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Research Article

Agronomic trait assessment and selection for number of capsules in determinate x indeterminate crosses of sesame

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Abstract: Despite the progress, improved determinate (*dt/dt*) lines of sesame are still low yielding. Further improvement may be achieved by crossing locally adapted indeterminate cultivars with desirable determinates from a broad-based composite population. In order to test this hypothesis, 43 F_2 base populations from these kinds of crosses were generated and a distinct variability among populations was observed for seed yield and other traits. A 20% positive selection for number of capsules as the most yield-related component was applied to the pairs of determinate and indeterminate segregating in each population. Although seed yield per plant, number of capsules per plant and number of seeds per capsule were lower in determinates than indeterminates, these gaps were closed in certain crosses sharing certain "*dt/dt*" parents. Despite the fact that the plants were short, days to flowering (in F_2) and days to maturity took longer in determinates. The effect of selection was not apparent in increasing mean of progeny population in F_3 for the character under selection but the determinate group had the highest coefficient of variation (CV) as a basis for further genetic gain. It was concluded that composite populations with suitable genetic backgrounds were valuable sources of "*dt/dt*" segregants; recurrent breeding efforts and the modification of farming systems are all necessary in order to adopt novel characteristics like determinacy.

Key words: Composite population, mutant modification, *Sesamum indicum* L., variability, yield component

Determinat x indeterminat susam melezlerinde tarımsal özelliklerin belirlenmesi ve kapsül sayısı için seleksiyon

Özet: Sağlanan gelişmelere rağmen, determinat susam hatları düşük verimlidir. Geniş tabanlı kompozit populasyonlarda açılma gösteren arzu edilir determinatlarla, lokal olarak adapte olmuş indeterminat tiplerin melezlenmesi determinat tiplerin verimlerini daha fazla artırabilir. Bu hipotezi test etmek için 43 F_2 başlangıç populasyonu oluşturulmuş ve tohum verimi ve diğer özellikler için populasyonlar arasında geniş bir varyasyon ortaya konmuştur. Daha sonra verimle en sıkı ilişkili verim komponenti olan kapsül sayısı için her bir populasyonda açılma gösteren determinat ve indeterminat çiftlerine % 20 pozitif seleksiyon uygulanmıştır. Tohum verimi, kapsül sayısı ve kapsülde dane sayısı determinatlarda indeterminatlara göre düşük bulunmakla birlikte, belli "*dt/dt*" ebeveynini paylaşan bazı populasyonlarda arzu edildiği gibi bu açıklık kapanmıştır. Determinatların bitki boyu kısalmış, çiçeklenme (F_2' de) ve olgunlaşma süresi uzamıştır. Kapsül sayısı için seleksiyonun etkisi çevresel nedenlerle F_3' te maskelenmekle birlikte, oransal değerler belirgin bir ilerlemenin sağlandığını ve determinat grupta gözlenen yüksek varyasyon katsayısı değerleri daha fazla genetik kazanç sağlanabileceğine işaret etmektedir. Ayrıca, determinat tiplerin elverişli genetik ortamlarla birlikte seçilmesi için kompozit populasyonların değerli kaynaklar oldukları, determinatlık gibi yeni bir özelliğin kazanılmasında tekrarlamalı seleksiyon yaklaşımlarının ve yetiştirme sistemlerinin modifikasyonunun gerekli olduğu kanısına varılmıştır.

Anahtar sözcükler: Kompozit populasyon, mutant modifikasyonu, *Sesamum indicum* L., varyabilite, verim komponenti

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Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest crops and is grown throughout the tropics and subtropics. Its seeds are widely used for confectionary purposes, extracting high quality edible oil and making tahini (Ashri, 1998). It is suitable for various cropping systems either as a main or second crop (Çağırgan, 1994). Sesame is considered a self pollinating crop but varying degrees of cross-pollination may occur depending on insect activity, environmental conditions and availability of other vegetation.

The main problems in its cultivation are seed shattering at maturity preventing combine-harvest; indeterminate growth habit causing non-uniform capsule maturation; and susceptibility to wilting under irrigation (Çağırgan, 1997). A mutation-breeding program aiming at isolating non-shattering sesame, initiated by Ashri (1981), produced the first determinate mutant of sesame, "dt45", induced by 500 Gy gamma rays in an Israeli cultivar, No. 45. Subsequent induction of true botanic determinates based on three different independent mutational events was achieved in Turkish cultivars irradiated with gamma rays (Çağırgan, 1997, 2001, 2006).

A common obstacle in relation to mutation techniques is that often a desired mutant genotype shows undesirable side effects in other characters due to pleiotropy or additional mutations, restricting its direct use (Gaul, 1964). Experience shows that unwanted side effects of an induced mutation are modifiable by changing the genetic background of the mutant isolated (Micke et al., 1990; Çağırgan, 1995). By employing this approach, desirable mutants with negative side effects could be modified, resulting in successful cultivars in other crops (Micke et al., 1990, Çağırgan, 1995, Ashri, 1998). Apart from the successful genetic modification of the desired mutant it is necessary to modify the agronomic practices in order to accommodate the new phenotype.

