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Genetic Variation among Cotton (*Gossypium hirsutum* L.) Cultivars for Seed-Set Efficiency

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Abstract: Seed-set efficiency (SSE) is one of the most important within-boll yield components in cotton production. Increased SSE can lead to increased seed number and, ultimately, to greater fiber yield. A field experiment was conducted during 2003-2004 to compare cotton cultivars (*Gossypium hirsutum* L.), in terms of the potential for improved SSE, in a Mediterranean region (Kahramanmaraş Agricultural Research Institute). SSE changed by year by about 1%-2%, averaging 94%-95%. Mean values for cultivars ranged from 95.78% (Deltaopal) to 93.98% (Nazilli 84S) in 2003, and from 95.67% (Sayar 314) to 94.75% (Carmen) in 2004. Cultivars were significantly different (2%-3%) only for the bolls located at the bottom (1st position) of the plants. Despite the difference being small, in general, the bottom and top bolls of the plants had higher SSE than middle bolls did. Also, average yield and SSE were higher in 2004 than in 2003. The results showed that SSE was significantly affected by genotype and year, but not from the position of the bolls. Additionally, SSE was significantly and positively (r = 0.69) correlated to yield (lint, seed, and seed cotton) in 2003. Since there was no significant difference in the seed number of the bolls formed early or late in the season, bolls harvested throughout the season could be used for seed production, but further investigation of seed characters (seed vigor) is warranted.

Key Words: Cotton, seed set, genotype

Tohum Tutma Etkinliği Yönünden Pamuk Genotipleri (*G. hirsutum* L.) Arasındaki Genetik Varyasyon

Özet: Tohum tutma etkinliği (TTE) pamuk üretiminde en önemli koza içi verim unsurlarından birisidir. TTE'nin artması ile tohum sayısı artacak ve sonuçta daha fazla verim alınmasını sağlayacaktır. Akdeniz Bölgesinde (Kahramanmaraş Tarımsal Araştırma Enstitüsü), potansiyel tohum tutma yeteneğinin arttırılmasını sağlamaya yönelik, pamuk (*Gossypium hirsutum* L.) çeşitlerini karşılaştırmak amacıyla, 2003-2004 büyüme sezonunda tarla denemesi kurulmuştur. TTE yıllara göre yaklaşık % 1-2 ortalama % 94-95 oranında değişmiştir. Çeşitler için, 2003 yılında ortalama değerler % 95.78 (Deltaopal) ile % 93.98 (Nazilli 84S) arasında ve 2004 yılı için % 95.67 ile % 94.75 arasında değişmiştir. Çeşitler arasında sadece bitkilerin alt bölümündeki (1. pozisyon) kozalar yönünden istatistiki olarak önemli düzeyde bir farklılık (%2-3) bulunmuştur. Farklılık az olmasına rağmen, genel olarak bitkinin alt ve üst kozalarında orta bölüm kozalara göre TTE daha fazla bulunmuştur. Aynı zamanda, 2004 yılı ortalama verim ve TTE 2003 yılından daha yüksek bulunmuştur. Sonuç olarak, TTE'nin çeşitlere ve yıllara göre önemli oranda değiştiği, fakat kozaların bitkideki konumlarına göre değişmediği belirlenmiştir. Ayrıca, 2003 yılında TTE ve verim (lif, tohum ve kütlü pamuk) arasında pozitif ve önemli (r = 0.69) bir ilişki saptanmıştır. Erken veya geç devrede oluşan kozalardaki tohum sayısı bakımından aralarında bir farklılık olmadığından dolayı, farklı zamanlarda hasat edilen bütün kozaların tohumluk üretimi amacıyla kullanılabileceği ancak tohum karakterleriyle (tohum canlılığı) ilgili çalışmalara ağırlık verilmesi gerektiği kanaatine varılmıştır.

Anahtar Sözcükler: Pamuk, tohum tutma, genotip

Introduction

Seed-set efficiency (SSE) is one of the most important within-boll yield components in cotton production. Seed number is closely associated with crop growth rate during the critical period for seed set (Vega et al., 2001). Increased SSE can lead to increased seed number and, ultimately, to greater fiber yield, in addition to reducing mote formation and thus producing higher fiber quality,

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which is important for the textile industry. Motes are unfertilized ovules or underdeveloped seeds in which embryos stopped growing after fertilization. Motes, having immature or dead fibers, can cause imperfections in yarn quality.

