 6 of them were collected from Gölbaşı district in 2019. Yalova Corbaci, Sera Demre and Cırgalan peppers were used as controls (Table 1).

Table 1. Pepper genotypes used in the experiment and their source

Genotype	Source	Genotype	Source
B1	Oyratlı Village/Besni	B16	Oyratlı Village /Besni
B2	Oyratlı Village /Besni	B17	Oyratlı Village /Besni
B3	Oyratlı Village /Besni	B18	Oyratlı Village /Besni
B4	Oyratlı Village /Besni	B19	Oyratlı Village /Besni
B5	Oyratlı Village /Besni	B20	Toklu Village /Besni
B6	Oyratlı Village /Besni	G1	Gölbaşı
B7	Oyratlı Village /Besni	G2	Gölbaşı
B8	Oyratlı Village /Besni	G3	Gölbaşı
B9	Oyratlı Village /Besni	G4	Maltepe Village /Gölbaşı
B10	Besni	G5	Maltepe Village /Gölbaşı
B11	Oyratlı Village /Besni	G6	Maltepe Village /Gölbaşı
B12	Oyratlı Village /Besni	C1 (Cırgalan)	Erciyes University
B13	Çamurcu Village /Besni	C2 (Yalova Çorbacı)	Erciyes University
B14	Çamurcu Village /Besni	C3 (Sera Demre)	Erciyes University
B15	Oyratlı Village /Besni		

Plant production and cultural practices

This study was carried out at the Erciyes University Agricultural Faculty in 2021**.** Twenty-five seeds from each pepper genotype were sown in multi-pots filled with a 2:1 peat and perlite mixture (2v:1v) on 02.04.2021 in an unheated greenhouse. Three seedlings with 3-4 true leaves from each genotype were transplanted in soil in an unheated greenhouse on May 5, 2021. The spacing was 100 cm (between rows) x 50 cm (within the row). Before transplanting, a drip irrigation system was established, and the soil surface was covered with black plastic mulch. Fertilizer was applied by fertigation method as 12 kg N/da, 5 kg P/da, 15 kg K/da, 5 kg Ca/ and 3 kg Mg/da (Şalk et al., 2008).

Morphological characterization

Pepper genotypes were morphologically characterized for 42 traits according to the descriptor list of pepper published by UPOV (International Union for Conservation of New Plant Varieties) and modified by Keleş (2007) (Table 2).

Stem diameter (mm), fruit length (cm), fruit diameter (cm), fruit pedicel length (cm), fruit wall thickness (mm) were measured with a digital caliper.

Cotyledon width, cotyledon length, leaf blade length (mm), leaf width, and the length of the petiole (mm) were measured with a ruler. Yield and fruit weight (g) was measured with a scales

Other parameters were evaluated visually.

Statistical analysis

Observed traits were presented as numbers corresponding to the phenotype presented in the descriptor list. Measured characteristics in plants were presented as a mean of 3 measurements while measured fruit and flower characteristics were presented as a mean of 10 measurements. SPSS program was used in the analysis of the data. The data were first subjected to Principal Component Analysis (PCA) and principal component (PC) axes of genotypes were obtained (Sneath and Sokal, 1973). PC axes, variation and cumulative variation ratios, and factor coefficients were determined. The data was subjected to cluster analysis to determine the relationship between genotypes using SPSS software using Between-group linkage.

Results

In this study, 26 pepper genotypes collected from Adıyaman province and 3 control pepper varieties were morphologically characterized for 26 observed and 16 measured characteristics. There was no variation between pepper genotypes in stem background color (all green), leaf shape (all lanceolate), flower position (all pendant), calyx margin (all dentate), coloration on the calyx (all absent), petal shape (all campanulate) and color (all white).

The cotyledon length ranged from 25,14 mm to 34,01 mm, and the mean cotyledon length was calculated as 28,29 mm. The longest cotyledon length was recorded in G3 (34,01 mm) and the shortest cotyledon was recorded in C3 with 25,14 mm. Pepper genotypes varied in cotyledon width. Pepper genotype B7 had the narrowest cotyledon with 7,62 mm while G3 had the widest cotyledon with 11,18 mm and the cotyledon width mean was calculated as 8,89 mm (Table 3).

Anthocyanin formation in hypocotyl showing variation was scored between 1-9. The highest anthocyanin formation was observed in B19 with 8, while the lowest anthocyanin formation on hypocotyl was determined in genotypes C1 and C3. Genotypes also differed in terms of anthocyanin formation on stems and nodes. While the lowest anthocyanin formation on the stem was observed in genotypes C1 and C3, the most intense anthocyanin formation was observed in genotype B19. While the highest anthocyanin concentration in the nodes was observed in B19 (9), the lowest anthocyanin intensity was observed in B6, B7, B8, B18, G3, G4, G5, and C3 (1) (Table 3).