Consequently, Ashri (1981) attempted modification of the mutant "dt45" by changing the original genetic background in order to improve its agronomic characteristics. Selected determinate lines were used as parents in breeding programs in many countries. However, advanced breeding lines did not yield as well as the local cultivars under commercial conditions (Ashri, 1991). As a next step, broad-based composite populations segregating for "*dt/dt*" were established with allowed bee activity to encourage out-crossing by the same researcher (Ashri, 1993, 1997) to generate a massive flow of genetic variability through large-scale crossing and to exploit it in different environments and conditions. Although "dt45" has been freely shared and used in the breeding of sesame in many countries, research progress was usually reported in terms of agronomic performance of improved lines (Ashri, 1991), lacked pair-base comparisons between determinates and indeterminates in early generations and the effect of selection on agronomic characters. Also, there was no comparative study assessing characters of determinates vs. indeterminates derived from a composite population used as parents for the new cycles of breeding.

The objectives of the study were to assess (i) the value of the agronomic traits in F_2 and F_3 generations of crosses between the composite-derived determinates (*dt/dt*) and locally adapted indeterminate cultivars, and (ii) the effect of selection for number of capsules per plant on other agronomic characters under second crop conditions. These findings would also be useful in revealing the suitability of a composite cross approach as a source of superior determinate plants and for maintaining a trait of interest in different genetic backgrounds as part of a gene pool.

Materials and methods

Genetic material and growing conditions: The desirable true botanic determinate single plants (*dt/dt*) segregating as part of the two broad-based composite populations were tagged at flowering as potential parents, either as female or male, and crossed with four locally adapted indeterminate cultivars, i.e. "Muganlı-57", "Özberk-82", "Gölmarmara" and "Çamdibi" basically in a Line x Tester scheme in 1994 in the Akdeniz University Campus, Antalya, Turkey. The F_1 generation was grown in the subsequent season in the same field. All F_1 plants of every cross combination between determinate and indeterminate were indeterminate, confirming the reported recessive inheritance for "dt45". The F_2 and F_3 trials were conducted under second crop conditions, sown after wheat harvest, in the experimental area (30° 44' E, 36° 52' N., 51 m above sea level) of the Mediterranean Research Institute of Agriculture in Aksu, Antalya, Turkey. The soil was an alkaline (pH 7.9) silt-loam with low organic matter content (1.48%). The seeds were sown in an irrigated seedbed including 50-50-50 kg ha^{-1} nitrogen, phosphorous and potassium applied during sowing. Plants were thinned by hand in the fourth week after sowing. Also, weeds were controlled by hand. Furrow irrigation was applied twice in July and August. In F_2, 43 base populations were sown in 10 rows each 2.5 m in length and then 2 rows of "Muganlı-57", a main local variety as a check, every 10 rows. Distance between the rows was 70 cm and within a row distance between plants was 5-6 cm.

Characters studied and selection: In each of the F_2 populations, 10 determinate and 10 indeterminate plants were tagged and the following characters were measured: seed yield per plant (g), number of capsules per plant, number of seeds per capsule, days to 50% flowering, days to maturity, plant height (cm). Statistical significance for the difference between the means of determinates and indeterminates was revealed by t-test. In F_2, considering its positive correlation with seed yield, a positive selection for number of capsules per plant was applied to the base populations with a selection pressure of 20%, each consisted of 2 sub-groups of determinate and indeterminate (n = 10 for each). Selected plants for the character under selection in both the determinate and indeterminate groups were advanced to F_3 as families in 2 groups, as determinate and indeterminate. Progenies of F_2 plants selected for number of capsules per plant in determinates and indeterminates were grown as progeny rows in $F_{3,}$ in 2.5 m lengths, 70 cm apart with 5-6 cm distance between plants in a row. The same characters were measured in three F_3 plants and expressed as the progeny mean of a line. Since there was no useful heritability estimation for number of capsules per plant but there was environmental variability between the two generations, response to selection for this character was expressed as the percent change over control. Consequently, group means in F_2 and F_3 were converted to percent giving a 100 to the control for both generations to reveal the effect of selection.

