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Determination of Morphological Variability among Cabbage (*Brassica oleracea* var. *capitata* L.) Hybrids and Their Parents

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ABSTRACT: This study carried out to determine morphological traits of new experimental hybrids of cabbage and their parents. To determine morphological variability among tested hybrids and parents, they were analyzed for 34 morphological traits using Principal Component Analysis (PCA) and Cluster Analysis (CA). Results of the PCA indicated that the first three principal components accounted for 39.76% of the total variability among the 28 cabbage hybrids and 45.34% of the total variability among 22 cabbage parents for all the traits investigated. The first principal component (PC1) were the most important component and cabbage traits that constitute the PC1 (such as plant height, plant diameter, weight of head, diameter of head and length of head) were in fact the characteristics considered by breeders to be of greatest importance in cabbage breeding. At the result of CA, the cabbage hybrids were divided into eleven clusters and the cabbage parents were divided into nine clusters. PCA and CA confirmed that the cabbage hybrids and their parents were highly variable and had principally a significant variation for yield and yield components.

Keywords: Breeding, cabbage, cluster analysis, morphological variation, principal component analysis

Beyaz Baş Lahana (*Brassica oleracea* var. *capitata* L.) Hibritleri ve Onların Ebeveynleri Arasındaki Morfolojik Varyabilitenin Belirlenmesi

ÖZET: Bu çalışma, yeni deneysel beyaz baş lahana hibritleri ve onların ebeveynlerinin morfolojik özelliklerini belirlemek için yürütülmüştür. İncelenen hibritler ve ebeveynler arasındaki morfolojik varyabiliteyi belirlemek amacıyla hibritler ve ebeveynler 34 morfolojik özellik için ana bileşen analizi ve kümeleme analizi ile analiz edilmiştir. Ana bileşen analizinin sonuçları ilk üç temel bileşenin araştırılan tüm morfolojik özellikler için 28 beyaz baş lahana hibriti arasındaki toplam varyabilitenin %39.76'sını ve 22 beyaz baş lahana ebeveyni arasındaki toplam varyabilitenin %45.34'ünü açıkladığını göstermiştir. İlk temel bileşen en önemli bileşen olarak bulunmuştur ve onu oluşturan özellikler (bitki boyu, bitki eni, baş ağırlığı, baş çapı ve baş yüksekliği) aslında lahana ıslahında ıslahçılar tarafından en büyük öneme sahip özellikler olarak düşünülmektedir. Kümeleme analizinin sonucunda beyaz baş lahana hibritlerinin 11 grupta ve ebeveynlerin 9 grupta kümelendiği belirlenmiştir. Ana bileşen analizi ve kümeleme analizi beyaz baş lahana hibritleri ve onların ebeveynlerinin oldukça değişkenlik gösterdiğini, verim ve verim bileşenleri için önemli bir varyasyona sahip olduklarını doğrulamıştır.

Anahtar kelimeler: Islah, lahana, kümeleme analizi, morfolojik varyasyon, ana bileşen analizi

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INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata* L.) is one of the most widely grown and important vegetable crops of *Brassicaceae* family consumed worldwide. The wide adaptability and easy-to-grow character of cabbage are no doubt responsible for the worldwide popularity of cabbage cultivation. In addition to their economic importance, the cabbage group vegetables (white, red and savoy cabbages, kale, broccoli, cauliflower, Chinese cabbages, Brussels sprouts and kohlrabi) are considered vital sources of vitamins, fibers, minerals (Rubatzky and Yamaguchi, 1997; Singh et al., 2010) and anti-carcinogenic compounds (Rosa et al., 1997; van Poppel et al., 1999).

The north European countries, the Baltic Sea coast (Monteiro and Lunn, 1998), and the Mediterranean region (Vural ve ark., 2000) are considered as centre for origin of cabbage. The Van region in Anatolia is thought to be the origin of the white head cabbage by Zhukovsky and the greatest cabbages of the world have been grown in this region (Bayraktar, 1981; Vural ve ark., 2000).

Cabbage production of Turkey in 2015 is 514 344 tons and most of the production (20.5 %) is provided from Samsun province in the Black Sea Region situated in the north of Turkey (TÜİK, 2015).

It is necessary to have appropriate cultivars for intensive cabbage production. Although, the traditional local cabbage landraces which are open pollinated populations have been widely cultivated in Turkey formerly, in recent years, these populations were rapidly replaced by many modern hybrid cultivars. Compared with the populations of Turkish cabbage, commercial hybrids are preferred because of uniformity, vigorous development, high yield, high income, high quality and high field durability. Nowadays, cabbage production in Turkey totally depends on foreign hybrid cultivars, which are mainly imported from Germany and Netherlands since no competitive local hybrids have been developed so far.

Yanmaz ve ark. (2000) introduced that the potential of cabbages genetic resources in Turkey with their work and stated that this wealth should be evaluated. Cabbage breeding studies at the Black Sea Agricultural Research Institute in Samsun were begun with a comprehensive collecting programme for the cabbage populations of Turkey in 1998.

Morphological traits have been widely used for the selection of lines with maximum variation for plant breeding programmes (Liu et al., 2007; Hartings et al., 2008; Zhang et al., 2008; Smykal et al., 2008). Morphological characterization is the first step in the description and classification of the germplasm (Smith and Smith, 1989). The multivariate analysis particularly PCA and CA are applied especially in genetic divergence studies and for evaluation of germplasm when studying various traits and a large number of accessions (Crochemore et al., 2003; Cerqueira-Silva et al., 2009; Viana et al., 2010). Results obtained from such analyses are very important for developing and recommending of best cultivar for production in a specific area, as a selection criteria for further genetic improvements and can enable objective estimation of experimental genotypes, hence, developing best possible varieties for official testing by national registration authorities (Marjanovic-Jeromela et al., 2008).

