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Genetic advance, heritability and inheritance in determinate growth habit of sesame

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Abstract

Determinate growth habit is a unique mutant character in sesame and crosses between mutant types and cultivars should provide opportunity for developing superior parental materials. This study was conducted with controlled crosses to understand the genetic potential of determinate growth habit in field environment during the 2008 to 2011 growing periods. Muganli-57 (♀) with indeterminate growth habit was crossed to ACS 337 (♂), which has determinate growth habit. In the F_1 generation, all the plants were indeterminate. In F_2 population, a 3:1 segregation ratio indicating determinate character was controlled by a single recessive gene. The determinate types showed no further segregation in F_3 generation and; thus, F_2 segregation ratio was supported. Heritability was estimated by parent-offspring regression and data were collected from F_1, F_2 and F_3 generations. To assess the cross effect on indeterminate and determinate sibs in F_2 generation, data for both phenotypes were separately generated. Heritability estimates in narrow sense were low for stem length to the first capsule, plant height, number of capsules per plant and seed yield in determinates. Genetic advance also had low values except for number of branches. Unlike determinate types, indeterminate types had high heritability values except for number of capsules per plant. Heritability values for both types in F_2 and F_3 generations were high for number of branches. This result showed that additive gene effect played an important role for both determinate and indeterminate types and these positive shifts continued in F_3 generation compared to parental lines.

Keywords: determinate growth habit, genetic parameters, heritability, *Sesamum indicum* L.

Introduction

Sesame (*Sesamum indicum* L.) is a very ancient oilseed crop (Ashri, 2007) and especially grows well and gives high yields in both tropical and temperate climates (Morris, 2009). It is often referred to by the epithet “the queen of oil seeds” because it is highly valued not only for its nutritive value but also for the quality and quantity of its oil ranging from 40 to 62.7% (Uzun et al., 2008). This oil is rich in antioxidants (Erbas et al., 2009) and has a significant amount of oleic and linoleic acids. Despite its long history and nutritional value, the crop has low yielding capacity compared to other oilseed crops, due to its low harvest index, susceptibility to diseases, seed shattering and indeterminate growth habit (Ashri, 1998; Yol and Uzun, 2012). The non-mechanized harvesting also prevents expansion of its cultivation as there is lack of high yielding non-shattering and determinate growth types (Uzun and Cagirgan, 2006; 2009).

Sesame has different developmental stages of capsules in a plant because plant growth is originally indeterminate. Capsules on middle and low position of stem are ripen almost enough but those of late bloom high on the stem remain immature (Doo et al., 2003). This wildish character causes unwanted agricultural issues such as non-synchronous maturity and incompatibility to combine harvesting. Determinate sesame makes a uniform maturity, which is a requirement for mechanical harvesting (Khan, 1992). In this type, the plants would stop flowering, shed their leaves and reach physiological maturity before their first capsules drying. Subsequently, the plants should dry as quickly as possible and release the seeds from the capsules in a way commensurate with the harvest and threshing methods (Van Zanten, 2001). Many researchers have become interested in determinate growth habit in sesame. This unique character was first discovered by Ashri (1981). The cultivar named dt45 was produced by irradiating dry seeds of the Israeli cultivar No. 45 with gamma rays (500 Grey) (Ashri, 1998). It was characterized by shorter unique plants with: telescoped internodes, presence of five to seven capsules clustered at the tips of the main stem and branches, and often had modifications of the apical flowers and capsules (Fig. 1) (Ashri, 2007).

Although determinate growth habit of sesame was discovered many years ago majority of the world’s sesame is indeterminate and most of the harvest is manual (Uzun and Cagirgan, 2006). The most important reason for non-adoption of the determinate mutant sesame was the pleiotropic effect of the mutation including severe reduction of plant height, inadequate capsule production, which results in low seed yield (Kang et al., 1993). Outcrosses between determinate and advanced cultivars should be useful to remove unwanted side effects and also improving traits of agricultural importance. According to Van Zanten (2001), crosses involving 'local varieties x mutants', 'mutants x mutants', and 'mutants x introduced lines', provide means to obtaining new genotypes that have more than one of the desired characters. This suggestion was valid for the mutant closed capsule x cultivar crosses in sesame because heterotic effects were obtained (Uzun et al., 2004).

