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Patterns of phenotypic variation in a germplasm collection of pepper (*Capsicum annuum* L.) from Turkey

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Abstract

Phenotypic diversity was assessed for quantitative and qualitative traits in a collection of pepper (*Capsicum annuum* L.) germplasm from different areas of Turkey. A total of 48 genotypes, including germplasm lines and commercial cultivars, were studied under field conditions at Izmir over two consecutive summers (2004 and 2005). All accessions were characterized for 67 agro-morphological traits from seedling emergence to crop maturity. Morphological data were subjected to principal components analysis followed by hierarchical agglomerative clustering. This provided seven groups based on morphological and agronomic properties. The first six principal components axes accounted for 54.29% of the variance among the 48 accessions and their lines. The greater part of variance was accounted for by traits such as fruit diameter, fruit weight, volume, fruit wall thickness, fruit productivity, and fruit soluble solid and dry matter content. The high diversity found in the collection showed its great potential for improving agronomic traits in pepper.

Additional key words: cluster analysis, genetic diversity, morphological characterisation, plant genetic resources.

Resumen

Patrones de variación fenotípica en una colección de germoplasma de pimiento (*Capsicum annuum* L.) de Turquía

En una colección de germoplasma de pimiento (*Capsicum annuum* L.) de Turquía se evaluó la diversidad fenotípica para caracteres cuantitativos y cualitativos. Se estudiaron en Izmir, en condiciones de campo, durante dos veranos consecutivos (2004 y 2005), un total de 48 genotipos, incluyendo líneas de germoplasma y cultivares comerciales. Todas las accesiones fueron caracterizadas para 67 caracteres morfológicos, desde la emergencia de las plántulas hasta la madurez del cultivo. Los datos morfológicos fueron sometidos a un análisis de componentes principales seguido de un agrupamiento jerárquico aglomerativo, que produjo siete grupos basados en las propiedades morfológicas y agronómicas. Los primeros seis ejes (componentes principales) representaron el 54,29% de la varianza entre los 48 genotipos. La mayor parte de la varianza estuvo representada por caracteres tales como diámetro de fruto, peso del fruto, volumen, espesor de la pared del fruto, productividad del fruto, y contenido de sólidos solubles y materia seca del fruto. La alta diversidad encontrada en la colección muestra su gran potencial para la mejora de caracteres agronómicos en pimiento.

Palabras clave adicionales: análisis cluster, caracterización morfológica, diversidad genética, recursos genéticos vegetales.

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Abbreviations used: AARI (Aegean Agricultural Research Institute), ACHRI (Atatürk Central Horticultural Research Institute), AFLP (amplified fragment length polymorphism), AVRDC (Asian Vegetable Research and Development Center), CATE (Tropical Agricultural Research and Training Centre), IPGRI (International Board for Plant Genetic Resources), PCA (principal component analysis), RAPD (random amplified polymorphic DNA), RFLP (restriction fragment length polymorphism).

Introduction

Pepper (*Capsicum* spp.) is one of the world's major vegetable and spice crops (Zewdie *et al.*, 2004). Csillery (2006) indicates that the first competent description of *Capsicum* was given in *Hungarian Herbal* by Dioszegi and Fazekas (1807), who used the nomenclature of Linnaeus to describe *C. annuum* (paprika, the Turkish pepper) and *C. sinense* (later *C. chinense*; the Chinese pepper). Pepper belongs to the family *Solanaceae* and includes 30 known species (Bosland and Votava, 2000). It is thought to originate from South America and has spread throughout the world, including the tropics, subtropics and temperate regions (Pickersgill, 1997). Peppers are tender perennials when grown in their native habitats. Of the 30 species included in the *Capsicum* genus, only five - *C. annuum, C. baccatum C. chinense, C. frutescens,* and *C. pubescens* - have been domesticated and cultivated.

Pepper is a very important crop in Turkey, where it has been cultivated for centuries; both hot and sweet varieties are grown. The country produces 410,000 tonnes of bell and 1,340,000 tonnes of long green peppers with an annual increase in production of about 4-10%. Ninety percent of the peppers produced are marketed fresh; the remaining 10% are processed (Abak, 1994). The most important processed forms of pepper are pepper paste, paprika and spice. Red sweet pepper is mainly used in the paste industry, while very hot and sweet peppers are used in the spice industry. The southern and southeastern cities of Turkey are the most important sources of red pepper for spices (Abak, 1994). However, it is not clear how peppers found their way into the country. Andrews (1999) suggests several possibilities, although the most accepted hypothesis is that in the 15th and 16th centuries they reached Istanbul from Portuguese East Africa and India, arriving via Arab Middle Eastern trade routes.

Turkey is one of the most important nations in the world for pepper genetic resources, and the large numbers of cultivars grown around the country provide an important source of variation for plant breeding. A number of accessions have been collected from different regions of Turkey (Anonymous, 2007) for this very reason, but no systematic study has ever been undertaken to investigate the extent of genetic variation nor the relationships between different Turkish pepper genotypes.

Most pepper cultivars currently grown in Turkey are open pollinated. Some local pepper landraces are still grown on many small farms due to consumer demand. For decades these have been cultivated in different environments and using different growing techniques. In general, they are genetically diverse and well adapted to the locations where they have been developed (Votava *et al.*, 2005). Although pepper plants are considered autogamous (Allard, 1960), high rates of cross pollination (7% to 90%) have been recorded in several studies, and cross pollination events could change the genetic identity of these landraces. Further, given the importance of commercial pepper production in Turkey, many growers have turned away from the traditional cultivars towards new, higher yielding cultivars that produce fruit suitable for processing. Certainly, hybrid varieties are used for greenhouse production.

Estimating genetic diversity and determining the relationships between germplasm collections helps ensure germplasm is efficiently collected and managed. Data on the level of genetic diversity of a germplasm collection may also increase the efficiency of efforts to improve a species (Geleta *et al.*, 2005). Plant breeders can use genetic similarity information to complement phenotypic information in the development of breeding populations (Nienhuis *et al.*, 1993; Greene *et al.*, 2004; Yüzbaşıoğlu *et al.*, 2006). The total seed protein content, isoenzyme profiles, and several types of molecular marker can be used to determine the variability and relationships among accessions (Rabbani *et al.*, 1998), and, indeed, *Capsicum* species has been analysed using morphological, cytogenetic and molecular markers (employing restriction fragment length polymorphism [RFLP], random amplified polymorphic DNA [RAPD], and amplified fragment length polymorphism [AFLP] techniques) (Conicella *et al.*, 1990; Lefebvre *et al.*, 1993, 2001; Zewdie and Zeven, 1997; Geleta *et al.*, 2004).

However, morphological characterisation is the first step in the description and classification of germplasm (Smith and Smith, 1989). The main aim of this study was to analyse the morphological and agronomic traits of Turkish pepper accessions collected from different parts of the country in order to assess their genetic diversity.

Material and methods

The experimental material included samples of 48 landraces and cultivars of pepper grown in Turkey (Table 1): 30 accessions from the Aegean Agricultural Research Institute (AARI) (collected from different regions), 14 local cultivars (both hot and sweet types

widely used for fresh consumption and processing), and four cultivars from the US Chile Pepper Institute (sweet and hot peppers) (Table 1).