A few studies on morphological characterisation in cabbage have been carried out by different researchers in Turkey (Balkaya et al., 2005; Kar ve ark., 2008; Kaygısız Aşçıoğul, 2009). However, there has not been any study about morphological characterisation of local cabbage hybrids and their parents using multivariate statistical analyses.

The objective of this study was to determine morphological variability in the cabbage hybrids and their parents, to show the structure of the variability and to group the characteristics possessing the highest level of variability using multivariate statistical analyses (Principle Component Analysis, Cluster Analysis).

MATERIAL AND METHODS

This study was conducted at the experiment field of Black Sea Agricultural Research Institute in Samsun province, Turkey (latitude 41°13'N, longitude 36°29'E and altitude 6 m) in 2010-2011 growing period. This location has a mild and humid climate with an annual rainfall of about 731 mm, annual relative humidity of 70.8%, and a mean annual air temperature of 16.5°C (minimum 8.4°C and maximum 28.4°C) (Anonim, 2010).

The cabbage inbred lines used in this study were developed at the Black Sea Agricultural Research Institute after inbreeding for 7 to 10 generations and their seeds were collected formerly from different regions of Turkey or obtained from USDA (The United

States Department of Agriculture). Their origins are presented in Table 1. A total of 50 cabbage materials were evaluated in this study. These included 22 inbred lines (Nos. 1 to 22) and 28 experimental hybrids (Nos. 1 to 28). The cross combinations used in the study are shown in Table 2.

Seeds of 50 cabbage materials (hybrids and their parents) were sown in multi-pot plastic trays consist of 45 pots (4 x 4 x 4 cm), containing a mixture of peat and perlite (3:1 v/v) on 15 July 2010. The seedlings were raised under plastic greenhouse conditions by the usual procedures. Thirty-three days later after sowing, twenty plants of each cabbage materials were transplanted into the open field at 4 true leaf stage on 18 August 2010. The experimental plots consisted of two rows of 7 m length with 10 plants in each row. Rows were spaced 100 cm apart and plants within rows were 70 cm apart. Conventional cultural practices were applied regularly during growing season.

Table 1. Origin and accession number of the cabbage inbred lines used in the study

Code	Accession Number	Origin	Code	Accession Number	Origin
1	531 Ç3	Samsun	12	508 T	Manisa
2	BY 29	Samsun	13	YBB 34	Sakarya
3	506 Ç	Sakarya	14	165 Ç	Samsun
4	4 Ç	Samsun	15	180	Bursa
5	P 61	USDA	16	519 Ç	Tokat
6	115 T	İzmir	17	542	Sakarya
7	530 Ç	Bursa	18	P 62-1	USDA
8	145	Niğde	19	531 Ç1	Samsun
9	148	İzmir	20	P 19-1	USDA
10	160	Balıkesir	21	P 47-2	USDA
11	166 T	Samsun	22	YBB 26	Erzincan

Table 2. The experimental hybrids and their parents used in the study

Hybrid No	Parents (♀) X (♂)	Hybrid No	Parents (♀) X (♂)
1	1X4	15	2X15
2	1X5	16	2X16
3	1X6	17	2X17
4	1X7	18	2X18
5	1X8	19	3X4
6	1X9	20	3X5
7	1X10	21	3X8
8	1X11	22	3X15
9	1X12	23	3X19
10	1X13	24	4X1
11	2X5	25	4X19
12	2X6	26	4X20
13	2X7	27	4X21
14	2X14	28	4X22

The plants were harvested for analysis when cabbage materials had completed head formation and all of the morphological properties were measured at the optimum time for consumption. According to different harvest periods of cabbage materials, the harvest started at the end of November of 2010 and lasted until the end of January of 2011. Morphological characterization were carried out on 10 plants harvested from each cabbage materials. All of the cabbage materials were evaluated for a total of 34 morphological traits (Table 3). Selection of traits and measurement techniques were based on International Union for the Protection of New Varieties of Plants (UPOV, 2004) and International Plant Genetic Resources Institute (IBPGR, 1990) descriptor lists developed for *B. oleracea* var *capitata* L.

Table 3. Morphological traits and their description used in the morphological characterization

Traits and Description	
Plant	
1.	Plant height (cm)
2.	Plant diameter (cm)
Outer leaf	
3.	Width of outer leaf (cm)
4.	Length of outer leaf (cm)
5.	Colour of outer leaf (1. yellow green; 2. light green; 3. green; 4. dark green; 5. blue green)
6.	Colour intensity of outer leaf (1. light; 2. medium; 3. dark)
7.	Waxiness in outer leaf (1. absent or very weak; 2. weak; 3. medium; 4. strong; 5. very strong)
8.	Blistering of outer leaf (1. absent or very weak; 2. medium; 3. strong)
9.	Size of blisters in outer leaf (1. small; 2. medium; 3. large)
10.	Attitude of outer leaves (1. erect; 2. semi-erect; 3. horizontal)
11.	Blade shape of outer leaf (1. elliptic; 2. broad ovate; 3. circular; 4. transverse broad elliptic; 5. obovate)
12.	Waviness in edge of outer leaf (1. entire; 2. sinuate; 3. lyrate; 4. lacerate)
13.	Shape of outer leaf apex (1. acute; 2. intermediate; 3. rounded; 4. broadly rounded)
14.	Contour of upper side of outer leaf blade (1. concave; 2. plane; 3. convex)
15.	Petiole and/or midvein enlargement (1. narrow; 2. intermediate; 3. enlarged)
16.	Shape of petiole section (1. round; 2. semiround; 3. flat)
17.	Colour of petiole and/or midvein (1. white; 2. light gren; 3. gren)
18.	Attitude of midvein (1. flat; 2. swollen; 3. flattened)
Head	
19.	Colour of cover leaf (1. yellow green; 2. light green; 3. green; 4. dark green; 5. grey gren; 6. blue gren; 7. violet)
20.	Anthocyanin coloration of cover leaf (1. absent or very weak; 2. weak; 3. medium; 4. strong; 5. very strong)
21.	Covering of head (1. not covered; 2. partially covered; 3. covered)
22.	Shape of head in longitudinal section (1. transverse narrow elliptic; 2. transverse elliptic; 3. elliptic; 4. circular; 5. broad elliptic; 6. broad obovate; 7. broad ovate; 8. angular ovate)
23.	Weight of head (g)
24.	Diameter of head (cm)
25.	Length of head (cm)
26.	Density of head (1. very loose; 2. loose; 3. medium; 4. dense; 5. very dense)
27.	Length of interior stem (cm)
28.	Diameter of interior stem (cm)
29.	Opening status of leaves (1. good; 2. medium; 3. bad)
30.	Position of maximum diameter (1. towards top; 2. at middle; 3. towards base)
31.	Internal color of head (1. whitish; 2. yellowish; 3. greenish; 4. cream; 5. violet)
32.	Shape of base in longitudinal section (1. rounded; 2. flat; 3. arched)
Earliness and resistance to cracking	
33.	Time of harvest maturity (days) (1. early; 2. medium; 3. late)
34.	Durability of mature head in the field (days) (1. short; 2. medium; 3. long)

