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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Evaluation of the Fruit Characteristics of Pepper (*Capsicum annuum* L.) Genotypes Collected from the Eastern Black Sea Region of Türkiye

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Abstract: *Capsicum annuum*, native to Central America, particularly Mexico, is widely cultivated in Türkiye, which ranked as the fourth-largest global producer in 2020, contributing 2.6 million tonnes to the global pepper production of 36.1 million tonnes. In Türkiye, the fruits, whether unripe green or ripe red, are commonly known as "biber." This study investigated the morphological diversity of *C. annuum* in the Rize province of Türkiye, encompassing both quantitative and qualitative traits. In total, 48 diverse genotypes representing a range of colours, shapes, and sizes were collected in 2014 from the Pazar district and surrounding villages. The seeds were planted in May 2015 in trays containing a 2:1 mixture of peat and perlite under greenhouse conditions. Once the seedlings developed 4-5 leaves, they were transplanted into the field in June 2015 for further growth and evaluation. Morphological traits of fruit were analysed using principal component analysis (PCA) and hierarchical clustering, revealing significant variability among genotypes. Key traits such as fruit length, width, and colour were found to differ considerably. This morphological diversity is crucial for identifying and selecting genotypes with desirable traits, offering valuable insights for geneticists and breeders to promote the conservation and utilisation of diverse *C. annuum* genotypes in future breeding programmes.

Keywords: Cluster analysis, genetic variation, morphological characterisation, pepper.

Türkiye Doğu Karadeniz Bölgesinden Toplanan Biber (*Capsicum annuum* L.) Genotiplerinin Meyve Özelliklerinin Değerlendirilmesi

***Sorumlu yazar:**
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Öz: Orta Amerika, özellikle Meksika'ya özgü *Capsicum annuum*, Türkiye'de yaygın olarak yetiştirilmektedir ve 2020 yılında Türkiye, dünya çapında 36.1 milyon tonluk biber üretimine 2.6 milyon ton katkı sağlayarak dördüncü en büyük üretici olmuştur. Türkiye'de bu bitkinin olgunlaşmamış yeşil veya olgun kırmızı meyveleri genellikle "biber" olarak adlandırılmaktadır. Bu çalışma, Türkiye'nin Rize ilinde *C. annuum*'un morfolojik çeşitliliğini hem niceliksel hem de niteliksel özellikleri kapsayarak araştırmıştır. 2014 yılında Pazar ilçesi ve çevresindeki köylerden renk, şekil ve boyut açısından farklılık gösteren toplam 48 genotip toplanmıştır. Toplanan tohumlar, 2015 yılı Mayıs ayında torf ve perlit karışımı (2:1) içeren tepsilere ekilmiş ve kontrollü sera koşullarında yetiştirilmiştir. Fideler 4-5 yaprak geliştirdiğinde, Haziran 2015'te tarlaya nakledilerek büyümeye ve değerlendirmeye alınmıştır. Meyvelere ait morfolojik özellikler, temel bileşen analizi (PCA) ve hiyerarşik kümeleme yöntemi ile analiz edilmiş ve genotipler arasında önemli bir değişkenlik ortaya konmuştur. Meyve uzunluğu, genişliği ve rengi gibi temel özelliklerin önemli ölçüde farklılık gösterdiği bulunmuştur. Bu morfolojik çeşitlilik, genetikçiler ve ıslahçılar için istenilen özelliklere sahip genotiplerin tanımlanması ve seçilmesi açısından büyük önem taşımakta olup, gelecekteki ıslah programlarında çeşitli *C. annuum* genotiplerinin korunması ve değerlendirilmesi için değerli bilgiler sunmaktadır.

Anahtar kelimeler: Genetik varyasyon, kümeleme analizi, morfolojik karakterizasyon, biber.

INTRODUCTION

Pepper, belonging to the *Capsicum* genus of the Solanaceae family, is the third most important vegetable species worldwide, after tomato and onion (FAOSTAT, 2020; Olutumise, 2022). Peppers are rich in nutrients, including 88% water, 40 kcal energy, 2.22 g protein, 8.9 g carbohydrates, 1.56 g fibre per 100 g, as well as calcium, iron, potassium, sodium, thiamine, riboflavin, niacin, and ascorbic acid (Gebhardt & Thomas, 2002; Güneş et al., 2023).

In 2020, global pepper production reached 36.1 million tonnes, with Turkey ranking as the world 's fourth-largest producer, contributing 2.6 million tonnes, cultivated across 91,491 hectares with a yield of 2.88 kg m^{-2} (FAOSTAT, 2022). The Adana, Mersin, Hatay, Kahramanmaraş and Osmaniye provinces in Türkiye produce 532,057 tonnes of pepper, comprising 50.7% of the Mediterranean Region and 20.2% of Türkiye's total production (TÜİK, 2020; Coşkun et al., 2021). Additionally, Türkiye houses a rich collection of pepper genetic resources with diverse cultivars, yet this valuable resource has received little attention in the literature regarding the assessment of genetic diversity or interrelationships among these genotypes (Bozokalfa et al., 2009). Assessment and characterisation of trait variations in pepper genetic resources are essential steps in agricultural research and breeding programmes These evaluations serve as the foundation for identifying pepper genotypes that not only yield high quantities but also possess qualities that appeal to consumers and meet market demands (Bozokalfa et al., 2009; Gündüz & Özbay, 2018; Bedjaoui et al., 2022).

The main objective of this study was to collect various genotypes of *C. annuum* from local farmers in the Pazar district and villages within Rize province, located along the Eastern Black Sea coastline. These acquired seeds were subsequently cultivated in a greenhouse under standardised conditions to evaluate their morphological diversity, which encompassed a range of quantitative and qualitative traits.

MATERIAL AND METHOD

Sampling: *Capsicum* genotypes differing in colour, shape, and size were acquired from local farmers in the Pazar district and villages of Rize province during 2014 (Table 1). The *C. annuum* seeds were planted in a 2:1 ratio of peat to perlite mixture in 45-cell trays on May 8, 2015. Seedlings grown in the Faculty of Agriculture greenhouse were transferred to the field on June 30, 2015. Eight plants from each genotype were spaced at 50x50 cm intervals when they had 3-4 leaves. Fertilization followed the guidelines of Vural et al. (2000).

