

Influence of Sowing Dates on Yield and Oil Content in Flax Diallel Crosses

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Abstract

Thirty-six entries of flax (*Linum usitatissimum*, L.) involving eight parental genotypes and their twenty-eight hybrids were evaluated for grain yield and its related traits and oil percentage in the F1 and F2 populations under early and late sowing dates in the Agricultural Research Station, Faculty of Agriculture, Ain Shams University, Shalakan, Kalubia Governorate. Highly significant variations were found for parental genotypes and hybrids for all studied traits in the F1, F2D1 and F2D2, indicate presence of wide genetic variability among studied genotypes. General and specific combining ability mean squares were highly significant for seed yield/plant and their related characters in F1, F2D1 and F2D2 with the exception of a few cases, indicating the importance of both additive and non-additive gene effects in the expression of seed yield and its components. Additive effects were more important than non-additive ones under all studied environments for number of fruiting branches per plant, number of capsules per plant, 1000-seed weight and oil percentage. On the other hand, the non-additive effects were more effective than additive effects for no. of seeds/capsule and harvest index. Some parents appeared to be the best general combiner under all respective environments for some studied traits. Some of the crosses exhibited highly significant and positive SCA effects included high × high and high × low general combiner parents, suggesting that breeding procedure utilizing both additive and non-additive genetic variances would be more effective for improvement of seed yield and its components of flax.

Keyword: Flax, performance, combining ability, gene action, sowing dates.

تأثير ميعاد الزراعة على المحصول ونسبة الزيت في الهجن التبادلية من الكتان

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المستخلص

أجرى هذا البحث بمحطة البحوث والتجارب الزراعية بشلقان - محافظة القليوبية والتابعة لكلية الزراعة جامعة عين شمس وذلك لتقييم 36 تركيب وراثي من الكتان أشتملت على 8 أباء ذات أصناف وسلالات محلية ومستوردة وذات أصول متباينة و 28 هجين ناتجة من دائرة تهجينات مع استبعاد الهجن العكسية. في الموسم الأول 2016/2015 تم تقييم الآباء والجيل الأول (F1) لجميع الهجن الفردية، في الموسم الثاني 2017/2016 تم تقييم الآباء والجيل الثاني الإنعزالي لجميع الهجن تحت ميعادين للزراعة أحدهما مبكر F2D1 والأخر متأخر F2D2 لمحصول الحبوب ومكوناته في الجيلين الأول والثاني. سجلت النتائج أن هناك اختلافات عالية المعنوية لمتوسط سلوك التراكيب الوراثية الأبوية والهجن لجميع الصفات المدروسة تحت البيئات المختلفة، مما يوضح وجود اختلافات وراثية واسعة بين التراكيب الوراثية محل الدراسة. أظهرت نتائج تحليل القدرة على التآلف وجود اختلافات عالية المعنوية في تباين كل من القدرة العامة والخاصة على التآلف محصول البذور/ نبات ومكوناته في الجيل الأول وعند ميعادى الزراعة المبكر والمتأخر في الجيل الثاني، مما يدل على أهمية الجينات المضيفة وغير المضيفة في وراثة الصفات المدروسة. أظهرت نتائج تأثيرات القدرة الخاصة على التآلف وجود اختلافات عالية المعنوية وموجبة لبعض الهجن تحت البيئات المدروسة حيث أشتملت هذه الهجن على أباء ذات قدرة أنتلافية تتمثل في (أب عالى × أب عالى) أو (أب عالى × أب منخفض) مثل الهجن (P5×P7) ، (P1×P3) ، (P2×P5) و (P1×P8) والتي أظهرت قدرة خاصة على الأنتلاف لمحصول البذور وبعض مكوناته وكذلك نسبة الزيت بالبذور، مما يوضح أن كل من التأثيرات المضيفة وغير المضيفة للجينات سوف يكون لها أهمية كبيرة في تحسين محصول البذور/نبات ومكوناته في الكتان.

الكلمات المفتاحية: الكتان، السلوك، القدرة على التآلف، الفعل الجيني، مواعيد الزراعة.

