Plant Omics Journal POJ

POJ 3(3):85-91 (2010) ISSN:1836-3644

The use of agro-morphological characters for the assessment of genetic diversity in sesame (*Sesamum indicum* L.)

Seymus Furat[1] & Bulent Uzun[2*]

[1]West Mediterranean Agricultural Research Institute, Aksu, Antalya, Turkey
[2]Department of Field Crops, Faculty of Agriculture, Akdeniz University, TR-07058, Antalya, Turkey

*Corresponding authors: bulentuzun@akdeniz.edu.tr

Abstract

Agro-morphological variation in the sesame germplasm was estimated using 21 morphologic and agronomic descriptors to characterize and identify genetic diversity. A total of 103 sesame landraces were collected from the sesame growing areas throughout Turkey. This collection was evaluated for seed yield, yield related characters and morphological characters in the two consecutive years (2004 and 2005). A great amount of variation was recorded for 17 morphologic and agronomic traits while four characters were found to be monomorphic as the plants with branching, white with pink shading flower color, shattering and indeterminate growth habit. Multivariate analyses were performed in order to establish similarity and dissimilarity patterns. Principal component (PC) analysis revealed that first three PC axes explained 43.4% of the total multivariate variation while the first seven PC axes explaining 69.9%. The developmental characters such as days to emergence, flowering and capsule initiation and seed yield were the major determinants of the genetic diversity in the collection. Cluster analysis identified eight main clusters based on agro-morphological characters indicating the diversity could mainly be attributed to diverse agro-climatic conditions. Single plant selection was made from these populations based on different agronomic characteristics and yield potential. These results have an important implication for sesame germplasm characterization, improvement, agro-morphological evaluation and conservation.

Keywords: Characterization; Genetic diversity; Germplasm; Selection; *Sesamum indicum* L.

Introduction

Sesame (*Sesamum indicum* L.) is an autogamous species, and populations often exist as a composite of various homozygous individuals. Genetic advance can easily be gained after selection for a few generations due to the combination of autogamy and heterogeneity. Although genetic variation exists for agronomically important traits, sesame yield is still poor. Genetic improvement of sesame has the potential to overcome many production constraints. The success in genetic improvement of the crop, however, depends on the availability of diverse genetic resources.

Sesame is known to be the most ancient oilseed crop dating back to 3050-3500 B.C. (Bedigian and Harlan, 1986). Anatolia played an important role for spreading sesame by being major crossroads of East and West trade in ancient times and it has many distinct sesame landraces that are grown by locals under a range of ecological conditions. The value of characterizing and preserving natural variation in sesame was recognized by numerous investigators (Hiltebrandt, 1932; Joshi, 1961; Demir, 1962; Ashri, 1990; Bedigian et al., 1986, Bisht et al., 1998; Bhat et al., 1999; Baydar et al., 1999; Xiurong et al., 2000). However, there are still many heterogeneous landraces in various growing areas (Ashri, 1998).

Turkey still exhibits a great deal of variation in sesame because heterogeneous landraces are grown in various growing areas for centruies. And the lack of improved breeding varieties for various ecological conditions throughout Turkey makes maintenance of landraces possible. The local varieties are an important source of raw material for breeders and still the backbone of agricultural production (Ali et al., 2009). Also, the characterization and conservation of sesame germplasm are essential for both safeguarding and the future use of the existing genetic resources of sesame. Thus, due to continuous genetic erosion of landraces, it is necessary to collect, describe and efficiently use sesame populations, and also to maintain them *in situ* and *ex situ*. Hence, this study was undertaken to characterize and identify genetic diversity of 103 cultivated sesame landraces collected from different ecological conditions throughout Turkey and to select sesame plants with different agronomic performances and yield potential from these valuable resources.

Materials and methods

A total of 103 cultivated sesame landraces were collected from the sesame growing areas of Turkey. The list of the genotypes and their oil characteristics were reported elsewhere (Uzun et al., 2008). The plant material was maintained at the West Mediterranean Agricultural Research Institute of Antalya, Turkey. The characterization site is located at 36° 52' N latitude, and 30° 50' E longitude, and about 15 m elevation of sea level. It has 1060 mm annual average precipitation and 18 °C annual average temperature. The experimental field can be characterized by a silty clay loam soils with a pH 7.8.