Plants were segregated into two groups as compact/intermediate (11) and erect (18) according to the plant growth habits. While all the control genotypes were in the erect growing group, 11 of the collected

pepper genotypes were in the compact growing group. Plant height varying from 103,33 cm to 73,33 cm showed significant variation between genotypes. Control plants produced taller plants than the collected pepper genotypes. While the average plant height of the control plants was 100,90 cm, the average plant height of the other genotypes was calculated as 88,51 cm. The tallest plants were recorded in C3 (103,33 cm) and the shortest plant was determined in B11 (73,33 cm).

Table 2. Descriptor list for pepper

Traits	Explanation
Anthocyanin on hypocotyl	Absent (1); present (9)
Anthocyanin on stem	Absent (1); present (9)
Cotyledon shape	Triangle (1); ovate (2); spear shape (3); ong triangle (4)
Cotyledon width and length	(cm)
Plant growth habit	Prostrate (3); intermediate (compact) (5); erect (7);oOther (9 specify)
Leaf color	Yellow (1); light green (2); green (3); dark green (4) Light purple (5); purple (6); variegated (7); other (8)
Leaf shape	Triangle (1); ovate (2); lanceolate (3)
Leaf margin	Absent or very light (1); intermediate (2); strong (3)
Leaf pubescence	Sparse (1); intermediate (2); dens (3)
Leaf length and width	(cm)
Petiole length	(cm)
Stem background color	Green (1); green with purple stripes (2); purple (3); other (4
Nodal anthocyanin	Absent (1); Present (9)
Intensity of nodal anthocyanin	Very little (1); less (3); intermediate (5); strong (7); very strong (9)
Stem shape	Cylindrical (1), angled (2); flattened (3)
Stem pubescence	Sparse (3), intermediate (5) dense (7)
Stem diameter	(mm)
Flower position	Pendant (3); intermediate (5) erect (7)
Calyx margin	Entire (1); intermediate (2); dentate (3); other (4)
Calyx annular constriction	Absent (0); present (1)
Calyx pigmentation	Absent (0); present (1)
Corolla color	White (1); light yellow (2); yellow (3); yellow-green (4); purple with white base (5); white with purple base (6) white with purple margin (7); purple (8); other (9)
Corolla shape	Rotate (1); campanulate (2); other (3)
Anther color	White (1); yellow (2); pale blue (3); blue (4); purple (5); other (6)
Fruit shape	Elongate (1); almost round (2); triangular (3); campanulate (4); blocky (5); other (6)
Fruit shape at pedicel attachment	Acute (1); obtuse (2); truncate (3); cordate (4); lobate (5)
Neck at base of fruit	Absent (0); present (1)
Fruit blossom end shape	Pointed (1); blunt (2); sunken (3); sunken and pointed (4), other (5)
Fruit blossom end appendage	Absent (0); present (1)
Placenta size	Small (3); intermediate (5); large (7)
Fruit cross-sectional corrugation	Slightly corrugated (3); intermediate (5); corrugated (7)
Fruit length and diameter	(cm)
Single fruit weight	Average of 10 mature fruits (g)
Fruit wall thickness	(mm)
Fruit color at intermediate stage	White (1); yellow (2); green (3); orange (4); purple (5); deep purple (6); other (7)
Number of loculus	(Number)
Fruit surface	Smooth (1); semi-wrinkled (2); wrinkled (3)
Plant height	(cm)
Fruit pedicel length	(cm)
Fruit shape (longitudinal section)	Round (1); heart shaped (2); square (3); rectangle (4); trapezoidal (5); triangle (6); narrow triangle (7);horn-shaped (8)
Yield	(g/plant)
Fruit number	(number)
Ripe fruit pungency	Sweet (1), pungent (2)

Table 3. Observed and measured seedling and plant characteristics

Genotypes	CL (mm)	CW (mm)	AH	AS	NAF	PGH	SD (mm)	PL (cm)	SS	SP
B1	30,84	9,19	6	6	5	5	18,6	86,7	1	5
B2	28,06	8,73	6	6	5	5	20,1	94,3	1	7
B3	28,83	8,58	5	4	5	5	22,5	81,7	1	7
B4	26,41	8,13	4	5	5	5	17,9	85,0	1	7
B5	25,64	7,64	5	4	3	7	19,8	90,0	1	7
B6	28,69	8,74	5	2	1	5	19,7	94,0	1	5
B7	25,4	7,62	4	2	1	5	23,2	101,7	2	5
B8	29,29	9,07	4	2	1	5	23,0	80,0	3	3
B9	25,95	8,68	6	5	5	5	22,4	88,3	3	5
B10	28,12	8,61	5	5	5	5	18,0	75,0	3	7
B11	29,73	8,92	4	6	5	5	18,4	73,3	1	3
B12	28,61	8,28	6	6	5	7	18,8	75,0	3	3
B13	29,69	9,16	4	5	3	7	20,0	76,0	1	7
B14	26,77	8,62	3	4	3	7	23,0	85,0	1	7
B15	28,21	8,62	6	4	3	7	16,0	85,0	1	3
B16	28,45	8,55	4	4	3	7	20,7	93,0	1	3
B17	29,31	8,44	5	5	5	7	18,1	83,3	1	3
B18	26,93	8,69	3	3	1	7	21,9	98,3	3	5
B19	28,23	9,09	8	8	7	7	21,6	86,7	3	5
B20	31,05	10,27	4	4	5	7	18,0	100,0	1	3
G1	28,45	9,11	4	4	3	7	21,9	91,7	1	3
G2	25,83	9,00	5	5	5	7	18,7	86,7	2	3
G3	34,01	11,18	4	0	1	7	20,5	90,0	1	3
G4	32,06	10,64	6	2	1	7	20,8	80,0	3	5
G5	26,65	9,25	4	4	1	7	21,5	96,7	1	3
G6	27,00	8,43	7	4	3	5	21,4	86,7	1	3
C1	32,97	9,67	1	1	3	7	14,3	97,7	1	3
C2	29,08	8,85	5	5	5	7	10,9	101,7	1	3
C3	25,14	8,14	1	1	1	7	16,0	103,3	1	3
Mean	28,29	8,89					19,59	88,51		
Minimum	25,14	7,62					10,93	73,33		
Maximum	34,01	11,18					23,23	103,33		