Introduction

Linseed or Flax (*Linum usitatissimum* L.) is a traditional oilseed just as a fiber yield and has a place with Linaceae family with chromosome number 30. Flax has traditionally been used for industrial purposes; more recently, its applications have extended to incorporate a scope of new potential outcomes, for example, cigarette papers, vehicle entryway boards and packed sheets. In any case, flax is becoming more and more popular as a healthy food. An essential component of human diets is alpha-linolenic corrosive, an omega-3 unsaturated fat present in flax seeds. It can reduce cholesterol and lessen coronary disease. Egypt

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developed flax for two uses: filaments and seeds. The diallel cross strategy proposed by Griffing (1956) has been broadly utilized for assessment of general joining capacity which is because of added substance quality activity and explicit consolidating capacity which is expected to non-added substance quality impacts. The trouble in delivering enough F1 mixture seeds in some self-pollinated crops has constrained the Patil & Chopde (1981). In any case, F2 diallels gauge predominance with just a large portion of the effectiveness of F1 diallels (Allard (1960) Non-additive variance had an important role in the inheritance of seed yield per plant and no. of capsules per plant as reported by El-Kady & Abo-Kaied (2010) and Abdel-Moneam (2014). With an extreme goal of selecting suitable guardians and superiority crosses that can be used in a reproducing program, the current study aims to estimate the magnitude of both general and specific combining ability for seed yield and its related characters in eight parental diallel crosses of flax in F1 and F2 generations under two different conditions.

Materials and Methods

For this study, eight flax genotypes—two new strains (S.2465/1/3 and S402/1), five indigenous cultivars (Sakha 6, Sakha 5, Giza 11, Sakha 2, and Giza 12), and the introduced cultivar (Gowhar)—were selected based on their diversity in some agronomic parameters. The Fiber Crops Research Section, Field Crops Research Institute, Agriculture Research Center (ARC), Giza, provided the genotype seeds. Table 1 presents the genotype characteristics of the material employed based on their names, type, pedigree, and paternal genotype origin.

Table 1. Name, type, pedigree and origin of the eight parental flax genotypes

Name	Type	Pedigree	Origin	
S. 2465/1/3	P1	Dual	Selected from Neelum (Indian)	Local strain
Sakha 6	P2	Dual	Giza 8 x S. 2419/1	Local c.v.
S. 402/1	P3	Dual	Giza 5 x I. 235 U.S.A	Local strain
Sakha 5	P4	Oil	I. 2561 X I. 370	Local c.v.
Giza 11	P5	Dual	Giza 8 x S. 2419/1	Local c.v.
Sakha 2	P6	Dual	I. 2348 x Hera	Local c.v.
Giza 12	P7	Dual	S. 2419/1 x S. 148/6/1	Local c.v.
Jowhar	P8	Oil	Introduction from India	India

The three consecutive seasons of 2014–15, 2015–16, and 2016–17 was used for this analysis. To collect the seeds of the parents and their 28 F1 crosses, the eight parents were crossed to create a half diallel set during the first growing season (2014–15). In the Experimental Farm of Ain Shams University's Faculty of Agriculture in Shoubra El-Kheima, Kalubia Governorate, Egypt, hybridization took place. In order to obtain the seeds of parents and their twenty-eight F2 hybrids, the parents and their twenty-eight F1 hybrids (36 entries) were sown on November 14, 2015, in the Agricultural Research Station, Faculty of Agriculture, Ain Shams University at Shalakan, Kalubia Governorate, during the second growing season (2015/16). In the third growing season (2016/17), seeds of each parent as well as seeds of each segregating F2 cross were sown in three rows. Parents and F2 populations were sown in two sowing dates (two environments) one early date and the other late. The early date was on 6th November (D1) while the late date was on 28th November (D2). The preceding summer crop in the second and third growing seasons was soybean (*Glycin max*, L.). Other cultural practices were followed as recommended for flax production. The field experiments were designed in a Randomized Complete Block (RCBD) with three replications in the second and third growing seasons. Each experimental plot consisted of one row for each genotype in 2015/16 growing season and three rows in 2016/17 growing season. Each row was 2.5m in length and 30cm width, seeds were spaced 10cm apart within rows, leaving one plant per hill.