All experiments were conducted on a sandy-loam soil at Ege University, Faculty of Agriculture, Department of Horticulture in Bornova, Izmir Province Turkey

Table 1. List of pepper genotypes studied

Accession No./ Cultivar name	Province/Country	Collection site and altitude (m)	Local name
Genetic sources			
TR 40316	Sanlıurfa-Turkey	Suruç, 520	Acı dolma biber
TR 40299	Gaziantep-Turkey	Oğuzeli, 680	Dolmalık acı biber
TR 40272	Gaziantep-Turkey	Kilis, 625	Yerli biber kurutmalık
TR 40343	Şanlıurfa-Turkey	Tülmen köyü, 580	Kurutmalık büyük biber
TR 40490	Van-Turkey	Şehir merkezi, 1630	Biber
TR 45880	Kars-Turkey	Tuzluca, 1000	Dolma biber
TR 48614	Gaziantep-Turkey	Oğuzeli-Havuçluçam, 550	Salçalık biber
TR 48945	Tokat -Turkey	Reşadiye-Soğukpınar, 660	Acı biber
TR 48948	Şanlıurfa-Turkey	Siverek, 400	Dolmalık biber
TR 52300	Kars-Turkey	Iğdır-Akveyis köyü, 850	Acı biber
TR 61634	Muğla -Turkey	Yaraş köyü, 650	Arnavut biberi
TR 62374	Çanakkale-Turkey	Kepen Aşağıokçular köyü, 70	Acı çiçek biberi
TR 62670	Manisa -Turkey	Gördes, 450	Acı biber siyah
TR 62777	Izmir-Turkey	Dikili, 15	Biber salçalık
TR 66097	Eskişehir-Turkey	Orhangazi-Bakırköy, 1020	Acı biber
TR 66278	Bilecik-Turkey	Osmaneli- Büyükyenice köyü, 240	Acı toz biber
TR 66299	Bursa-Turkey	M.Kemalpaşa- Behram köyü, 50	Acı çiçek biberi
TR 66392	Bilecik-Turkey	Kayınbeli köyü, 250	Çok acı saksı biberi
TR 66406	Bursa-Turkey	Orhangazi –Bakırköy, 200	Çiçek biberi yuvarlak acı
TR 66656	Isparta-Turkey	Şakirkocaağaç Feleç köyü, 1220	Acı Çin biberi
TR 66678	Isparta-Turkey	Sütçüler Karadiken, 1080	Acı biber
TR 68464	Sakarya-Turkey	Gevye- Umurbey, 191	Beyaz acı biber
TR 68485	Sakarya-Turkey	Karasu- Karapınar köyü, 25	Acı biber
TR 69068	Konya-Turkey	Çumra- Yeniköy, 965	Acı yaprak biber
TR 69070	Konya -Turkey	Çumra-Yeniköy, 965	Acı küt biber
TR 69110	Antalya-Turkey	Demre-Yavu köyü, 420	Büyük cin biber
TR 69119	Aksaray-Turkey	Güzelyurt-Ihlara, 1250	Acı uzun biber
TR 69128	Aksaray-Turkey	Gülağaç merkez, 1025	Acı biber
TR 69723	Kırşehir-Turkey	Akpınar merkez, 1020	Acı sivri biber
TR 69724	Kırıkkale-Turkey	Keskin-Ortasöken, 725	Cin biberi
Local cultivars		***Seed source***	***Cultivar names***
Neobi ege acı sivri	Turkey	Istanbul Seed	Acı sivri
Istanbul acı ılıca	Turkey	Istanbul Seed	Acı sivri
Elitra ege acı sivri	Turkey	Elitra Seed	Acı sivri
Elitra acı sivri ılıca	Turkey	Elitra Seed	Acı sivri
Acı süs	Turkey	Toros Seed	Acı süs
Menderes acı kıl	Turkey	Toros Seed	Acı ince
Sarı sivri (Y. çorbacı)	Turkey	Yalova ACHRI	Çarliston
Yalova yağlık	Turkey	Yalova ACHRI	Yağlık
Yalova çarliston	Turkey	Yalova ACHRI	Çarliston
Tatlı kıl sivri	Turkey	Istanbul Seed	Tatlı sivri
Doruk dolmalık	Turkey	Istanbul Seed	Dolmalık
Yunan biberi	Turkey	Istanbul Seed	Turşuluk
Acı şahnalı	Turkey	Pinaper Seed	Acı sivri
Acı Süs	Turkey	Pinaper Seed	Acı süs
Foreign cultivars		***Seed source***	***Species***
Numex Primavera	USA	Chile Pepper Institute	*Capsicum annuum*
Numex Joe E. Paker	USA	Chile Pepper Institute	*Capsicum annuum*
Numex Jalmundo	USA	Chile Pepper Institute	*Capsicum annuum*
Jupiter	USA	Chile Pepper Institute	*Capsicum annuum*

(38° 28' N, 27° 15' E; altitude 25 m). The experiment was performed twice, once each in the summer of 2004 and 2005. Seeds were sown in soil under low-tunnel conditions on the 10th and 15th of March in 2004 and 2005 respectively. On the 15th and 25th of April (5 weeks after sowing, 3-4 leaf stage), seedlings were transplanted at a spacing of 40 x 75 cm.

The experimental design was a randomised complete block with three replicates; each plot consisted of 20 plants. Data were collected from 10 plants. Five unharvested plants were left to collect data regarding full fruit maturity, and five were left to reduce side effects. Each accession was evaluated. Some accessions showed very strong variation among genotypes, thus, in the first year 48 genotypes were examined but in the second 94 genotypes and germplasm lines were recognised and examined. Soil preparation, fertilization and plant protection were undertaken following the usual practices for pepper in Turkey (Vural *et al.*, 2000).

Data were collected on 67 morphological and physiological traits defined by the International Board for Plant Genetic Resources Descriptors for *Capsicum* (IPGRI, AVRDC and CATE, 1995) and more recent investigations (AOAC, 1995; Ngouajio *et al.*, 2003; Gibbs and O'Garo, 2004) (Table 2).

Genotype characteristics were recorded as quantitative or qualitative values as required. The methodology used to record qualitative values from seedling to harvest was obtained from the descriptor for *Capsicum* (IPGRI, AVRDC and CATE, 1995) (Table 2) (Zewdie and Zeven, 1997). Principal component analysis (PCA) was performed on all variables. Hierarchical agglomerative clustering was then performed on the principle component axes obtained, using the Ward criterion (Sneath and Sokal, 1973). This was preferred because it tends to produce compact clusters (Zewdie and Zeven, 1997). Within-cluster means and standard deviations of quantitative variables were calculated for ease of interpretation. All calculations were performed using STATISTICA software (Statsoft Inc., 2004).

Results

The quantitative and agronomic traits assessed showed wide variation. Among the agronomic traits, all the pepper genotypes examined had white hypocotyls with no pubescence. The cotyledon colour ranged from light to dark green. All had a yellow corolla except for TR 62374. No spots or stripes were seen on the corolla, the shape of which was rotate and campanulate. Stem colour was green for all genotypes; no anthocyanin was visible in the internodes or on the anther and stigma, except in TR 69723. No male sterility was seen nor were anthocyanin spots or stripes observed on fruit. The range of variation for most morphological traits was very large. For example, fruit shape ranged from pointed to sunken, and pointed fruit colour varied from lemon-yellow to red. The number of flowers per axil was usually one, only TR 62374 and TR 69068 had either one or two flowers per axil. These accessions are used for pickling.