In order to determine the morphological variation among hybrids and their parents, the obtained results were analyzed by using Principal Component Analysis (PCA) and Cluster Analysis (CA). PCA is a multivariate analytical method, which is used to downsize the dimensions of a data set, while maximally retaining its variability. CA is used to determine differences and similarities among the genotypes, and the distance measure used was Euclidean distance as the parameter that best reflects differences existing among the genotypes (Kendall, 1980; Gvozdanovic-Varga, 2004). PCA was carried out using SPSS (16.0). CA was performed by the unweighted pair-group method for arithmetic averages (UPGMA) method using the computer program NTSYS-pc, version 2.2 (Rohlf, 1992). The results of CA were presented in the form of dendrograms. The means and standard deviations for quantitative characters within each cluster were calculated to estimate the inter cluster variation.

RESULTS AND DISCUSSION

The trial involved 22 cabbage inbred lines, 28 experimental cabbage hybrids and 34 morphological traits. The Principle Component Analysis (PCA) was applied to identify the traits which were the main source of the variability and to explain the genetic diversity among hybrids and their parents. At the end of PCA, factor coefficients of identifying qualities were evaluated and the attributes scoring a coefficient value higher than 0.6 in the first three PCA were determined (Jeffers, 1967). The results of the PCA are presented in Table 4. The first three principal components (PCs) accounted for 39.76% of the total variability among the 28 cabbage hybrids for all the traits investigated. The first principal component (PC1), which is the most important component, explained 15.77% of the total variability and was related to plant height, plant diameter, width of outer leaf, length of outer leaf, weight of head, diameter of head and length of head. These traits have a great influence on the formation of yield. The second principal component (PC2) had 14.32% of the total variation in morphological traits. Colour of outer leaf, colour intensity of outer leaf, waxiness in outer leaf and opening status of leaves contributed positively to PC2. In contrast, blade shape of outer leaf and length of interior stem contributed negatively to PC2. The third principal component (PC3) exhibited 9.68% of the total morphological variability and was associated with petiole and/or midvein enlargement and shape of petiole section (Table 4).

The fact that eigen values are above 1 indicates that the evaluated principle component weight values are reliable. CA is more sensitive and reliable when 25% of the total variation or more is explained by the first two or three axes in PCA (Mohammadi and Prasanna, 2003). In the our study, the first three principal components (PCs) explained 39.76% of the total variability.

Tanaka and Niikura (2003) analyzed the characteristics of early cabbage hybrids and grouped them on the basis of the PCA. These authors also obtained 4 major groups which shared the variance in the following way: PC1 52.3, PC2 13.1, PC3 9.1 and PC4 7.0% of the total variance, and their cumulative variance amounted to 81.5%. Cervenski et al. (2011a) used the PCA to determine variability of characteristics in new experimental hybrids of early cabbage. The first four principal components that explain 87.2% of the total variance. PC1 accounted for 45.3% of the variance. Seven traits had the highest communality with the first principal component and these were plant height, rosette diameter, the weight of the whole plant, head weight, the usable part of the head, head height and head diameter.

Our results show a group of three principal components, with similar percentages of variance. The highest percentage of variance is also in the first group, as in the case of the above authors. Our results are also in agreement with those of Vasic et al. (2008), Cervenski et al. (2011a, b) and Kaygısız Aşçıoğul (2009) who named the first principal component of the yield and yield components.

PCA of cabbage traits studied for cabbage parents focused on the variability of the first three principal components. Results of the PCA indicated that the first three principal components explained 45.34% of the total variability among the 22 cabbage parents. The first principal component (PC1) had 20.23% of the morphological variation. Plant height, plant diameter, width of outer leaf, length of outer leaf, weight of head and diameter of head were important variables composing PC1. This is an indication of the importance of the yield components. The second principal component (PC2) exhibited 15.18% of the total morphological variability and was positively associated with colour of outer leaf, attitude of outer leaves, waviness in edge of outer leaf, colour of cover leaf and shape of base in longitudinal section. Whereas, shape of outer leaf apex was negatively associated with PC2.

The third principal component (PC3) constituted 9.93% of the total variation and only contour of upper side of outer leaf blade contributed negatively to PC3 (Table 4). PCA demonstrated that the first three principal components could explain the total variance that was observed to a large degree. Lezzoni and Pritts (1991) stated that when principle component analysis explains the majority of the variation of the first two or three components it would be a very suitable technique for grouping.