CL: Cotyledon length; CW. Cotyledon width, AH: Anthocyanin on hypocotyl; AFS: Anthocyanin on stem; NAF: Nodal anthocyanin formation; SD: Stem diameter; PGH: Plant growth habit; PL: Plant length; SS: Stem shape; SP: Stem pubescence.

A significant variation was detected in stem diameter. While the pepper genotype C2 had the lowest stem diameter of 10,93 mm, the largest stem diameter was measured in the B7 genotype with 23,23 mm, and the mean stem diameter was calculated as 19,59 mm. In terms of stem shape, genotypes were divided into three groups as 20 cylindrical, 2 angular, and 7 flattened. All three control pepper cultivars had flattened stems, while the other genotypes had all three stem shapes. As in stem shape, genotypes formed three groups in terms of stem hairiness as sparse (15), intermediate (7), and dense (7). While sparse pubescence was observed in three control cultivars, collected pepper genotypes showed sparse (12), intermediate (7), and dense (7) pubescence on the stem (Table 3).

The measurement and observation in leaves and anther color are given in Table 4. The petiole length varied between 4,16 cm and 9,83 cm and the average petiole length was calculated as 7,33 cm. The longest and shortest petiole were measured in B14 and G2, respectively. Leaf color was recorded as dark green (4) in B20, G2, G3, G4, G5, G6, and green for all other genotypes. G3 and G4 genotypes had ovate leaves, while other genotypes had lanceolate leaves. Genotypes are divided into two groups according to lamina margin as entire and undulate. B4, B7, B12, B13, B15, C3 had entire lamina margins while other genotypes had undulate lamina margins.

In leaf pubescence, sparse pubescence was observed in 24 genotypes, medium pubescence in three genotypes, and dense pubescence in one genotype (G1). A difference in leaf length was 7,33 cm between genotypes with the longest and the shortest leaves. The longest and shortest leaves were measured as 11,66 and 19,00 cm in genotypes G2 and G4 taken from Gölbaşı district, respectively, and the mean leaf length was calculated as 15,1 cm. The variation in leaf width was lower than that in leaf length. The leaf width varied between 6,00 cm (B7) and 10,83 cm (G4) and the average leaf width was calculated as 8.4 cm. Genotypes were divided into three groups according to anther color: blue (1), pale blue (23), and purple (5). B7, B18, G3, G4, C3 had purple anthers, B20 had blue anthers and the other 23 genotypes had pale blue anthers (Table 4).

The yield and some measured fruit characteristics are presented in Table 5. Yield per plant ranged from 155,33 g/plant to 795,83 g/plant. The difference between the lowest and the highest yielding genotype

was approximately five folds. All three control cultivars had lower yields than the other genotypes. While the highest yield was recorded in the genotype G5 with 795,83 g/plant, the lowest yield was obtained from C2 with 155,33 g/plant.

Table 4. Leaf characteristics and anther color

Genotypes	PL (cm)	LC	LS	LMS	LP	LL (cm)	LW (cm)	AC
B1	7,33	3	3	2	1	15,33	8,33	3
B2	7,00	3	3	2	1	14,00	8,33	3
B3	7,33	3	3	2	1	12,66	7,33	3
B4	7,00	3	3	1	1	14,00	8,00	3
B5	7,33	3	3	2	2	13,66	7,83	3
B6	7,83	3	3	2	1	15,66	9,00	3
B7	6,83	3	3	1	1	12,66	6,00	5
B8	8,83	3	3	2	1	15,33	8,00	3
B9	8,00	3	3	2	1	16,83	9,00	3
B10	6,50	3	3	2	1	15,66	8,66	3
B11	8,16	3	3	2	1	15,50	8,50	3
B12	7,50	3	3	1	1	14,83	7,83	3
B13	9,66	3	3	1	1	17,66	8,83	3
B14	9,83	3	3	2	1	17,33	9,33	3
B15	6,33	3	3	1	2	15,33	7,83	3
B16	6,83	3	3	2	1	16,33	9,33	3
B17	7,33	3	3	2	2	14,50	7,83	3
B18	9,33	3	3	2	2	15,33	9,50	5
B19	7,83	3	3	2	1	19,00	10,00	3
B20	6,66	4	3	2	1	15,33	8,33	4
G1	7,50	3	3	2	3	14,66	8,33	3
G2	4,16	4	3	2	1	11,66	7,33	3
G3	8,33	4	2	2	1	14,50	8,33	5
G4	8,33	4	2	2	1	19,00	10,83	3
G5	9,00	4	3	2	1	14,00	8,66	3
G6	8,33	4	3	3	1	14,66	8,00	3
C1	4,50	3	3	2	1	15,33	8,33	3
C2	4,16	3	3	2	1	15,33	8,33	3
C3	5,00	3	3	1	1	12,00	7,00	5
Mean	7,33					15,21	8,42	
Minimum	4,16					11,66	6,00	
Maximum	9,83					19,00	10,83	