Table 1. Altitude, latitude, and longitude of sampled locations for pepper (*Capsicum annuum* L.) genotype collection in the Eastern Black Sea Region of Türkiye.

Location	Altitude m	Latitude °N	Longitude °E
Merkez-Kirazlık Mah-1	67.3	41.177	40.903
Merkez-Kirazlık Mah-2	72.7	41.180	40.898
Kesikköprü Village-1	232.0	41.145	40.893
Kesikköprü Village-2	233.6	41.147	40.893
Elmalık Village	328.8	41.118	40.891
Alçılı Village	355.8	41.135	40.864

The experiment was concluded when air temperature dropped and plant growth halted. Plants with distinct characteristics for each genotype were labelled with different letters. Harvesting was conducted once between November 23 and 25, 2015, based on the colour and ripeness of the fruits, which were categorised into three groups: red, orange, and green. For each group, the total fruit weight per plant, total number of fruits, total number of discards, and total discard weight were recorded separately.

Fruit measurements were performed on 10 ripe red fruits. The morphological characteristics of fruits, including weight (g), width (mm), fruit length (cm), stalk length (mm), and stalk diameter (mm), were measured. A scale with 0.01 g precision was used for fruit weight, while fruit length and width (just below the calyx where the fruit is at its maximum diameter), stalk length, and stalk diameter were measured using a digital calliper.

Colour measurements were performed using a chroma metre (Minolta CR 400, Konica Minolta, Japan). The colour of the ripe red fruits was assessed for both the external skin colour and the internal fruit colour. These measurements were expressed using three coordinates (L*, a*, b*) within the CIE-LAB colour space. The L* coordinate indicates the brightness of the object, the a* value represents the red to green chroma, and the b* value denotes the yellow to blue chroma.

This study was conducted in trial plots at the Faculty of Agriculture at Recep Tayyip Erdoğan University. The soil characteristics of the trial plots were determined as follows: pH: 4.42 (acidic); EC: 0.49 ds/m (non-saline); organic matter: 1.54%; lime content: 0.13% (low lime); available phosphorus: 3.52 mg/kg; exchangeable potassium: 0.61 cmol(+) /kg, and the soil type was clayey. Due to the region's high rainfall, irrigation was performed only when necessary using a hose. Weed control and irrigation were conducted uniformly across all genotypes. Climatic data (air temperature, air relative humidity, and soil temperature)

for the trial year during the growing season were recorded using a data logger and are shown in Figure 1.

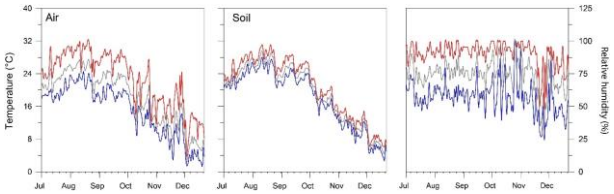

Figure 1. Temperature (°C) and relative humidity (%) in a greenhouse cultivating pepper genotypes from the Pazar district and surrounding villages in Rize, Türkiye.

Statistical analysis: Data on weight, length, width, stalk length, and stalk diameter for the 48 pepper genotypes are presented as means with standard deviations (s.d.), along with their minimum and maximum ranges.

Principal component analysis (PCA) was performed on all recorded morphological characteristics. Additionally, dendrogram and multidimensional scaling (MDS) analyses were conducted to identify similarities among different genotypes based on their morphological characteristics. For these analyses, the data were standardised and log-transformed before performing PCA, dendrogram, and MDS analyses (Karataş, 2022). All data analyses were performed using R software v. 4.4.1.

RESULTS

Capsicum annuum samples exhibited variations in terms of their overall appearance and colour. Detailed results for these samples are presented in Table 2, which includes CIELAB colour data for 48 different genotypes, and in Figure 2, which shows representative photographs of the pepper genotypes.

Table 2. Results of colour pigment analysis for 48 distinct pepper (*Capsicum annuum* L.) genotypes, measured in the CIELAB colour space for the inner flesh and outer skin.

Genotype	Fruit Inner (Flesh) Colour			Fruit Outer (Skin) Colour		
	L	*a*	*b*	*L*	*a*	*b*
2A	31.23	34.45	13.22	27.35	28.47	10.25
2B	42.93	26.88	19.19	33.02	35.22	13.18
2C	35.05	35.92	16.83	29.4	36.71	12.24
2D	41.27	28.97	17.73	30.6	30.05	11.14
3	36.49	30.97	17.10	30.99	33.63	11.73
4	40.09	30.27	19.60	30.46	34.61	11.78
4A	43.82	27.53	20.70	31.25	36.37	31.79
4B	37.02	33.13	17.40	29.58	35.24	11.17
6	29.66	25.71	12.53	29.84	33.68	11.82
7	33.57	33.4	15.63	29.42	32.51	10.81
7A	32.85	34.92	14.88	30.38	31.03	10.55
8	30.15	27.11	12.94	29.26	33.82	11.69
8B	32.27	33.2	14.29	29.75	35.41	11.99
9	63.58	32.21	16.97	31.44	36.27	12.35
9A	33.53	33.72	15.1	27.49	32.03	9.30
9B	37.19	27.09	16.52	34.40	39.59	15.26
10A	31.21	33.8	13.79	28.78	34.23	9.98
10B	35.44	31.61	15.14	28.3	31.51	10.03
11	45.91	31.07	22.63	33.96	38.88	14.42
12	33.93	31.61	15.86	28.37	28.68	9.75
13	29.33	31.46	11.82	25.67	26.14	7.26
14	43.94	19.38	18.06	28.65	30.52	9.61
14A	29.59	32.06	12.73	25.66	31.78	9.73
15A	36.04	33.32	15.98	27.94	31.87	9.48
15B	35.25	34.50	15.92	28.2	29.10	8.87
16	32.16	29.26	12.42	25.42	31.59	9.63
16A	44.69	29.70	19.54	35.49	36.13	15.08
16B	34.44	29.39	16.31	30.72	35.21	14.07
16C	32.65	34.44	14.75	29.37	28.78	8.96
16E	32.76	30.15	15.41	29.24	32.89	10.53
16D	30.65	28.60	12.54	28.68	28.28	9.08
17	45.09	34.78	22.58	37.61	32.52	31.97
19	44.37	33.57	21.38	39.00	38.74	19.36
19A	45.05	24.98	20.96	36.88	33.43	16.81
20	41.1	31.29	20.44	33.17	35.27	13.96
20A	37.03	30.15	17.26	34.98	36.27	15.08
20B	32.44	32.29	14.76	29.35	31.53	11.40
20C	36.78	32.45	16.44	29.35	32.32	10.58
21	33.27	34.43	14.05	25.40	30.42	8.79
21A	36.3	29.19	17.80	33.79	32.79	13.14
21C	37.94	29.25	15.37	26.00	28.23	8.12
23	30.82	28.77	13.49	29.09	28.83	8.75
25	28.81	26.08	12.15	27.37	25.20	7.86
27	31.77	32.23	14.69	31.51	34.61	13.40
27B	36.30	29.34	13.86	30.49	37.22	12.16
28	35.00	29.57	13.91	27.40	29.68	9.09
28A	36.36	30.25	15.42	29.00	36.37	12.57
29	35.56	33.53	14.72	29.93	32.85	10.84