When crosses are made, genetic parameters should be well defined. These parameters are very useful perceiving genotype and environmental interaction in crosses providing beneficial data for identification of genetic and agronomic potential. The knowledge of genetic components of a trait enables the plant breeders to predict the response to selection (Waqar-ul-haq et al., 2008). It also provides information on the extent to which a particular character can be transmitted to the successive generations. Genetic information like heritability and genetic advance of several yield contributing characters would be of great value enabling development of new genotypes with improved yield and quality traits and having broadened genetic base (Mangi et al., 2007).

Although determinate sesame has agricultural advantages; unfortunately, it has reduced capsule production, plant height and seed yield. As a part of the strategy to increase genetic variability in sesame and to make the desired changes in the mentioned quantitative characters, crosses involving mutant x cultivars might be sought. In this point of view, the objective of the present investigation was to obtain desirable traits with a cross between an indeterminate cultivar and determinate mutant using quantitative assessment tools namely heritability, genetic advance and inheritance.

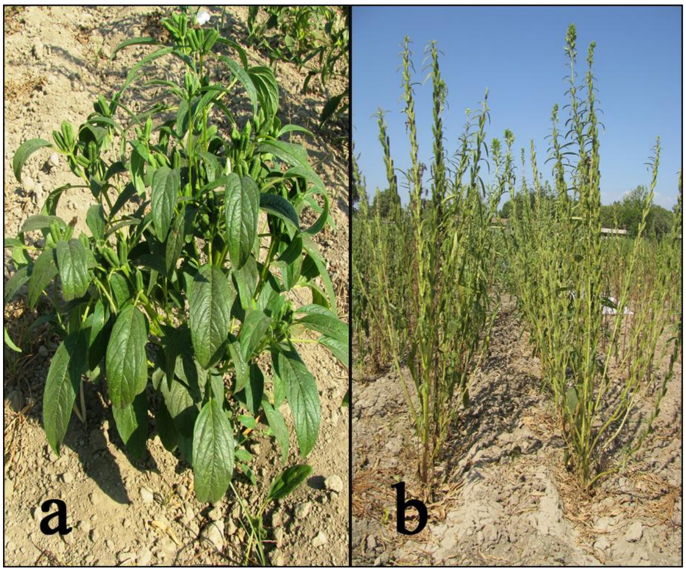

Fig 1. Determinate and indeterminate sesame genotypes in the field. (a) indicates determinate growth habit character; (b) indicated indeterminate (normal) growth habit character.

Results

Heritability and genetic advance

Heritability estimates in the narrow sense for the indeterminate x determinate growth habit cross were calculated for seven quantitative characters (Table 1). The highest heritability estimated was for number of branches (0.89), while the lowest for seed yield (0.19) in determinate types at F_2. Across these traits, number of seeds per capsule and 1000 seed weight showed relatively high heritability values (0.87 and 0.77, respectively). Heritability estimates were comparatively low for number of capsules per plant (0.31) and plant height (0.30). Among the traits, genetic advance (GA) expected from selection of the progenies was the highest for number of branches (26.8%) and lowest for number of capsules per plant (1.0%). Apart from the latter, GA estimate was relatively low for stem length to the first capsule (11.8%). GA estimates for 1000 seed weight, number of seeds per capsule, plant height, and seed yield were low with values of 7.4%, 4.3%, 4.0% and 3.4%, respectively.

Heritability estimates for indeterminate F_2s were higher than those of determinate types (Table 1). Estimates of heritability varied from 0.55 for number of capsules per plant to 0.96 for number of branches. A relatively high heritability estimate was also obtained for stem length to the first capsule (0.82). Generally, intermediate estimates were noted for number of seeds per capsule (0.75), 1000 seed weight (0.75), plant height (0.71) and seed yield (0.69). Number of capsule per plant, number of seeds per capsule, 1000 seed weight and plant height depicted GA values lower than 15% (Table 1). Relatively high GA expectations were obtained for number of branches (31.6%) and stem length to the first capsule (30.9%). In contrast, seed yield had a very high GA value (71.3%).