PL: Petiole length; LC: Leaf color; LS: Leaf shape; LMS: Leaf margin shape; Leaf pubescence; LL Leaf Length; Leaf width

The average yield of control cultivars and other pepper genotypes was calculated as 213,40 g/plant and 448,37 g/plant, respectively. Variation in single fruit weight was also significant. The heaviest fruit weight was 153,44 g in genotypes B20, while the lightest fruit weight was 4,66 g in B7 and the average single fruit weight was calculated as 58,77 g. The number of fruits per plant varied between 26,22 and 4,33 fruit/plant. The highest and lowest fruit number were recorded in B7 and B14 with 26,22 and 4,33 fruit/plant, respectively.

As in yield parameters, fruit length and fruit diameter also showed significant variation. The variation in fruit diameter (about 9 folds) was higher than the variation in fruit length (3 folds). The longest and shortest fruits were determined in genotypes B8-B9 and C3 with 4,67 and 15,00 cm, respectively. While C1 had fruit length close to genotypes taken from Adıyaman, C2 and C3 had longer fruits. Fruit diameter ranged from 0,97 cm to 5,40 cm and the average fruit diameter was calculated as 3,92 cm. The largest and lowest fruit diameters were measured as 0,97 cm and 5,40 cm, respectively, in B7 and G2 genotypes. The fruit diameter of the genotypes taken from Adıyaman was two times higher than the fruit diameter of the control cultivars (Table 5).

The fruit wall thickness ranged from 0,97 mm to 2,93 mm, and the average fruit wall thickness was 1,93 mm. The thinnest fruit wall was determined in the B7 genotype (0,97 mm), and the thickest fruit wall was determined in the B20 genotype (2,93 mm). The minimum and maximum fruit pedicel length of pepper genotypes were measured as 3,33 and 6,50 cm, respectively, and the mean fruit pedicel length was calculated as 4,33 cm (Table 5).

The results of the observations on fruit characteristics are given in Table 6. In terms of placenta size, it was observed that 13 of the genotypes had large, 11 intermediates, and 5 small placentas. Control cultivars had smaller placentas than other pepper genotypes. Three different fruit shapes (elongated; campanulate and blocky) were observed in the evaluated pepper genotypes. With 19 genotypes, campanulate fruit shape was found as a dominant fruit shape, 7 genotypes had elongated fruits and 3 genotypes had blocky fruits. Pepper genotypes are divided into two groups as smooth (10) and semi-wrinkled (19) in terms of fruit surface structure. In terms of fruit color in the intermediate

stage, while the majority of pepper genotypes were green, 3 of them had yellow fruit color. The number of locules in pepper genotypes ranged from one to four. In pepper genotypes collected from Adıyaman, genotypes had 4 locules except for B7 and B2 (2). While neck formation was not observed in 7 of the pepper genotypes, neck formation was detected in 22 of them. Pepper genotypes were divided into four groups as pointed, blunt, sunken, and pointed according to the blossom end shape. The most commonly observed blossom end shape was sunken in 21 genotypes. Four different pedicel attachment patterns were observed in pepper genotypes. These are lobate (17), obsute (6), cordate (5), and acute (1). Fruit blossom appendage was observed in 26 of the pepper genotypes, but not in three of them. According to the pungency in ripe fruit determined by tasting, 26 of the pepper genotypes were found to be pungent and 3 of them were sweet. Genotypes were divided into three groups in terms of fruit cross-section shape as slightly corrugated (8), medium (19), and corrugated (2).

Principal Component Analysis (PCA) was applied to the investigated traits and the principal components, eigen values, variance, and total variance are presented in Table 7. In PCA, factors with an eigen value greater than 1 were considered significant (Dunteman, 1989; Karaağaç and Balkaya, 2010). As a result of principal component analysis, 10 PC related to 37 morphological features were obtained. These PC's represent 86.38% of the total variance. The eigen values of 10 PC's varied from 10,50 to 1,10. The first three PC's explain 51,20% of the total variance. The first PC axis accounted for 28,38% of the variation, whereas the second and third axes accounted for 12,32% and 10,50%, respectively (Table 7). In the PCA, it has been reported that the first three axes should explain more than 25% of the variation (Mohammadi and Prasanna, 2003).

