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The Morphological Diversity and Fruit Characterization of Turkish Eggplant (*Solanum melongena* L.) Populations

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ABSTRACT

Turkey is one of the most important countries in the world for plant genetic resources and genetic diversity. Genetic resources are characterized by morphological and agronomical traits. There is a need to collect, characterize and evaluate remnants of local populations before they disappear. Morphological characterization is the first stage of the identification and classification of genetic resources. In this study, the aim was to determine the similarities and differences in the morphological variations of the eggplant populations collected from different eco-geographical regions of Turkey. Seventy five populations of eggplant were characterized using standard morphological descriptors specified by the IBPGR. The phenotypic diversity in their fruit characters was also assessed. Cluster and Principal Component Analysis (PCA) was performed to determine the relationships among these accessions and to obtain information on the fruit characteristics for the definition of groups. The principal component analysis showed that the first four principal component axes explained 71.38% of the total multivariate variation. The results demonstrated many differences in fruit traits in the detailed eggplant populations. Clustered into nine groups, a dendrogram was prepared to evaluate the morphological differences among the populations. It revealed a high degree of variation. The results provided information on the diversity, and this identified eggplant genetic resources to be evaluated for the development of new candidate varieties in future breeding activities.

Keywords: *Solanum melongena,* genetic resources, characterization, classification, diversity, Turkey

Introduction

The eggplant (*Solanum melongena* L.) is a very important commercial vegetable crop. It is grown widely throughout tropical zones and in the temperate regions of the world. Eggplant production varies according to the country and continent. China and India are the major producers in the world. The eggplant is one of the most important *Solanaceae* vegetable crops in Turkey. The total eggplant production in Turkey was 827,830 tonnes and was ranked fifth in the world (TUIK 2016). Turkey is important producer country within Europe in terms of eggplant production.

The eggplant was first cultivated in India, which is regarded as the primary centre of origin and diversity (Kumar *et al*., 2013). La Malfa (1990), listed China as the secondary centre of diversification. The eggplant arrived in Europe around 1300, and the eggplant fruits were used as food after the sixteenth century (D'Anna and Sabatino 2013). The introduction of the eggplant to the west was primarily around the Mediterranean region, which is the secondary "domestication region" and covers Turkey, Syria and Persia (Küçük 2003; Daunay *et al*., 2001; Tümbilen 2007). Many local eggplant landraces are found in Turkey. These landraces are grown by producers in almost all regions (Balkaya and Karaagac 2005). These traditional landraces are an

important genetic resource for plant breeders because of their considerable genotypic variation.

Crop improvement to increase productivity has always relied on genetic diversity, and therefore, on the ability of the crop to adapt to soil and climate changes; it is due to this selection process, used by farmers over the years, that most of the biodiversity has been preserved (Schippmann *et al*., 2002). The local populations are genotypes of remarkable intrinsic value; their ability to adapt to their original environment could make them more suited to sustainable horticulture than hybrids and varieties created in different soil and climate conditions, and which often require higher energy inputs (D'Anna and Sabatino 2013). A morphological characterization is the first step in the description and classification of local genetic resources (Smith and Smith 1989). There was a need to characterize the eggplant populations collected so that they could then be used as lines for the development of new varieties.

Morphological identification using conventional descriptors has proved useful for describing and establishing relationships among local eggplant genetic resources in Turkey. Similar collecting studies have also been carried out in different regions of Turkey (Filiz and Özçalabı 1992; Pirinç 1999; Tümbilen 2007; Boyaci *et al*., 2010; Topcu 2014). According to these literatures, similarities and differences were found regarding morphological variations in eggplant genetic resources collected from different eco-geographical regions of Turkey. Conservation and maintenance of these valuable genetic resources are necessary because these populations are important sources of diversity that can be used in future breeding programs (Balkaya and Karaagac 2005).