At harvest, a sample of 70 plants was taken from each plot of F2 segregating crosses, while a sample of 10 plants was taken from each plot of parents or F1s. The following characters' data were noted for the two generations:

1. Seed yield (g plant⁻¹).
2. Number of fruiting branches per plant (branch plant⁻¹)
3. Number of capsules per plant (capsule plant⁻¹).
4. Number of seeds per capsule (seed capsule⁻¹).
5. Seed index: expressed as 1000-seed weight (g).
6. Harvest index: expressed as (straw yield/seed yield) ×100
7. Oil percentage in the seeds was determined according to the extraction diethyl method by using the Soxhlet apparatus (A.O.A.C. 2005).

Statistical procedures used in this study were done according to analysis of variance for randomized complete blocks design as outlined by (Snedecor & Cochran, 1980). The analysis of variance for general and specific combining abilities were estimated according to Griffing's (1956) method 2 model 1.

Results and Discussion

Mean square estimates:

For seed yield/plant, number of fruiting branches/plant, number of capsules/plants, number of seeds/capsules, oil percentage, and harvest index in the F1 and F2 generations, the analysis of variance shown in Table 2 revealed that mean squares due to all

36 genotypes as well as mean squares due to parents and crosses were highly significant. This demonstrated the existence of sufficient genetic variability in the genotypes under study. As a result, the different comparisons that have been recommended are legitimate and ought to be carried out in order to fulfill the goals of the current investigation. Rastogi et al. (2011) observed that the analysis of variance showed significant differences among parents for capsules per plant and seed yield per plant. Hassanein et al. (2012) stated that the mean squares exhibited highly significant effect for flax yield attributes, i.e., number of fruiting branches/plant, number of capsules/plants, seed index and seed yield/plant. Gul et al. (2016) found that the analysis of variance suggested significant variations among linseed genotypes for seeds/capsule, capsules/plant, 1000-seed weight and seed yield per plant. The mean squares with regards to linseed yield and its contributing traits of various genotypes showed that all the genotypes differed significantly from each other for their yield and its components.

Mean performance of genotypes:

Seed yield per plant (g plant⁻¹)

Table 3 shows the average seed yield/plant performance for parental genotypes and hybrids. There is a great deal of genetic diversity across the genotypes under study, as seen by the very significant differences between genotypes for this attribute in both seasons. With regard to parents, Giza 11 and Sakha 2 ranked the first in seed yield/plant giving 14.34 and 11.66g plant⁻¹, respectively, in the F1 hybrid whereas, in the F2 hybrid, at early sowing date, Giza 11 and Sakha 5 heaviest for seed yield/plant which gave values of 11.87 and 11.23g plant⁻¹, respectively, at late sowing date, Jowhar and Sakha 6 ranked the first seed yield/plant giving 10.33 and 9.31g plant⁻¹, respectively. On the other hand, Jowhar, Sakha 6 and S. 2465/1/3 parents produced the minimum values of seed yield/plant giving 9.07, 8.52 and 7.77g plant⁻¹, in the F1 hybrid and at early and late sowing dates in the F2 hybrid, respectively. The average mean performance of parents recorded 10.94, 10.29 and 8.96g plant⁻¹ in the F1 and at early and late sowing dates in the F2, respectively. It was noted that in F2, delaying sowing date (D2) caused reduction for seed yield/plant than early sowing date (D1) by about 14.84%.

Regarding the mean performance of crosses, the crosses P5×P7, P1×P2 and P1×P3 produced the highest seed yield/plant giving 13.77, 12.76 and 11.72g plant⁻¹, 13.55, 13.82 and 11.67g plant⁻¹ and 13.13, 13.52 and 11.62g plant⁻¹ in the F1 hybrid and at early and late sowing dates in the F2 hybrid, respectively. Whereas P5×P8 cross recorded the lowest mean performance values for seed yield/plant giving 7.75, 7.63 and 7.07g plant⁻¹, respectively, for the same order with the average mean performance of crosses recorded 11.65, 11.19 and 9.86g in the F1 and at early and late sowing dates in the F2, respectively. Delaying sowing date in F2 hybrid caused reduction for seed yield/plant than early sowing date (D1) by about 13.49%. The overall mean of crosses was markedly higher than the overall mean of their respective parents, indicating the presence of substantial heterotic effects in the hybrid populations in the F1 and F2 hybrids. It is clear from the results that the delay in the planting date (F2D2) for parents and cross gave low values than the earlier in planting date (F2D1) for seed yield/plant, indicating that the delay in planting date has a detrimental effect on this trait and may be attributed to the suitable climate conditions.