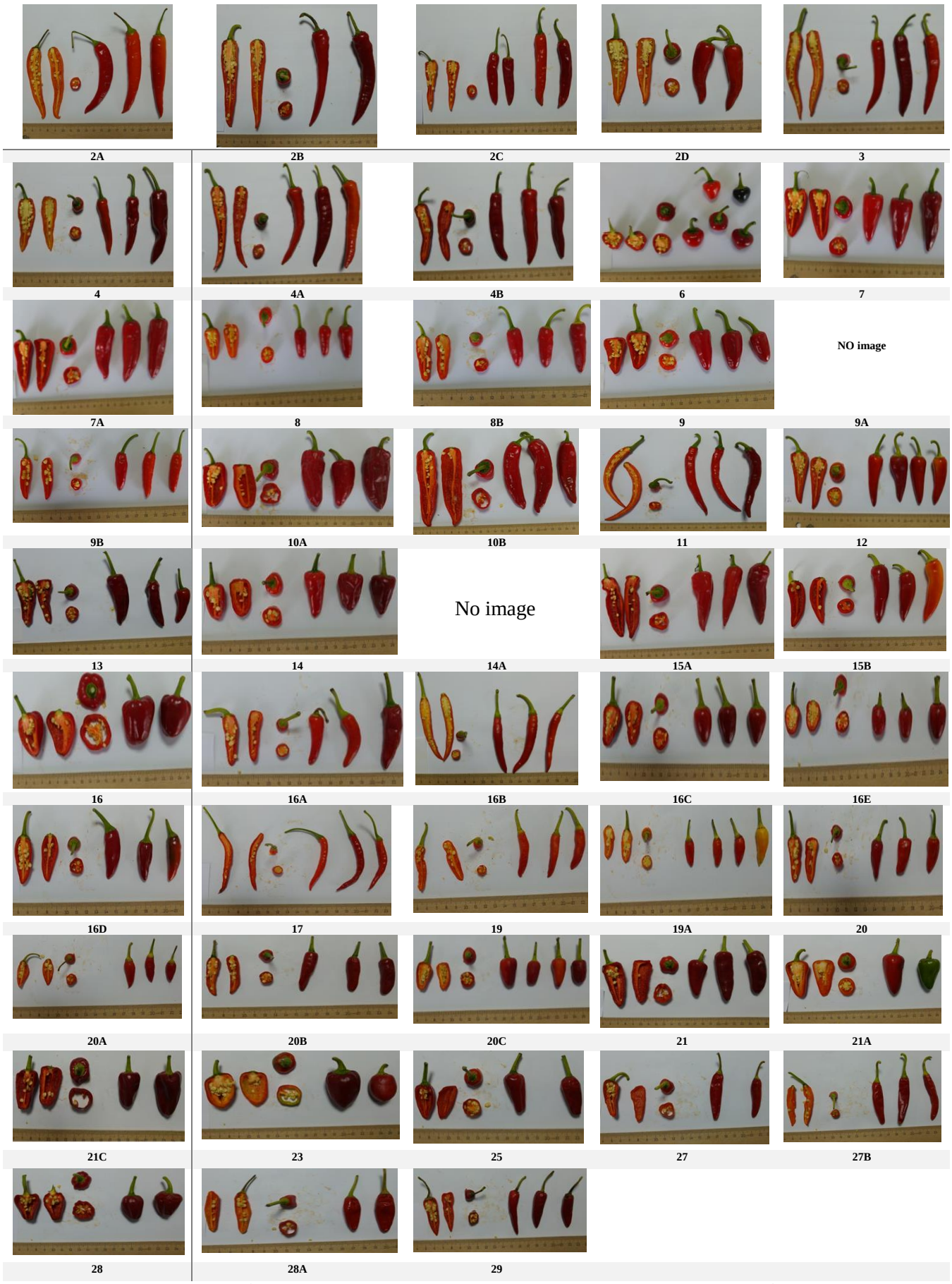

Figure 2. Representative photographs of 48 distinct pepper (*Capsicum annuum* L.) genotypes, showing both whole and sliced fruit specimens.

Fruit characteristics

Fruit weight: The genotypes exhibited varying mean fruit weights. The lowest recorded values were 1.2 and 1.5 g for two different genotypes. The highest mean fruit weight was observed in genotype 10B, which reached 14.9 g. Genotype 16 followed closely with a mean fruit weight of 14.8 g, whereas genotype 7A had a mean fruit weight of 11.5 g (Table 3).

Fruit length: The minimum mean fruit lengths were recorded as 22.95 mm for genotype 16E, 24.79 mm for genotype 6, and 25.63 cm for genotype 20A. In contrast, the maximum mean fruit lengths were observed for genotypes 11 (133.5 mm), genotype 3 (112.0 mm), and genotype 4A (106.5 mm) (Table 3).