Table 4. Principal component analysis (for the first three PCs) of cabbage traits studied for cabbage hybrids and parents (Characters with high coefficients in the PC axes should be considered more important, thus eigen vectors above 0.60 are shown in bold)

	PC axis					
	Hybrids			Parents		
	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
Eigen values	5.360	4.868	3.290	6.879	5.160	3.377
Proportion of variation (%)	15.766	14.318	9.677	20.232	15.177	9.931
Cumulative variation (%)	15.766	30.084	39.761	20.232	35.410	45.341
Traits	**Eigen vectors**					
Plant height	**0.831**	0.067	0.208	**0.704**	-0.289	0.161
Plant diameter	**0.668**	0.258	-0.054	**0.739**	0.038	0.443
Width of outer leaf	**0.860**	0.157	0.194	**0.662**	0.426	-0.211
Length of outer leaf	**0.778**	0.091	-0.132	**0.838**	0.112	-0.031
Colour of outer leaf	-0.028	**0.770**	-0.006	0.355	**0.615**	0.442
Colour intensity of outer leaf	0.147	**0.731**	0.340	0.579	0.365	0.224
Waxiness in outer leaf	-0.040	**0.632**	-0.348	0.383	0.137	0.175
Blistering of outer leaf	0.333	0.423	0.146	0.445	0.209	-0.145
Size of blisters in outer leaf	0.116	0.304	0.190	0.264	-0.251	-0.459
Attitude of outer leaves	-0.432	0.041	-0.388	-0.232	**0.684**	-0.151
Blade shape of outer leaf	0.163	**-0.757**	0.261	0.243	-0.413	-0.329
Waviness in edge of outer leaf	-0.248	-0.234	0.030	-0.337	**0.611**	0.278
Shape of outer leaf apex	-0.012	0.034	0.517	-0.354	**-0.694**	0.138
Contour of upper side of outer leaf blade	-0.180	0.024	0.002	0.144	0.359	**-0.608**
Petiole and/or midvein enlargement	0.062	0.050	**0.697**	0.422	0.321	-0.313
Shape of petiole section	-0.200	-0.034	**0.673**	-0.095	-0.329	-0.316
Colour of petiole and/or midvein	-0.303	0.199	-0.448	0.012	-0.420	-0.092
Attitude of midvein	0.091	-0.220	0.226	-0.350	-0.002	0.553
Colour of cover leaf	-0.054	0.355	0.017	-0.311	**0.838**	0.028
Anthocyanin coloration of cover leaf	-0.179	-0.102	0.384	-0.164	-0.212	0.382
Covering of head	-0.053	0.098	0.357	-0.582	-0.483	0.040
Time of harvest maturity	0.271	-0.280	-0.375	0.076	-0.710	0.236
Durability of mature head in the field	-0.003	-0.169	0.081	-0.564	0.273	-0.002
Shape of head in longitudinal section	-0.248	0.042	0.197	-0.005	-0.216	0.116
Weight of head	**0.784**	-0.312	-0.075	**0.827**	0.061	0.247
Diameter of head	**0.747**	-0.348	-0.128	**0.636**	-0.024	0.393
Length of head	**0.678**	-0.431	-0.059	0.559	-0.341	0.402
Density of head	-0.176	0.568	0.325	0.433	-0.115	-0.434
Length of interior stem	0.437	**-0.668**	0.010	0.510	-0.074	-0.139
Diameter of interior stem	0.413	0.557	-0.078	0.304	0.080	-0.080
Opening status of leaves	-0.180	**0.664**	0.309	0.318	-0.022	-0.556
Position of maximum diameter	-0.219	0.050	0.141	0.253	-0.106	0.514
Internal color of head	0.012	0.201	0.464	-0.278	0.062	0.293
Shape of base in longitudinal section	0.045	-0.145	0.538	-0.413	**0.683**	0.151

In the study conducted by Kaygısız Aşçıoğul (2009), the first three principal components (PCs) explained 42.6% of the total variability among cabbage genotypes, which was collected from different regions of Turkey. PC1 accounted for 20.9%, PC2 12.5% and PC3 9.2% of the total variation in 34 morphological traits. In the study, average head weight, yield, head size according to the plant, diameter of head, width of outer leaf, length of outer leaf were important variables composing PC1. Eigen values, proportion of variation and cumulative variation in our results are similar with values of Kaygısız Aşçıoğul (2009). Cervenski et al. (2011b) studied the diversity in Serbian local cabbage populations and 15 cabbage morphological traits analysed by using PCA. The first three principal components gave Eigen values greater than 1.0 and explained 99.99% of the total variability among the cultivars and populations for all the traits investigated. In the study, PC1 accounted for 50.2%, PC2 27.9% and PC3 21.9% of the total variation in morphological traits.

For a successful breeding program, genetic diversity and variability play a vital role. It is a useful and essential tool for parents' choice in hybridization to develop high yield potential cultivars and to meet the diversified goals of plant breeding (Arslanoglu et al., 2011). PCA is useful as it gives information about the groups where certain traits are more important allowing the breeders to conduct specific breeding programs (Yousuf et al., 2011). Therefore, the parents should be selected considering results of PCA.

For a better overview of diversity in the cabbage hybrids and parents, CA was also used. The data to be used in the CA are evaluated taking also into consideration the PCA results. Genetic similarity among hybrids was estimated using UPGMA cluster analysis based on morphological traits. Dendrogram of cabbage hybrids obtained from CA is shown in Figure 1. In the dendogram, dissimilarity coefficients among hybrids ranged from 0.56 to 1.54. At the result of CA based on thirty four morphological traits, the cabbage hybrids were divided into eleven clusters. Hybrids with greater similarity for morphological traits were placed in the same cluster. Among the eleven different clusters, the biggest group was Cluster D that include 14 hybrids, while cluster A, G, H, I, J and K comprised only one hybrids. Cluster B, C, E and F contained two hybrids (Figure 1). It was determined that hybrids used as parent of 4 numbered genotype (1x4, 4x1, 4x20 and 4x22) had more different morphological structure according to other hybrids. To increase the variability, it is considered that more use of this genotype as parent in hybridizations in the future.