Environmental conditions have effects on the cotton plant, its boll, and fiber development. Furthermore, the fruiting site of a boll and SSE represent unique combinations of temperature, light, and metabolic resource allocation (Bradow et al., 1996).

The seed-set ratio can change for different plant species and even within species for many reasons (Gervais et al., 1993), such as poor fertility, unfavorable weather conditions, effects of insects and fungi (Gustafsson and Simak, 1963), genetic structure (Casper and Wiens, 1981), low and high temperature (Clarke and Siddique, 2004; Prasad et al., 2006), water limitation (Akhalkatsi and Lösch, 2005), size and spatial structure of populations (Morgan, 1999), competition among gametophytes or embryos of different genetic quality (Lee, 1984), lethal mutations of female gametophytes (Christensen et al., 1998), interactions between endosperm and embryo (Carputo et al., 1999), or direct control from the parent plant (Grossniklaus et al., 1998).

Cotton pollen is extremely sensitive to moisture at the time of pollination (Burke, 2002). Rain, sprinkle irrigation, or high moisture during the time of pollination, even that falling shortly thereafter, affects the number of ovules receiving pollen tubes by interfering either with pollen deposition on the stigma or with pollen tube growth (Pearson, 1949).

In very high temperatures (> 37 °C) or cold weather (< 19 °C) few pollen germinate or anther development can be arrested (McMichael and Powell, 1971). Thus, identifying and developing heat-tolerant, early maturing cultivars will lead to efficient cotton pollination. Viable pollen production was not detected in 5 cotton varieties grown at 29.4 °C (Powell, 1969).

Seed set rate has been studied by different researchers for different plant species (Reddy et al., 2000; Sato et al., 2000; Ishii and Kadono, 2002; Prasad et al., 2003). Ragsdale and Smith (2003) used 8 parents and their F_1 progeny to evaluate SSE. They found significant genotype × year interaction and highly significant genotypic effects on SSE. As a pollinator insect, honeybees mostly prefer nectar on flowers rather than pollen, and can cause pollen movement from one flower to another (Waller et al., 1981). Therefore, pollinator insect populations in the region, quantity of nectar and its sugar content, as well as flower structure (petal color, etc.), could affect the frequency of insects landing on the plants. Thus, SSE can be changed by genotype and the time of the growing season (early vs. late). The out-crossing ratio for cotton in the region where an experiment was conducted ranged from 3% to 12% (Sen et al., 2004).

There is a need to establish the SSE for cotton cultivars to provide information for breeding programs. This study was conducted primarily to compare and establish SSE based on growth stages for 10 commonly grown cotton cultivars over 2 years.

Materials and Methods

The study included 10 upland cotton (*Gossypium hirsutum* L.) cultivars that were field tested over 2 years at the Kahramanmaraş Agricultural Research Institute under irrigated conditions. The average annual rainfall over the previous 20 years was 770 mm, with most of the rainfall occurring in December to March. Very little rain falls in June to September (16 mm average; data obtained from the Turkish State Meteorological Service). Soil type was alluvial an pH 7.6, containing 265 g kg^{-1} of $CaCO_2$, 13 g kg^{-1} of organic matter, 0.9 g kg^{-1} total salinity, 0.47 kg ha^{-1} of P_2O_5, and 4.1 kg ha^{-1} of K_2O, at a depth of 0-200 mm. Of the 10 cultivars registered in Turkey, 5 (Çukurova 1518, Gürelbey, Maraş-92, Nazilli 84-S, and Sayar-314) were developed in Turkey and 5 (Carmen, Deltaopal, Stoneville 453, Suregrow 125, and Tex) were introduced.

The experiment was conducted in 2003 and 2004 as a randomized block design with 4 replications. Cultivars were randomized within each of the blocks. Plots were 12 m in length with 2 rows 0.70 m apart.

Acid-delinted cotton seed (20 g) was planted in each plot in early to mid-May. Plants were thinned to give a stand of approximately 50 to 60 plants per plot (5 to 6 plants per meter), and the numbers of plants were counted. Standard production practices were applied each year.