Stalk length: The genotypes also exhibited variation in stalk length. The highest mean stalk lengths were 5.6 mm for genotype 23, 5.1 mm for genotype 7A, and 5.0 mm for genotype 25. Conversely, the lowest mean stalk lengths were 2.8 mm for genotype 2A, 2.9 mm for genotype 9B, and 3.1 mm for genotype 8B (Table 3).

Fruit width: For fruit width, the minimum mean values were 7.8 mm for genotype 17, 9.1 mm for genotype 16B, and 19 for another genotype. In contrast, the maximum mean fruit width was 35.8 mm for genotype 16, 28.6 mm for genotype 23, and 27.2 mm for genotype 6 (Table 3).

Principal component analysis: Principal component analysis (PCA) was used to assess variability among the 48 genotypes. The first six principal axes collectively explained approximately 79% of the total variance, each possessing Eigenvalues exceeding 1 (6.3, 3.9, 2.7, 2.6, 1.5, and 1.2). Notably, the first four components accounted for approximately 67% of the total variance, thus representing the most significant contributors to the overall variance. In evaluating the importance of a specific trait in contributing to a component's variability, a vector loading value exceeding 0.33 for that component and falling below 0.33 for the others was considered significant (Kothari, 2000). Morphological characteristics of fruits, such as weight (g), width (mm), fruit length (cm), stalk length (mm), and stalk diameter (mm), were primarily associated with the first three principal components, with vector loading values ranging from 0.81 to -0.59. The colour of the fruit's outer skin displayed loading values between -0.534 and -0.673, primarily linked to the second component. Characteristics related to ripe (red) fruits, including weight (g), quantity (pcs), discard weight (g), and discard quantity (pcs), exhibited vector loading values of 0.628–0.739 for the first and second components, thus signifying their substantial contributions to the overall variability. The highest vector values for unripe (immature, mixed colour) and green (mature) fruits were predominantly loaded onto PC4 (refer to Table 4). These PCA results underscore the discernible separation among genotypes, highlighting significant morphological variations within this dataset.

Table 4. Eigenvectors of six principal components of different traits in 48 pepper (*Capsicum annuum* L.) genotypes.

	Principal Component					
	Prin1	**Prin2**	**Prin3**	**Prin4**	**Prin5**	**Prin6**
Eigenvalue	6.299	3.882	2.696	2.551	1.537	1.210
Percentage variations	27.386	16.878	11.723	11.093	6.681	5.260
BARTLETT'S TEST						
ChiSquare	1018.460	837.325	710.497	613.276	494.615	422.012
DF	250.368	239.219	224.026	207.171	190.875	173.359
Prob>ChiSq	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
FRUIT						
Weight (g)	-0.456	0.370	**0.720**	0.096	0.173	0.043
Width (mm)	**-0.744**	0.380	0.262	0.011	0.260	0.136
Length (cm)	0.152	0.234	**0.813**	-0.096	-0.104	-0.224
Stalk length (mm)	0.328	0.093	**0.619**	-0.331	-0.258	-0.091
Stalk diameter (mm)	**-0.589**	0.197	0.318	0.183	0.356	0.340
FRUIT INNER (FLESH) COLOUR						
L	**0.521**	-0.430	0.296	0.036	0.431	0.036
a	-0.069	-0.043	0.242	0.009	**-0.778**	-0.114
b	**0.550**	-0.551	0.373	0.194	0.277	0.083
FRUIT OUTER (SKIN) COLOUR						
L	0.586	**-0.673**	0.112	0.011	0.154	0.067
a	0.459	**-0.594**	0.199	0.061	0.025	-0.388
b	0.647	**-0.534**	0.297	-0.037	0.035	0.113
RIPE(RED) FRUIT						
Weight (g)	0.387	**0.660**	0.159	-0.223	0.027	0.150
Number (pcs)	**0.628**	0.568	-0.094	-0.304	-0.106	0.179
Discard Weight (g)	**0.630**	0.414	-0.330	-0.105	0.299	0.035
Discard Number(pcs)	**0.739**	0.268	-0.416	-0.151	0.168	-0.041
UNRIPE (IMMATURE, MIX COLOUR) FRUIT						
Weight (g)	**0.656**	0.274	0.205	0.040	-0.143	0.143
Number (pcs)	**0.807**	0.051	-0.166	0.046	-0.241	0.220
Discard Weight (g)	0.515	0.026	0.087	0.474	-0.234	**0.534**
Discard Number(pcs)	0.302	0.279	-0.130	**0.687**	0.025	-0.135
GREEN FRUIT (MATURE)						
Weight (g)	**0.560**	0.539	0.350	-0.185	0.112	0.063
Number (pcs)	0.433	0.484	-0.040	-0.312	0.252	**-0.530**
Discard Weight (g)	0.161	0.344	0.015	**0.839**	-0.019	-0.130
Discard Number(pcs)	0.239	0.343	0.078	**0.797**	0.016	-0.307

Hierarchical clustering: The genotypes were categorised into four primary clusters, each with several sub-clusters. The first main cluster was predominantly composed of the 21A genotype, which exhibited a distinct separation from all other genotypes and was characterised by the highest dissimilarity percentage of approximately 30.8%. The second main cluster was primarily comprised of the 17 genotypes, which displayed the second-highest dissimilarity when compared with all other genotypes, with an approximately 22.5% dissimilarity. The third main cluster was centred around the 16E genotype, exhibiting an average dissimilarity of approximately 16.0%. The fourth main cluster encompassed all remaining genotypes, which were further divided into two primary sub-clusters. The first sub-cluster within the fourth main cluster consisted of the following genotypes: 16, 7, 21C, 10B, 15A, 2C, 20B, 20C, 23, 2D, 4B, 10A, 21, 2B, 7A, 19A, 16C, 14A, and 20. The second sub-cluster in the fourth main cluster was characterised by genotypes 16D, 4, 16B, 11, 15B, 6, 9A, 8, 20A, 27B, 8B, 27, 9, 16A, 28A, 25, 19, 9B, 29, 4A, 3, 14, 28, 13, 2A, and 12 (Figure 3). This clustering of genotypes appeared to reflect a geographic pattern, suggesting that genotypes from similar sampling areas tended to group together (see Figure 4).

Table 3. Descriptive Statistics of 48 pepper (*Capsicum annuum* L.) genotypes after 120 days of field cultivation.