Heritability and genetic advance of determinate and indeterminate types of sesame were also calculated in F_3 generations to observe genetic stability of the characters. In determinate types, the highest heritability was estimated for number of branches (0.89) which was followed by number of seeds per capsule (0.89) and plant height (0.88). These characters were followed by 1000 seed weight (0.64), stem length to the first capsule (0.64) and seed yield (0.60). Among the traits, GA expected from selection of the progenies was the highest for number of capsules per plant (15.6%) and the lowest for 1000 seed weight (0.1%). The maximum heritability estimate was for number of seeds per capsule (0.96), while the minimum for 1000 seed weight (0.62) in indeterminate growth types. Across these traits, plant height and number of branches showed relatively high heritability values (0.88 and 0.87, respectively) (Table 1). Mean values for all the F_2 and F_3 characters were compared with their parents using the *t-test*. Number of capsules per plant and plant height in determinate plants in F_2 had higher means than the parental line, ACS 337, statistically (Table 2). This positive shift was also observed for F_3. In F_2 indeterminate progeny, number of branches and number of capsule per plant had higher mean values than parent, Muganli-57. Correlatively, these characters indicated significantly better selection progress in indeterminate F_3 plants compared to parent (Table 2).

Inheritance and correlation

Following to Muganli-57 (♀) x ACS 337 (♂) cross, all the F_1 plants had indeterminate growth habit demonstrating that this character is dominant over determinate growth habit. In the F_2 generation, the population consisted of 439 indeterminate and 148 determinate plants. The observed number of indeterminate and determinate plants fitted the expected 3:1 (indeterminate:determinate) ratio (χ^2 = 0.014, p = 0.91) (Table 3). When F_2 plants were separately advanced to F_3 generation as either determinate or indeterminate, all the plants in F_3 originating from determinate genotypes in F_2 were also determinate (Table 4). Among the indeterminate plants in F_3, 131 plants sourced from 3 offsprings showed indeterminate growth habit (Table 4) and no determinate plant was observed. However, 2 offsprings showed segregation in F_3 and consisted of 126 indeterminate and 39 determinate plants. This segregation also fitted the expected 3:1 ratio of indeterminate-to-determinate (Table 4).

Correlation coefficients of seed yield and yield components were displayed in Table 5. In determinate types, number of branches and number of capsules per plant characters indicated positive correlation and they had also positive relationship with seed yield. Similar results were also observed for indeterminate types.

Table 1. Heritability (h^2) of by parent-offspring regression and standard errors of indeterminate x determinate cross and its genetic advance (GA).

Traits	F_1 to F_2				F_2 to F_3 (*dt* to *dt* and *Dt* to *Dt*†)			
	h^2	GA (%)	h^2	GA (%)	h^2	GA (%)	h^2	GA (%)
	Determinate growth types	Determinate growth types	Indeterminate growth types	Indeterminate growth types	Determinate growth types	Determinate growth types	Indeterminate growth types	Indeterminate growth types
SLFC	0.38 ±0.7	11.8	0.82 ±1.3	30.9	0.64 ±0.2	4.9	0.82 ±0.4	11.4
PH*	0.30 ±0.7	4.0	0.71 ±0.8	10.6	0.88 ±0.2	13.1	0.88 ±0.4	19.3
NB	0.89 ±0.3	26.8	0.96 ±0.5	31.6	0.89 ±0.8	3.6	0.87 ±0.2	1.6
NCP	0.31 ±0.1	1.0	0.55 ±0.3	9.7	0.70 ±1.4	15.6	0.85 ±0.1	13.4
NSC	0.87 ±0.4	4.3	0.75±0.4	2.6	0.89 ±0.3	4.8	0.96 ±0.3	3.3
TSW	0.77 ±0.7	7.4	0.75 ±0.3	1.9	0.64 ±0.1	0.1	0.62 ±0.7	0.1
SY	0.19 ±0.1	3.4	0.69 ±1.0	71.2	0.60 ±0.4	1.0	0.75 ±0.1	4.9

†*dt* is stand for determinate growth types; *Dt* is stand for indeterminate growth types. *SLFC is stand for stem length to the first capsule; PH is stand for plant height; NB is stand for number of branches: NCP is stand for number of capsules per plant; NSC is stand for number of seeds per capsules; TSW is stand for 1000 seed weight; SY is stand for seed yield.

Table 2. Means and standard errors of the parental lines, F_1, F_2 and F_3 generations for yield and yield components.