Results

Base (F_2) populations: In each of the 43 F_2 base populations, 10 pairs of determinate and indeterminate plants were sampled to assess the value of the populations and to obtain generation means of F_2 for the characters studied. There were clear differences among mean performances of the populations for seed yield and number of capsules per plant (Figure 1) and other characters (Figures 2, 3). All the determinate sub-groups had lower means than their indeterminate counterparts (Figure 1) and the differences were statistically significant in 29 populations ($P < 0.05$ or $P < 0.01$). In some of the 14 populations showing non-significant difference, the gap in seed yield between determinates and indeterminates was small. Among them, "36 × M" had the best determinate mean, closest to the mean of indeterminate control "Muganlı-57", which were followed by "36", "36 × Ö", "36 × G" and "11 × Ö". It should be noted here that among others, "36" was one of the *"dt/dt"* parents used in crossing and segregated for indeterminates in F_2 as a result of out-crossed capsule(s) by bee activity in the course of crossing. Similarly, the mean number of capsules per plant was lower in determinates than their indeterminate counterparts and these differences were significant in 28 pairs (Figure 1). However "36", "23 × Ç", "36 × M", "36 × G", "6 × M" and "14 × 17" were the pairs of wherein determinates surpassed indeterminates in number of capsules per plant both in the grand mean of determinates and the control, "Muganlı-57". Determinates and indeterminates of "36" and "36 × M" showed the highest mean values for number of capsules per plant in each group (Figure 1). Also, number of seeds per capsule was lower in determinates than indeterminates; the differences were statistically significant in 32 pairs. However, reductions in this character were not drastic compared to seed yield and number of capsules per plant. While none of the determinate subgroups surpassed the control for number of seeds per capsule, ten indeterminates did. Among them, "36 × Ö", "36 × M", "23 × G", "17 × Ö", "G × 17" and "23 × M" were worth mentioning (Figure 2). All determinates were shorter than both their indeterminate counterparts and the control group. Also, the differences between the subgroups of each pair were statistically significant ($P < 0.01$), except in "3 × M" and "41 × M". Also, the mean of indeterminates was close to those of the control group. Despite the