Geographical origin	Genotype code	Weight(g)		Length (mm)		Width(mm)		Stalk Length(mm)		Stalk Diameter(mm)	
		Mean ± s. d.	Min. – Max.	Mean ± s. d.	Min. – Max.	Mean ± s. d.	Min. – Max.	Mean ± s. d.	Min. – Max.	Mean ± s. d.	Min. – Max.
Merkez-Kirazlık Mah-1	3	10.86 ± 2.44	7.88 – 15.45	112.0 ± 1.01	100.0 – 130.0	16.02 ± 1.29	14.88 – 19.03	31.51 ± 2.45	26.30 – 34.21	3.51 ± 0.80	2.70 – 5.60
Merkez-Kirazlık Mah-1	4	4.25 ± 1.11	3.55 – 7.24	54.02 ± 0.66	50.01 – 70.01	13.19 ± 1.79	11.78 – 17.28	18.59 ± 6.44	12.46 – 30.30	3.25 ± 0.35	2.86 – 3.80
Merkez-Kirazlık Mah-1	2A	7.03 ± 1.84	4.94 – 10.22	89.50 ± 0.96	75.00 – 105.0	15.31 ± 2.30	12.57 – 19.33	32.61 ± 3.64	26.80 – 38.55	2.82 ± 0.38	2.24 – 3.40
Merkez-Kirazlık Mah-1	2B	10.61 ± 1.55	8.17 – 12.92	98.00 ± 0.98	80.00 – 110.0	17.85 ± 1.57	14.56 – 19.93	28.56 ± 4.38	20.88 – 35.85	4.17 ± 0.79	2.95 – 5.27
Merkez-Kirazlık Mah-1	2C	3.76 ± 1.64	2.01 – 6.52	57.50 ± 1.27	45.02 – 85.00	14.96 ± 1.64	12.52 – 18.05	28.01 ± 2.70	23.50 – 31.81	3.17 ± 0.40	2.65 – 4.07
Merkez-Kirazlık Mah-1	2D	8.29 ± 1.58	5.45 – 10.35	63.02 ± 0.59	55.00 – 70.01	19.07 ± 1.71	15.21 – 21.23	29.93 ± 2.46	25.58 – 34.22	3.59 ± 0.37	3.18 – 4.20
Merkez-Kirazlık Mah-1	4A	9.11 ± 1.92	6.30 – 11.65	106.5 ± 0.82	95.01 – 120.0	17.59 ± 2.83	14.21 – 24.20	30.76 ± 2.92	25.39 – 34.37	4.38 ± 0.95	3.34 – 6.12
Merkez-Kirazlık Mah-1	4B	7.46 ± 1.77	4.91 – 10.79	71.00 ± 0.77	55.00 – 80.01	17.05 ± 1.66	14.39 – 19.64	30.65 ± 2.69	25.62 – 33.90	3.44 ± 0.37	2.95 – 4.23
Merkez-Kirazlık Mah-2	19	1.49 ± 0.21	1.15 – 1.80	40.29 ± 3.20	34.05 – 43.29	9.11 ± 0.95	7.67 – 11.08	22.79 ± 1.84	20.33 – 24.77	3.27 ± 0.48	2.52 – 3.89
Merkez-Kirazlık Mah-2	20	1.47 ± 0.31	1.10 – 2.10	28.68 ± 2.91	23.31 – 34.42	11.81 ± 1.02	10.41 – 13.00	19.15 ± 2.37	15.06 – 22.53	3.69 ± 0.90	2.64 – 5.25
Merkez-Kirazlık Mah-2	19A	1.59 ± 0.45	1.13 – 2.25	29.25 ± 4.78	21.83 – 36.37	10.24 ± 1.36	8.37 – 12.66	18.31 ± 1.35	16.44 – 20.44	3.20 ± 0.63	2.49 – 4.13
Merkez-Kirazlık Mah-2	20A	1.16 ± 0.26	0.70 – 1.65	25.63 ± 3.56	19.03 – 30.36	10.53 ± 1.12	8.90 – 12.61	18.61 ± 1.78	15.22 – 20.73	3.40 ± 0.77	2.48 – 4.85
Merkez-Kirazlık Mah-2	20B	2.52 ± 0.62	1.68 – 3.65	40.40 ± 2.82	34.95 – 45.04	11.81 ± 1.41	9.70 – 14.26	20.83 ± 1.80	18.46 – 24.95	4.13 ± 0.51	3.43 – 5.04
Merkez-Kirazlık Mah-2	20C	2.99 ± 0.91	1.93 – 5.20	26.04 ± 2.96	20.83 – 30.12	15.46 ± 1.48	13.99 – 19.15	21.01 ± 1.56	18.93 – 23.98	4.54 ± 0.45	3.97 – 5.50
Kesikköprü Village-1	6	7.62 ± 1.33	5.35 – 9.98	24.79 ± 1.93	22.21 – 28.92	27.18 ± 1.36	25.02 – 29.97	23.78 ± 3.14	18.68 – 29.86	4.49 ± 0.59	3.54 – 5.54
Kesikköprü Village-1	7	10.27 ± 2.36	7.06 – 13.38	54.66 ± 3.48	50.67 – 62.79	24.66 ± 3.38	19.73 – 28.90	23.13 ± 2.83	19.23 – 27.65	4.51 ± 0.50	3.98 – 5.51
Kesikköprü Village-1	8	2.75 ± 0.48	2.05 – 3.60	28.75 ± 3.46	24.10 – 35.35	15.39 ± 0.96	14.14 – 17.07	18.70 ± 1.39	15.80 – 20.22	3.07 ± 0.25	2.62 – 3.42
Kesikköprü Village-1	9	2.97 ± 0.69	2.10 – 3.90	36.64 ± 5.41	28.55 – 44.08	15.87 ± 1.17	14.17 – 17.26	23.49 ± 2.77	19.75 – 29.72	3.54 ± 0.39	2.94 – 4.18
Kesikköprü Village-1	11	10.97 ± 3.11	7.15 – 18.75	133.5 ± 1.45	105.0 – 160.0	15.48 ± 2.19	12.45 – 20.86	31.34 ± 3.78	23.27 – 37.89	4.29 ± 0.48	3.70 – 5.18
Kesikköprü Village-1	12	10.70 ± 1.58	7.90 – 12.35	62.50 ± 0.49	55.01 – 70.02	23.10 ± 2.40	17.20 – 25.35	31.54 ± 2.76	27.29 – 35.04	4.40 ± 0.61	3.62 – 5.36
Kesikköprü Village-1	10A	6.91 ± 1.52	4.15 – 9.01	54.21 ± 6.71	43.31 – 69.96	23.43 ± 3.79	15.45 – 28.55	22.46 ± 1.72	19.86 – 25.27	3.94 ± 0.59	2.95 – 5.35
Kesikköprü Village-1	10B	14.92 ± 4.15	9.70 – 21.50	98.80 ± 1.29	73.00 – 110.0	24.74 ± 2.03	20.98 – 27.60	29.19 ± 3.14	25.01 – 34.47	4.93 ± 0.84	3.88 – 6.10
Kesikköprü Village-1	7A	11.52 ± 4.67	6.95 – 22.95	66.10 ± 0.62	60.02 – 75.00	25.68 ± 3.21	20.49 – 32.81	22.22 ± 2.10	19.40 – 26.42	5.15 ± 0.87	3.86 – 6.95