Cluster means and standard deviations for 34 traits in 28 cabbage hybrids are shown in Table 5. Head weight is a major component of the yield of cabbage. In the study, the values of head weight of the experimental hybrids ranged from 2073 g (Cluster C) to 5875 g (Cluster H). As weight of head, the highest diameter of head (34 cm) and length of head (27 cm) were found in cluster H. On the other hand, Cluster G and C had the lowest diameter of head and length of head. Time of harvest maturity were considerably variable. Although, Cluster A and G were classified as early (103 days), Cluster H was classified as late (160 days). It may concuded that the late hybrids have bigger and heavier heads than the early ones. The hybrids in Cluster F and J had anthocyanin coloration of cover leaf which is an undesired property. Shape of head in longitudinal section of cabbage hybrids was mostly elliptic or transverse narrow elliptic (Table 5). The results of CA suggested that there is enough variation among the hybrids for different morphological traits. However, there were minimal variations among hybrids in some of the qualitative characters such as, waviness in edge of outer leaf, attitude of outer leaves and anthocyanin coloration of cover leaf.

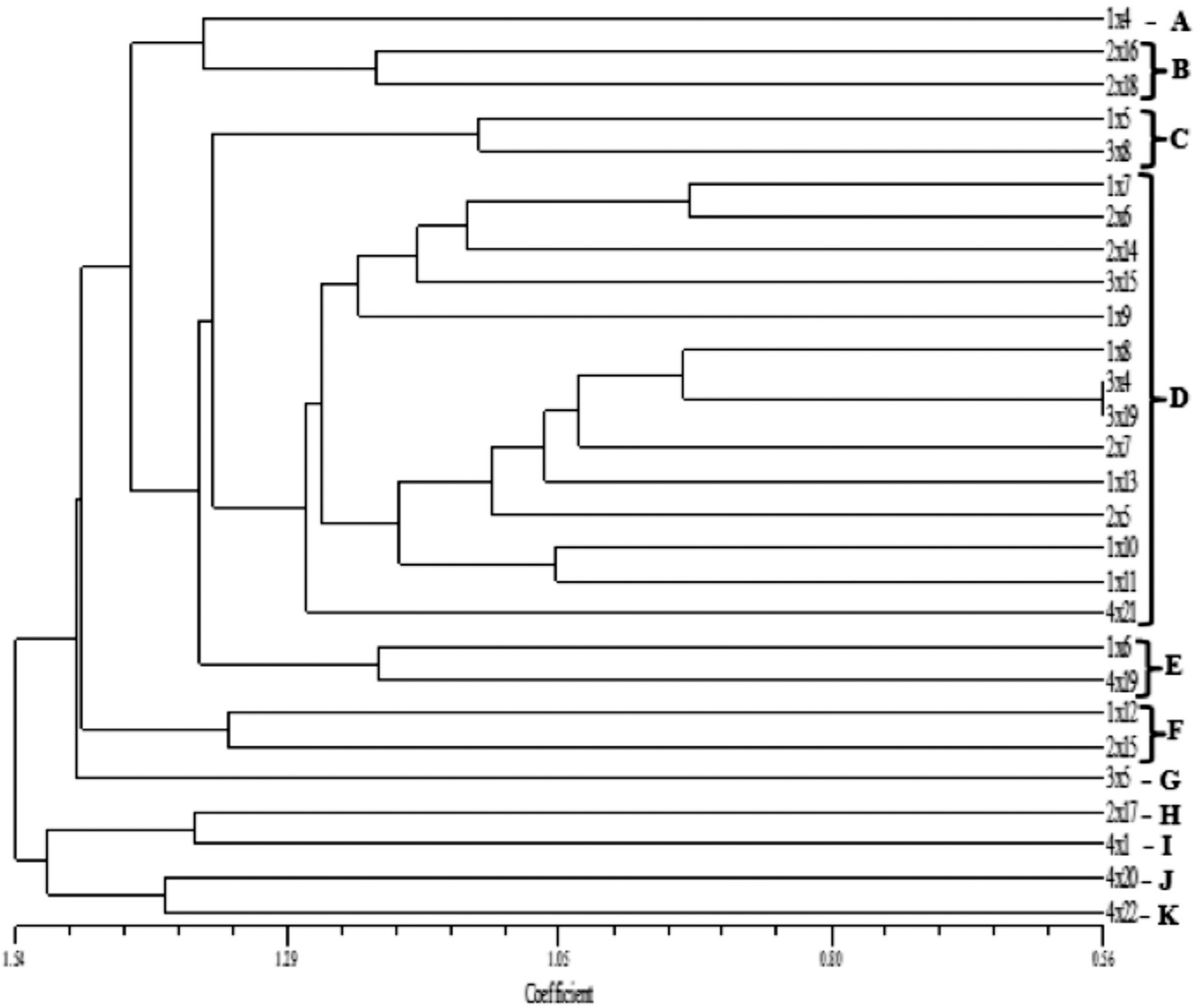

Figure 1. Dendrogram of cabbage hybrids obtained from cluster analysis based on morphological traits

In order to choose the best hybrids to be registered, differences among them are important. Weight of head, diameter of head, length of head, length of interior stem, opening status of leaves, internal color of head, anthocyanin coloration of cover leaf, covering of head, time of harvest maturity and durability of mature head in the field are economically important characters of cabbage. When taken into consideration above traits 1x5, 1x8, 1x13, 2x18, 3x4, 3x19 and 4x21 numbered hybrids were suitable for sarmalik (sarma is a traditional Turkish food prepared by wrapping cabbage leaf around rice and other products) production. We consider that 1x6 and 1x12 numbered hybrids are more suitable for pickled consumption. Therefore these hybrids were found to be promising for registration studies.