Evaluation of genetic diversity is important to identify the source of genes for a particular trait within the available germplasm (Quamruzzaman *et al*., 2009; Karim *et al*,. 2016). There has been great morphological diversity observed in several characteristics among eggplant populations. To date, several traits have been used for evaluation of plant diversity. Fruit colour, fruit size, fruit shape and taste are the most noticeable traits, and differences were shown for each eggplant genotype (Daunay *et al*., 2001; Kashyap *et al*., 2003; Prohens *et al*., 2005; Tümbilen *et al*., 2011). The fruit of the eggplant is classified as a non-climacteric berry that can grow to various sizes, and in various shapes and colours depending on the genotype. Fruit colour can vary from white to black with variations in purple, yellow and green. Other variable fruit characteristics for eggplants are the fruit shapes (round, egg shaped, oblong, pear shaped, long and curved) and fruit sizes (Tümbilen 2007). In Turkey, small oblong or rounded fruit types are stuffed or preserved; long cylindrical types are grilled, fried or stuffed and large round or longish oblong types are stewed or fried (Tümbilen *et al*., 2011). The eggplant populations of Turkey showed a high variability in fruit sizes, fruit shape, fruit color and fruit weight (Tümbilen 2007). Unfortunately, this considerable variation is not adequately characterized. To date, there has been no detailed investigation of variations in the fruit traits of eggplant populations in Turkey. Therefore, the aim of this study was to analyse genotypic variations among seventy five populations of eggplant fruits in Turkey. These findings should also help with the selection of core collections and accessions that can be used for eggplant breeding in the near future.

Material and Methods

***Materials*:** This study used a total of seventy five eggplant populations of fruit and/or seeds collected from different regions of Turkey (Table 1, Figure 1). Forty accessions of the *S. melongena* populations were obtained from the USDA-ARS National Germplasm Bank, twenty accessions of the *S. melongena* populations were provided from the Turkish National Seed Gene Bank (AARI) and fifteen accessions of the *S. melongena* populations were collected by Prof. Dr. Ahmet Balkaya, of the Horticulture Department of the Faculty of Agriculture of Ondokuz Mayıs University (Table 1). The genetic material consisted of landraces and native populations maintained by farmers for generations.

Growth conditions: The field component of this study was carried out in the Samsun province in 2016 year. The soil of the experimental area was sandy loam with a pH of 6.5. The seeds of all populations were sown into plug trays containing peat and perlite (in the ratio 3:1) on April 16, 2016. Forty seedlings from each population were field planted at the 4 to 5 true leaf stage at a spacing of 60 × 40 cm on June 13. Soil tests were done before and after planting. Standard fertilization and weed control practices were applied.

Characterization: The plants were harvested manually at full maturity. The harvest period began at the end of July 17 and lasted until the middle of September, because the populations had different maturation periods. The selected fruit characteristics were described according to the IBPGR *Solanum melongena* descriptors list, the characteristics of the genetic material and previous field observations (Table 2).

All fruit characteristics were measured at the normal harvest time, and their scales are presented in Table 2. Fruit characteristic analyses were carried out on 10 fruits from each of the population of 40 plants. Fruit dimensions: length, width and fruit stalk length were all measured. The fruit weight in grams was the mean of a sample of 20 fruits, when fruits were at the optimal maturity stage for fresh consumption. To obtain a better description of the eggplant populations, fruit shape, fruit apex shape, fruit colour, colour distribution and fruit glossiness traits were also recorded.

Data analysis: Statistical analysis was performed using the statistical software package SPSS (21.0 for Windows). For a better overview of diversity in the local eggplant populations, Cluster analysis was also used. Hierarchical cluster analyses were performed using Ward's criteria, minimizing the total sum of the squared distances of objects to the cluster centres. Ward's criteria were preferred because they tend to produce desirable compact clusters (Zewdie and Zeven 1997). In the Principal Component Analysis (PCA) and the load coefficient values which relate the values, those principal components with eigenvalues >1.0 were selected and those characters with load coefficient values >0.6 were considered highly relevant characters cores for principal components (Jeffers 1967; Balkaya *et al*., 2009).

Results and Discussion

Principal Component Analysis (PCA) was used for revealing the general differences between genotypes as numerical values, which indicate the traits that could be used to differentiate between genotypes (Balkaya *et al*., 2010). In this study, a PCA was performed on eggplant populations that considered fruit characteristics that included 4 quantitative and 7 qualitative variables. The principal component axes accounted for 71.38% of the total multivariate variation among the detailed eggplant accessions. The first principal component axis accounted for 34.55% of the variation, whereas the second and third axes accounted for 16.76% and 10.8%, respectively (Table 3). The first three principal component axes explained 62.11% of the variation, suggesting considerable diversity among the fruit characters (Figure 2). In this study, traits with high coefficients in the first, second and the third principal components should be considered more important since these axes explain the biggest share of the total variation. Though clear guidelines do not exist to determine the significance of a character coefficient, one rule of thumb is to treat coefficients >0.6 as having a large enough effect to be considered important (Jeffers 1967; Balkaya *et al*., 2009). Characteristics with high coefficients are: fruit shape (0.87), fruit curvature (0.83), fruit apex shape (-0.82), fruit length (0.78) and fruit diameter (-0.61) for principal component 1; fruit glossiness (0.67) and fruit colour (0.64) for the second principal component, and fruit stalk length (0.66) for the third principal component. These traits are considered to be the most important, since they define the axes which explain 62.11% of the total variation (Table 3, Figure 2). Finally, principal component 4 was mainly related to fruit calyx prickles (0.75). Earlier results indicated that the Turkish eggplant populations could be distinguished by fruit shape, fruit curvature, fruit apex shape, fruit length and fruit diameter, which had the highest coefficients on the first principal component axis.