The accessions were grown in 5 m long 2 row plots with a row to row spacing of 70 cm and plant to plant spacing of

Table 1. Range of variation in quantitative characters and predominance of qualitative descriptors

Characters	Min.	Max.	Range	Mean ± S.D.	C.V.
Days to emergence	5.7	7.5	1.8	6.7 ± 0.4	6.0
Stem height to the first capsule	30.0	55.7	25.7	42.8 ± 5.2	12.1
Plant height	117.7	158.3	40.6	139.8 ± 8.2	5.9
Days to flower initiation	43.0	47.0	4.0	45.3 ± 0.9	2.0
Number of fruiting branches	2.3	5.3	3.0	3.7 ± 0.6	16.2
Days to 50% flowering	46.7	51.3	4.6	49.2 ± 1.0	2.0
Days to capsule initiation	48.7	53.7	5.0	50.9 ± 1.0	2.0
Number of capsules per plant	69.0	154.7	85.7	115.2 ± 18.3	15.9
Number of seeds per capsule	66.7	85.3	18.6	75.3 ± 4.1	5.4
1000-seed weight	3.2	4.1	0.9	3.7 ± 0.2	5.4
Seed yield	321.3	977.0	655.7	652.5±141.7	21.7
Branching habit: Branching (100%)					
Stem hairiness: Sparse (49.5%) followed by hair absent (47.6%)					
Leaf hairiness: Hair absent (66.0%) followed by sparse (33.0%)					
Leaf arrangement: Mixed (60.2%), alternate (39.8%)					
Flower colour: White with pink shading (100%)					
Number of flowers per leaf axil: Predominantly one (97.1%), more than one (2.9%)					
Plant growth type: Indeterminate (100%)					
Number of carpels per capsule: Bicarpellate (95.1%), tetracarpellate (4.9%)					
Capsule hairiness: Sparse hair (66.0%), hair absent (28.2%), strong or profuse (5.8%)					
Capsule dehiscence at ripening: Completely shattering (100%)					

10 cm. The experimental design was an augmented block design in 2004 and a randomized complete blocks design with two replications in 2005. Based on different agronomic characters and yield potential, 42 different single plants were selected from these populations in 2005. Each selected single plants were sown in 5 m long 2 row plots using randomized complete blocks design in 2006. The well adapted dominant variety, Muganlı-57, was used as the control in this experiment. The management conditions were similar for the three experiments. Weeds were controlled by hand and pesticides were not used in the experiments. A doze of 60 kg/ha nitrogen, phosphorus, and potassium was applied as composite fertilizers at sowing.

A total of 21 morphological and agronomical characters were recorded for each plot following to Descriptors of Sesame (IPGRI and NBPGR, 2004). The qualitative characters were branching habit, stem hairiness, leaf hairiness, leaf arrangement, flower color, number of flowers per leaf axil, plant growth type, number of carpel per capsule, capsule hairiness, and capsule dehiscence at ripening.

The quantitative characters obtained on plot basis were days to emergence, days to flower initiation, days to 50% flowering, days to capsule initiation, 1000-seed weight (g), number of fruiting branches, and seed yield (kg/ha). Stem height to the first capsule (cm), plant height (cm), number of capsules per plant, and number of seeds per capsule were measured from three representative plants. Seed yield was recorded in g per plot and then converted to hectare basis.

The data were subjected to principal component analysis (PCA). PCs with Eigen-values > 1.0 were selected, as proposed by Jeffers (1967). Correlations between the traits and the respective PCs were obtained. In addition, cluster analysis was also performed to assess the level of dissimilarity among the accessions. A dendogram was constructed with Euclidian distance.