Kesikköprü Village-1	8B	2.63 ± 0.50	1.98 – 3.40	38.78 ± 5.14	30.48 – 47.78	13.38 ± 1.20	11.24 – 15.23	22.73 ± 2.28	19.47 – 25.74	3.06 ± 0.20	2.64 – 3.43
Kesikköprü Village-1	9A	4.31 ± 1.43	2.55 – 6.50	35.70 ± 6.62	27.85 – 45.25	18.97 ± 2.44	15.39 – 22.17	25.47 ± 2.12	22.06 – 29.57	3.87 ± 0.44	2.97 – 4.27
Kesikköprü Village-1	9B	1.80 ± 0.37	1.20 – 2.35	42.01 ± 3.86	34.05 – 47.26	11.16 ± 2.38	9.24 – 17.37	23.14 ± 1.80	18.71 – 25.20	2.94 ± 0.49	2.15 – 3.65
Kesikköprü Village-2	13	4.14 ± 0.80	3.20 – 5.50	47.80 ± 0.60	45.00 – 60.00	17.04 ± 1.71	14.75 – 19.78	24.90 ± 4.17	16.39 – 29.52	3.43 ± 0.30	2.85 – 3.71
Kesikköprü Village-2	14	4.73 ± 1.02	3.50 – 6.15	34.67 ± 3.90	29.71 – 44.01	20.38 ± 2.93	17.04 – 24.60	18.54 ± 4.03	15.02 – 29.04	4.24 ± 0.79	2.86 – 5.13
Kesikköprü Village-2	14A	3.28 ± 0.64	2.50 – 4.50	51.10 ± 1.00	40.01 – 70.02	17.25 ± 3.27	13.17 – 22.38	22.29 ± 1.50	19.94 – 24.85	3.80 ± 0.59	3.20 – 5.20
Kesikköprü Village-2	15A	10.65 ± 4.26	4.50 – 19.13	82.70 ± 1.01	60.02 – 100.0	21.95 ± 6.25	6.50 – 27.38	19.80 ± 3.17	11.50 – 22.44	4.83 ± 0.77	3.20 – 5.90
Kesikköprü Village-2	15B	7.11 ± 1.87	4.01 – 10.00	53.01 ± 0.79	45.00 – 70.02	17.27 ± 0.76	16.17 – 18.75	19.08 ± 1.98	15.62 – 21.59	4.53 ± 0.96	3.50 – 6.55
Elmalık Village	16	14.80 ± 2.19	11.26 – 19.00	42.46 ± 3.41	37.19 – 47.06	35.80 ± 2.72	31.91 – 39.36	25.27 ± 2.49	21.26 – 29.22	4.81 ± 1.02	3.36 – 6.62
Elmalık Village	17	1.98 ± 0.42	1.35 – 2.93	68.02 ± 1.03	50.01 – 80.00	7.81 ± 0.80	6.65 – 9.46	35.48 ± 4.14	25.84 – 41.26	3.49 ± 0.59	2.68 – 4.15
Elmalık Village	16A	4.26 ± 1.20	2.80 – 6.90	52.09 ± 6.01	44.01 – 63.80	14.03 ± 2.26	10.45 – 19.09	29.23 ± 2.55	25.59 – 34.13	4.50 ± 0.89	3.50 – 6.07
Elmalık Village	16B	3.05 ± 0.65	2.25 – 4.00	64.50 ± 0.64	60.01 – 75.02	9.06 ± 0.95	7.49 – 10.41	27.23 ± 3.17	22.23 – 33.17	3.86 ± 0.27	3.52 – 4.22
Elmalık Village	16C	4.73 ± 1.19	3.25 – 6.95	30.02 ± 3.96	24.07 – 37.42	18.53 ± 1.22	16.44 – 20.63	22.30 ± 2.14	17.95 – 25.07	3.88 ± 0.46	2.89 – 4.55
Elmalık Village	16D	2.98 ± 0.79	2.15 – 4.78	40.60 ± 0.45	35.01 – 50.02	14.26 ± 1.40	11.53 – 16.54	26.11 ± 3.41	20.83 – 33.51	4.16 ± 0.76	3.26 – 5.89
Elmalık Village	16E	3.45 ± 0.79	2.70 – 4.90	22.95 ± 1.79	20.50 – 25.51	16.53 ± 1.87	13.53 – 19.12	17.42 ± 2.04	14.66 – 20.16	3.97 ± 0.52	3.24 – 4.72
Alçılı Village	21	7.29 ± 2.00	4.55 – 10.03	56.40 ± 0.68	49.10 – 70.02	22.16 ± 4.20	16.70 – 29.35	19.27 ± 2.56	14.75 – 23.51	4.99 ± 0.47	4.28 – 5.80
Alçılı Village	23	10.13 ± 2.82	6.85 – 15.40	34.75 ± 6.59	26.38 – 45.89	28.61 ± 3.37	24.02 – 34.58	18.62 ± 2.91	12.86 – 23.14	5.59 ± 1.19	4.25 – 8.04
Alçılı Village	25	3.77 ± 1.13	2.15 – 5.50	38.21 ± 3.61	31.87 – 45.65	19.49 ± 3.55	14.09 – 26.23	23.21 ± 2.24	19.10 – 26.43	5.02 ± 0.57	4.20 – 5.96
Alçılı Village	27	2.44 ± 0.28	2.10 – 2.96	42.89 ± 5.23	35.16 – 52.90	14.03 ± 1.77	11.92 – 16.68	23.90 ± 2.47	19.73 – 27.64	3.40 ± 0.70	2.40 – 4.62
Alçılı Village	28	4.25 ± 0.92	3.15 – 5.65	28.53 ± 2.84	23.81 – 32.90	25.29 ± 2.32	22.66 – 28.86	21.72 ± 2.97	16.31 – 26.68	4.56 ± 0.61	3.79 – 5.62
Alçılı Village	29	2.31 ± 0.54	1.40 – 2.98	41.97 ± 4.05	36.33 – 48.51	12.26 ± 1.32	10.79 – 14.63	24.95 ± 2.51	20.87 – 30.04	3.24 ± 0.87	1.76 – 5.12
Alçılı Village	21A	9.03 ± 3.02	5.40 – 14.00	41.38 ± 7.45	29.04 – 53.94	24.95 ± 2.73	20.98 – 29.05	22.54 ± 3.25	17.70 – 28.58	4.70 ± 0.57	3.52 – 5.36
Alçılı Village	21C	5.32 ± 1.59	3.16 – 9.15	37.38 ± 4.29	31.40 – 42.86	25.46 ± 3.50	22.55 – 34.37	15.27 ± 1.54	13.36 – 18.60	4.61 ± 0.60	3.64 – 5.55
Alçılı Village	27B	2.87 ± 0.35	2.55 – 3.66	62.00 ± 0.71	55.01 – 75.00	13.21 ± 2.43	8.91 – 15.94	31.65 ± 3.91	24.38 – 37.70	4.20 ± 0.97	3.11 – 6.25
Alçılı Village	28A	2.40 ± 0.59	1.78 – 3.85	45.03 ± 3.75	39.79 – 50.32	14.57 ± 1.53	12.08 – 16.54	29.95 ± 1.71	27.28 – 32.53	3.68 ± 0.57	2.77 – 4.72