To better understand the overall diversity of the Turkish eggplant populations, the data were analysed by Cluster analysis that revealed the distribution of genetic diversity and is displayed in Table 4. In this study, cluster analysis grouped the populations into nine clusters. The related dendogram is shown in Figure 3. The means and standard deviations of some of the traits for each cluster are given in Table 4. Among the nine different groups, group F and group H were divided into five subgroups, group E into four subgroups, and groups A, C, D, and group G into three subgroups. Group B and group I were both divided into two subgroups (Figure 3). The nine groups and 30 subgroups can be considered to be distinct germplasm pools. This study shows that there is considerable morphological variability between the eggplant populations sampled. No association was observed for clusters within the collection zone (Table 1, Figure 3).

General fruit characteristics of the investigated Turkish eggplant populations are as follows:

Group A: This group consisted of three subgroups. There were a total of 18 populations in group A. The fruit diameter (8.05 cm) is very large compared to the other groups. Fruits are long, straight and have an ellipsoidal shape (Table 4). The fruit colours were purple to purple black tones. There were either no fruit calyx prickles or just a few levels. The average fruit weight in this group was 382.87 g, higher than all the other groups.

Group B: There were five populations in this group. It included two subgroups: a fruit length of 16.68 cm and a fruit diameter of 6.71 cm, ranking second out of all the groups. All populations have globular and ellipsoidal fruit shapes. The fruit colours

were purple-black to black tones. The fruit colour distribution was very uniform. The fruit stalk length of 7.72 cm was identified as an intermediate value. The average fruit weight in group B was 277.18 g and it was higher than any group except group A (Table 4).

Group C: This group consisted of nine populations. Genotypes in this group were clustered into three subgroups. Fruits in this group had the shortest lengths (16.52 cm). Fruits were globular and ellipsoidal in shape (Table 4). The fruit apex shape was depressed. There were no fruit calyx prickles. In this group, the fruit brightness exhibited was very shiny. The average fruit weight was found to be 241.51 g.

Group D: There were six populations in this group. The fruit lengths of the populations were short. All fruits were straight, ellipsoidal or cylindrically shaped. The fruit apex had a protruding shape. Fruit colours changed according to genotypes and were green, lilac and purple tones. The fruit stalk length was 7.90 cm, and this was identified as an intermediate value. The fruit brightness was identified as very shiny.

Group E: This group included fourteen populations. It had the biggest cluster of genetic groups. The fruits were long, but slightly curved or curved. This group had cylindrical and long cylindrical fruits (Table 4). The fruit apex had a protruding shape. Fruit colours were lilac, purple and purple-black tones. The fruit brightness was found to be shiny or very shiny. The average fruit weight was 225.88 g. The fruit stalk length was 6.93 cm and this value was identified as an intermediate value.

Group F: This group consisted of eleven populations. It had the second biggest cluster of all groups. Genotypes in this group were clustered into five subgroups. The fruit length was 27.27 cm. This value was the longest of all the groups (Table 4). The fruit diameter had the shortest widths (4.05 cm). All fruits had a long cylindrical shape. The fruit had a protruding apex shape. The fruit stalk length was long (8.39 cm) and the fruit colours were purple-black to black tones. The fruit colour distribution was very uniform.

Group G: This group included eight populations. It had the biggest cluster of genetic groups. The fruit length was 24.41 cm. The fruit length of this group was the second longest value of all the groups (Table 4).The fruits were cylindrical or had a long cylindrical curved shaped. The fruit stalk length was the longest (8.61 cm) of all the clusters. The fruit calyx prickles were either absent or only had a few levels. The average fruit weight in this group was 284.80 g and was higher than all the other groups, except for group A.

Group H: There were six populations in this group. The fruit length of the populations was long (21.52 cm). The fruit diameter of this group was the second widest value of all the groups (Table 4). The fruits were cylindrical or long and cylindrical. The fruit had a protruding or rounded apex shape. The fruit stalk length was 7.25 cm and this was identified as an intermediate value. The average fruit weight was 190.36 g and was the lowest among all groups (Table 4).