Results and discussion

Genetic diversity and characterization

The range of variation observed among the accessions for 10 morphological and 11 agronomic descriptors is presented in Table 1. Variation for stem hairiness, leaf hairiness, leaf arrangement, number of flowers per leaf axil, number of carpels per capsule and capsule hairiness as morphological descriptors were recorded. However, variation did not exist for branching habit, flower color, plant growth type and capsule dehiscence at ripening among the accessions (Table 1). All the landraces grown throughout Turkey consisted of the plants with branching, shattering and indeterminate growth habit (Uzun et al., 2003; Uzun et al., 2004; Uzun and Cagirgan, 2006; Uzun and Cagirgan, 2009 a,b). There was only white flower color with pink shading. This type of flower color was quite similar to Indian sesame collection with predominantly white with deep purple shading.

Number of flowers per leaf axil is one of the important characters for plant breeding programs. Most of the varieties had one flower per axil (97.1%). Of 103 sesame germplasm, only four sesame varieties, Ant64, 39702, Çamdibi and H4 varieties bear three flowers per axil. Because number of capsules per plant is the most contributing character for seed yield of sesame (Ibrahim et al., 1983; Osman, 1989), plants with three flowers per leaf axil are an important resource for plant breeding programs.

Hairiness is a typical character of sesame and can be seen in many parts of the plant such as stem, leaf, corolla, and capsule (Weiss, 1983). There were large variations in stem, leaf and capsule hairiness among the accessions. Most of the accessions had either sparse or no hairs on stem, leaf and capsule. Strong or profuse hair was observed in a few accessions. However, Ant-46 collected from Antalya provi-

Table 2. Percentage and cumulative variances and Eigen-vectors on the first seven principal components for each character in 103 sesame accessions

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigen-values	3.76	2.21	1.84	1.43	1.29	1.04	1.02
Explained Proportion of Variance (%)	20.9	12.3	10.2	7.9	7.1	5.8	5.7
Cumulative Proportion of Variation (%)	20.9	33.2	43.4	51.3	58.5	64.3	69.9
Variable	*Eigen-vectors*						
Days to emergence	-0.391	-0.083	-0.002	0.011	-0.117	-0.175	-0.113
Days to flower initiation	-0.467	-0.160	0.090	-0.025	-0.052	-0.022	-0.099
Days to 50% flowering	-0.458	-0.153	0.142	-0.046	-0.057	0.011	-0.054
Days to capsule initiation	-0.404	-0.233	0.064	-0.148	-0.059	-0.009	-0.031
Stem height to the first capsule	-0.275	0.430	0.018	0.016	-0.015	0.243	-0.185
Number of capsules per plant	0.154	-0.070	0.591	0.031	0.143	0.069	-0.044
Number of fruiting branches	0.145	-0.110	0.553	0.019	-0.071	0.196	-0.172
Plant height	-0.131	0.441	0.281	0.024	0.192	0.142	-0.046
Number of seeds per capsule	-0.022	-0.063	0.118	-0.030	0.685	-0.242	0.334
1000-seed weight	-0.056	0.415	0.015	0.012	-0.280	-0.235	0.316
Seed yield	-0.149	0.425	0.124	-0.100	-0.051	-0.045	0.397
Stem hairiness	-0.143	-0.095	-0.029	0.564	0.239	0.022	0.122
Leaf hairiness	-0.051	0.096	0.134	0.551	0.037	-0.368	-0.265
Leaf arrangement	-0.162	0.190	-0.234	0.058	0.345	-0.060	-0.213
Flower colour	-0.108	0.050	0.058	-0.462	0.339	0.164	-0.090
Number of flowers per leaf axil	0.099	0.145	-0.308	-0.030	0.228	0.163	-0.446
Number of carpels per capsule	-0.111	-0.242	-0.160	-0.015	0.135	0.094	0.370
Capsule hairiness	-0.095	-0.025	-0.087	0.350	-0.028	0.726	0.248