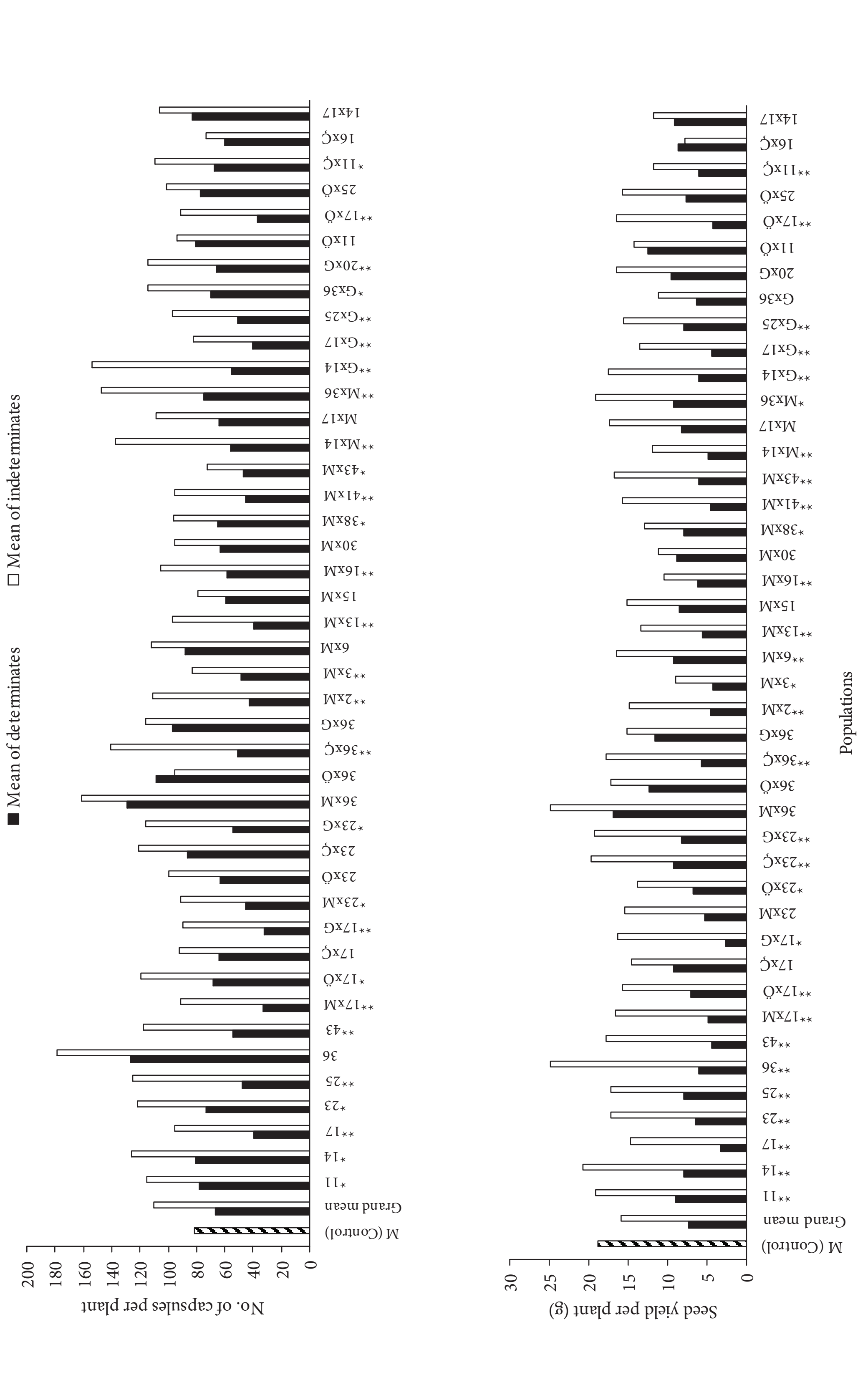

Figure 1. Mean of control, determinate and indeterminate growth types, and t-tests for seed yield per plant (g) and number of capsule per plant measured in F_2 base populations (*P < 0.05, ** P < 0.01 for the difference between means of the two growth types. Numbers on the axis refer to parents selected from the composites and single letters, i.e., "M", "Ö", "Ç", and "G", to locally adapted cultivars, "Muganlı-57", "Özberk-82", "Çamdibi" and "Gölmarmara", respectively).

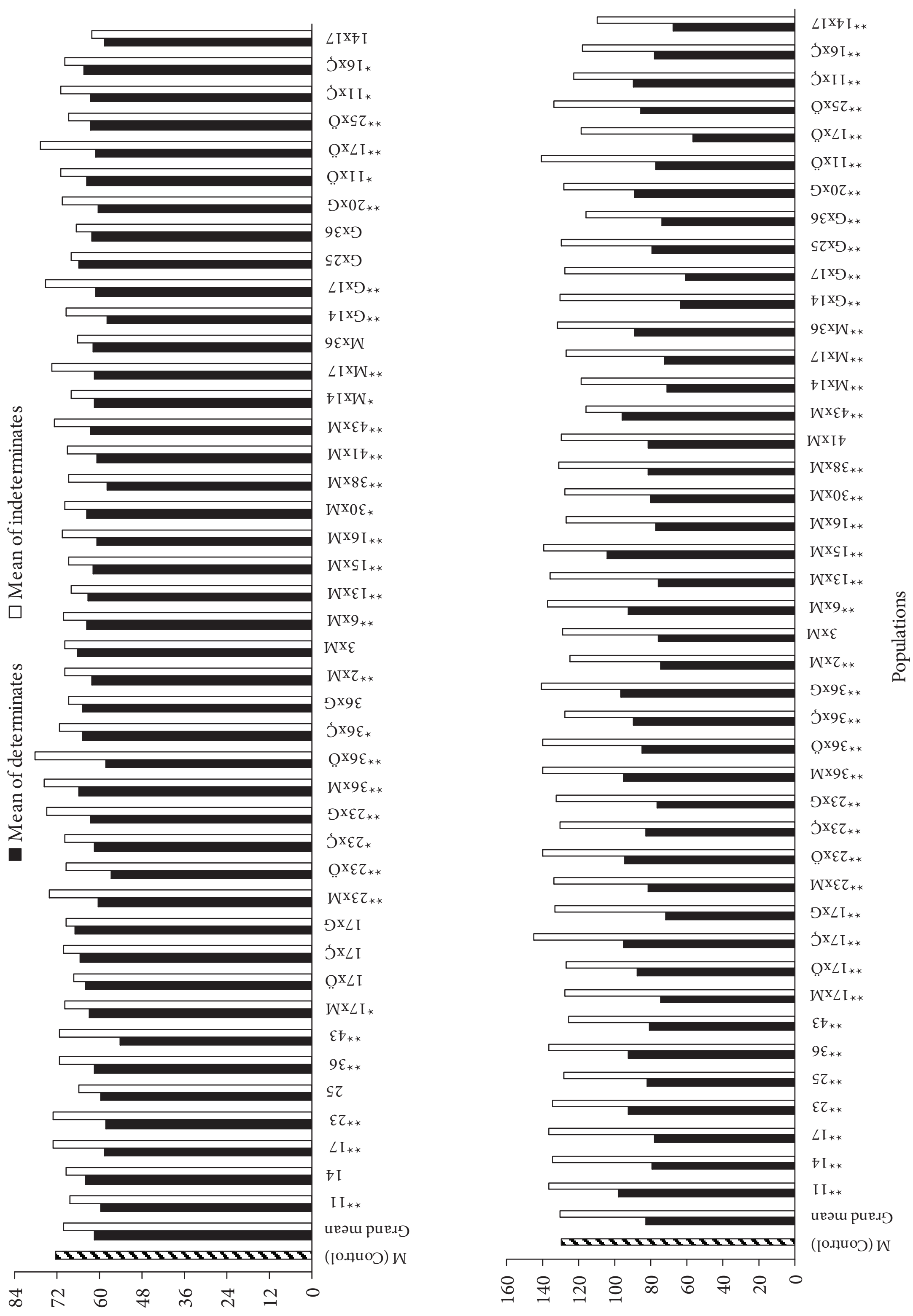

Figure 2. Mean of control, determinate and indeterminate growth types, and t-tests for number of seeds per capsule (g) and plant height (cm) measured in F_2 base populations (*P < 0.05, ** P < 0.01 for the difference between means of the two growth types. Numbers on the axis refer to parents selected from the composites and single letters, i.e., "M", "Ö", "Ç", and "G", to locally adapted cultivars, "Muganlı-57", "Özberk-82", "Çamdibi" and "Gölmarmara", respectively).