Cervenski et al. (2010) applied the method of hierarchical clustering to differentiate the experimental hybrids and commercial cultivars in cabbage as clearly as possible. The dendrogram clustered the genotypes on the basis of all characters under examination (head weight, usable part of the head, head diameter, yield). Two clusters were formed. The first included the experimental hybrids, two commercial cultivars (Futoški and SM-10) and one commercial hybrid (Coronet-F1). The second included the commercial hybrids and the other two commercial cultivars.

Table 5. Mean values and standard deviations of 11 clusters based on 34 morphological traits of cabbage hybrids

Trait	Clusters										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
1	48.5	43.5±7.1	36.5±2.1	48.4±3.9	50.5±6.4	50.3±11.7	48.5	48	59.5	43.5	43.5
2	89	98.5±12.7	84±4.2	97.5±19.6	91±12.7	112±17.0	92.5	109	109	86.5	79
3	40.5	40.75±4.3	32.25±1.8	41.8±3.9	41±4.2	46.5±4.9	40	43	47	40	32.5
4	45	49.75±5.1	42.5±3.5	52.3±5.5	48.8±1.8	48±2.1	50.5	56	58	40	39
5	5	3	5	3, 4, 5	4, 5	5	4	3	3	3	3
6	2	2, 3	2	2, 3	3	3	3	2	2	2	2
7	4	4	4	2, 3, 4	4	3	4	2	2	3	2
8	1	1, 3	2	1, 2, 3	3	3	2	2	2	2	1
9	1	2, 3	2	2, 3	2, 3	3	1	1	2	3	1
10	2	2, 3	2, 3	2, 3	2	2	2	2	2	2	2
11	3	3	1, 3	1, 3, 5	3	3	3	5	5	5	5
12	2	1	2	2	2	2	2	2	2	2	1
13	4	4	4	2, 3, 4	3, 4	3	3	4	4	4	4
14	1	2	3	2, 3	2, 3	2, 3	3	2	3	3	2
15	3	2, 3	1	1, 2, 3	2, 3	3	3	3	1	2	3
16	2	2	1	1, 2, 3	2, 3	2	2	1	1	2	3
17	2	2	1	2	1	2	2	2	2	2	2
18	1	1	1, 2	1, 2, 3	1, 2	2	2	2	2	2	2
19	2	2, 6	3	2, 3, 6	3, 6	3	2	3	3	3	3
20	1	1	1	1	1	1, 3	1	1	1	3	1
21	2	3	3	1, 2, 3	1, 2	2, 3	2	2	3	2	2
22	3	3	3	1, 3	1, 3	3, 4	3	3	1	4	3
23	2615	4030±973.8	2073±67.2	3296±580	3583±95.5	3335±1435.4	2230	5875	5545	3530	3150
24	23.5	26.75±2.3	22±0.7	26.0±3.3	26.8±3.2	23±2.1	21	34	33	26	22
25	21	21±2.0	17±1.4	19.5±1.5	21.3±0.4	19.3±4.6	17.5	27	24.5	25	18.5
26	1	3, 4	3	1, 3, 4	3, 5	4, 5	5	3	2	3	3
27	9.5	10±3.0	7.75±0.4	9.8±1.8	6.5±0.7	6.5±0.7	6	11	13	14.5	8
28	4	4±0.0	3.25±0.4	4.0±0.3	4.3±0.4	3.8±0.4	4	4	3.5	3.5	3
29	1	1, 2	1	1, 2	1, 3	2, 3	3	1	1	1	1
30	3	2	2	1, 2	2	2, 3	2	2	3	2	2
31	4	1, 4	1	1, 4	1	2, 4	4	1	1	1	4
32	1	1	1	1, 2, 3	1	1, 2	1	1	1	1	2
33	103	119±11.6	126±0.0	112.5±4.6	143±24.0	108.5±7.8	103	160	124	112	124
34	30	30±5.0	30±7.1	30.7±4.3	32.5±3.5	32.5±3.5	20	30	30	35	35

Genetic grouping of 22 cabbage parents using the UPGMA clustering algorithm is shown in Figure 2. Looking at the dendrogram it can be observed that dissimilarity coefficients among parents ranged from 0.84 to 1.82. The cabbage parents were divided into different clusters by their distribution on the dendogram. In the present research, nine clusters were occured at the result of the CA, in terms of morphological traits. Cluster A consisted of 5 genotypes. There was a total of 7 genotypes in Cluster B the biggest group. Cluster C had 3 genotypes. Cluster D contained two genotypes. However, there was only one genotype in Cluster E, F, G, H and I (Figure 2).