Table 3. The list of selected lines and their agronomic performances

Genotype	Days to 50% flowering	Days to capsule initiation	Plant height (cm)	Stem height to the first capsule (cm)	Number of fruiting branches	Number of capsules per plant	Number of seeds per capsule	1000-seed weight (g)	Seed yield (kg/da)
Ant-33/2	42	42	148	56	7	154	74	3.7	96
28/9-2-3/1	43	44	174	55	6	149	70	3.6	85
B-2/1	39	41	163	55	6	114	74	4.1	84
15/10-1-1/1	42	42	152	52	6	149	74	3.8	80
38192/1	43	45	149	58	4	78	72	3.7	79
Ant-66/1	43	43	167	59	3	74	70	3.7	75
Ant-58/1	44	43	155	53	5	118	74	3.9	74
Ant-66/2	42	44	165	64	3	76	72	4.0	73
Ant-53/1	39	40	144	52	5	97	78	3.8	72
Margo-3/2	46	46	142	49	4	136	66	3.5	69
Ant-71/1	43	44	143	48	5	117	74	3.6	69
42884/2	42	43	146	57	5	88	70	4.2	66
Ant-58/2	43	44	159	58	5	132	76	4.1	65
Ant-47/1	42	42	153	49	7	144	78	3.6	65
Ant-32/1	43	45	130	39	3	93	70	3.7	65
H-8/2	43	43	135	44	5	88	78	3.7	61
5/10-4-2/1	45	44	149	53	5	112	70	3.8	61
Ant-21/1	41	42	156	57	5	122	82	3.7	60
B-3/1	44	43	148	53	4	109	78	3.8	56
38253/1	46	43	164	58	6	161	74	3.6	55
1/10-7-2/1	44	46	164	54	5	116	70	3.8	55
B-1/1	45	46	132	43	7	126	72	3.7	53
42884/1	39	40	138	52	5	91	70	4.2	53
Ant-26/1	43	43	133	49	5	83	70	3.8	52
Yolcu/2	44	43	167	58	4	111	74	3.6	52
22/9-1-1/1	44	45	168	52	5	94	82	3.6	50
Ant-21/2	41	42	140	40	3	71	78	3.9	50
Margo/1	46	45	162	72	5	87	72	3.5	50
Yolcu/1	44	43	156	69	5	94	70	3.5	50
42259/1	44	43	144	54	6	116	72	3.7	50
29/9-1-2/2	38	40	155	47	6	135	64	3.7	48
38128/1	43	42	158	49	5	143	82	3.9	44
Ant-33/1	45	45	154	52	4	102	74	3.6	41
Margo-3/1	44	43	144	48	3	116	72	4.1	41
H-8/4	44	43	137	39	5	117	76	4.1	40
H-8/3	41	41	129	42	5	93	77	3.9	38
Ant-22/1	45	43	144	44	4	71	74	3.6	36
39702/1	48	49	154	44	4	114	76	3.7	36
H-8/1	43	42	153	59	8	151	66	3.5	35
39700/26-6/1	43	43	141	43	4	93	72	3.7	35
29/9-1-2/1	44	44	160	56	5	134	64	3.9	32
Ant-51/1	43	45	154	41	5	134	82	3.7	32
Muganlı-57	41	43	149	62	4	101	78	3.9	104
C.V.	0.90	1.00	6.80	13.3	27.6	24.5	8.27	6.15	22.6
LSD	0.82	0.88	20.6	13.95	2.56	55.3	12.27	0.46	26.3
Prob	**	**	**	**	ns	*	ns	ns	**

* and ** are statistically significant at 0.05 and 0.01 level, respectively, ns: not significant.

nce, exhibited strong stem, leaf and capsule hairiness. This could be evaluated as advantages for insect pests and diseases of sesame.

Some accessions, 3/10-2-2, 31594, 37486, 38128, and 38253 had tetracarpellate capsule structure. This type of capsules potentially enlarges the space for more seeds to fit and a structural modification converting the two extra-floral nectaries to capsule (Bedigian, 2003). However, plants with tetracarpellate capsule exhibit flatness on the stem which is rarely seen in bicarpellate sesame genotypes.