Group I: This group included three populations. It had the smallest cluster of genetic materials. The fruits were cylindrical or long and cylindrical. The fruit colour tone was lilac. The fruit colour distribution was mottled or striped, and the fruit stalk length was the shortest at 6.93 cm. There were many fruit calyx prickles found on very many levels.

The knowledge of the extent of genetic diversity, and the identification, differentiation and characterization of genotypes and populations, provides an information tool for the detection of duplicates in collections and also delivers better characterization and utilization in breeding (Hornokova *et al*., 2003). The clustering of eggplant genetic resources of Turkey on the dendogram in 9 separate groups resulted from their different morphological structure and special fruit characteristics. This study showed that there is considerable morphological variability because of the introduction of diverse eggplant genetic materials to Turkey from different countries. Cluster groups were not associated with the geographical origins of the eggplant genotypes. There is no clear relationship between clusters and the coastal or inland areas of Turkey (Table 1; Figure 2). In other research, it has been determined that there are many significant morphological differences between local eggplant genetic resources (Tümbilen *et al*., 2011). This absence of association may be a result of continuous conscious and unconscious seed transport by humans. Secondly, it may be a result of previous selection for different uses (Filiz and Özçalabı 1992; Pirinç 1999; Tümbilen 2007; Boyaci *et al*., 2010).

At the end of this study, we have found that genetic diversity within landraces and populations of eggplant is high, including variations in fruit shape, fruit weight, fruit size (length, diameter), fruit glossiness and the colour of fruits. Reliable information on characteristic variability within germplasm collections is very useful to breeders in planning eggplant variety improvement programs.

Conclusion

In conclusion, we have presented some fruit characteristics of eggplant populations grown in Turkey. In addition, the components of the fruit characteristics of *S. melongena* were demonstrated by applying multivariate techniques to the morphological data sets. Fruit traits proved useful in assessing the diversity and relationships of Turkish eggplant genetic resources.The current study revealed considerable diversity in some fruit characteristics of the eggplant populations. The potential use of Turkey's eggplant genotypes as genetic resources in breeding programmes was highlighted for further investigation. In addition all eggplant populations used for this study are also generated as inbred lines for variety breeding programs in another study.

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Figure 1. The view of the diversity fruit size, shape and color for Turkish *Solanum melongena* populations