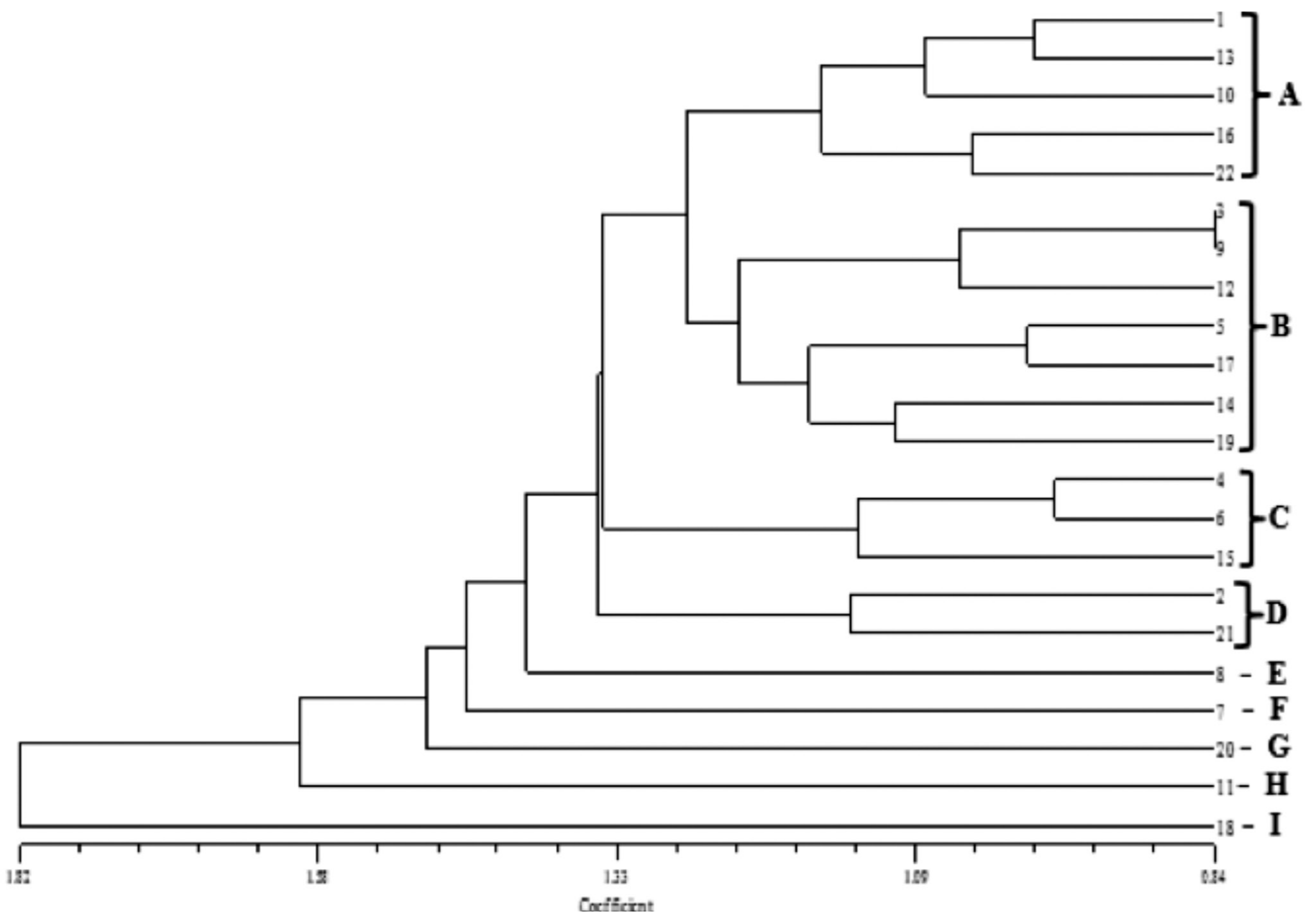

Figure 2. Dendrogram of cabbage parents obtained from cluster analysis based on morphological traits

Mean values and standard deviations for each cluster based on morphological traits of cabbage parents are presented in Table 6. In the study, the values of head weight of the parents ranged from 1530 g (Cluster F) to 3690 g (Cluster C). Although the highest mean for diameter of head and length of head were found in Cluster C, D and G, Cluster F and H had the lowest. When taken into consideration weight of head, diameter of head, length of head Cluster C, D and A can be used to develop a new hybrid cultivar. Since anthocyanin coloration of cover leaf is an undesired property, genotypes in Cluster F and G should not be used as parent in hybrid cabbage breeding. Also genotype in Cluster F should not selected for hybrid cabbage breeding because it has not covered head. Cluster E, H and I were classified as early. These genotypes were harvested at 98 days. Cluster F was classified as late and harvested at 155 days (Table 6). The morphological variability among cabbage parents could be related primarily to their geographical origin. This variability is very important for breeding studies and the promising genotypes which has superior for important plant characteristics could be successfully utilized in breeding programs that are aimed to develop a new hybrid cabbage cultivar.

Balkaya et al. (2005) studied morphological variation in white head cabbage genotypes collected from different eco-geographical regions of Turkey. Cluster analysis based on 12 quantitative and 10 qualitative variables identified 10 groups. The dendogram was prepared to evaluate morphological similarity among the white head cabbage genotypes. Morphological variability was found high among the white head cabbage genotypes of Turkey. Similar conclusions were obtained by Kaygısız Aşçıoğul (2009) in a study that assessed morphological and molecular traits of 36 leaf and head cabbage genotypes, which was collected from different regions of Turkey. Results of present study are in agreement with those of Balkaya et al. (2005) and Kaygısız Aşçıoğul (2009).

Table 6. Mean values and standard deviations of 9 clusters based on 34 morphological traits of cabbage parents

Trait	Clusters								
	A	B	C	D	E	F	G	H	I
1	46.4±3.7	48.3±6.7	50.2±9.6	54±5.7	46	45	47	41	39.5
2	102.7±22.7	94.7±16.3	106.5±28.7	103±12.7	81	73	118	90.5	88.5
3	40.5±4.2	34.6±6.2	45.8±5.5	41.5±0.7	36	34	30	46	37
4	49.1±4.6	46.3±7.2	57.2±11.3	45.5±2.1	42	36	47	48	39.5
5	3, 4, 5	3, 5	4, 5	3, 4	3	3	4	5	4
6	2, 3	2, 3	3	3	2	2	3	2	3
7	3, 4	2, 3, 4	4	2, 3	2	3	3	4	3
8	2, 3	1, 2	2, 3	1	2	1	2	3	1
9	1, 2	2	2, 3	2	2	2	2	3	1
10	2	2	2	2	2	2	2	3	3
11	1, 3	1, 3, 5	5	3, 5	5	3	1	3	3
12	2	2	2	2	2	2	2	2	1
13	2, 3, 4	2, 3, 4	4	4	4	2	3	4	4
14	3	3	2, 3	3	2	3	3	1	3
15	2, 3	1, 2, 3	3	2, 3	3	1	3	3	2
16	1, 3	1, 2	1, 2	1	2	1	1	1	1
17	2	1, 2	2	2	2	2	2	2	2
18	1, 2, 3	1, 2	1, 2	1	1	2	1	1	2
19	2, 3, 6	3, 6	3	3	6	3	3	6	2
20	1	1	1	1	1	3	3	1	1
21	1, 2, 3	2	2, 3	2,3	2	1	3	3	3
22	3	1, 3, 4	3, 4	1, 3	1	3	3	3	3
23	3111±796.9	2425±571	3690±585	3233±11	1915	1530	3375	2450	2365
24	23.8±1.4	22.9±2.4	24.2±0.8	25±1.4	23.5	20	25.5	20.5	22
25	18.7±1.9	19±2.3	20.8±1.6	18±2.8	16	16	20.5	15	17
26	2, 3	1, 2, 3, 4	3, 4	4, 5	2	3	2	3	2
27	8±1.6	8.1±1.1	9.8±1.0	9±0.0	7.5	8	9	7.5	8
28	3.7±0.4	3.7±0.8	3.5±0.5	3.8±0.4	4	2.5	4.5	3.5	3
29	1	1, 2	1, 2	2, 3	1	1	1	2	1
30	2	2	2	2	3	2	1	2	2
31	2, 4	1, 4	1, 4	4	4	2	4	1	4
32	1, 2	1, 2	1	1	2	1	1	1	3
33	115.6±27.3	130.6±26.9	118.3±9.8	138±0.0	98	155	124	98	98
34	25±3.5	30±5	26.7±7.6	22.5±3.5	30	25	25	25	40