Number of fruiting branches per plant (branch plant⁻¹)

Mean performance of parental genotypes and hybrids for No. of fruiting branches per plant in the F1 and F2 hybrids is shown in Table 3. Highly significant variations are observed between studied genotypes for this trait in F1 and F2 at early and late sowing dates, indicating presence of wide genetic variability among studied genotypes. With regard to parents, Giza 11 and Sakha 2 recorded the highest mean values for No. of fruiting branches/plant giving 42.40, 42.52 and 33.91 and 43.00, 42.57 and 34.59 branch plant⁻¹ in the F1 and F2 (at early and late sowing dates), respectively. On the other side, S. 2465/1/3 recorded the lowest mean values for No. of fruiting branches per plant giving 35.72, 33.50 and 24.61 in the same order, respectively. The average of parents recorded 38.91, 37.63 and 29.54 in the F1 hybrid and at early and late sowing dates in the F2 hybrid, respectively. With respect to crosses, the averages mean performance for No. of fruiting branches per plant for all crosses recorded 39.11, 38.00 and 30.81 branch plant⁻¹ in the F1 hybrid and at the early and late sowing dates in the F2 hybrid, respectively. Mean performance values for this trait ranged from 51.85 for the cross (P4×P6) at early sowing date to 23.35 for the cross (P4×P5) at late sowing date in the F2 hybrid, with note that the highest mean performance values under all respective environments for this trait were obtained by flax crosses P4×P6 and P3×P5 which gave values of 48.40, 51.85 and 44.68 and 45.47, 44.77 and 43.69 branch plant⁻¹ in the F1 and F2 at early (D1) and late (D2) sowing dates, respectively. The overall mean of crosses was markedly higher than the overall mean of their respective parents, indicating the presence of substantial heterotic effects in the hybrid populations in the both hybrids. The results observed indicate that the delay in the planting date (F2D2) gave low values than the earlier in planting date (F2D1) for No. of fruiting branches/plant, indicating that this trait has been affected by environmental influences.

Number of capsules per plant (branch plant⁻¹)

Mean performance of parents and crosses for number of capsules/plant in the F1 and early and late sowing date in the F2 are presented in Table 3. Concerning mean performance of parents, data revealed that the parents Jowhar and Sakha 6 were the highest mean values for number of capsules/plant giving 242.32, 240.32 and 208.47 and 233.70, 221.84 and 190.43 branch plant⁻¹, respectively, in the F1 and at early and late sowing dates in the F2 while S. 402/1 and Giza 11 parents produced the lowest number of capsules/plant which gave values of 124.10 in the F1 hybrid and 128.05 and 11.30 branch plant⁻¹, respectively, at early and late sowing dates in the F2 hybrid. The average mean performance of parents recorded 173.35, 174.58 and 145.60 branch plant⁻¹, respectively, in the F1, F2D1 and F2D2. Mean performance of all crosses for the same trait were 167.67, 160.08 and 125.61, respectively, in the F1, F2D1 and F2D2. Values of mean performance for No. of capsules/plant to the 28 crosses in the F1 hybrid ranged from 128.13 to 227.47 branch plant⁻¹, while in the F2 hybrid, the values ranged from 102.65 branch plant⁻¹ to 209.37

branch plant- at early sowing date and from 82.63 to 175.82 branch plant-1at late sowing date. The cross (P6xP7) was exceeded values for number of capsules per plant giving 224.12, 209.37 and 175.82 branch plant-1, respectively, under all studied environments. It is clear from the results that the delay in the planting date (F2D2) gave low values than the earlier in planting (F2D1) for number of capsules per plant, indicating that the delay in planting date reduced no. of capsules per plant.