Boll samples were collected from the first positions of fruiting branches of the bottom (1st), middle (6th), and top (11th) of each plant sampled, and 10 bolls were harvested (September 24, in both years) for each randomly selected plant. After counting the number of motes and seeds for each boll, SSEs were calculated by using the following equation:

[(number of seeds per boll/number of motes per boll + number of seed per boll) × 100]

Data were analyzed by sampling date for each year and combined over years using analysis of variance statistical procedures (SAS Institute Inc., 1985, User's Guide, Version 5). Means were separated using Fisher's protected least significant difference (LSD) test and P = 0.05 denotes the level of significance.

Results

Variance analysis showed significant differences in SSE between years. Genotypes were significantly different for SSEs of the bottom bolls (1st sympodia) in both years. On the other hand, no significant differences were found for the top- or late-set bolls (11th sympodia) or for the middle-set bolls (6th sympodia) in both years (Tables 1 and 2). Additionally, SSEs of the bolls sampled from different plant positions were not significantly different from each other. Moreover, significant relationships were found between SSE and year (P = 0.05), SSE and boll position (P = 0.01), SSE and genotype, and boll position (P = 0.05) (Table 1).

Table 1. Analysis of variance for SSEs from the first positions of the 1st (bottom), 6th (middle), and 11th (top) sympodial branches in 2003 and 2004.

Source	df	MS	F
Year (Y)	1	21.56	34.15**
Genotype (G)	9	3.35	5.30**
Position (P)	2	1.22	1.94
Y × G	9	1.21	1.92*
Y × P	2	4.52	7.16**
G × P	18	1.02	1.61
Y × G × P	18	1.21	1.92*
Error	180	0.63	
Corrected Total	239		
CV%		0.84	
Mean		94.95	

*,** Significant at P = 0.05 and P = 0.01, respectively.

Means of SSEs (%) and LSD groupings of the cotton (*Gossypium hirsutum* L.) cultivars with bolls sampled from the first 1st (bottom), 6th (middle), and 11th (top) sympodial branches in 2003 and 2004 are given in Table 2.

While average SSE was 94.65%, the highest was 95.78% (Deltaopal) and the lowest was 93.98% (Nazilli 84S) in 2003. In 2004 the average was 95.25%, while the highest was 95.67% (Sayar 314) and the lowest was

Table 2. SSE means (%) and LSD groupings of the cotton cultivars with bolls sampled from the first positions of the 1st (bottom), 6th (middle), and 11th (top) sympodial branches in 2003 and 2004.

Cultivars	2003				2004			
	Bottom	Middle	Top	Average	Bottom	Middle	Top	Average
Deltaopal	96.96 a	94.89 a	95.50 ab	95.78 a	95.74 ab	95.00 b	95.87 a	95.54 a
Sayar 314	95.69 b	94.45 ab	95.10 ab	95.08 b	95.54 ab	96.22 a	95.24 ab	95.67 a
Suregrow 125	95.02 c	94.61 ab	95.32 ab	94.98 b	95.62 ab	95.18 ab	94.69 b	95.16 ab
Stoneville 453	94.56 cd	94.71 ab	95.53 ab	94.93 b	96.45 a	95.38 ab	94.84 ab	95.55 a
Tex	94.36 cde	94.42 ab	95.22 ab	94.66 bc	95.38 b	95.17 ab	95.24 ab	95.26 ab
Maraş 92	94.04 def	94.46 ab	94.21 b	94.24 cd	95.07 bc	95.24 ab	94.97 ab	95.09 ab
Carmen	93.88 efg	94.20 ab	95.62 a	94.57 bcd	94.38 c	94.88 b	95.00 ab	94.75 b
Çukurova 1518	93.57 fg	94.06 ab	94.74 ab	94.12 cd	95.54 ab	95.04 ab	94.60 b	95.06 ab
Nazilli 84S	93.56 fg	93.70 b	94.67 ab	93.98 d	95.65 ab	95.14 ab	94.90 ab	95.23 ab
Gürelbey	93.35 f	94.81 ab	94.45 ab	94.20 cd	95.16 bc	94.69 b	95.60 ab	95.15 ab
LSD	0.66**	1.11	1.37	0.62**	0.98*	1.21	1.10	0.65
CV%	0.48	0.81	1.00	0.81	0.71	0.88	0.80	0.84
Mean	94.50	94.43	95.04	94.65	95.45	95.21	95.10	95.25

94.75% (Carmen). Mean SSE was higher in 2004 (95.25%) than in 2003 (94.65%) (Table 2).