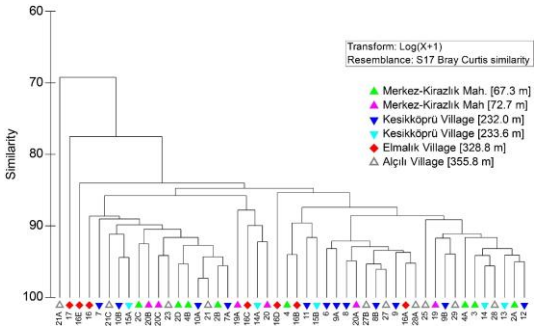

Figure 3. A dendrogram depicting the relationships among characterised pepper (*Capsicum annuum* L.) genotypes based on combined data: quantitative and qualitative trait.

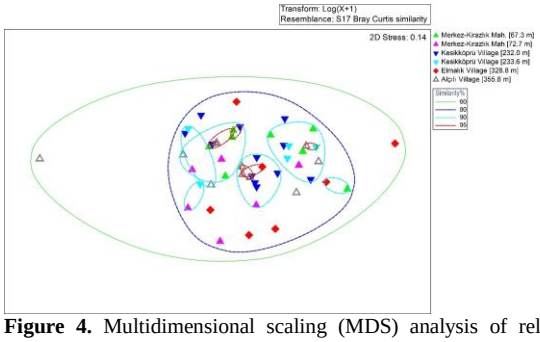

Figure 4. Multidimensional scaling (MDS) analysis of relationships among characterised pepper (*Capsicum annuum* L.) genotypes using quantitative and qualitative trait.

DISCUSSION

The assessment and description of trait variations in *C. annuum* from the Eastern Black Sea region of Türkiye have received little attention, resulting in limited documentation in the existing literature regarding the various genotypes of *C. annuum* from this specific geographical area. Evaluation and description of trait variations are vital steps in the commencement of programmes aimed at identifying genotypes that yield high quantities and possess qualities that appeal to consumers (Bozokalfa et al., 2009; Gündüz & Özbay, 2018; Bedjaoui et al., 2022). The quantitative and qualitative characteristics of 48 different genotypes of *C. annuum* collected from local farmers in Rize province showed considerable variations strongly regulated by genotype. Several studies have shown that fruit quality is strongly regulated by genetic factors, whereas geographical origin or growing altitude has a lesser effect on fruit quality (Gündüz & Özdemir, 2014; Gündüz & Özbay, 2018). The association between geographic distance and genetic similarity is not consistently clear (Sonnante & Pignone, 2007). The genetic variability observed among the studied

genotypes is likely influenced by their geographical origins, suggesting that the specific regions from which these genotypes originate may have had a significant impact on their genetic diversity and traits (Geleta et al., 2005).

The considerable variation observed in the present study indicates substantial potential for the development of pepper varieties tailored to various processing needs, including drying, pepper paste and hot sauce production, capsaicin extraction, and pickling (Zewdie & Zeven, 1997; Bozokalfa et al., 2009). This study also demonstrated that fruit colour also ranged from red to yellow, growth habit ranged from prostrate to erect, and plant height ranged from short to tall, which is consistent with the results of Bozokalfa et al. (2009). PCA and hierarchical clustering have been shown to effectively identify key yield-attributing and quality traits (Del et al., 2007; Lahbib et al., 2012; Rana et al., 2014; Singh et al., 2020; Taş & Balkaya, 2021) . In this study, the first four principal components collectively explained approximately 67% of the total variance, capturing the majority of significant yield and quality traits. Fruit yield, length, and weight exhibited the highest positive vector loadings on PC1, PC2, and PC3, with values ranging from 0.6 to 0.8. These results align with those of Rana et al. (2014) and Singh et al. (2020), who also reported that fruit length, average fruit weight, and fruit yield per plant had the highest positive values. However, in contrast to these studies, fruit width in this study showed the highest negative loading on PC1 (-0.744), differing from the positive values observed by aforementioned studies. These findings underscore both the similarities and differences with earlier work, highlighting the complex interplay of morphological traits in determining yield and quality attributes.