Table 5. Yield and fruit characteristics based on measurement

Genotypes	TFW (g/plant)	SFW (g)	FN (number)	FL (cm)	FD (cm)	FWT (mm)	FPL (cm)
B1	439,00	72,83	7,44	7,33	4,52	1,83	4,17
B2	470,09	56,72	7,22	6,33	4,02	1,80	4,17
B3	451,70	69,91	7,11	7,83	5,19	2,33	4,17
B4	369,09	61,36	5,67	8,17	4,73	2,40	3,67
B5	406,19	51,02	6,33	6,00	4,36	1,73	4,33
B6	577,40	55,14	7,67	7,33	4,52	2,17	4,83
B7	479,70	4,66	26,22	6,33	0,97	0,97	5,67
B8	481,69	71,26	5,78	4,83	4,04	2,10	3,83
B9	553,00	62,58	6,00	4,83	3,66	1,70	4,33
B10	382,20	68,07	7,44	6,17	4,19	1,67	4,00
B11	441,09	57,07	8,33	5,00	4,38	1,70	4,00
B12	530,33	48,40	7,44	7,00	4,44	2,03	3,33
B13	418,00	64,62	5,00	5,50	4,26	1,87	3,50
B14	360,00	61,77	4,33	6,33	4,43	1,70	4,50
B15	420,90	60,14	6,67	6,83	5,27	2,27	4,17
B16	427,83	54,67	7,00	4,67	2,78	1,40	3,83
B17	516,09	59,72	6,44	8,50	5,08	2,33	3,83
B18	470,60	59,40	6,44	5,00	3,53	1,33	4,00
B19	414,90	68,28	6,00	7,83	5,06	2,10	3,33
B20	608,00	153,44	4,89	9,50	4,95	2,93	6,50
G1	463,09	68,67	8,00	8,33	4,66	2,40	3,67
G2	460,83	85,17	4,89	6,83	5,40	2,87	3,67
G3	624,33	56,50	12,56	8,17	4,19	1,97	5,00
G4	427,60	61,21	4,67	6,67	4,13	1,77	6,00
G5	795,83	27,44	17,22	8,33	3,04	2,40	3,67
G6	371,50	67,95	5,89	6,50	3,92	1,77	4,67
C1	238,33	24,77	10,00	6,17	2,60	1,53	4,50
C2	155,33	20,64	5,67	13,83	1,10	1,20	6,17
C3	248,09	31,10	6,78	15,00	1,40	1,60	5,33
Mean	448,37	58,77	7,76	7,28	3,92	1,93	4,37
Minimum	155,33	4,66	4,33	4,67	0,97	0,97	3,33
Maximum	795,83	153,44	26,22	15,00	5,40	2,93	6,50

TFW: Total fruit weight; SFW: Single fruit weight; FL: Fruit length; FD: Fruit diameter; FN: Fruit number; FWT: Fruit wall thickness; FPL: Fruit pedicel length.

Table 6. Observational fruit characteristics

Genotypes	PS	FS	FSr	FCGM	LN	NFP	BES	PAS	FBEA	FCSS	RFP
B1	5	3	2	3	4	1	4	5	1	5	2
B2	7	3	2	3	4	1	3	5	1	5	2
B3	7	3	1	3	4	1	3	5	1	5	2
B4	5	3	1	3	4	1	3	4	1	3	2
B5	5	4	2	3	4	1	3	5	1	5	2
B6	7	3	2	3	4	1	3	5	1	5	2
B7	3	1	1	3	1	0	1	2	1	3	2
B8	7	3	1	3	4	1	3	4	1	3	2
B9	5	3	1	3	4	0	3	4	1	3	2
B10	7	3	1	3	4	1	3	5	1	3	2
B11	5	4	2	3	4	1	3	5	1	7	2
B12	5	3	2	3	4	1	3	5	1	5	2
B13	5	4	2	3	4	1	4	5	1	5	2
B14	7	3	2	3	4	1	3	5	1	5	2
B15	7	3	2	3	4	1	3	5	1	5	2
B16	5	3	1	3	4	0	3	2	1	3	2
B17	5	3	2	3	4	1	3	5	1	5	2
B18	7	3	2	3	4	1	3	4	1	5	2
B19	7	3	2	3	4	1	3	5	1	5	2
B20	7	1	1	3	2	1	1	2	0	3	2
G1	5	1	2	3	4	1	3	5	1	5	2
G2	7	3	1	2	4	1	4	5	0	5	2
G3	5	3	2	3	4	1	3	5	1	5	2
G4	7	3	2	3	4	1	3	2	1	5	2
G5	3	1	1	2	4	0	2	2	1	3	2
G6	7	3	2	3	4	1	3	5	1	7	2
C1	3	1	2	3	3	0	3	4	1	3	1
C2	3	1	2	2	1	0	1	1	0	3	1
C3	3	1	2	3	1	0	1	2	1	3	1

PS: Placenta size; FS: Fruit shape; FSr: Fruit surface; FCGM: Fruit color at green maturity; LN: Loculus number, NFP: Neck formation on pedicel; BES: Blossom end shape; PAS: Pedicel attachment shape FBEA: Fruit blossom end appendage; FCSS: Fruit cross-section shape; RFP: Ripe fruit pungency