Number of seeds per capsule (seed capsule⁻¹)

Results presented in Table 3 show highly significant mean performance of parents and crosses for No. of seeds/capsule in the F1 and early and late sowing dates in the F2, indicating sufficient variability is existed in the populations for this trait. Regarding mean performance of parents, Sakha 5 and Giza 12 recorded the highest number of seeds per capsule giving 8.67, 8.64 and 8.63 and 8.56, 8.54 and 8.47 seed capsule-1, respectively, in the F1 and at early and late sowing dates in the F2. On the other hand, Jowhar recorded the lowest values for the same trait giving 7.80, 7.74 and 7.70 seed capsule-1 in the same order, respectively. The average mean of parents recorded 8.24, 8.22 and 8.17 seed capsule-1 in the F1 and at early and late sowing dates in the F2, respectively. With respect to crosses, the average mean for number of seeds per capsule for all crosses recorded 8.32, 8.33 and 8.33 seed capsule-1 in F1, F2D1 and F2D2, respectively. The highest mean values for this trait were obtained by flax crosses P2xP4 and P2xP5 giving 9.27, 9.32 and 9.23 and 9.08, 9.03 and 9.13 seed capsule-1 in the F1 hybrid and at early and late sowing dates in the F2 hybrid, respectively. On the other hand, the lowest mean performance values for this trait obtained by P7xP8 (7.64 seed capsule-1) in the F1 and P1xP6 (7.56 seed capsule-1) and P7xP8 (7.72 seed capsule-1) at early and late sowing dates in the F2, respectively.

1000-seed weight (g)

The data presented in Table 3 show highly significant mean performance of parents and crosses for 1000 - seed weight in the F1 and F2 hybrids Regarding parents, results illustrate that Giza 11 ranked in the first 1000- seed weight giving 10.42 and 9.65g, respectively, in the F1 and late sowing date in the F2 hybrid, while Giza 12 gave the highest value for 1000- seed weight (10.34g) at early sowing date in the F2 hybrid. With an average value was 9.26, 9.35 and 8.74g, respectively, in F1, F2D1 and F2D2. Also, the parent's genotypes; S. 402/1, Giza 12 and Jowhar recorded heaviest values for 100-seed weight were 9.80, 10.34 and 9.39 in the same order, respectively. Concerning the mean performance of 28 hybrids, the crosses; P5xP6, P5xP7 and P2xP7 ranked the maximum 1000 - seed weight giving 10.21, 10.15 and 9.86g, 10.12, 10.09 and 9.74g and 10.17, 10.06 and 9.73g, respectively, in the F1 and early - late sowing dates in the F2 hybrids. On the other side, P1xP8cross recorded the lowest values for the same trait which gave vales of 6.30, 6.68 and 5.62g, respectively, in the same order. The average mean of crosses recorded 9.11, 8.96 and 8.68g in the F1 and at early and late sowing dates in the F2, respectively.

Oil percentage (%)

Mean performance of parents and crosses for oil percentages in the generations two hybrids are presented in Table 3. Regarding mean performance of parents, Sakha 5 produced the highest percentage of oil recorded (44.76, 44.85 and 44.28%, respectively), in the F1 and early and late sowing dates in the F2 hybrids followed by parent line; S. 2465/1/3 which surpassed the other parents genotypes for oil % under all studied environments and gave values of 40.95, 40.55 and 40.02%, respectively, in the F1 and early and late sowing dates in the F2 hybrid. On the other side, S. 402/1 produced the lowest percentage of oil recorded 37.75, 37.44 and 37.09%, respectively, in the same order, with an average value of 39.92, 39.86 and 39.30%, respectively, in the F1 and early and late sowing dates in the F2 hybrid. With respect to mean performance of crosses, the mean values ranged from 40.26, 37.97 and 37.40% recorded by the cross (P7xP8) to 46.43 by the cross (P2xP4) and 46.47 and 45.93% by the cross (P1xP4), respectively, in the F1 and early and late sowing dates in the F2. The highest three crosses in this respect were P1xP4, P2xP4 and P3xP4; highest parent Sakha 5 (P4) in oil percentage was involved in these three crosses. With an average mean performance value were 42.76, 41.36 and 40.90%, respectively, in F1, F2D1 and F2D2.