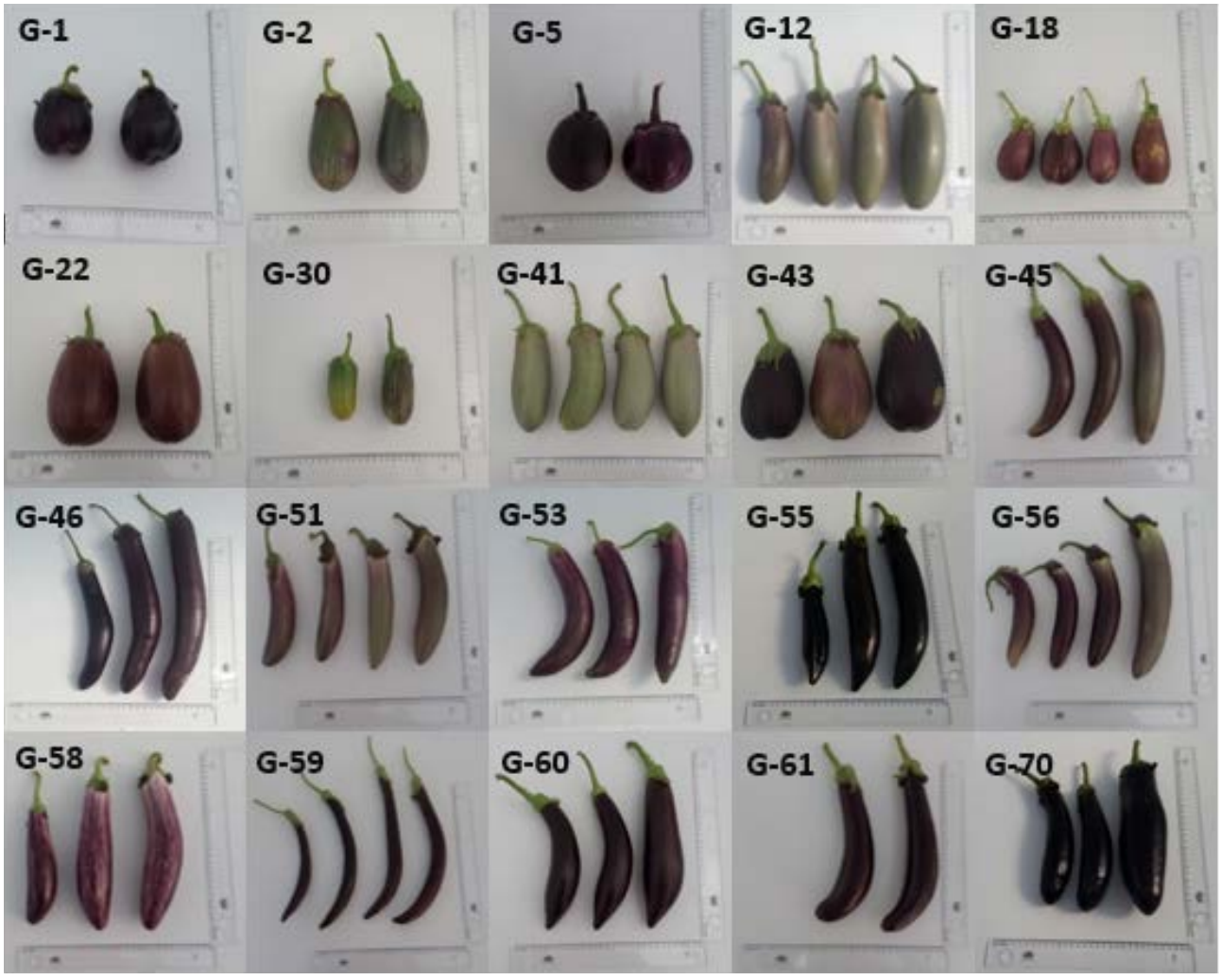

Figure 2. Scatter plot constructed at the basis the first three principal component axes, which contain 62.2% of total variation