Traits	Parental lines		Muganli-57 x ACS 337								
	Muganli-57	ACS 337	F_1	$F_{2\text{-dt}}$§	$F_{2\text{-dt}}$¥	$F_{2\text{-DT}}$	$F_{2\text{-DT}}$	$F_{3\text{-dt}}$	$F_{3\text{-dt}}$	$F_{3\text{-DT}}$	$F_{3\text{-DT}}$
SLFC (cm)	52.0 ±4.9	49.0 ±1.9	37.8 ±1.7	53.0	ns	40.0	ns	51.4	ns	44.2	ns
PH (cm)	127.0 ±8.9	62.0 ±3.4	133.0 ±4.1	80.0	**	126.0	ns	80.6	*	139.0	ns
NB	3.8 ±0.2	8.0 ±0.6	4.4 ±0.5	9.6	*	6.0	*	11.4	ns	7.2	**
NCP	56.0 ±1.0	34.0 ±3.8	82.2 ±7.6	56.6	**	84.2	**	84.2	**	103.2	**
NSC	77.6 ±0.7	72.8 ±1.5	73.6 ±1.0	74.4	ns	77.2	ns	75.6	ns	78.0	ns
TSW (g)	3.0 ±0.1	3.1 ±0.1	3.1 ±0.1	3.3	*	3.3	*	3.3	ns	3.4	**
SY (g)	5.9 ±1.9	1.9 ±0.3	8.5 ±1.4	2.5	ns	10.6	ns	3.67	*	13.4	*

§$F_{2\text{-dt}}$ is determinate genotypes in F_2, $F_{2\text{-DT}}$ is indeterminate genotypes in F_2. $F_{3\text{-dt}}$ is determinate genotypes in F_3, $F_{3\text{-DT}}$ is indeterminate genotypes in F_3. ACS 337 is determinate growth habit parent; Muganli-57 is indeterminate growth habit parent. ¥All the F_2 and F_3 characters were statistically compared with their parental line (ACS 337 or Muganli-57) using *t-test*. * and ** significant at $p \leq 0.05$ and significant at $p \leq 0.01$, respectively. ns is non-significant.

Table 3. Segregation ratio of determinate and indeterminate character of sesame in F_2.

Cross	Experimental		Theoretical		χ^2	P	Ratio
	Indeterminate growth types	Determinate growth types	Indeterminate growth types	Determinate growth types			
Muganli-57 x ACS 337	439	148	440.25	146.75	0.014	0.85-0.95	3:1

Discussion

Heritability and genetic advance

Indeterminate growth habit had higher heritability values than determinates. In addition, in terms of plant height, mean values for all the traits in F_2 were greater than those in F_1 (Table 2). Seed yield in particular showed higher value and its genetic advance was so high. This positive shift in indeterminate F_2s might be explained by the additive gene effect due to the cultivar x mutant cross (Hoballah, 2001). Such an interaction with the mutated genes may result in a higher seed yield (Maluszynski et al., 2002). Similar heterotic effects were observed in number of branches, possibly deriving from the additive gene effects in both indeterminate types and hence, selection would be effective in enhancing this trait.

Normally, stem length to the first capsule indicates a wide range of variations due to the fact that it is highly affected by environmental and/or agricultural conditions. On the contrary, this character showed high heritability and genetic advance in indeterminate F_2 progenies and maintained similar high heritability and genetic advance at F_3 in our study. As mutant determinate types had genetic stability for stem length to the first capsule, this mutant cross would affect the genetic behaviour of this character even in the progeny of the indeterminates. The uniform distance of the first capsule from the ground in sesame may prove advantageous when swathing and/or in direct combining in mechanized harvesting because the cutter bar works at the same level. Other yield components, such as plant height, the number of seeds per capsule and 1000 seed weight had moderate heritability values in indeterminate progenies of F_2.

If sesame harvesting is not mechanized by the next twenty years, its world's production will decrease markedly as it will not be among crops chosen by farmers for commercial cultivation (Langham and Weimers, 2002). The main reason for this is that the manual labor, which is required for weed culling and harvesting is becoming scarce and expensive even in developing countries (Ashri, 2007). Therefore, breeding efforts in recent years have focused on the development of a non-shattering capsule and determinate growth habit in sesame because they are the most important criteria for employing mechanized harvesting. When swathing sesame or indirect harvest, the plants should be short enough so that the reel pulls in the plants rather than first pushing them out and then pulling them in (Langham and Wiemers, 2002). However, since sesame plants are too tall for platform headers, short types are required. Short plants are also useful for improving lodging resistance when lodging is a problem for sesame cultivation (Kang et al., 1993). Reducing plant height seems a partly viable solution and; therefore, determinate mutants may offer a good method for effectively manipulating plant height and also lodging because of their short stature (Uzun and Cagirgan, 2006). The low plant height appears to be a handicap with regard to high seed yield since plant height is one of the important contributors to seed yield (Yol et al., 2010). According to Ashri (1994), this undesirable situation should be tolerated due to increased population density by narrowing the spacing between the rows. However, our results indicated that the yield of the determinate plants was very low compared to its indeterminate counterparts (Table 2). This also reported by Kang and Van Zanten (1996). Instead of direct usage of determinate lines, outcrossing should be more suitable for achieving desirable traits (Uzun et al., 2004). In order to obtain desirable traits the cross breeding approaches has also been suggested by Van Zanten (2001) among mutants. This approach was useful for increasing number of capsules in determinate types in F_2 and F_3 in this study (Table 2). Similar positive effect was also observed for the number of branches presented in indeterminate types in F_2 and F_3 (Table 2). In addition, it was clear from the comparison between determinate progeny in the F_3 generation and the parental line ACS 337, that the additive gene effect was sustained in the subsequent generations (Table 2).