On the bolls sampled from the bottoms (1st sympodia) of the plants, SSEs ranged from 96.96% (Deltaopal) to 93.35% (Gürelbey), differing by 3.61% in 2003 and from 96.45% (Stoneville 453) to 94.38% (Carmen), differing by 2.07% in 2004 (Table 2). SSEs of the cultivars differed between years, except Sayar 314 (Figure 1).

Mean SSEs of the cultivars for middle-set bolls ranged from 94.89% (Deltaopal) to 93.70% (Nazilli 84S), differing by 1.19% in 2003 and from 96.22% (Sayar 314) to 94.88% (Gürelbey), differing by 1.34% in 2004 (Figure 2). The difference between years was 0.78%. SSEs of middle-set bolls for all cultivars, except Gürelbey and Deltaopal, differed between years (Table 2).

SSE means ranged from 95.62% (Carmen) to 94.21% (Maraş 92), differing by 1.41% in 2003 and from 95.87% (Deltaopal) to 94.60% (Çukurova 1518), differing by 1.27% in 2004 (Figure 3).

SSE of Sayar 314, Tex, Çukurova 1518, and Nazilli 84S had almost the same trend between years, in contrast to other the cultivars with SSEs that ranged from 0.5% to 1.0% for the late-set bolls (Figure 3). Cultivars Carmen, Deltaopal, and Sayar 314 had significant differences in the bolls sampled from different positions of the plant in 2003 (Table 3). SSE of the early-set bolls (96.97%) was significantly higher than middle- (95.50%) and late-set bolls (94.88%) for cultivar Deltaopal in 2003, while late-set bolls had higher a SSE than middle- and early-set bolls in 2004. The same trend was observed for cultivar Sayar 314, but the SSE of middle-set bolls was higher than the other positions in 2004, instead of late-set bolls (Table 3). Stoneville 453 had a significant SSE, which was higher in the early-set bolls than in middle- and late-set bolls in 2004.

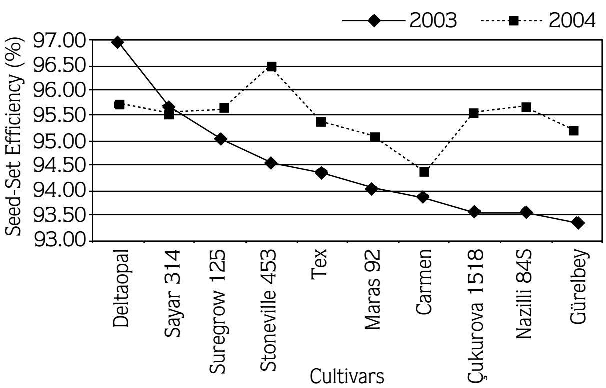

Figure 1. Mean SSEs of the cultivars for early-set bolls (bottom, 1st sympodia) in 2003 and 2004.

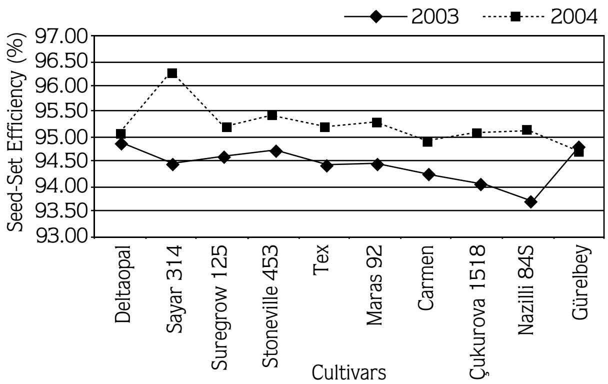

Figure 2. Mean SSEs of the cultivars for medium-set bolls (middle, 6th sympodia) in 2003 and 2004.