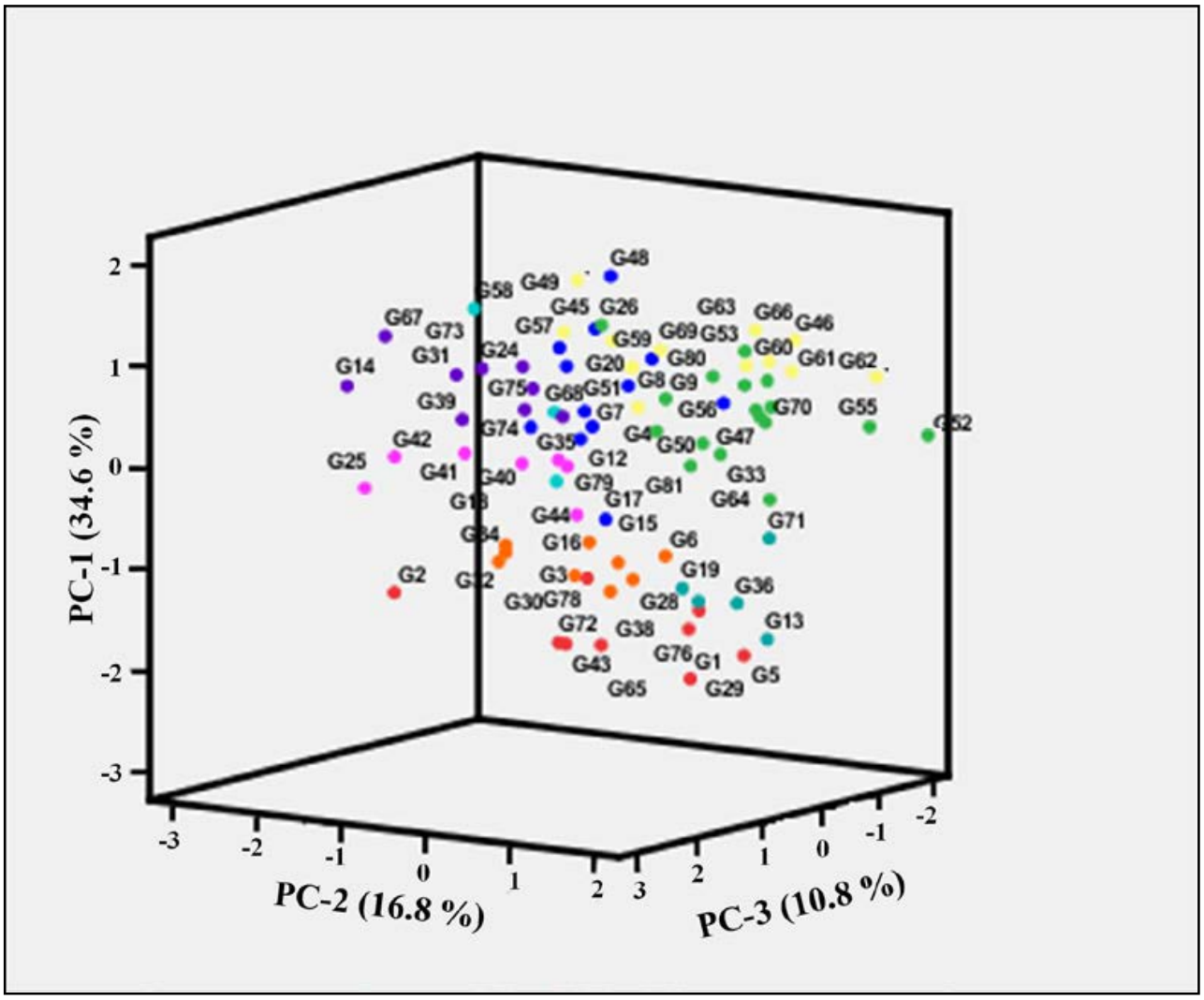

Figure 3. Dendrogram of eggplant populations obtained from cluster analysis of eleven fruit traits