PCA was used to examine the variation of the pepper genotypes. The first six axes accounted for 54.29% of the variability among the 48 accessions and their lines. Figure 1 provides a dendrogram for the studied accessions. The first axis was mainly related to variation in fruit diameter, fruit weight, fruit volume, edible fruit rate, wall thickness, and fruit soluble solid and dry matter contents (Tables 2, 3). The second axis was mainly concerned with pedicel length, fruit length and pH. The remaining eight axes were related to other fruit and plant traits (Table 3). The high total variance explained by the first three axes was shown in a 2D and 3D screen plot; each cultivar is plotted based on its principal components score (the cumulative proportion of variance) for each of the first three axes (Figs. 2 and 3).

To determine the hierarchical similarity among genotypes, a dendogram of genetic distance was made using the PCA data employing the Ward criterion (Fig. 1). Seven groups were obtained, mainly based on fruit shape and fruit agronomic traits.

Group A

This group contains 22 genotypes clustered into two subgroups. All these genotypes were obtained from the AARI, except for 'Acı süs' and 'Acı şahnalı', which are local cultivars. Group A fruits are used for either fresh consumption or processing, such as pickling or making hot sauce. The average fruit diameter of this group is 4.57 cm; fruits are small and narrow (average 1.66 cm) and the mean fruit weight is 6.28 g (Table 4). Fruit volume varies from 1.8 to 25.4 cm^3. Fruit colour is mainly dark green. The earliest flowering genotypes (56.8 days) belong to group A. The plants of least height (55.52 cm) but highest capsaicin content (62.67 mg $100g^{-1}$) also fall into group A. Compared to other groups, yields are moderate.

Table 2. Morphological and agronomic traits recorded in the *Capsicum annuum* accessions/cultivars

Character no.	Code	Character and descriptive value
Seedling stage		
1	HC	Hypocotyl colour: 1 = white, 2 = green, 3 = purple
2	HP	Hypocotyl pubescence: 3 = sparse, 5 = intermediate, 7 = dense
3	CLC	Cotyledon leaf colour. 1= light green, 2 = green, 3 = dark green, 4 = light purple, 5 = purple, 6 = dark-purple, 7 = variegated, 8 = yellow, 9 = others
4	CLS	Cotyledon leaf shape: 1= deltoid, 2 = ovate, 3 = lanceolate, 4 = elongated-deltoid
Vegetative characters		
5	SC	Stem colour: 1 = green, 2 = purple
6	NA	Anthocyanin on the nodes: 1 = green, 3 = light purple, 5 = purple, 7 = dark purple
7	SS	Stem shape: 1 = cylindrical, 2 = angled, 3 = flattened
8	SP	Stem pubescence: 3 = sparse, 5 = intermediate, 7 = dense
9	PH	Plant height at fruit ripening (red): measured in cm from soil level to highest point
10	PW	Plant width: measured in cm at widest point
11	PG	Plant growth: 3 = prostrate, 5 = compact, 7 = erect
12	SL	Stem length: measured in cm from soil level to first branch
13	SD	Stem diameter: widest point of stem (cm)
14	BH	Branching habit: 3 = sparse, 5 = intermediate, 7 = dense
15	LD	Leaf density: 3 = sparse, 5 = intermediate, 7 = dense
16	LC	Leaf colour: 1 = light green, 2 = green, 3 = dark green, 4 = light purple, 5 = purple, 6 = dark purple
17	LS	Leaf shape: 1 = deltoid, 2 = ovate, 3 = lanceolate
18	LM	Lamina margin: 1 = entire, 2 = undulate, 3 = ciliate
19	LL	Mature leaf length: measured in cm at the longest part of the leaf
20	LW	Mature leaf width: measured in cm at the widest point of the leaf
Inflorescence and fruit traits		
21	DTF	Days to flowering: from sowing to 50% of plants flowered
22	NF	Number of flowers per axil: 1 = one, 2 = two, 3 = three or more
23	PP	Pedicel position at anthesis: 3 = pendant, 5 = intermediate, 7 = erect
24	CC	Corolla colour: 1 = white, 2 = green white, 3 = lavender, 4 = blue, 5 = violate, 6 = other
25	CSC	Corolla spot colour: 1 = white, 2 = yellow, 3 = green-yellow, 4 = green, 5 = other, 9 = absent
26	CS	Corolla shape: 1 = rotate, 2 = campanulate, 3 = other
27	CL	Corolla length (mm)
28	AL	Anther length (mm)
29	FC	Filament colour: 1 = white, 2 = blue
30	FLL	Filament length (mm)
31	SPA	Stigma position in relation to anthers at full anthesis: 3 = included, 5 = same level, 7 = exerted
32	MS	Male sterility: 0 = absent, 1 = present
33	CP	Calyx pigmentation : 0 = absent, 1 = present
34	CMS	Calyx margin shape: 3 = smooth, 5 = intermediate, 7 = dentate
35	ACP	Annular constriction at junction of peduncle: 0 = absent, 1 = present
36	DF	Days to fruit maturity (day)
37	AF	Anthocyanin in ripe fruit: 0 = absent, 1 = present
38	FCL	Fruit colour at immature stage: measured Minolta CR-300 colorimeter L, a, b
39	FS	Fruit set: 3 = low, 5 = intermediate, 7 = high
40	FBP	Fruit bearing period (day)
41	FSP	Fruit shape: 1 = elongate, 2 = round, 3 = triangular, 4 = campanulate, 5 = blocky, 6 = other
42	FL	Fruit length (cm)
43	FWD	Fruit diameter (cm)
44	FP	Fruit position: 3 = declining, 5 = intermediate, 7 = dentate
45	FWG	Fruit weight (g)
46	FPL	Fruit pedicel length (cm)

Table 2. Continued

Character no	Code	Character and descriptive value
47	FWT	Fruit wall thickness (mm) was measured using a Mitutoyo (Kanawaga, Japan) digital micrometer
48	FPL	Fruit placenta length (mm)
49	PSP	Fruit shape at pedicel attachment: 1 = acute, 3 = obtuse, 5 = truncate, 7 = cordate, 9 = lobate
50	FSB	Fruit shape at blossom end : 3 = pointed, 5 = blunt, 7 = sunken
51	FCC	Fruit cross-sectional corrugation: 3 = slightly corrugated, 5 = intermediate, 7 = corrugated
52	FNL	Number of locules (chambers)
53	FSR	Fruit surface : 1 = smooth, 2 = semi-wrinkled, 3 = wrinkled
54	PL	Placenta length (cm)
55	VMC	Varietal mixture condition: 3 = slight, 5 = medium, 7 = serious
56	L	Fruit lightness measured in 25 fruit using a Minolta CR-300 (Osaka, Japan) colorimeter CIE L*a*b
57	HUE	Fruit colour was measured with a Minolta CR-300 colorimeter (Osaka, Japan) CIE L*a*b were calculated using the formula °H=tan-1(b/a)
58	CRM	Fruit colour measured with a Minolta CR-300 (Osaka, Japan) colorimeter CIE L*a*b and chroma were calculated using the formula C*=√(a2+b2)
59	TSS	The total soluble solids content in the juice was measured using a Atago refractometer (Tokyo, Japan)
60	pH	Fruit juice acidity was measured using a Mettler Toledo MP220 pH meter (Giessen, Germany)
61	FER	Edible fruit rate (%): the whole fruit was weighed, then the removed seeds and peduncle and the edible portions weighed separately. The percentage difference between whole fruit weight and that of the edible portion was then calculated.
62	DMC	Fruit dry matter content (%): the fruit pedicel was removed and dried in an oven at 65ºC until weight loss between measurements was <0.05 g. The percentage difference between the fresh and dry weights was used to calculate the dry matter content of the fruit.
63	CAP	Capsaicin content (mg/100 g) measured using a UV spectrophotometer (VARIAN, Cary, 100 Bio) (Gibbs and O'Garo, 2004)
64	VTC	The 2, 6-dichloroindophenol titration method (AOAC, 1995) was used to determine the ascorbic acid content of the fruit juice. Results were expressed as mg ascorbic acid/100 mL fruit juice.
65	FVL	Fruit volume was calculated as VF=1.1*D2*L*π*6, VF: fruit volume, D: fruit diameter, L: fruit length (Ngouajio *et al.*, 2003)
66	TA	Titratable acidity was measured by titration with 0.1 N NaOH to pH 8.1; the results were expres sed as mg citric acid 100 mL fruit juice.
67	YLD	Yield per hectare