There has been a great variation for agronomic characters among the accessions (Table 1). The mean values of the germplasm for days to emergence, days to flower initiation, days to 50% flowering, and days to capsule initiation were 6.7, 45.3, 49.2, and 50.9 with a range of 5.7 and 7.5, 43.0 and 47.0, 46.7 and 51.3, and 48.7 and 53.7, respectively. These characters could be evaluated to identify for both early and late maturity. The genotype 38253 had the maximum values for these four characters while there were several varieties available in the collection for earliness. These are also very valuable sources for plant breeding programs aiming for adaptation of sesame to different environments as well as for studies on thermo- and photo-period sensitivity (Suddihiyam et al., 1992; Ashri, 1995; Rehman et al., 2009).

The highest seed yield was found in 42259 collected from Cizre, Mardin province. The average seed yield was 652.5 kg/ha with a range of 321.3 and 977 kg/ha. The variation for seed yield a little higher than the provincial seed yield of Turkey. The average seed yield of the accessions was also a bit higher than that of Turkey. This difference can be contributed to the cultivation conditions in the study. These results supported that the local varieties were still widely maintained by farmers in the lack of improved breeding cultivars suited for different ecological conditions.

The means for stem height to the first capsule, plant height, number of fruiting branches, number of capsules per plant, number of seeds per capsule and 1000-seed weight in the collection were 42.8, 139.8, 3.7, 115.2, 75.3 and 3.7, respectively. The range was between 30 and 55.7 for stem height to the first capsule, 117.7 and 158.3 for plant height, 2.3 and 5.3 for number of fruiting branches, 69 and 154.7 for number of capsules per plant, 66.7 and 85.3 for number of seeds per capsule, and 3.2 and 4.1 for 1000-seed weight. These characters also revealed a large genetic diversity. The accessions with a wide range of variation for agronomic characters had potential to determine the best genotypes for different environments.

Multivariate analysis of the accessions revealed that the first seven PCs (PC1 to PC7) gave Eigen-values > 1.0 and cumulatively accounted for 69.9% of the total variation (Table 2). The first PC axes account for 20.9% of the total multivariate variation, while the second account for 12.3% and the third for 10.2%. The cumulative proportion of the variation reached 43.4% in the first three PC axes, and 69.9% in the first seven axes. The high degree of variation in the first seven PC axes indicates a high degree of variation for these characters.

There are no guidelines to determine the significance or importance of a coefficient, that is, Eigen-vector (Düzyaman, 2005). However higher coefficients for a certain trait indicate the relatedness of that trait to respective PC axes (Sneath and Sokal, 1973). The variation in PC1 was mainly associated with days to flower initiation, days to 50% flowering, days to capsule initiation, and days to emergence, in PC2 with plant height, stem height to the first capsule, seed yield, and 1000-seed weight, and in PC3 number of capsules per plant and number of fruiting branches. The fourth PC axis separated stem hairiness and leaf hairiness. PC5 and PC6 were mainly number of seeds per capsule and capsule hairiness, respectively while PC7 was associated with number of flowers per leaf axil. Characters with high coefficients in the PC1 to PC4 should be considered as more important since these axes explain more than half of the total variation.

PCA analysis indicated that days to flower initiation, days to 50% flowering, days to capsule initiation, days to emergence, plant height, stem height to the first capsule, seed yield, 1000-seed weight, number of capsules per plant, number of fruiting branches, stem hairiness and leaf hairiness were among the most important descriptors which accounted for more than 50% of the phenotypic variation expressed in this germplasm collection. These descriptors were therefore found to be most useful for studying the variability of populations. It is suggested that the use of these characters will save considerable amount of time for identification of sesame germplasm.

The cluster analysis based on agro-morphological traits assigned the 103 sesame germplasm accessions into eight main clusters. A dendogram grouped the sesame accessions into individual groups (Fig 1). The cluster analysis did not separate the germplasm based on their geographical origins. This result is in agreement with findings of Dixit and Swain (2000) and Gupta et al. (2001). This may be migration of the sesame materials from one region to another in collection sites. Although sesame has been described as an autogamous plant, recent evidence raises the possibility of natural outcrossing in sesame (Pathirana, 1994; Baydar and Gurel, 1999). Some ecological conditions could also lead to gene flow between populations from different geographical origins.