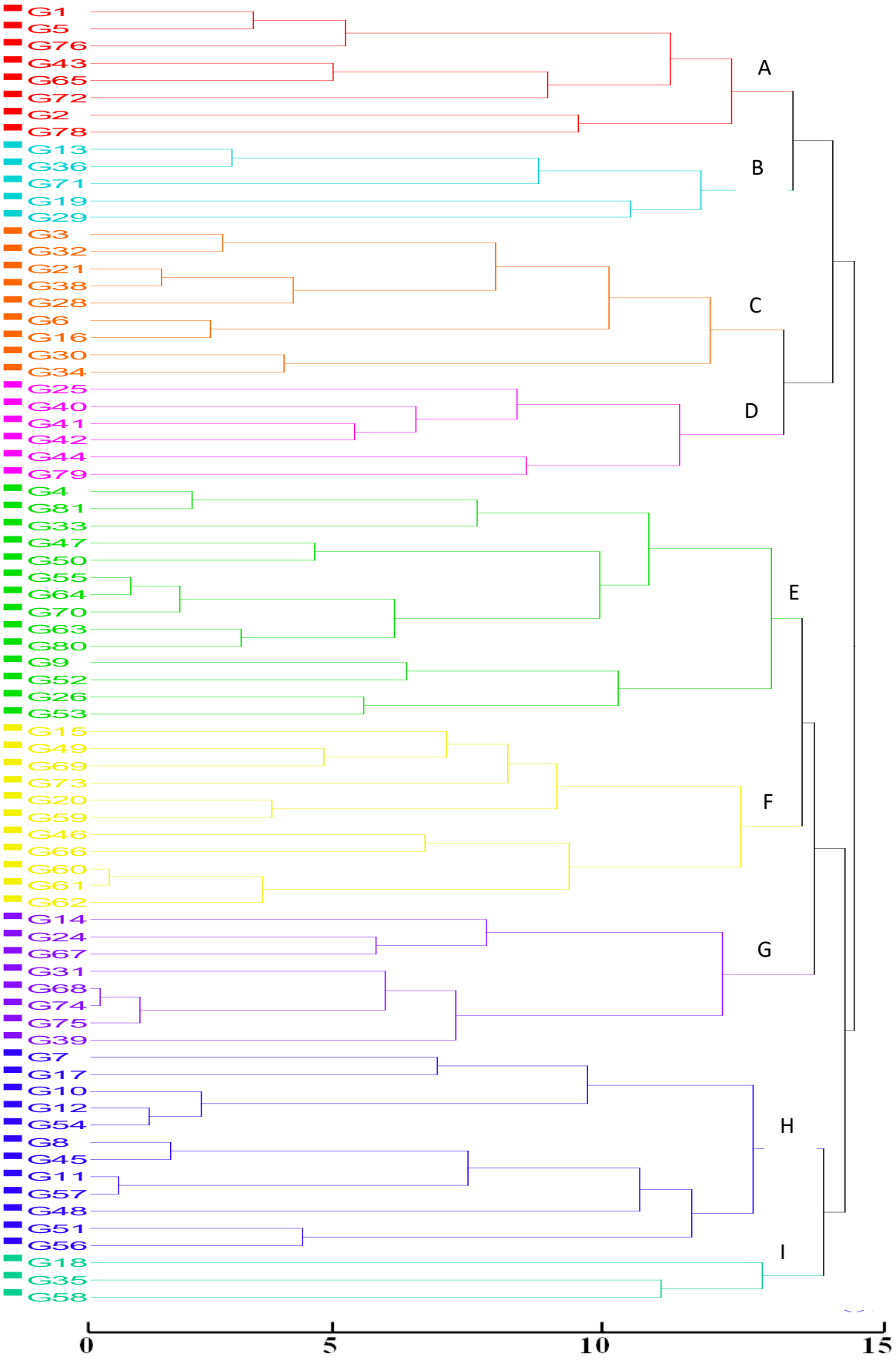

Table 1. Code, accession number and collected sites of *Solanum melongena* in Turkey.

Code	Accession Number	Collected Sites	Code	Accession Number	Collected Sites
G1	PI 166994 01	Hatay/USDA	G43	PI 204630 01	Kayseri
G2	PI 167381 01	Adana/USDA	G44	PI 204731 01	Kayseri
G3	PI 169642 01	Aydın/USDA	G45	TR 61766	Muğla
G4	PI 169644 01	Muğla	G46	TR 55995	Trabzon
G5	PI 169649 01	İzmir	G47	TR 70757	Samsun
G6	PI 169658 01	Kırklareli	G48	TR 70758	Samsun
G7	PI 169667 01	Kocaeli	G49	TR 70756	Amasya
G8	PI 171850 01	Kastamonu	G50	TR 69835	Çorum
G9	PI 171851 01	Samsun	G51	TR 70768	Kastamonu
G10	PI 171853 01	Tokat	G52	TR 70767	Kastamonu
G11	PI 173104 01	Artvin	G53	TR 70766	Sinop
G12	PI 173106 01	Ağrı	G54	TR 68531	Bartın
G13	PI 173111 01	Kahramanmaraş	G55	TR 68532	Bartın
G14	PI 174359 01	Van	G56	TR 68528	Zonguldak
G15	PI 174360 01	Diyarbakır	G57	TR 55678	Giresun
G16	PI 174362 01	Mardin	G58	TR 77307	Edirne
G17	PI 174369 01	Gaziantep	G59	TR 69211	Antalya
G18	PI 174371 01	Gaziantep	G60	TR 75349	Artvin
G19	PI 174373 01	Malatya	G61	TR 70764	Sinop
G20	PI 174374 01	Elazığ	G62	TR 70765	Sinop
G21	PI 175909 01	Balıkesir	G63	TR 75345	Artvin
G24	PI 175913 01	Çorum	G64	TR 70759	Samsun
G25	PI 175914 01	Yozgat	G65	OMU-ZF/BAH	Aydın
G26	PI 175916 01	Kayseri	G66	OMU-ZF/BAH	Aydın
G28	PI 176758 01	Niğde	G67	OMU-ZF/BAH	Manisa, Salihli
G29	PI 176760 01	Konya	G68	OMU-ZF/BAH	Aydın, İncirliova
G30	PI 176761 01	Konya	G69	OMU-ZF/BAH	Aydın
G31	PI 176762 01	Bilecik	G70	OMU-ZF/BAH	Kemer
G32	PI 176763 01	Eskişehir	G71	OMU-ZF/BAH	İzmir, Bayındır
G33	PI 177073 01	Çanakkale	G72	OMU-ZF/BAH	Aydın
G34	PI 177074 01	Kayseri	G73	OMU-ZF/BAH	Diyarbakır
G35	PI 177076 01	Konya	G74	OMU-ZF/BAH	Hatay,Samandağ
G36	PI 179045 01	Tekirdağ	G75	OMU-ZF/BAH	Aydın, Nazilli
G38	PI 179496 01	Bursa	G76	OMU-ZF/BAH	Şanlıurfa, Birecik
G39	PI 179498 01	İstanbul	G78	OMU-ZF/BAH	Mersin, Mut
G40	PI 182299 01	Muş	G79	OMU-ZF/BAH	Bursa
G41	PI 182300 01	Kahramanmaraş	G80	OMU-ZF/BAH	Mersin, Mut
G42	PI 183718 01	Kahramanmaraş			

Table 2. List of morphological traits used in characterization of Turkish eggplant populations.