Group B

Group B contains 15 genotypes clustered into two subgroups. All four foreign genotypes fell into this group, as did the local cultivar 'Yunan biberi', which in Turkish means Greek pepper. This seed is imported by international seed companies but it is strange that this genotype should fall in with foreign cultivars in the cluster analysis. The peppers of this group are mainly produced for the fresh market and are used in salads. The group B genotypes mainly produce either large or small block type fruit and have low capsaicin content. Although the dry matter content is low (9.56%), the yield is high (18160.3 kg ha^{-1}). The genotypes that belong to this group have the largest fruit volume (70.41 cm^3), the highest edible fruit rate (74.15%), and have a very dark colour. The genotypes with the lowest soluble solid content (6.10%) also belong to group B. Days to maturity is longer than in the other groups. The plants in this group have fruits with a thin wall (1.89 cm) and have a long fruit bearing period (99.36 days).

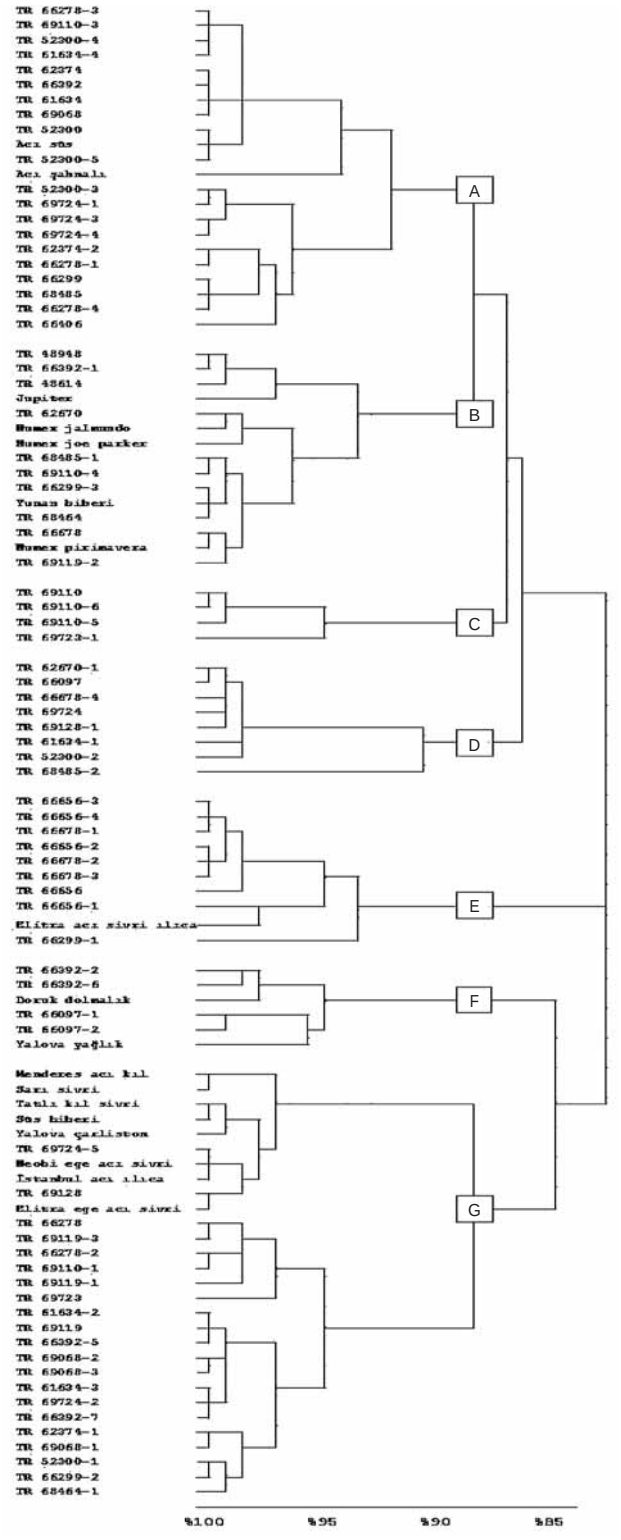

Figure 1. Dendogram for the 48 pepper genotypes/lines obtained from different regions of Turkey, produced by Ward's clusters analysis; clusters are based on morphological traits (scale: Euclidean distance).

Group C

This contains four genotypes from the AARI clustered into two subgroups, one with only one genotype. The fruits of group C are used for fresh consumption and pickling. On average these genotypes have fruits of diameter 2.07 cm, a weight of 14.07 g, a volume of 30.42 cm^3, a wall thickness of 1.89 cm, and a soluble solid content of 6.62%. The mean plant stem length of group C genotypes is 8.51 cm, and the leaves are large (width 4.38 cm, length 8.03 cm). In addition, the fruits are long (9.30 cm), dark green, the pedicel quite long (3.88 cm), and the leaves dark green in colour. The capsaicin content is 47.45 mg/100 g – Group C is the second placed group for capsaicin content.

Group D

Group D contains eight genotypes, all from the AARI, clustered into two subgroups. These genotypes are used for dry pepper production (the fruits are mainly ground). Turkey's climate is very suitable for sun-drying in the summer period, especially in southwest Anatolia. Group D genotypes are grown over large areas in this region. The fruit wall is thin (1.74 cm) and the mean fruit dry matter content is 14.20%. The highest capsaicin content is seen in this group (117.83 mg/100 g); capsaicin content is affected by genotype, environment (high temperatures and water deficit increase fruit capsaicin content), growing season, cultivation practices and fruit maturity stage. Thick-walled peppers take longer to sun-dry, and some of the outer skin can peel off. The members of group D also showed a high edible fruit rate (61.68%). The fruits are dark-light green colour.

Group E

Group E consists of 10 genotypes clustered into two subgroups. They are used at the green stage for salads or "dolma" (a traditional Turkish food prepared by stuffing peppers with rice, onion and other ingredients). Ripe, red ripe fruits are suitable for paste production (these peppers develop a good red colour). Fruit yield is high. The fruits are narrow, have a low fruit volume, and have a high soluble solid and dry matter content. The plants of this group have a characteristic compact growth, a long stem with a large diameter, and a long fruit bearing period. The highest vitamin C content (131.33 mg/100 g) is seen in this group.