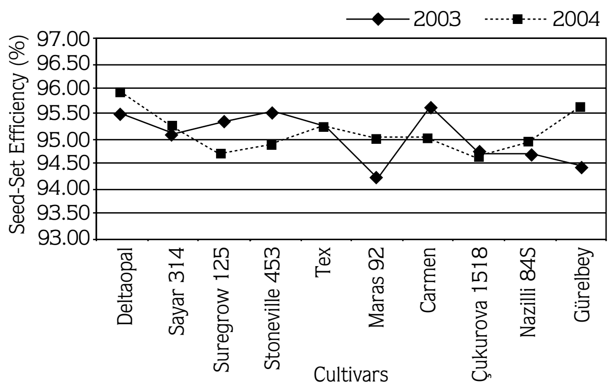

Figure 3. Mean SSEs of the cultivars for late-set bolls (top, 11th sympodia) in 2003 and 2004.

Correlations between SSE and yield (lint, seed, and seed cotton) were significant (r = 0.69) in 2003, but they were not significant in 2004 (Tables 4 and 5). Average seed cotton yield was 3003 kg ha^{-1} in 2003, while it was 3189 kg ha^{-1} in 2004 (Table 4).

Discussion

In the present study, 10 cotton cultivar SSEs were compared according to different plant positions (bottom, middle, and top) and significant differences were only obtained among cultivars for the bottom bolls in 2003

Table 3. SSE means (%) and LSD groupings of the cotton cultivars with bolls sampled from the first positions of the 1st (bottom), 6th (middle) and 11th (top) sympodial branches in 2003 and 2004.

Cultivars	Plant Position	Years	
		2003	2004
Carmen	Bottom	93.88 b	94.38 a
	Middle	94.20 b	94.88 a
	Top	95.62 a	95.00 a
Çukurova 1518	Bottom	93.57 a	95.54 a
	Middle	94.06 a	95.04 a
	Top	94.74 a	94.59 a
Deltaopal	Bottom	96.97 a	95.73 a
	Middle	94.88 b	95.00 a
	Top	95.50 ab	95.87 a
Gürelbey	Bottom	93.11 a	95.16 a
	Middle	94.81 a	94.68 a
	Top	94.45 a	95.60 a
Maras 92	Bottom	94.16 a	95.07 a
	Middle	94.46 a	95.43 a
	Top	94.21 a	94.97 a
Nazilli 84S	Bottom	93.74 a	95.65 a
	Middle	93.70 a	95.13 a
	Top	94.67 a	94.90 a
Sayar 314	Bottom	95.48 a	95.54 a
	Middle	94.46 c	96.22 a
	Top	95.10 b	95.24 a
Stoneville 453	Bottom	94.56 a	96.45 a
	Middle	94.71 a	95.38 b
	Top	95.53 a	94.84 b
Suregrow 125	Bottom	95.02 a	95.62 a
	Middle	94.61 a	95.18 a
	Top	95.32 a	94.69 a
Tex	Bottom	94.36 a	95.38 a
	Middle	94.41 a	95.17 a
	Top	95.22 a	95.24 a

Table 5. Correlation coefficient values between yield components and SSEs in 2003 and 2004.

Yield (kg ha^{-1})	Seed Set Efficiencies of the Cotton Cultivars	
	2003	2004
Lint Wt. (kg)	0.69*	NS
Seed Wt. (kg)	0.69*	NS
Seed Cotton Wt. (Total, kg)	0.69*	NS

NS: Not significant.
*Significant at P = 0.05.

and 2004. This may have been caused by the differential reactions of the cultivars to the environmental factors at the beginning of flowering. It is also supported by the significant ($P < 0.05$) cultivar and year interaction during early boll set of the plants. SSEs of the cultivars were significantly different for bottom-set (early) bolls by about 1%-2% both years, except Sayar 314 (Table 2). Similar results were also reported by Casper and Wiens (1981).

SSEs of the bolls sampled from different positions of the plant were slightly different between years and cultivars. In these cultivars, bolls from the bottom position in 2003 and from the top position in 2004 had higher SSEs, ranging from 0.5% to 2.0% (Tables 2 and 3). Significant differences among the positions of the same plant could have been due to different temperature conditions. Humidity, and minimum and maximum temperatures in both years were 57%-58%, and 22-23

Table 4. Mean yields (kg ha^{-1}) and LSD groupings of the cotton cultivars in 2003 and 2004.