Selection studies

The germplasm represents a valuable source of genetic diversity that would be highly useful breeding programs. Genetic advance in sesame can easily be gained after selection for a few generations due to the combination of autogamy and heterogeneity. Thus, 42 lines were selected for further work based on their yield potential and several agronomic traits such as number of capsules per plant and number of fruiting branches. The list of selected lines and their agronomic performances are presented in Table 3.

A large variation has also been observed among the selected single plants (Table 3). Ant-33/2, 28/9-2-3/1, B-2/1, 15/10-1-1/1 and 38192/1 took place in the same group with the control for seed yield character. In this group, there was a positive shift in mean values for the characters studied. For instance, while Ant-33 showed 776 kg/ha seed yield performance in base population (data not shown), the single plant selection of this genotype, Ant-33/2, yielded 960 kg/ha (Table 3). Similar positive shifts for seed yield were observed for the selected lines of 28/9-2-3/1 from 558 to 850, B-2/1 from 616 to 840, 15/10-1-1/1 from 755 to 800 and 38192/1 from 696 to 790 kg/ha. The increase in mean values was also valid for the rest of the characters studied especially in number of capsules per plant and number of fruiting branches. While, the mean values of Ant-33 in the base population for the number of capsules per plant and number of fruiting branches were 92 and 2, respectively, their selected line, Ant-33/2, exhibited 154 capsules per plant and 7 fruiting branches. These results indicated that the rapid advance under selection could easily be gained in sesame if there is a considerable amount of variation available in the germplasm.