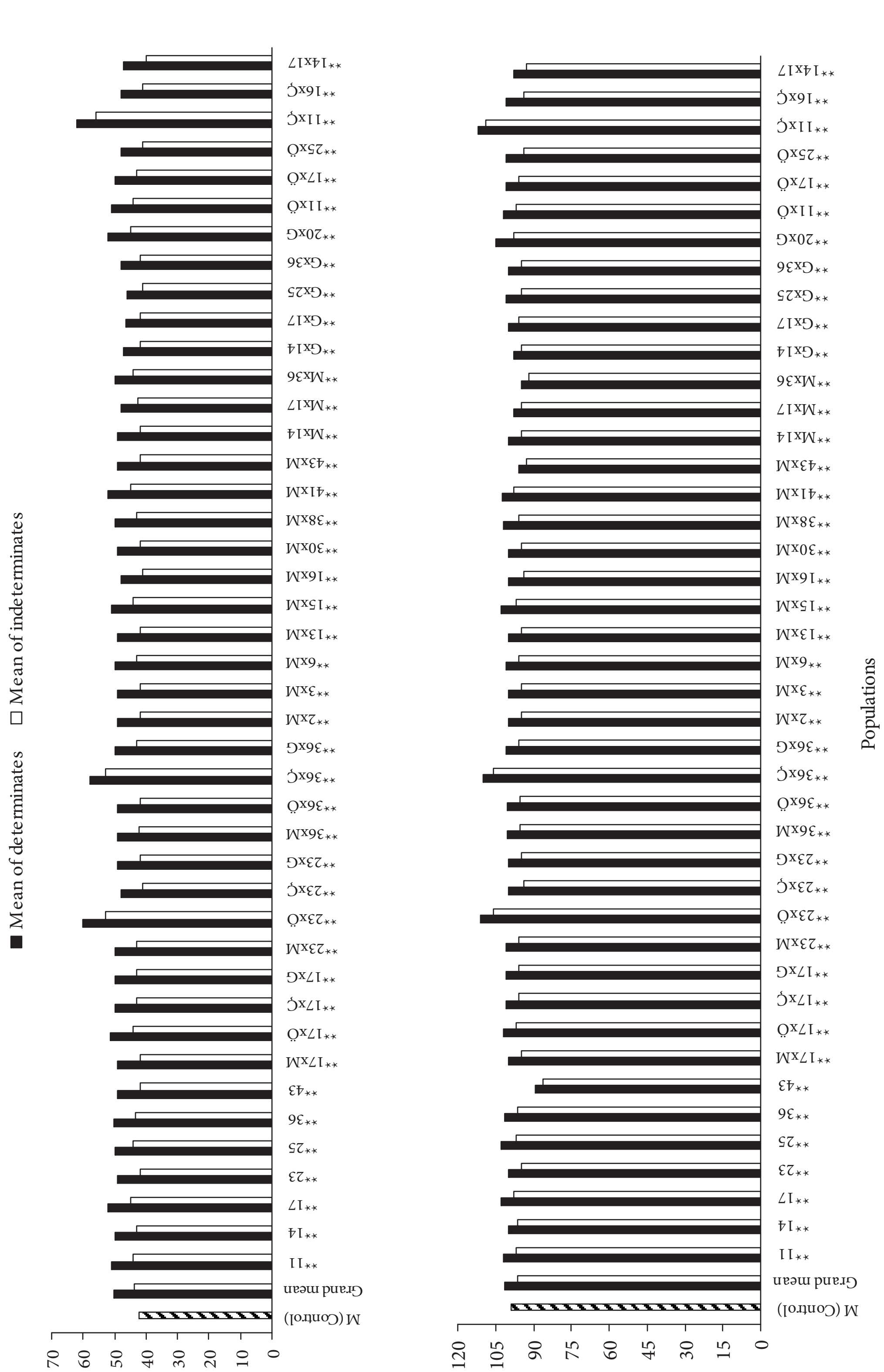

Figure 3. Mean of control, determinate and indeterminate growth types, and t-tests for days to flowering and days to maturity measured in F_2 base populations (*P < 0.05, ** P < 0.01 for the difference between means of the two growth types. Numbers on the axis refer to parents selected from the composites and single letters, i.e., "M", "Ö", "Ç", and "G", to locally adapted cultivars, "Muganlı-57", "Özberk-82", "Çamdibi" and "Gölmarmara", respectively).

clear-cut reduction in plant height of determinates (Figure 2), it is interesting to note that for height of the first capsule there was no apparent difference between the grand mean for determinates and indeterminates, which means both sub-groups set capsules at similar heights (data not shown).