Cultivars	Lint Wt. (kg ha^{-1})	Seed Wt. (kg ha^{-1})	Lint Wt. (kg ha^{-1})	Seed Wt. (kg ha^{-1})	Seed Cotton Wt. (kg ha^{-1})	
	2003		2004		2003	2004
Deltaopal	1799.64 a	2320.71 a	1491.07 abc	2148.21 a	4120.36 a	3639.29 ab
Carmen	1568.57 b	1991.79 b	1633.93 a	2137.50 ab	3560.36 b	3771.43 a
Tex	1413.21 c	1770.71 bc	1248.21 dc	1683.93 cd	3183.93 c	2932.14 c
Stoneville 453	1361.43 cd	1632.86 cde	1366.07 bcd	1807.14 abc	2994.29 cd	3173.21 bc
Gürelbey	1295.71 dc	1683.21 cd	1319.64 bcd	1821.43 abc	2978.93 cd	3141.07 bc
Suregrow 125	1305.36 dc	1570.36 cdef	1308.93 dc	1716.07 cd	2875.71 cd	3025.00 c
Maras 92	1214.29 de	1463.57 def	1373.21 bcd	1789.29 bcd	2677.86 d	3162.50 bc
Sayar 314	1220.71 de	1456.43 ef	1555.36 ab	2096.43 ab	2677.14 d	3651.79 ab
Nazilli 84S	1266.43 dc	1394.64 fg	1221.43 d	1446.43 d	2661.07 de	2667.86 c
Çukurova 1518	1112.54 e	1187.90 g	1185.71 d	1535.71 cd	2300.44 e	2721.43 c
Mean	1355.79	1647.22	1370.36	1818.21	3003.01	3188.57
LSD (0.05)	151.54	222.28	246.32	357.95	365.68	588.41

°C and 36-38 °C, respectively, during the beginning, peak, and end of the flowering stages. The pollinator insect population, which was high in the experimental area, could have been another reason (Sen et al., 2004). It may also have been due to the preference of pollinator insects increasing with an increase in the number of flowers per plant. The quantity of nectar and its sugar content produced by the plant could have been another factor that contributed to the differences. Similar results were also reported by Akhalkatsi and Lösch (2005), Bradow et al. (1996), Burke (2002), Gervais et al. (1993), and Vega et al. (2001).

The cultivars were significantly different in SSE at the bottom bolls in both years; the difference was about 2%-3%. Bolls formed in the middle or late flowering period showed the same rate or 1% difference in the seed setting. In this case, there will be no difference in seed production between the early- and late-harvested cotton, but there is a need for further research on the seed and fiber characters of bolls that develop in different conditions. In respect to seed production, in addition to SSE early or late in the season, seed vigor also needs to be determined.

SSE was positively and significantly correlated to lint, seed, and seed cotton in 2003 only. This significant correlation was not observed in 2004, but cultivars that had higher SSE also had higher yield (Figure 4). This is because cotton yield is a combination of seed and lint cotton, which was also affected by the number of bolls and plants per area, number of seeds per boll (a result of SSE), seed weight, number of fibers per seed, average length of the fibers, and lint weight.

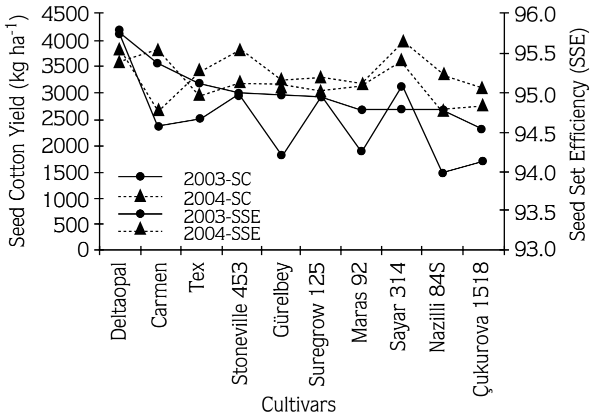

Figure 4. Correlations between SSE and yield.
SC: Seed cotton yield.

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