Table 3. Eigen values and proportion of variance explained by the 10 principal components with respect to 48 pepper germplasm traits

	PC axis									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Eigen-values	4.19	3.25	2.42	2.41	2.04	1.97	1.52	1.25	1.21	1.2
Explained proportion of variation (%)	13.98	10.84	8.06	8.02	6.81	6.57	5.05	4.15	4.03	3.99
Cumulative proportion of variation (%)	13.98	24.82	32.88	40.9	47.72	54.29	59.34	63.49	67.53	71.52
Character	**Eigen vectors**									
Fruit diameter	0.92	-0.09	-0.02	-0.02	-0.13	0.00	0.03	-0.01	-0.02	-0.07
Fruit weight	0.91	0.05	-0.10	0.01	-0.02	0.11	0.08	0.03	0.00	0.03
Fruit volume	0.87	0.02	0.04	-0.01	-0.08	0.03	-0.03	-0.08	-0.03	-0.03
Fruit wall thickness	0.70	-0.04	-0.07	0.03	0.07	0.11	0.02	0.07	-0.23	0.17
Fruit edible rate	0.50	0.19	-0.08	0.31	0.24	-0.13	0.02	-0.28	0.21	0.16
Soluble solid content	-0.46	-0.39	0.17	0.09	0.11	-0.04	-0.27	-0.18	0.20	-0.13
Dry matter content	-0.45	-0.30	0.04	-0.18	0.08	0.07	-0.40	0.05	-0.08	0.33
Pedicel length	-0.04	0.86	0.09	0.01	0.15	0.19	-0.03	-0.16	-0.03	0.01
Fruit length	0.03	0.82	0.13	0.00	0.19	0.17	0.05	-0.24	0.04	0.15
pH	0.00	0.76	0.03	0.00	0.07	-0.03	0.00	0.09	-0.02	-0.05
Chroma	-0.23	0.23	0.87	-0.06	-0.04	-0.06	-0.05	0.12	0.08	-0.11
Lightness	-0.14	0.40	0.78	-0.08	0.00	-0.05	0.05	0.13	0.10	0.01
Hue	-0.20	0.24	-0.76	0.05	-0.22	-0.09	-0.08	0.05	-0.03	-0.07
Days to flowering	0.02	-0.02	-0.07	0.96	-0.01	0.12	-0.02	0.03	-0.07	-0.02
Fruit days to maturity	0.02	-0.02	-0.07	0.96	-0.01	0.12	-0.02	0.03	-0.07	-0.02
Ascorbic acid	0.03	0.01	0.00	0.55	0.15	0.02	0.12	0.04	0.47	0.24
Plant height	-0.25	0.24	0.16	0.04	0.71	0.04	0.05	-0.04	-0.12	-0.03
Plant stem length	0.09	0.28	-0.01	0.01	0.65	0.09	-0.35	-0.13	0.05	0.05
Plant width	-0.26	-0.08	0.09	0.04	0.57	-0.19	0.29	0.11	-0.13	0.02
Leaf width	0.24	-0.02	-0.33	-0.04	0.47	0.22	0.35	0.13	0.28	-0.08
Leaf length	0.31	0.18	-0.42	0.12	0.44	0.36	-0.04	0.22	0.16	-0.04
Filament length	0.01	-0.16	0.05	0.15	0.01	0.78	0.09	0.10	-0.32	-0.01
Corolla length	0.21	0.19	-0.10	0.17	0.11	0.67	0.08	0.04	0.11	-0.27
Peduncle length	-0.02	0.27	-0.02	0.00	-0.03	0.66	0.20	-0.16	0.12	0.17
Anther length	0.05	-0.03	0.04	0.04	-0.02	0.19	0.79	-0.05	-0.06	0.05
Yield	0.11	0.25	0.07	-0.16	0.29	0.21	0.42	-0.10	-0.07	-0.07
Plant stem diameter	-0.11	-0.22	0.10	0.11	-0.01	0.04	-0.12	0.76	0.09	0.12
Titratable acidity	-0.23	-0.50	-0.05	0.06	-0.05	0.12	-0.13	-0.51	0.11	0.01
Fruit bearing period	-0.27	-0.11	0.18	-0.10	-0.16	-0.05	-0.15	0.04	0.72	-0.01
Capsaicin content	0.10	0.08	-0.01	0.05	-0.02	-0.05	0.01	0.09	0.05	0.88

Group F

Group F includes six genotypes clustered into two subgroups. The fruit wall is 3.61 cm thick. These fruits have a large diameter and the highest fruit volume. These genotypes also have the highest edible fruit rate (74.34%), a soluble solid content of 6.55%, a very short 'days to flowering' value (56.97 days), but a longer 'days to maturity' value (84.04 days). They produce compact plants with long, wide leaves. The yield is some 16,850 kg ha^{-1}. The pungency of the fruit is medium. The titratable (0.17) acidity of these green-red fruits is low.

Group G

This group included 29 genotypes clustered into three subgroups. The second and third subgroup includes genotypes from the AARI collection. The genotypes in the first subgroup are all local cultivars except TR 69724-5 and TR 69128. The fruit of these genotypes are moderately pungent. Plants are quite tall (74.52 cm) but the fruit volume low (21.43 cm^3). The average soluble solid content is 6.73%. This mean dry matter content was the highest recorded (14.3%). Mean yield (17,340 kg ha^{-1}) and edible fruit rate (67.63%) are also high.