Figure 3 shows the results obtained in two phenological characters. Regarding days to flowering, all determinates flowered later than both their indeterminate counterparts as well as the control group. Also, the mean differences were statistically significant (P < 0.01) in all pairs. For pairs "11 × Ç", "23 × Ö" and "36 × Ç", both determinates and indeterminates flowered apparently later than both the control and other pairs. Although the grand mean for indeterminates was slightly above the control, this was caused by a skewing effect on the grand mean by the mean of three crosses indicated above that flowered latest. Excluding this effect, indeterminates of the pairs flowered close to the control. Slightly earlier flowerings (at most 2 days) than the control were noticed only in some of the indeterminates of some pairs, e.g., "14 × 17". Similarly, all determinates matured later than their indeterminate counterparts as revealed by days to maturity. These differences were statistically significant (P < 0.01) in every pair. Compared to the control, an apparent early maturity was observed in "43" (another out-crossed parent), followed by slightly early maturity in "43 × M" and "M × 36". The latest maturing pairs for both determinates and indeterminates were in "11 × Ç", "36", "23 × Ö" and "36 × Ç". Excluding these extremes in either side, pairs matured similarly to the control group but with a tendency towards lateness in determinates.

Selected subpopulations grown in F3: Table 1 summarizes mean, range, CV of the characters studied in the F_3 of determinates and indeterminates

Table 1. Simple statistics and t-tests for determinate, indeterminate and control groups in the selected subpopulations grown as F_3.

Traits/growth type	Mean	Range	CV(%)	t- test (a)
Seed yield per plant (g)				
determinate	6.9	1.2 - 15.6	38.5	(1) -9.50**
indeterminate	11.4	4.9 - 21.9	27.8	(2) -2.37*
control	13.3	7.2 - 17.5	22.4	(3) -10.40**
No. of capsules per plant				
determinate	48.1	17 - 113	35.4	-9.35**
indeterminate	84.5	37- 201	31.4	4.01**
control	71.3	51 - 84	10.7	-10.94**
No. of seeds per capsule				
determinate	65.3	48 - 77	7.7	-8.95**
indeterminate	68.9	59 - 82	6.3	-6.82**
control	76.1	70 - 84	5.2	-5.07**
Plant height (cm)				
determinate	88.8	55 - 144	17.2	-23.82**
indeterminate	134.4	100 - 175	10.2	-4.61**
control	144.8	129 - 156	5.3	-21.12**
Days to flowering				
determinate	40.2	31 - 51	8.2	-33.9**
indeterminate	55.9	50 - 63	6.1	6.25**
control	53.4	51 - 57	2.8	-30.8**
Days to maturity				
determinate	104.4	97 - 110	5.1	1.54
indeterminate	100.1	97 - 110	4.4	-2.12*
control	102.5	97 - 110	4.2	5.83**

t-test for the difference of F_3 means between (1) determinate and control, (2) indeterminate and control, and (3) determinate and indeterminate (* P < 0.05, **P < 0.01).

as selected portions from the F_2 base populations and t-tests for the differences among the means of subgroups. It was evident that mean of seed yield per plant and number of capsules per plant and number of seeds per capsule was lower in the determinate subgroup than in the indeterminate and control. While days to first flowering took longer in both components of the pair than in the control, determinates lasted flowering earliest, consequently showed shortest flowering period. However, days to maturity took longest in the determinate sub-group but plant height was shortest in the determinate group. Ranges were wider either or both side generally, suggesting possibility of response to selection further beyond the control. CV values were higher for all the characters studied in the determinate and indeterminate subgroups than in the control, showing genotypic variability in the subgroups. Differences among the means of sub-groups and control were statistically significant except for some contrasts in phenological traits.

Effect of selection: Figure 4 summarizes the F_2 and F_3 generation means as percent over the control for the selected character itself as well as monitoring effect of selection for number of capsules per plant on other agronomic traits by comparing relative performance. After the selection in F_2, both growth types and the unselected control group showed lower actual values for number of capsules per plant in F_3 than in F_2 (Figure 4). However, a clear relative increase of seed yield per plant was noticed in the F_3 determinate group while no difference was apparent between the two generations for the indeterminate group. While a slight relative increase in number of seeds per capsule was noticed in the determinate group in F_3 compared to F_2, the indeterminate subgroup responded to selection with a decrease. Plant height was shorter in the determinate than in the control and indeterminate groups; however, days to flowering (in F_2) and days to maturity tended to be greater in determinates.