Table 7. The number of factors related to eigen value statistics determined by principal component analysis and percentages of variance explained

	Components									
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigen values	10,50	4,56	3,88	3,26	2,48	1,81	1,64	1,51	1,22	1,10
% of variance	28,38	12,32	10,50	8,80	6,71	4,89	4,43	4,07	3,30	2,97
Cumulative %	28,38	40,70	51,20	60,00	66,72	71,61	76,04	80,11	83,41	86,38

Correlation coefficients of 10 PCs explaining 86% of the total variation are given in Table 8. According to the results of the current study, it has been determined that the traits in the first three PC's that explain a significant portion of the total variation and that have a coefficient value above 0,3 should be considered (Brown, 1991). In the first PC, which constitutes 28% of the total variation, the contribution of 11 characteristics to the variation was positively high, while the contribution of 5 traits was negatively significant. Of the 16 features that contributed significantly to the variation in the first PC, 6 were measured and 10 were observed characteristics. In PC1, locus number, fruit diameter, fruit shape, blossom end shape, fruit neck formation, fruit pedicel attachment shape, pungency, placenta size, stem pubescence, fruit cross-section shape, anthocyanin formation on the hypocotyl contributed positively to the variation, while the contribution of plant height, fruit height, fruit stem length, anther color and fruit number per plant to variation was negatively significant. The traits with high coefficients in the second principal component were cotyledon length (0,887) leaf color (0,813), cotyledon width (0,622), fruit weight, and leaf shape (0,646). In the third main component, while the blossom end appendage, petiole length, stem diameter, and fruit color at green maturity contributed positively to the variation, presence of nodal anthocyanin, nodal anthocyanin density, and fruit wall thickness contributed significantly negative (Table 8).

To better understand the overall diversity among pepper genotypes, the data were subjected to Cluster analysis revealing genetic similarities, and groups are presented Figure 1. Pepper genotypes did not group

according to their origin. Pepper genotypes were primarily divided into two groups as the first main group containing three control varieties (Çırgalan, Demresivri and Yalova corbacı), and the second main group containing 26 other genotypes collected from different villages of Besni and Gölbaşı districts. The second main group divided into two subgroups as the first subgroup contains B6, B9, G3, G5, and G20 and the second subgroup contains the other 21 genotypes. The 21 pepper genotypes in the second subgroup were divided into two groups, which included 9 (2-2-1) and 12 (2-2-2) pepper genotypes. In the clustering analysis, the most distant genotypes were C2 and B13 among all genotypes, while the two most distant genotypes among the collected genotypes were B13 taken from Çamurcu village and G5 from Maltepe village (Figure 1).

Table 8. Correlation coefficients between investigated characteristics and factors

	Correlation coefficient									
Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Number of loculus	**0,895**		0,104			-0,335			-0,101	-0,123
Fruit diameter	**0,848**	0,257	-0,284	-0,114	0,237			-0,159		
Fruit shape	**0,813**	-0,162		0,146			-0,236		0,132	-0,224
Blossom end shape	**0,811**			0,151	0,127	-0,295	-0,218			-0,23
Neck at base of fruit	**0,782**	0,211	-0,11		0,32	0,335			0,161	
Fruit stem and shape	**0,775**	-0,202			0,418		-0,189			
Fruit pungency	**0,762**		0,186	-0,507					0,159	0,121
Plant height	**-0,751**					0,112	0,39	0,158	-0,231	
Placenta size	**0,734**	0,25				0,424	0,128			-0,249
Stem pubescence	**0,702**	-0,422		0,14		0,127	0,327		-0,161	
Fruit length	**-0,654**	0,163	-0,374	0,181	0,177	0,179			0,181	
Fruit cross section shape	**0,614**			0,225	0,413			0,528	0,13	
Fruit pedicel length	**-0,596**	0,429	0,112	0,106	-0,149	0,511		0,227		
Anthocyanin on hypocotyl	**0,565**		-0,244		-0,318			0,454	0,303	0,26
Anther color	**-0,503**		0,456	-0,18	0,251	0,388			0,237	
Fruit number	**-0,462**	-0,185	0,437	-0,455		-0,216	-0,167	0,192	0,135	0,327
Cotyledon length		**0,887**	0,201	0,175			-0,133	-0,13		0,128
Leaf color		**0,813**		-0,324		-0,121		0,278	0,123	-0,161
Leaf shape		**-0,646**	-0,505	-0,195			0,261		-0,292	
Cotyledon width		**0,622**	0,173	0,417			-0,349	-0,168	-0,195	0,338
Fruit weight	0,490	**0,518**	-0,347	-0,219		0,406	0,156	-0,221	-0,159	
Stem pubescence	0,372	**-0,394**	0,114		-0,219	0,368	-0,152			-0,187
Intensity of nodal anthocyanin	0,329	-0,129	**-0,749**	0,106	-0,252		-0,117			0,306
Fruit blossom end appendage	0,344	-0,461	**0,657**	0,101	0,153	-0,133				0,167
Nodal anthocyanin	0,481	-0,276	**-0,6**		-0,306	-0,115	0,122	0,126	0,197	0,282
Petiole length	0,577		**0,595**	-0,124			0,214			0,103
Stem diameter	0,472		**0,547**	-0,52			0,214			
Fruit wall thickness	0,352	0,459	**-0,488**	-0,412	0,288			-0,265		
Fruit surface	0,117		0,121	**0,768**	0,43		0,136	0,289	0,13	0,119
Yield	0,32	0,393	0,119	**-0,692**		-0,186	0,108			0,287
Stem shape	0,235		0,212		**-0,529**		0,134	-0,152	0,405	-0,161
Leaf length	0,411	0,212	0,256	0,516	**-0,521**		0,221	-0,146		0,194
Leaf width	0,417	0,362	0,247	0,45	**-0,462**	-0,145	0,316			
Fruit color at green maturity	0,374	-0,216	0,446	0,181	0,156	**0,506**		-0,255	-0,163	0,3
Leaf pubescence	0,148	-0,12			0,574		**0,594**			
Plant growth habit	-0,229	0,374		0,328	0,24	-0,306	0,456	-0,255	0,328	-0,129
Leaf margin	0,261	0,373			-0,16		0,146	0,547	-0,543	-0,138