The plot of cabbage hybrids on first three PCs obtained from analysis of 34 morphological traits is presented in Figure 3. The scatter diagram of the cabbage hybrids showed that there was high a level of morphological diversity and the cabbage hybrids had significant differences in the important plant traits.

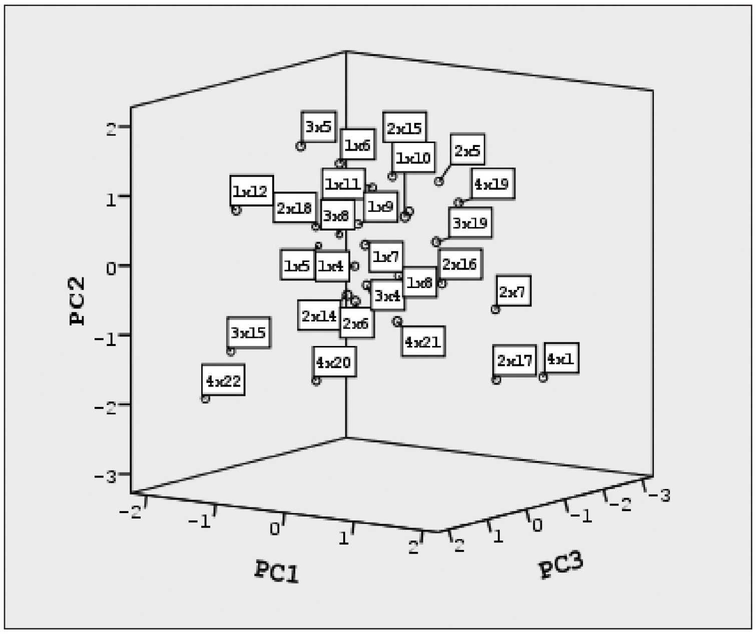

Figure 3. Scatter diagram based on the first three principal component (PC) axes in 28 cabbage hybrids

Scatter diagram of 22 cabbage genotypes for the first three principal components is shown in Figure 4. Genotypes that appear one on the top of the other or coincident on three dimensional graphic are very close or similar in terms of one or a few morphological features. 18 numbered genotype, P 62-1 which obtained from USDA, situated at the top of the PC2 and was clearly separated from other genotypes. This genotype was suitable for sarmalik production because of its leaf characteristics and earliness. It was also used previously as a parent in a breeding program and had high combination ability. As seen in Figure 4, the cabbage parents had a significant variation in morphological plant characteristics. This variation is very important in breeding of hybrid varieties. The lower the degree of relationship between the parents, or the more the genetic distance between them, the higher heterosis occur (Miller and Fick, 1997).

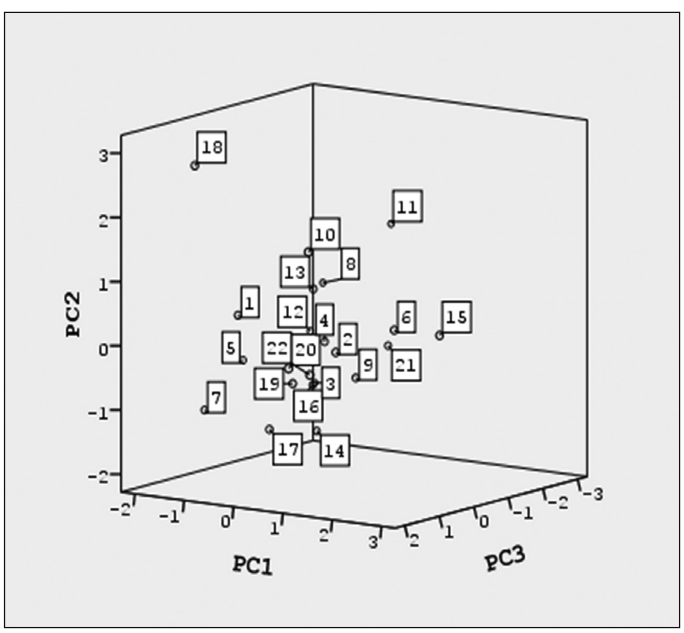

Figure 4. Scatter diagram based on the first three principal component (PC) axes in 22 cabbage parents

CONCLUSION

As a result, we have found that the cabbage hybrids and parents had a significant variation in terms of morphological plant characteristics. These findings are important for breeding of hybrid variety studies in the future. In conclusion, this work has contributed to better understanding of variability of the studied characteristics. These characteristics can effect directly registration of new varieties, the market value of new hybrids and recognizable of them by consumers.

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