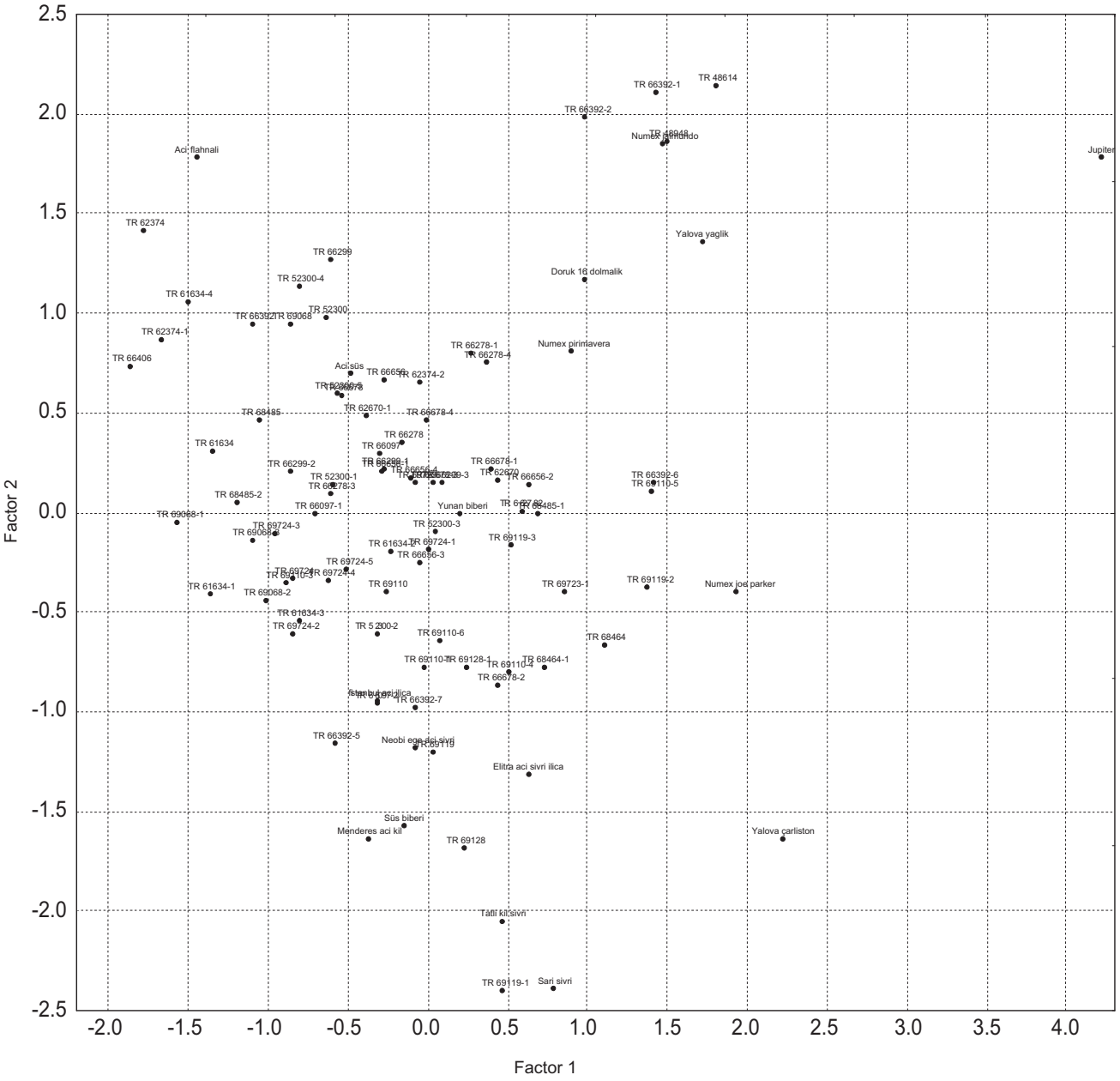

Figure 2. Relationships among Turkish pepper genotypes shown by a 2D scatter for first two principal components (based on morphological traits).

Discussion

The assessment and description of trait variation is important in the initiation of programs aimed at the selection of genotypes providing high yields and which have qualitative traits acceptable to consumers. The assessment of genetic variability among genotypes is useful for the conservation of genetic resources, for broadening the genetic basis of cultivars, and for cultivar protection (Yüzbaşıoğlu *et al.*, 2006). The degree of genetic diversity among cultivated crops depends on their reproductive behaviour (Geleta *et al.*, 2005). Lefebvre *et al.* (1993) noted that *C. annuum* is fairly variable compared to other self-pollinated species, and

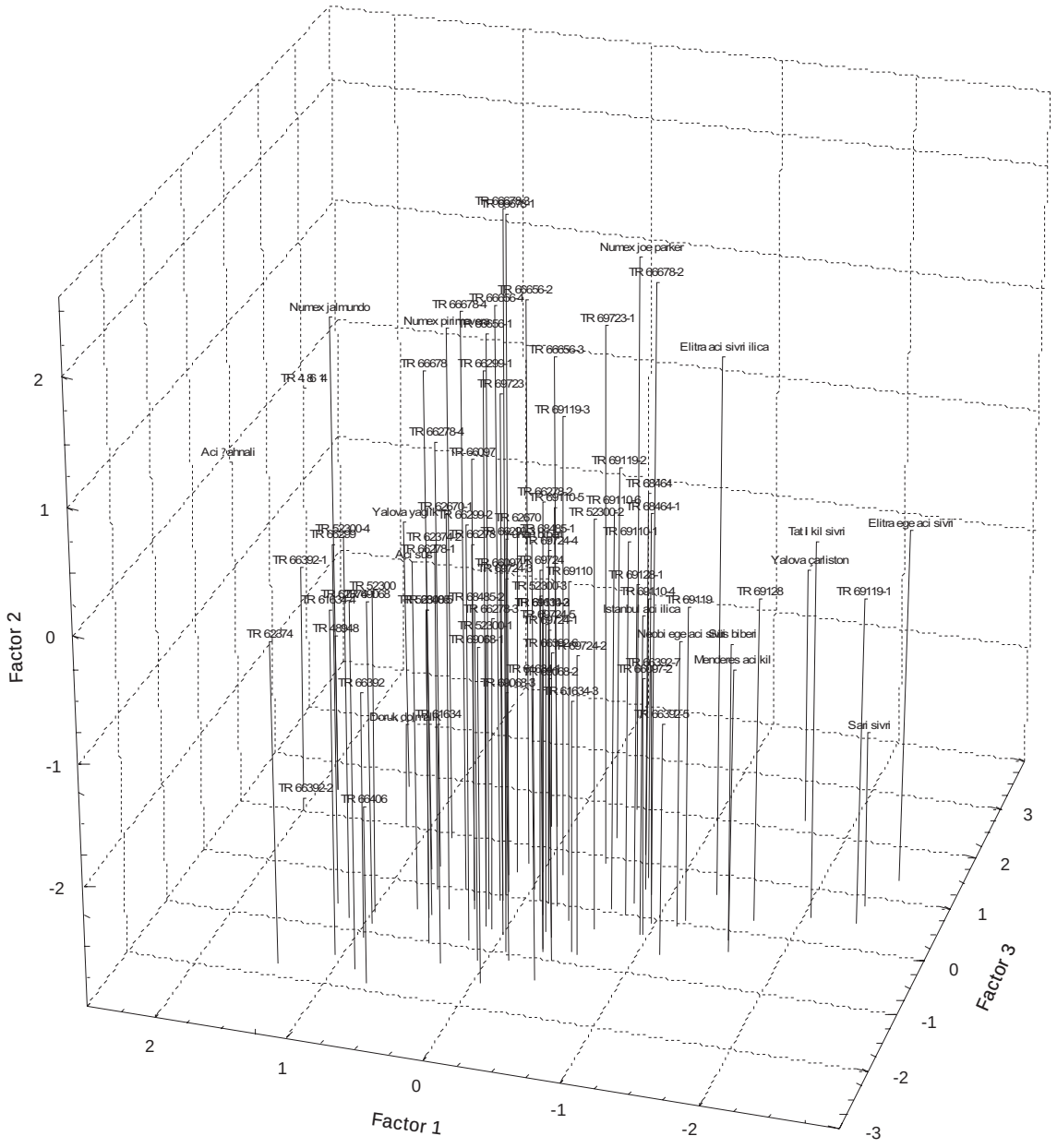

Figure 3. Relationships among Turkish pepper genotypes shown by a 3D scatter diagram of first three principal components (based on morphological traits).

also suggest this may be related to its reproductive behaviour. The association between genetic similarity and geographic distance among landraces is not always clear (Sonnante and Pignone, 2007). Geographical origin probably contributes to the genetic variability among the genotypes studied (Geleta *et al.*, 2005).

In general, qualitative traits may be expected to contribute to the clustering of genotypes, but the quantitative traits are of most interest here given their importance in improvement programs (Lotti *et al.*, 2007). The variation found in quantitative traits is useful for developing varietal descriptors and in variety identification. Since quantitative traits are of agronomic interest they are of much interest in improvement programs (Panthee *et al.*, 2004).