Considering the means of plant height and number of capsules per plant in F_2 and F_3, determinate growth habit types showed significant progress compared to the corresponding parent ACS 337 (Table 2). This cross; therefore, has been helpful for repressing any mutant negative effect, which was clearly observed in the character of number of capsules, since determinate progenies in F_2 had very high capsule production. This might lead to seed yield increasing in F_3 determinate types compared to parent (ACS 337) because higher capsule production has positive relationship with seed yield (Yol et al., 2010). The results obtained in indeterminate types indicated that the characters of number of branches and number of capsules per plant had higher mean values according to parental line (Muganli-57), indicating mutant cross provided further improvement in the mentioned characters.

Inheritance and correlation

This cross showed that growth habit in sesame is under control of a single gene with complete dominance. F_2 segregation revealed that determinate growth habit had monogenic inheritance and it was controlled by a recessive allele. In F_3 generation, determinate types derived from F_2 did not segregate, while some indeterminate offsprings in F_3 segregated to either indeterminate or determinate with a ratio of 3:1. The results obtained in F_2 were supported by segregation analysis of F_3 progeny.

The characters of number of branches and number of capsules indicate the positive relationship with seed yield. This situation should be one of the important points in yield increasing in sesame. Because these characters evaluated as selection criteria in breeding programs to increase sesame yield (Yol et al., 2010). Similar positive relation was observed in closed capsule and cultivar crosses in sesame and it can be speculated that the increase in number of capsules per plant as a yield component positively affected (Uzun et al., 2004).

Materials and methods

Site description

Field trials were carried out at the West Mediterranean Agricultural Research Institute's fields of Antalya (36°52'N. 30°50'E. 15 m elevation) on the Mediterranean Sea coast. The Station receives 1060 mm annual average precipitation and has an annual average temperature of 18°C (TSMS, 2010).

Plant materials and genetic study

Sesame germplasm with determinate growth habit was kindly provided by USDA, ARS, Georgia, USA with a PI number of 542048 and included in our genetic stock as ACS 337. The 'Muganlı-57' is a registered variety widely grown in Turkey. 'Muganli-57' with indeterminate growth habit (♀) was crossed with ACS 337 (♂) in 2008. F_1 plants were selfed in

Table 4. Segregation ratio of determinate and indeterminate characters of sesame in F_3.

Cross	Number of plants			
Muganli-57 x ACS 337	Indeterminate growth types	Determinate growth types	Ratio	Symbol
Determinate types obtained from F_2				
Offspring 1	0	15	0:1	*dt/dt*[*]
Offspring 2	0	27	0:1	*dt/dt*
Offspring 3	0	38	0:1	*dt/dt*
Offspring 4	0	33	0:1	*dt/dt*
Offspring 5	0	58	0:1	*dt/dt*
Indeterminate types obtained from F_2				
Offspring 1	48	0	1:0	*Dt/Dt*
Offspring 2	28	0	1:0	*Dt/Dt*
Offspring 3	55	0	1:0	*Dt/Dt*
Offspring 4	45	16	3:1 (*P=0.82*)	*Dt/dt*
Offspring 5	81	23	3:1 (*P=0.49*)	*Dt/dt*

[*]*Dt* is indeterminate growth habit (dominant); *dt* is determinate growth habit (recessive)

Table 5. Correlation coefficients between yield and yield components for indeterminate growth types (above diagonal) and determinate growth types (below diagonal) in the F_2 generation.