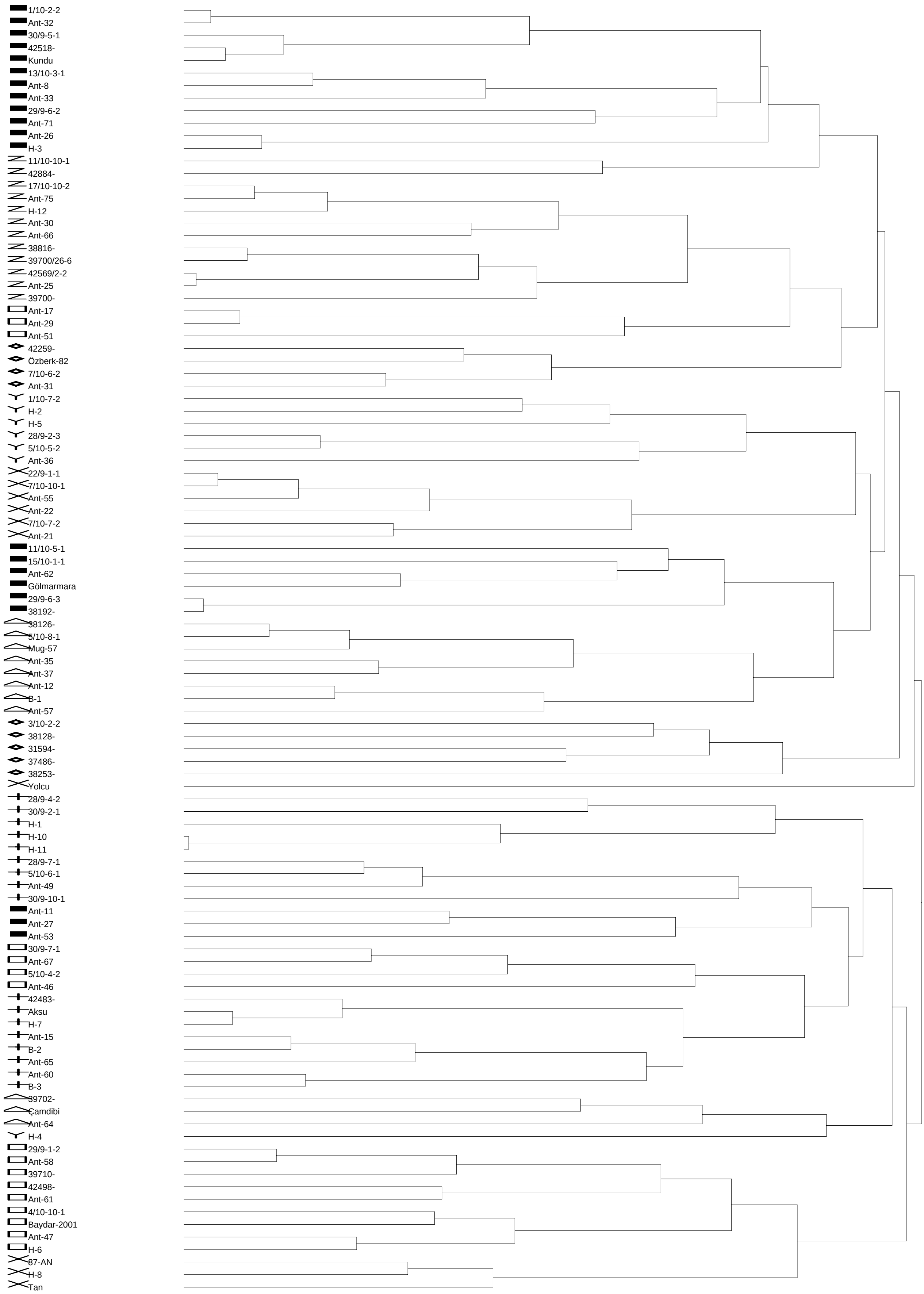

Fig 1. A dendogram illustrating dissimilarity based on hierarchical cluster analysis.

Conclusions

The results showed that there was high genetic diversity with regard to morphologic and agronomic characters in the sesame collection. The diversity could mainly be attributed to diverse agro-climatic conditions in the country. Accessions from different regions were sometimes closely related and accessions from the same region had different genetic background. The intraregional diversity could be as a valuable source as interregional diversity for sesame improvement.

The germplasm represents a valuable source of genetic diversity that is expected to be highly useful for future breeding programs. The success in genetic improvement of the crop, however, depends on the availability of genetic resources and their diversity.

Acknowledgements

The authors gratefully acknowledge the Akdeniz University Scientific Research Project Unit.

References

Ali MA, Niaz S, Abbas A, Sabir W, Jabran K (2009) Genetic diversity and assessment of drought tolerant sorghum landraces based on morph-physiological traits at different growth stages. POJ 2:214-227.

Ashri A (1990) Sesame genetic resources: collection, evaluation and conservation. In: Omran A (ed) Oil crops: sesame and sunflower subnetworks. IDRC-MR271e, IDRC Ottawa, pp. 2-9.

Ashri A (1995) Sesame research overview: current status, perspectives and priorities. In: Bennett MR, Wood IM (eds) Proceedings of sesame workshop. NT Dept. Primary Industry and Fisheries, Darwin, pp. 1-17.

Ashri A (1998) Sesame breeding. Plant breeding reviews 16:179-228.

Baydar H, Gurel F (1999) The effects of honey bees on cross-pollination and hybrid seed production in sesame (*Sesamum indicum* L.). Turk J of Field Crops 4:21-24.

Baydar H, Turgut I, Turgut K (1999) Variation of certain characters and line selection for yield, oil, oleic, and linoleic, acids in the Turkish sesame (*Sesamum indicum* L.) populations. Turk J Agric For 23:431-441.

Bedigian D, Harlan JR (1986) Evidence for cultivation of sesame in the ancient world. Econ Bot 40:137-154.

Bedigian D, Smyth CA, Harlan JR (1986) Patterns of morphological variation in *Sesamum indicum*. Econ Bot 40:353-365.

Bedigian D (2003) Evolution of sesame revisited: Domestication, diversity and prospects. Genet Resour Crop Evol 50:779-787.

Bhat KV, Prashant PB, Lakhanpaul S (1999) Study of genetic diversity in Indian and exotic sesame (*Sesamum indicum* L.) germplasm using random amplified polymorphic DNA (RAPD) markers. Euphytica 110:21-33.