In conclusion, this study demonstrated that *C. annuum* genotypes originating from the Eastern Black Sea region of Türkiye (specifically Rize) can be effectively categorised into a minimum of four distinct groups through hierarchical clustering analysis. Furthermore, analysis of variance for key traits such as fruit weight, fruit length, stalk length, and fruit width among *C. annuum* genotypes revealed a substantial degree of morphological diversity. This study revealed the genetic diversity and orphological variations among *C. annuum* genotypes sampled from local farmers, which should contribute to the selection of populations for future pepper breeding programmes.

REFERENCES

Bedjaoui, H., Boulelouah, N., Mehaoua, M. S., & Baississe, S. (2022). Exploring agro-morphological diversity of Algerian hot pepper (*Capsicum annuum* L.) accessions using multivariate statistics. *Emirates Journal of Food and Agriculture*, ***34*** (10), 836-849.

Bozokalfa, M. K., Esiyok, D., & Turhan, K. (2009). Patterns of phenotypic variation in a germplasm collection of pepper (Capsicum annuum L.) from Turkey. *Spanish Journal of Agricultural Research **(1)***, 83-95.

Coşkun, F., Alptekin, Y., & Demir, S. (2021). Reaction of Different Pepper (Capsicum annuum L.) Cultivars to Isolates of Verticillium dahliae Kleb. from Various Hosts . Yuzuncu Yıl University Journal of Agricultural Sciences , ***31 (4)*** , 838-846 . DOI: 10.29133/yyutbd.882449.

Del, E., Moreno Pérez, C., Cruz Álvarez, O., Avendaño Arrazate, C., Martínez Damián, M., & Peña Lomelí, A. (2007). Morphological variation in Guajillo chili pepper plants (Capsicum annuum L.). *Proceedings African Crop Science Conference*, ***8***, 327–332.

FAOSTAT. (2020). Food and agriculture data. *Crop Statistics. Available online: http://www. fao. org/faostat (accessed on 14 August 2020)*.

FAOSTAT. (2022). Green chili production in 2020; Crops/World Regions/Production Quantity/Green Chillies and Peppers from pick lists". UN Food and Agriculture Organization, Statistics Division (FAOSTAT). 2022. Retrieved 02 September 2023.

Gebhardt, S., & Thomas, R. (2002). *Nutritive value of foods. Home and garden bulletin, vol 72. USDA Agricultural Research Services, Washington, p 97*: US Department of Agriculture, Agricultural Research Service.

Geleta, L., Labuschagne, M., & Viljoen, C. (2005). Genetic variability in pepper (Capsicum annuum L.) estimated by morphological data and amplified fragment length polymorphism markers. *Biodiversity & Conservation, **14***, 2361-2375.

Gündüz, K., & Özbay, H. (2018). The effects of genotype and altitude of the growing location on physical, chemical, and phytochemical properties of strawberry. *Turkish Journal of Agriculture and Forestry, **42***(3), 145-153.

Gündüz, K., & Özdemir, E. (2014). The effects of genotype and growing conditions on antioxidant capacity, phenolic compounds, organic acid and individual sugars of strawberry. *Food chemistry, **155***, 298-303.

Güneş, A., Keçe, Y. M., & Beyzi, E. (2023). The Effects of Using Organic and Chemical Fertilizers on Yield and Yield Parameters in Different Pepper (Capsicum annuum L.) Varieties. *Gesunde Pflanzen*,***75***(5),1945-1952. DOI:10.1007/s10343-022-00811-2.

Karataş, A. (2022). Effects of different agro-industrial waste as substrates on proximate composition, metals, and mineral contents of oyster mushroom (Pleurotus ostreatus). *International Journal of*

Food Science & Technology, ***57***(3), 1429-1439. DOI:https://doi.org/10.1111/ijfs.15506

Kothari, C. R. (2000). *Research methodology: Methods and techniques. 2nd ed. Wishwa Prakashan, New Delhi 468pp*: New Age International.

Lahbib, K., Bnejdi, F., & El-Gazzah, M. (2012). Genetic diversity evaluation of pepper (Capsicum annuum L.) in Tunisia based on morphologic characters. *African Journal of Agricultural Research,* ***7***(23), 3413-3417.

Olutumise, A. I. (2022). Determinants of market participation and preference for production of pepper (Capsicum spp.) among farmers in southwest, Nigeria. *Heliyon,* ***8***(9), e10585. DOI:https://doi.org/10.1016/j.heliyon.2022.e10585

Rana, M., Sharma, R., Sharma, P., Bhardwaj, S., Kumar, S., Brar, S., Sharma, M., & Dogra, R. (2014). Studies on genetic variability and divergence in Capsicum for fruit yield and quality traits in North-Western Himalayas. *Ecology. Environment and Conservation,* ***21***, 429-435.

Singh, P., Jain, P., & Tiwari, A. (2020). Principal component analysis approach for yield attributing traits in chilli (Capsicum annum L.) genotypes. *Chemical Science Review and Letters,* ***9***(33), 87-91.

Sonnante, G., & Pignone, D. (2007). The major Italian landraces of lentil (Lens culinaris Medik.): their molecular diversity and possible origin. *Genetic Resources and Crop Evolution,* ***54***(5), 1023-1031.

Taş, K., & Balkaya, A. (2021). Determination of morphological variation by principal component analysis and characterization of the Capsicum chinense genetic resources. *Ekin Journal of Crop Breeding and Genetics,* ***7***(2), 86-105.

TÜİK (Turkish Statistical Institute). (2020). Crop production statistics. https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr. Last Accessed Date: 21 September 2023.

Vural, H., Eşiyok, D., & Duman, İ. (2000). Kültür Sebzeleri (Sebze Yetiştirme). Ege Üniversitesi Ziraat Fakültesi Bahçe Bitkileri Bölümü, İzmir: 394-408.

Zewdie, Y., & Zeven, A. (1997). Variation in Yugoslavian hot pepper (Capsicum annuum L.) accessions. *Euphytica,* ***97***, 81-89.