	SLFC	PH	NB	NCP	NSC	TSW	SY
SLFC[β]		0.48	0.38	-0.27	-0.18	0.15	0.03
PH	0.74		-0.57	-0.78	-0.05	-0.44	-0.62
NB	-0.80	-0.62		0.59	0.01	0.59	0.56
NCP	-0.89*	-0.64	0.97**		-0.57	0.89*	0.15
NSC	-0.14	0.06	0.46	0.28		-0.78	0.59
TSW	-0.94*	-0.52	0.86	0.93*	0.31		-0.10
SY	-0.52	-0.01	0.77	0.77	0.44	0.77	

* and ** significant at $p \leq 0.05$ and significant at $p \leq 0.01$, respectively.

[β]SLFC is stand for stem length to the first capsule; PH is stand for plant height; NB is stand for number of branches: NCP is stand for number of capsules per plant; NSC is stand for number of seeds per capsules; TSW is stand for 1000 seed weight; SY is stand for seed yield.

the growing season of 2009 and F_2 and F_3 populations were developed in two subsequent years of 2010 and 2011.

The crosses between 'Muganlı-57' and ACS 337 were made using flower buds emasculated just before anthesis and pollinated the second day with pollen grains from freshly dehisced anthers of the male parents (Falusi and Salako, 2003). F_1s were selfed in the growing season of 2009 and F_2 populations were developed in 2010. All the plants in F_2 were counted with either determinate or indeterminate growth habits. F_2 progenies with both growth habits were also sown in single rows separately in 2011. Parents, F_1, F_2 and F_3 progeny were grown at a spacing of 70 cm between rows 10 cm between plants in a row. Standard cultural practices like regular weed culling, irrigation and fertilization were followed.

Fertilizer was applied at rates of 60 kg N, 60 kg P_2O_5 and 60 kg K_2O per hectare just prior to sowing. F_1, F_2 and F_3 generations were grown at the same location. For heritability, each indeterminate and determinate plants in F_2 and F_3 were scored and measured separately to obtain F_2 and F_3 values for the estimation of narrow sense heritability and genetic advance of the traits studied. Sesame descriptors according to IPGRI and NBPGR (2004) were used for recording quantitative observations; stem length to the first capsule (SLFC), plant height (PH), number of branches (NB), number of capsules per plant (NCP), number of seeds per capsules (NSC), 1000 seed weight (TSW) and seed yield (SY).

Statistical analysis for heritability and genetic advance

Parent-offspring method was used to work out heritability estimates in narrow sense (h_{rg}^2) according to Smith and Kinman (1965); $h_{rg}^2 = b/2r_{op}$, where, b is regression coefficient or slope and r_{op} is relationship of parents-offspring.

A 20% selection intensity was applied for the genetic advance calculations. Genetic advance was calculated using the following formula; GA = K (S_{ph}) (H),
Where, K is a constant which at a selection intensity of 20% is about 1.40; S_{ph} is the phenotypic standard deviation ($\sqrt{V_{ph}}$); H is the heritability ratio.

Statistical analysis for inheritance and correlation

A chi-square ($\chi 2$) goodness-of-fit test was performed on the F_2 population against a possible theoretical segregation ratio using the formula: $\chi 2 = \Sigma (Oi - Ei)^2 / Ei$,
Where, Oi and Ei are the observed and expected values, respectively (Steel and Torrie, 1980). In F_3 generation, determinate and indeterminate types obtained from selfing F_2 plants were planted separately and possible theoretical segregation ratios calculated according to Steel and Torrie (1980). The correlation coefficient was carried out by using the formula suggested by Kwon and Torrie (1964).

Conclusion

The determinate mutant was developed with induced mutations by Ashri (1981) who called the determinate type "*recessive*", and assigned it the genotype *dt/dt*. Even though the single gene effect was identified, the determinate growth habit types show deleterious characteristics such as low capsule production and low yield as a result of unwanted side-effects. Despite intensive breeding efforts by many sesame researchers, the desired determinate could not be separated from the undesirable side effects, suggesting pleiotropism (Ashri, 2007). Determinate types, which have some desirable aspects; therefore, did not yield as well as their wild types and counterparts (Uzun and Cagirgan, 2006). Making crosses from different backgrounds had a good impact on having ideal determinate sesame as partly shown in the present report. To this end, breeding for high yielding determinate sesame is currently not a far-fetched idea. It would be achieved by using different and exotic genetic backgrounds as previously done for determinate soybean.

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