Bisht IS, Mahajan RK, Loknathan TR, Agrawal RC (1998) Diversity in Indian sesame collection and stratification of germplasm accessions in different diversity groups. Genet Resour Crop Evol 45:325-335.

Demir I (1962) Türkiye'de yetiştirilen önemli susam çeşitlerinin başlıca morfolojik, biyolojik ve sitolojik vasıfları üzerinde araştırmalar (in Turkish with German abstract). Ege Üniversitesi Ziraat Fakültesi Yayınları: 53, s. 160, İzmir.

Dixit UN, Swain D (2000) Genetic divergence and heterosis in sesame. Indian J Genet 60:213-219.

Düzyaman E (2005) Phenotypic diversity within a collection of distinct okra (*Abelmoschus esculentus*) cultivars derived from Turkish landraces. Genet Resour Crop Evol 52:1019-1030.

Gupta RR, Parihar BMS, Gupta PK (2001) Genetic diversity for some metric characters in sesame (*Sesamum indicum* L.). Crop Res 21:350-354.

Hiltebrandt VM (1932) Sesame (*Sesamum indicum* L.). Bull Appl Bot Plant Breed 9:1-114.

Ibrahim AF, El-Kadı DA, Ahmed AK, Shrief SA (1983) Interrelationships and path-coefficient analysis for some characters in sesame (*Sesamum indicum* L.). J Agronomy and Crop Science 152:454-459.

IPGRI, NBPGR (2004) Descriptors for sesame (*Sesamum* spp.). International Plant

Genetic Resources Institute, Rome, Italy; and National Bureau of Plant Genetic Resources, New Delhi, India.

Jeffers JNR (1967) Two case studies in the application of principal component analysis. Appl Stat 16:225-236.

Joshi AB (1961) *Sesamum*. Indian central oilseeds committee. Hyderabad, India.

Osman HE (1989) Heterosis and path coefficient analysis in sesame (*Sesamum indicum* L.). Acta Agron Hung 38:105-112.

Pathirana R (1994) Natural cross-pollination in sesame (*Sesamum indicum* L.). Plant Breeding 112:167-170.

Rehman AU, Habib I, Ahmad N, Hussain M, Khan MA, Farooq J, Ali MA. (2009) Screening wheat germplasm for heat tolerance at terminal growth stage. POJ 2: 9-19.

Sneath PHA, Sokal RR (1973) Numerical taxonomy. W.H. Freeman and Company, San Francisco.

Suddihiyam P, Steer BT, Turner DW (1992) The flowering of sesame (*Sesamum indicum* L.) in response to temperature and photoperiod. Aust J Agric Res 43:1101-1116.

Uzun, B, Lee D, Donini P, Cagirgan MI (2003) Identification of an AFLP marker linked to the closed capsule mutant trait in sesame. Plant Breeding 122 (1): 95-97.

Uzun B, Ozbas, MO, Canci H, Cagirgan MI (2004) Heterosis for agronomic traits in sesame hybrids of cultivars x closed capsule mutants. Acta Agric Scand Sect B Soil and Plant Sci 54: 108-112."

Uzun B, Arslan Ç, Furat Ş (2008) Variation in fatty acid compositions, oil content and oil yield in a germplasm collection of sesame (*Sesamum indicum* L.). J Am Oil Chem Soc 85: 1135-1142.

Uzun B, Cagirgan MI (2009a) Identification of molecular markers linked to determinate growth habit in sesame. Euphytica 166: 379-384."

Uzun B, Cagirgan MI (2009b) Comparison of determinate and indeterminate lines of sesame for agronomic traits. Field Crops Res 96:13-18.

Weiss EA (1983) Oilseed crops. Longman, NY.

Xiurong Z, Yingzhong Z, Yong C, Xiangyun F, Qingyuan G, Mingde Z, Hodgkin T (2000) Establishment of sesame germplasm core collection in China. Genet Resour Crop Evol 47:273-279.