No	Traits
1	**Fruit length** [**1.** very short (<1 cm), **3.** short (~2 cm), **5.** intermediate (~5 cm), **7.** long (~20 cm), **9.** very long (>30 cm)]
2	**Fruit diameter** [**1.** very small (<1 cm), **3.** small (~3 cm), **5.** intermediate (~5 cm), **7.** large (~10 cm), **9.** very large (>10 cm)]
3	**Fruit curvature** [**1.** none (fruit straight), **3.** slightly curved, **5.** curved, **7.** snack shaped **8.** sickle shaped, **9.** U shaped]
4	**Fruit shape** [**1.** globular, **3.** obovate, **5.** ellipsoid, **7.** cylindrical, **9.** long cylindrical]
5	**Fruit apex shape** (**3.** protruded, **5.** rounded, **7.** depressed]
6	**Fruit colour** [**1.** green, **3.**white, **4.** lilac, **5.** purple, **7.** purple black, **9.** black]
7	**Fruit glossiness** [**3**. dull, **5.** shiny, **7.** very shiny]
8	**Fruit calyx prickles** [**0.** none, **1.** very few (<3), **3.** few (~5), **5.** intermediate (~10), **7.** many (~20), **9.** very many (>30)]
9	**Fruit stalk length** [**1.** very short (<3 cm), **3.** short (~5 cm), **5.** intermediate (5-8 cm), **7.** long (~10 cm), **9.** very long (>10 cm)]
10	**Fruit colour distribution** [**1.** uniform, **3.** mottled, **5.** netted, **7.** striped]
11	**Fruit weight** [**1.** <150 g, **3.** 150-250 g, **5.** 250-350 g, **7.** >350 g]

Table 3. Principal component (PC) coefficients of each fruit trait in Turkish eggplant populations. Proportions of variations are associated with first four PC axes, which correspond to eigenvalues greater than 1.

	PC Axis			
Eigen values	3.80	1.84	1.19	1.02
Explained proportion of variation (%)	34.55	16.76	10.80	9.27
Cumulative proportion of variation (%)	34.55	51.31	62.11	71.38
Traits	**PC1**	**PC2**	**PC3**	**PC4**
Fruit length (cm)	**0.78**	0.77	0.18	0.21
Fruit diameter (cm)	**-0.61**	0.34	0.34	0.18
Fruit curvature	**0.83**	0.24	0.09	0.22
Fruit shape	**0.87**	-0.13	0.06	0.01
Fruit apex shape	**-0.82**	0.26	-0.19	-0.11
Fruit colour	0.41	**0.64**	-0.52	0.01
Fruit glossiness	0.40	**0.67**	-0.21	0.22
Fruit calyx prickles	-0.22	-0.18	-0.42	**0.75**
Fruit stalk length (cm)	0.17	0.38	**0.66**	0.21
Fruit colour distribution	-0.34	-0.50	0.18	0.49
Fruit weight (g)	-0.44	**0.69**	0.16	0.11

Table 4. Average values of the traits used in identify Turkish eggplant populations.

Cluster Groups	Traits*										
	1	2	3	4	5	6	7	8	9	10	11
A	17.32±3.16	8.05±0.98	1	3	5	5,7	5	0,1	7.62±1.82	1,3	382.87±48.55
B	16.68±2.96	6.71±1.35	1	1,5	5	7,9	3,7	3,5	7.72±1.17	1	277.18±51.73
C	16.52±3.30	6.18±0.62	1	1,5	5	1,4,5	3	1	6.72±0.67	1,3	241.51±71.26
D	18.46±2.89	5.49±0.65	1	5,7	3	1,4,5	3	0,1,3	7.90±0.78	1	233.83±55.83
E	23.36±2.08	5.06±0.53	3,5	7,9	3	4,5,9	3,5	1,3,5	6.93±0.60	1	225.88±35.00
F	27.27±4.40	4.05±0.91	3,5	9	3	7,9	5,7	0,1,3	8.39±0.90	1	206.15±28.71
G	24.41±2.18	5.61±0.56	5	7,9	3	1,5,9	3,5	1,3	8.61±0.50	1,3	284.80±55.15
H	21.52±2.90	4.39±0.77	1,3,5	7,9	3,5	1,4,9	3,5	1,3	7.25±0.74	1,3	190.36±39.69
I	19.30±6.67	5.36±0.16	1,5	7,9	3,5	4	3,5	3,5,7	6.93±0.75	3,7	198.23±80.73

* 1. Fruit length (cm), 2. Fruit diameter (cm), 3. Fruit curvature, 4. Fruit shape, 5. Fruit apex shape, 6. Fruit colour, 7. Fruit glossiness, 8. Fruit calyx prickles, 9. Fruit stalk length (cm), 10. Fruit colour distribution, 11. Fruit weight (g)

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