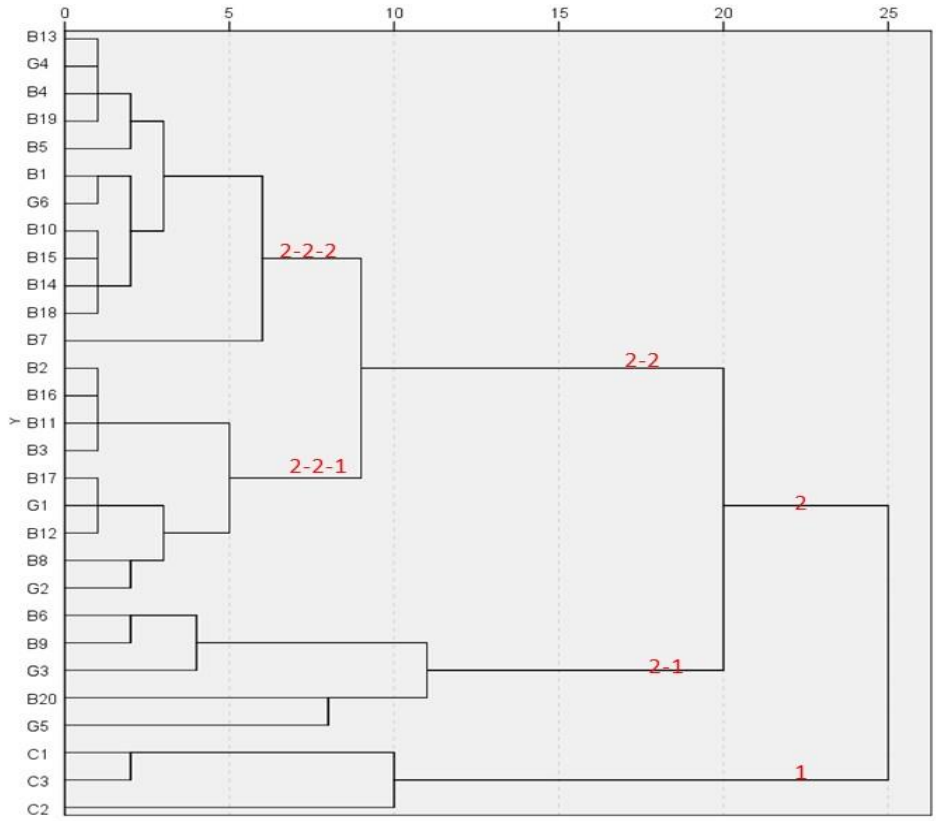

Figure 1. Grouping of 29 pepper genotypes for morphological traits in cluster analysis

Discussion

In the exploitation of plant genetic resources (preservation and breeding), determining the existing agronomic and morphological variations within the species and revealing the distribution of this variation provide important advantages (Hawkes, 1991; İlhan, 2017). As in many plant species, the agronomic and morphological characterization of pepper genotypes obtained from different sources has been studied by many researchers (Berletti and Quagliotti, 1982; Gonzalez and Azurdia, 1985; Pentcheva, 1987; Cole, 1993; Carvalho et al., 2003; Zewdie et al., 2004; Düzyaman and Duman, 2004; Keleş, 2007; Mutlu et al., 2009; Bozokalfa and Eşiyok, 2010; Karaağaç ve Balkaya, 2010; Virga et al., 2020, Başak, 2019; Taş and Balkaya, 2021). A rich genetic diversity in plant genetic resources that form the basis of plant breeding is desirable. This genetic diversity mostly depends on the formation process of the studied plant genetic resources, the fertilization biology of the species (self-pollinated or cross-pollinated), and the diversity (climate and soil) and size of the collection areas. In accordance with the present study, variations at different rates have been reported in previous morphological characterization studies in pepper plants (Karaağaç and Balkaya, 2010; Bozokalfa and Eşiyok, 2010; Başak, 2019). In this study, among the 42 features used for morphological characterization, no variation was observed in a total of 7 features such as petal color, calyx coloration, leaf shape, and stem background color. This result was expected because the collection area was narrow, all the collected genotypes belonged to the cultivated *C. annuum* species, and the farmers exchanged seeds among themselves. Similar results regarding the aforementioned characteristics in pepper were also reported in *C. annuum* (Keleş, 2007; Binbir ve Baş, 2010; Karaağaç and Balkaya, 2010; Keleş et al., 2016; Başak, 2019). The measured characteristics showed higher variation than the observed characteristics, which supports previous studies (Bozokalfa and Eşiyok, 2010; Başak, 2019).