Discussion

The results obtained from F_2 and F_3 showed that there were distinct differences between determinate and indeterminate components of the pairs for the characters studied. Determinates performed poorly for seed yield and number of capsules per plant but acceptably for number of seeds per capsule in comparison to their indeterminate counterparts. However, the difference for these characters were reasonably small in some base populations sharing the certain "*dt/dt*" parents (Figure 1) and therefore showed the potential for composite populations providing potent parents which interacted better with the genetic background and environment in question. Despite progress, low seed yield for improved determinates derived from "dt45" were also reported in earlier studies (Ashri, 1991; Kang and van Zanten 1996; Wongyai, 1997; Özerden, 1998). To overcome this barrier, Ashri (1993) changed the genetic background of the determinate character into many different sesame cultivars from various regions and aimed to obtain high yielding and early maturing determinates with good quality characters and enhanced dormancy to prevent vivipary. The resulting broad-based composite populations were highly heterozygous and heterogeneous for many different characters, suitable to be exploited in different agro-ecological conditions as the sources of "*dt/dt*" segregants. Though improvements were promising (Ashri, 1997), the determinate lines were still low yielding because they had fewer capsule bearing nodes compared to their indeterminate counterparts (Wongyai, 1997; Day et al. 2002), and thus produced fewer capsules per plant, as also found in the present study. The simple solution to this problem would be to find sesame mutants, which are able to increase their number of fruits per inflorescence to compensate for the fewer capsule bearing nodes, as soybean determinates do. Kilgore-Norquest and Sneller (2000) reported that yields of determinate and indeterminate lines of soybean were equal in all irrigation x planting date combinations. Though there was a trend that the determinate lines yielded better than the indeterminate lines with early planting and irrigation in the soybean study, the indeterminate growth habit may confer a yield advantage over the determinate growth habit in environments with limited yield and growth potential in the case for sesame under low-input conditions.

Short plant height provides determinates good lodging resistance and better performance in dense conditions. In the present study, despite the drastic reduction in height of the determinates, the height of