Harvest index (%)

Data in Table 3 show highly significant mean performance of parents and crosses for harvest index in the F1 and early and late sowing dates in the F2 hybrid. Concerning harvest index parents, Giza 11, Sakha 2 and Jowhar gave the highest values; 35.06, 31.62 and 32.65% in the F1 and F2 (at early and late sowing dates), respectively. On the other hand, S. 402/1 recorded the lowest values for harvest index giving 25.83 and 26.33% in the F1 and at early sowing date in the F2, respectively, while S. 2465/1/3 gave the lowest value for the same trait at late sowing date in the F2 which recorded 24.84%. Average mean values for parents were recorded 29.36, 28.86 and 29.10% in the same order, respectively. Mean values for crosses ranged from 20.58, 20.21 and 21.56% for the cross (P2x P7) to 35.46% for the cross (P2xP4), 35.74% for the cross (P2x P3) and 33.97% for the cross (P7xP8), respectively, in the F1and F2 at early and late sowing dates. Two crosses recorded highest values for harvest index under all studied environments (P1xP3 and P1xP5). Average mean performance values of crosses recorded 29.25, 29.39 and 29.45%, respectively, in the same order. With regard to the results obtained in the study, similar results were found by many researchers likes, Kandil et al. (2010) showed that seed yield/plant and its related characters significantly affected by sowing dates. Sown on 20th October gave the highest seed yield/ plant and its related characters. They also found that significant variations were observed between genotypes for seed yield/plant and its related traits, The two examined cultivars showed notable variances for nearly all attributes, according to Abd El-Mohsen et al. (2013). In terms of seed yield and related characteristics, the early planting on November 15 was better than the other two dates on November 30 and December 15, According to Ghanbari-Odivi et al. (2013), the number of capsules in the plant, seed production, and oil percent at the 1% and 5% levels were all significantly impacted by the sowing date. The average comparison showed that early sowing dates had high levels of yield, yield components, and oil yield. Genotype was not any significant difference in all traits, Bakry et al. (2014) and El-Shimy et al. (2015) revealed significant difference among

all flax genotypes in seed yield and their related characters and seed oil percentage, Elayan et al. (2015) indicated that sowing dates, significantly affected on yield and yield components and oil percentage in both seasons, where the first week of November sowing gave the highest averages for all characters i.e., number of capsules/plant, number of seeds/capsule, seed index, seed yield/plant and oil yield/fed and According to Maurya et al. (2017), the crop sown on November 4 was significantly better than the crop sown on November 11 and 18. Additionally, there was a significant difference between the cultivars (Shekhar, Neelam, and T-397) in yield attributes (number of capsules/plant and number of seeds/capsule) and yield (grain yield/ha⁻¹ and harvest index%).

Table 2. Mean squares for studied characters in eight parent-half diallel crosses of flax in 2015/2016 (F₁) and 2016/2017 (F₂) at early (F₂D₁) and late (F₂D₂) sowing dates

Source of variance	d.f.	Seed yield per plant (g plant ⁻¹)			No. of fruiting branches per plant (branch plant ⁻¹)			No. of capsules per plant (Capsule plant ⁻¹)		
		F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
Replicates	2	2.22	3.30	0.38	5.76	2.34	2.06	363.62	24.57	424.77
Genotypes	G 35	7.44**	6.82**	4.55**	43.33**	63.96**	67.28**	3301.49**	2846.05**	2534.73**
Parents	P 7	7.56**	3.44**	1.66**	24.13**	38.54**	37.34*	6104.50**	4862.62**	3841.86**
Crosses	C 27	7.33**	7.38**	4.92**	49.88**	72.82**	76.41**	2674.79**	2283.42**	2013.29**
P vs C	1	9.53*	15.44**	14.94**	0.76	2.61	30.28	601.13	3921.19**	7463.73**
Error	70	1.87	1.08	0.26	3.82	25.14	16.96	328.32	199.35	193.34