In the present study, the most representative variables for describing the phenotypic diversity of the genotypes were defined by PCA (Sneath and Sokal, 1973). Cluster

Table 4. Means and standard deviations of traits used in the classification of each of the seven pepper clusters

Character	Grouping in the cluster analysis													
	Group A		Group B		Group C		Group D		Group E		Group F		Group G	
Fruit diameter	1.66	0.80	3.57	1.79	2.07	1.35	1.90	0.64	1.46	0.57	4.57	2.74	1.63	0.61
Fruit weight	6.28	4.12	31.05	24.10	14.07	16.45	11.58	7.18	8.28	5.04	33.35	18.96	11.00	8.44
Fruit volume	12.82	13.56	70.41	59.49	30.42	39.31	23.02	25.97	9.73	10.09	118.83	121.10	21.43	20.05
Fruit wall thickness	1.77	0.40	2.70	0.81	1.89	0.71	1.74	0.23	1.90	0.35	3.61	2.50	1.89	0.43
Fruit edible rate	60.09	8.82	74.15	5.78	68.11	5.53	61.68	9.04	65.70	12.29	74.34	8.36	67.63	11.24
Soluble solid content	6.78	0.75	6.10	0.72	6.62	0.51	7.18	0.53	7.01	0.61	6.55	0.93	6.72	0.93
Dry matter content	13.78	3.70	9.56	3.02	10.07	2.86	14.20	2.40	13.51	2.91	11.14	1.03	14.30	4.52
Pedicel length	2.61	1.08	3.73	1.66	3.88	0.84	3.59	1.35	4.46	1.48	3.12	1.95	5.31	2.52
Fruit length	6.51	2.05	9.07	3.39	9.30	2.12	8.39	3.50	9.45	3.74	8.08	3.33	11.75	4.32
pH	5.78	0.18	5.90	0.25	5.74	0.11	5.77	0.18	5.84	0.23	5.67	0.27	5.96	0.27
Chroma	44.23	5.63	36.96	7.07	42.76	9.00	51.00	5.64	44.61	6.00	52.54	9.15	48.80	7.38
Lightness	55.86	6.40	52.88	10.86	53.18	8.16	62.28	5.77	55.22	5.22	64.48	12.68	61.72	7.67
Hue	115.75	7.53	120.78	7.75	116.65	10.02	109.98	5.45	114.95	4.10	79.37	32.86	112.57	6.89
Days to flowering	56.48	1.35	59.65	3.19	62.38	4.71	57.55	5.47	56.78	1.88	56.97	1.31	57.81	3.63
Fruit days to maturity	82.62	1.98	87.25	4.67	83.38	2.46	83.19	4.47	95.88	5.25	84.04	3.65	81.79	2.11
Ascorbic acid	87.61	34.94	114.92	40.04	118.10	14.97	141.93	19.46	131.33	30.32	107.47	18.88	99.04	31.92
Plant height	55.52	7.34	56.90	15.12	82.74	7.97	65.00	11.99	69.75	9.91	59.44	12.20	74.52	9.49
Plant stem length	2.90	1.22	6.52	3.85	8.51	10.84	7.85	3.26	7.71	3.18	8.96	3.40	10.13	5.38
Plant width	54.71	9.97	48.87	7.47	56.95	7.91	49.36	6.58	50.56	6.57	44.16	8.78	51.87	9.99
Leaf width	3.35	1.40	4.56	0.94	4.38	1.04	3.79	0.37	3.68	0.60	3.71	1.17	3.94	0.90
Leaf length	6.66	2.07	9.30	1.63	8.03	2.36	8.59	0.37	8.37	1.42	7.13	1.69	7.93	1.50
Filament length	0.51	0.18	0.54	0.12	0.50	0.08	0.56	0.08	0.73	0.25	0.55	0.08	0.52	0.08
Corolla length	0.74	0.21	0.93	0.18	0.79	0.13	0.99	0.19	0.94	0.24	0.77	0.12	0.83	0.20
Peduncle length	1.93	0.49	2.40	0.31	2.28	0.32	2.41	0.56	2.52	0.40	2.24	0.34	2.42	0.46
Anther length	0.50	0.19	0.57	0.14	1.26	0.56	0.54	0.09	0.53	0.06	0.52	0.07	0.53	0.10
Yield	14350	5250	18160	7970	19010	6950	14230	3210	17490	6620	16850	9560	17340	7660
Plant stem diameter	1.21	0.43	0.91	0.43	0.74	0.09	1.97	2.40	1.41	0.46	0.90	0.37	0.89	0.48
Titratable acidity	0.20	0.04	0.15	0.03	0.18	0.03	0.19	0.05	0.20	0.03	0.20	0.08	0.17	0.04
Fruit bearing period	92.35	3.00	99.36	6.29	97.88	1.99	97.19	6.47	98.02	9.25	99.29	5.12	97.68	6.97
Capsaicin content	62.67	23.58	42.01	24.77	47.45	22.50	117.83	33.49	33.42	18.60	42.41	42.73	42.53	21.95

analysis was then performed to establish groups; due to low Eigen vector values it would have been difficult to group genotypes based solely on the PC axes obtained. Lotti *et al.* (2007) reported no evident or significant groups among melon genotypes and variables transformed into new co-ordinates in a multi-dimensional space represented by six principal component axes. Peppers are classified into different commercial varieties based on fruit traits (Greenleaf, 1986; Geleta *et al.*, 2005). In this study, pepper genotypes with similar fruit characteristics clustered together.

This study also investigated the genetic variability and relationships among the clusters of these pepper resources. The dendogram obtained consisted of seven groups and a number of subgroups resulting from different morphological and agronomic traits. The range of variation for most morphological traits was large, including fruit wall thickness, fruit capsaicin content, and vitamin C content; these are affected by genotype, environment, growing season, growing practice and fruit maturing stage (Lindsay and Bosland, 1996; Martinez *et al.*, 2005). The level of variation found in the present collection shows there to be very high potential for developing pepper varieties for different processing purposes such as for drying, making pepper paste and hot sauce, capsaicin extraction, and pickling. Zewdie and Zeven (1997) report very large variation among Yugoslavian hot pepper accessions, and indicate their fruit size to range from small and circular to large and bell shaped. Fruit colour also ranged from red to yellow, growth habit ranged from prostrate to erect, and plant height from short to tall. Similar observations were made in the present work. The present study shows that the peppers distributed over the wide range of geogra-

phic conditions of Turkey show significant variation in terms of most of their morphological traits. Indeed, many of the lines observed showed properties different to those of their mother plants. The greater part of the variation was accounted for by the fruit diameter, fruit weight, fruit volume, fruit wall thickness, edible fruit rate, and the soluble solid and dry matter contents. Cluster analysis grouped together accessions with greater morphological similarity, as reported by Zewdie and Zeven (1997) who examined variation among hot pepper accessions. These authors indicate the distribution produced by cluster analysis in their work to be mainly a consequence of the number of fruits per plant, fruit weight, and 1000 seed weight.

Estimating genetic diversity and determining the relationships between collections are very useful strategies for ensuring efficient germplasm collection and management. Different markers, including the total seed protein content, isozyme profiles and several types of molecular markers, are available for studying variability among accessions (Rabbani *et al.*, 1998). Several techniques have been used to classify and measure the patterns of phenotypic diversity in the relationships of species and germplasm collections for a variety of crops. However, morphological characterisation is the first step in the description and classification of germplasm. Further information can then be obtained using DNA markers and molecular techniques. Geleta *et al.* (2005) described that both morphological traits and AFLP markers generally separate pepper genotypes according to fruit traits, and a significant positive correlation between the morphological data and AFLP marker-based matrices indicates that AFLP distances tend to reflect morphological distances. Lefebvre *et al.* (2001) indicated that relationships between molecular distances and phenotypic distances show that inbred lines with different phenotypes also differ in terms of their AFLP markers. Thus, a genotype can be easily discriminated with the use of phenotypic distances only (Geleta *et al.*, 2005).

In conclusion, this work shows that Turkish pepper genotypes can be divided into seven groups based on their morphological and agronomic traits. The analysis of variance carried out on these agronomic and morphological properties showed considerable morphological variation among pepper genotypes, a consequence of the introduction of different pepper genetic material to Turkey since the 16th century (Andrews, 1999).

Some genotypes that are interesting in terms of their capsaicin, dry matter and ascorbic acid contents, as well as for their fruit morphology, shape, and suitability for processing, are highlighted. The material investigated in this study indicates Turkey be very rich in pepper germplasm. Advantage could be taken of this diversity in breeding programs.