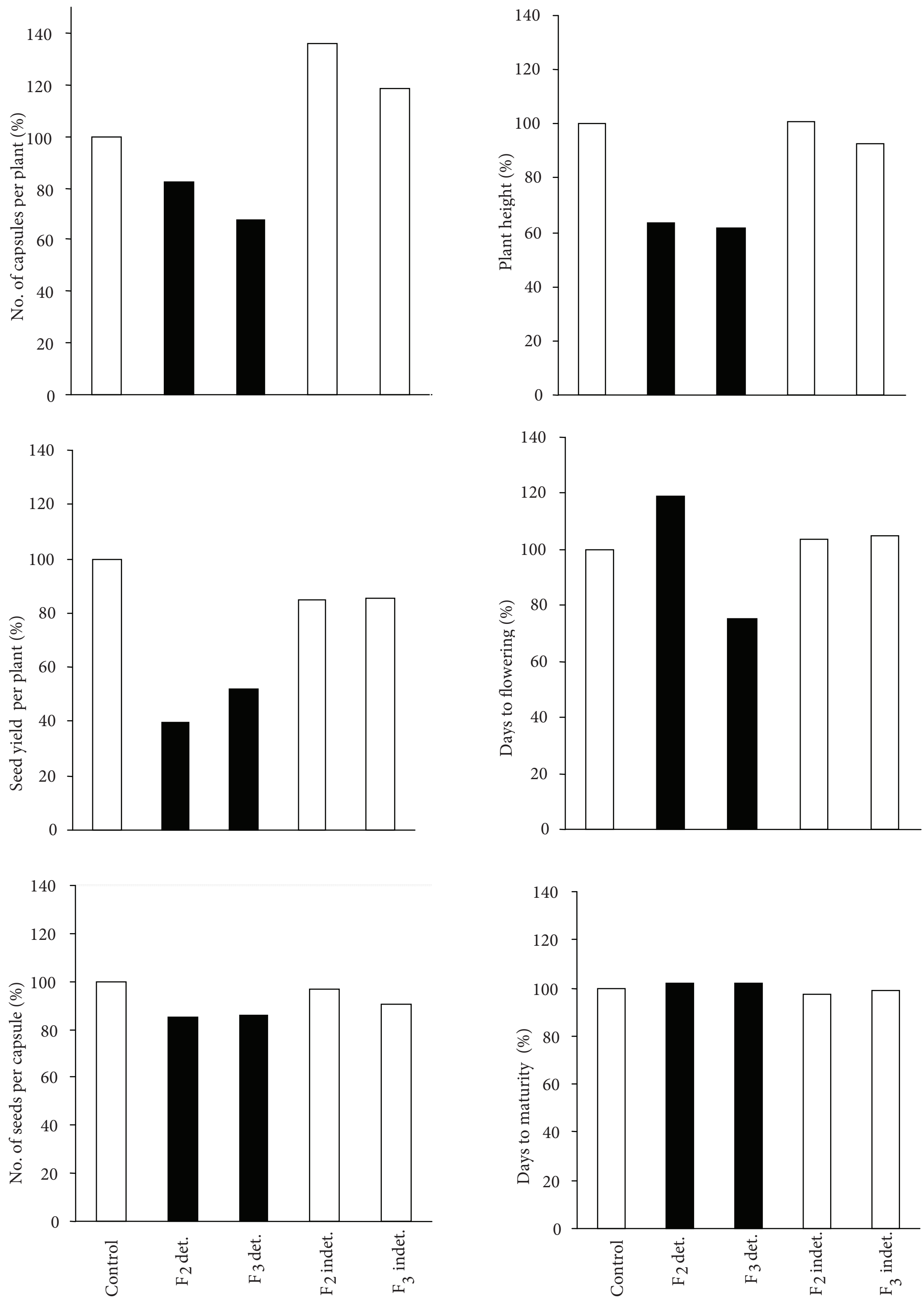

Figure 4. F_2 and F_3 generation values as a percentage over the control and relative effect of selection in F_2 for number of capsules per plant on the selected character and other agronomic characters in F_3 as expressed percent changes over control standardized for both generations.

the first capsule did not differ (data not shown) between the two growth types of both generations. Consequently, for the harvesting of sesame, determinates should be suitable for partial mechanization by mowers in order to reduce manual labour. Comparing determinates with indeterminates for the stem growth termination characteristics in sesame, Wongyai (1997) reported that plant height of the determinate lines was half that of the indeterminates, and that plant height at the beginning of flowering was not affected by stem growth but rather by differences that had occurred after flowering.

The study also showed that determinates tended to flower and mature later in comparison to indeterminates in F_2. After the selection for number of capsules per plant, determinate F_3 families took fewer days to flower than the indeterminates but still matured late under intensive management. All the known sesame cultivars in the world are indeterminate, producing leaves, flowers and capsules as long as conditions permit. The "dt45" is the true botanical determinate but its capsules do not mature uniformly; branching is profuse, termination of shoot growth appears to trigger sylleptic outgrowth of branches upon which new flowers are formed (Day et al. 2002). Determinates, in our study, had an apparently shorter flowering period (data not shown) than their indeterminate counterparts, but capsule maturation was prolonged and occasionally caused vivipary. The most promising determinate lines developed in Thailand ranged 22-34 days and 22-29 days for flowering and capsule maturation period, respectively (Wongyai, 1991). In eleven pairs of soybean isolines varying for determinate and indeterminate growth habit, Kilgore-Norquest and Sneller (2000) found that in all crosses and production systems, determinate lines of soybean were shorter, matured earlier, and had less lodging than indeterminate lines, suggesting possibilities for further improvements for short maturity in sesame. It should be noted that the maturity period should be used rather than the flowering period to evaluate determinate sesame for certain conditions. Because of profuse basal or upper branching, fruiting zone length is not indicative of the yielding ability of true botanic type determinates.

The objective of selection for the character of interest is to increase the population mean in the selected progenies (Allard, 1960; Falconer, 1981). However, the prediction of the response introduces several problems. First, a problem arises from the variability of generation means. To overcome this restriction, the effect of selection is apparent when data is expressed as relative change over control. Consequently, seed yield per plant was evidently greater in the determinate group indirectly compared to indeterminate one showing a slight relative increase in F_3.

In plant breeding, sufficient progress cannot be achieved through only a few steps such as newly introduced characters into breeding populations. Determinate growth habits arising from the requirements of today's modern agriculture should be improved step by step with breeding systems of self-pollinated crops with reduced cycles between crossing and selection. Apart from the availability of genetic male sterility, crosses are easily made in sesame, therefore recurrent selection strategies of out-pollinated crops offering faster progress should be modified. However, inclusion of a male sterility factor for random out-crossing by insects allows for the distinguishing of cross-pollinated capsules, thus maintaining variability for the characters of interest. There is considerable knowledge about barley, soybean and sorghum using a male sterility facilitated recurrent selection method (Suneson, 1951; Ramage, 1987; Çağırgan and Ullrich 1991), which would be insightful if applied as a strategy to sesame.

In conclusion, the determinate habit would be advantageous for sesame, both under low and high input conditions. Although determinate growth tends to restrict vegetative development in sesame, side branching is encouraged in yielding and sparse sowing conditions. Short maturation, high number of capsules and seeds per capsule are the criteria to evaluate in an index selection in order to improve further yielding capacity of determinates by positive correlated responses facilitated by recurrent selection strategies. Apart from the successful genetic modification of the desired mutant, it is necessary to modify the agronomic practices in order to accommodate the new phenotype.

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