In the study, it was determined that fruit characteristics contributed the most to the variation and had high factor coefficients. In the first three PCs explaining 51,2% of the total variation, 19 out of 29 characteristics explaining the total variation consisted of morphological and agronomic characteristics of the fruit. Consistent with our findings, it was reported that the agronomic and morphological characteristics of the fruit contributed the most to the variation (Düzyaman and Duman, 2004; Mutlu et al., 2009; Bozokalfa and Eşiyok, 2010; Başak, 2019; Taş and Balakaya, 2021). Cross-pollination, which can sometimes reach high rates in pepper due to flower structures, and farmer selection based on fruit characteristics have a large share in the formation of high variability in fruit characteristics. Because in farmer conditions, seed production is carried out without isolation (physical or distance) and the characteristics of the male parents are ignored.

The yield of all genotypes used in the study was found to be higher than the control varieties. 13 genotypes had significantly higher yields than the average and commercial varieties. High yielding genotypes produced higher yield either by having heavier fruits or by increasing fruit number. While the high yielding genotypes B20, B9, and G3 had higher yield by having heavier fruits, G5 produced higher yield by increasing fruit numbers. These four genotypes with high yield were included in the first subgroup of the second main group in the cluster analysis (Figure 1).

Productivity in pepper is affected by traits such as plant vigor, fruit number per plant, fruit weight, and fruit flesh thickness (Arif et al., 2012). The inheritance of these characters is managed by the additive gene, dominance, and additive gene-dominance systems (Hasanuzzaman and Golam, 2011; Santos et al., 2014). In this study, high yielding genotypes produced high yields either by increasing the fruit number (G5) or weight (B20) or by increasing both (G3) (Table 5).

Characterization studies on pepper genotypes provided from different sources (collected or introduced) were carried out by various researchers. In a study by Düzyaman and Duman (2004), in which 25 different table and processing pepper genotypes were characterized in terms of 15 phenotypic characteristics, PC analysis created 4 autonomous PC axes representing 81,77% of the total variation. In the characterization study performed according to phenotype (54 traits) in 29 pepper genotypes collected from different regions of Turkey, it was determined that 9 PC's represented 85,35% of the total variation (Binbir and Baş, 2010). Karaağaç and Balkaya (2010) defined 8 groups in a clustering analysis based on 20 morphological characteristics of 56 capia pepper populations collected from Bafra. In PCA, the first three PC axes explained 74.,3% of the total variance. Variables with the highest contribution for principal component analysis were associated with plant structure and fruit descriptors in pepper and they explained 70.8% of the total variation (Villota-Cerón et al., 2012). In another characterization study conducted by Başak (2019) in 99 pepper genotypes collected from Kırşehir-Turkey region for 48 morphological traits, 75% of the total variation was explained by 17 PC's. Taş and Baklaya (2021) reported that six PC's with an Eigenvalue greater than 1 explained 70.99% of the total variation in *C. chinense*. PCA analysis is more reliable if 25% or more of the total variation in PCA analysis is explained by the first 2 or 3 axes and PC axes explain 2/3 of the total variation (Mohammadi and Prasanna, 2003; Özdamar, 2004). In the present study, 10 PC's with eigenvalues higher than 1 explained 86% of the total variation, while the first three PC's explained more than 50% of the total variation. These results show that there is significant variation between genotypes and that the study is reliable and consistent with previous studies.

Conclusion

In this study, 26 genotypes from the Besni pepper population were characterized agronomically and morphologically, and an important variation was identified that could contribute to establishing a genetic resource for future pepper breeding studies. The presence of superior genotypes to control varieties in terms of yield and fruit characteristics indicates that there are genotypes that can be used in open-pollinated or hybrid variety breeding programs. Some of these genotypes can be used as donor or recipient parents since all of the genotypes studied are pungent and the local people prefer the hot peppers with fruit characteristics that they are familiar. To exploit genotypes that have superior characteristics in their genetic makeup in future breeding programs, pure lines should be produced either by the classical inbreeding method or by dihaploidization method. For this reason, our studies continue to determine the response of genotypes to anther culture. In addition, molecular characterization studies are being continued with different DNA markers to confirm the variation detected in the present morphological study. In today's world where local cuisines are given importance, transferring the desired characters from local genotypes to new varieties is the primary factor in ensuring the sustainability of local tastes.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential, or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Not applicable.

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Data availability

Not applicable.

Consent for publication

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