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References

ABAK K., 1994. Pepper production in Turkey, breeding programs and their objectives. Cap Eggp News 13, 31-35.

ALLARD R.W., 1960. Principles of plant breeding. Wiley, NY, USA.

ANDREWS J., 1999. The pepper trail: history and recipes from around the world. University of North Texas Press. Denton, Texas, USA.

ANONYMOUS, 2007. ECP/GR pepper database. Available in http://www.etae.gov.tr/capsicum/browse_capsicum_db.php.[10,01, 2007].

AOAC, 1995. Official methods of analysis. Association of Official Analytical Chemists, 16th ed. Arlington, Virginia, USA.

BOSLAND P.W., VOTAVA E.J., 2000. Peppers: vegetable and spice capsicums. CABI Publishing, Oxon, UK and New York.

CONICELLA C., ERRICO A., SACCARDO F., 1990. Cytogenetic and isozyme studies of wild and cultivated *Capsicum annuum*. Genome 33, 279-282.

CSILLERY G., 2006. Pepper taxonomy and the botanical description of the species. Acta Agron Hungarica 54, 151-166. doi:10.1556/AAgr.54.2006.2.5.

DIOSZEGI S., FAZEKAS M., 1807. Magyar füveszkönyv (Hungarian Herbal). Nyomtatta Csathy György Debreczenbenn [In Hungarian].

GELETA N., DABA C., GEBEYEHU S., 2004. Determination of plant proportion and planting time in maize-climbing bean intercropping system. Proc. 10th Annual Conference of the Crop Science Society of Ethiopia. pp. 176–182.

GELETA L.F., LABUSCHAGNE M.T., VILJOEN C.D., 2005. Genetic variability in pepper (*Capsicum annuum* L.)

estimated by morphological data and amplified fragment length polymorphism markers. Biodivers Conserv 14, 2361-2375. doi:10.1007/s10531-004-1669-9.

GIBBS H.A.A., O'GARO L.W., 2004. Capsicin content of West Indies hot pepper cultivars using colorimetric and chromatographic techniques. HortScience 39(1), 132-135.

GREENE S.L., GRITSENKO M., VANDEWARK G., 2004. Relating morphological and RAPD marker variation to collecting site environment in wild population of red clover (*Trifolium pratense* L.). Genet Resour Crop Evol 51(6), 643-653. doi:10.1023/B:GRES.0000024655.48989.ab.

GREENLEAF W.H., 1986. Pepper breeding. In: Breeding vegetable crops (Bassett M.J., ed), AVI, Westport, Connecticut, USA. pp. 67-134.

IPGRI, AVRDC and CATE, 1995. Descriptors for Capsicum (*Capsicum* spp.). International Plant Genetic Resources Institute, Rome, Italy.

LEFEBVRE V., PALLOIX A., RIVES M., 1993. Nuclear RFLP between pepper cultivars (*Capsicum annuum* L.). Euphytica 71, 189-199. doi:10.1007/BF0004040.

LEFEBVRE V., GOFFINET B., CHAUVET J.C., CAROMEL B., 2001. Evaluation of genetic distances between pepper inbred lines for cultivation protection purposes: comparison of AFLP, RAPD and phenotypic data. Theor Appl Genet 102, 741-750. doi:10.1007/s001220051705.

LINDSAY K., BOSLAND P.W., 1996. A field study of environmental interaction on pungency. Capsicum Eggplant News 14, 36-38.

LOTTI C., MARCOTRIGIANO A.R., DE GIOVANNI C., RESTA P., RICCIARDI A., ZONNO V., FANIZZA G., RICCIARDI L., 2007. Univariate and multivariate analysis performed on bio-agronomical traits of *Cucumis melo* L. germplasm. Genet Resour Crop Evol 55(4), 511-522. doi:10.1007/s10722-007-9257-y.

MARTINEZ S., LOPEZ M., RAURICH M.G., ALVAREZ A.B., 2005. The effects of ripening stage and processing systems on vitamin content in sweet peppers (*Capsicum annuum* L.). Int J Food Sci Nutr 56(1), 45-51. doi:10.1080/09637480500081936.

NGOUAJIO M., KIRK W., GOLDY R., 2003. A simple model for rapid and nondestructive estimation of bell pepper fruit volume. HortScience 38(4), 509-511.

NIENHUIS J., SLOCUM M.K., DEVOS D.A., MUREN R., 1993. Genetic similarity among *Brassica oleraceae* L. genotypes as measured by restriction fragment length polymorphisms. J Am Soc Hort Sci 118(2), 298-303.

PANTHEE D.R., RB K.C, REGMI H.N., SUBEDI P.P., BHATTARAI S., DHAKAL J., 2004. Diversity analysis of garlic (*Allium sativum* L.) germplasm available in Nepal based on morphological characters. Genet Resour Crop Evol 53, 205-212 doi:10.1007/s10722-004-6690-z.

PICKERSGILL B., 1997. Genetic resources and breeding of *Capsicum* spp. Euphytica 96, 129-133 doi:10.1023/A:1002913228101.

RABBANI M.A., IWABUCHI A., MURAKAMI Y., SUZUKI T., TAKAYANAGI K., 1998. Genetic diversity mustard (*Brassica juncea* L.) germplasm from Pakistan as determined by RAPDs. Euphytica 103(2), 235-242. doi:10.1023/A:1018304921526.

SMITH J.S.C., SMITH O.S., 1989. The description and assessment of distances between inbred lines of maize: the utility of morphological, biochemical and genetic descriptors and a scheme for the testing of distinctiveness between inbred lines. Maydica 34, 151-161.

SNEATH P.H.A., SOKAL R.R., 1973. Numerical taxonomy: the principle and practice of numerical classification. WH Freman and Co., San Francisco, USA.

SONNANTE G., PIGNONE D., 2007. The major Italian landraces of lentil (*Lens culinaris* Medik.): their molecular diversity and possible origin. Genet Resour Crop Evol 54, 1023-1031. doi:10.1007/s10722-006-9153-x.

STATSOFT, 2004. Statistica software, version 6.0. Statsoft, Inc., Tulsa, OK, USA.

VOTAVA E.J., BARAL B.J., BOSLAND P.W., 2005. Genetic diversity of Chile (*Capsicum annuum* var. *annuum* L.) landraces from Northern New Mexico, Colorado, and Mexico. Econ Bot 59(1), 8-17. doi:10.1663/0013-0001(2005)059[0008:GDOCCA]2.0.CO;2.

VURAL H., EŞIYOK D., DUMAN I., 2000. Kültür Sebzeleri (Sebze Yetiştirme). Ege Üniversitesi Matbaası, Bornova, İzmir [In Turkish].

YÜZBAŞIOĞLU E., ÖZCAN S., AÇIK L., 2006. Analysis of genetic relationships among Turkish cultivars and breeding lines of *Lens culinatis* Mestile using RAPD markers. Genet Resour Crop Evol 53, 507-514. doi:10.1007/ s10722-004-2030-6.

ZEWDIE Y., ZEVEN A.C., 1997. Variation in Yugoslavian hot pepper (*Capsicum annuum* L.) accessions. Euphytica 97, 81-89. doi:10.1023/A:1003028703431.

ZEWDIE T., TONG N.K., BOSLAND P.W., 2004. Establishing core collection of Capsicum using a cluster analysis with enlightened selection of accessions. Genet Resour Crop Evol 51, 147-151.doi:10.1023/B:GRES.0000020858.96226.38.