Source of variance	d.f.	No. of seeds per capsule (Seeds capsule ⁻¹)			1000-seed weight (g)			Oil percentage (%)		
		F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
Replicates	2	0.05	0.20	0.09	0.17	0.49	0.05	0.59	0.09	0.16
Genotypes	G 35	0.44**	0.49**	0.45**	1.85**	1.85**	2.00**	15.47**	15.06**	14.68**
Parents	P 7	0.31*	0.34**	0.30*	1.57**	1.21**	1.68**	16.26**	16.26**	15.95**
Crosses	C 27	0.49**	0.54**	0.49**	1.98**	1.98**	2.15**	10.53**	13.75**	13.14**
P vs C	1	0.12	0.22	0.48*	0.42	2.76**	0.06	143.32**	42.00**	47.47**
Error	70	0.17	0.11	0.11	0.16	0.17	0.16	0.34	0.42	0.39

Source of variance	d.f.	Harvest index (%)		
		F ₁	F ₂ D ₁	F ₂ D ₂
Replicates	2	11.87	10.32	4.96
Genotypes	G 35	40.58**	41.81**	32.41**
Parents	P 7	24.98**	9.35	21.28**
Crosses	C 27	46.12**	51.59**	36.40**
P vs C	1	0.22	5.26	2.38
Error	70	6.80	9.23	2.22

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Table 3. Mean performance of the eight parents and their 28 hybrids for studied characters during 2015/2016 (F1) and 2016/17 (F2) seasons at early (F2D1) and late (F2D2) sowing dates

Genotypes	Parents	Seed yield/plant (g plant ⁻¹)			No. of fruiting branches/plant (branches plant ⁻¹)			No. of capsules/plant (capsule plant ⁻¹)			No. of seeds/capsule (seed capsule ⁻¹)		
		F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
S. 2465/1/3	P1	10.24	10.39	7.77	35.72	33.50	24.61	168.31	167.22	136.22	8.04	7.99	8.07
Sakha 6	P2	10.30	8.52	9.31	38.74	35.16	27.89	233.70	221.84	190.43	8.30	8.14	8.24
S. 402/1	P3	10.13	10.18	8.75	40.43	39.23	31.19	124.10	131.28	115.48	8.37	8.54	8.33
Sakha 5	P4	10.39	11.23	8.88	38.60	38.17	29.95	155.13	160.16	125.63	8.67	8.64	8.63
Giza 11	P5	14.34	11.87	8.39	42.40	42.52	33.91	125.32	128.05	110.30	8.36	8.32	8.07
Sakha 2	P6	11.66	10.40	9.18	43.00	42.57	34.59	187.88	189.48	150.97	7.82	7.87	7.83
Giza 12	P7	11.39	10.59	9.06	35.97	34.20	26.51	150.03	158.26	127.33	8.56	8.54	8.47
Jowhar	P8	9.07	9.10	10.33	36.44	35.67	27.67	242.32	240.32	208.47	7.80	7.74	7.70
Parents mean		10.94	10.29	8.96	38.91	37.63	29.54	173.35	174.58	145.60	8.24	8.22	8.17
	P1xP2	13.55	13.82	11.67	39.30	33.90	26.52	190.10	193.10	162.96	8.05	8.01	8.18
	P1xP3	13.13	13.52	11.62	34.63	33.82	25.90	153.83	155.77	125.59	8.21	8.42	8.33
	P1xP4	11.01	10.39	9.52	40.68	40.16	29.31	173.92	170.91	133.68	8.44	8.48	8.47
	P1xP5	12.79	12.02	10.07	38.20	36.62	29.26	130.17	128.79	94.94	8.86	8.67	8.93
	P1xP6	12.06	11.23	9.10	36.00	35.00	28.49	150.77	133.10	101.62	7.90	7.56	7.98
	P1xP7	10.83	10.77	9.55	40.06	37.23	30.73	149.05	149.35	114.06	8.24	8.36	8.17
	P1xP8	12.40	12.21	10.04	36.50	33.63	28.14	132.77	132.85	101.88	8.84	8.85	8.93
	P2xP3	13.27	12.88	10.59	39.27	35.27	29.55	163.97	159.44	126.55	8.38	8.35	8.50
	P2xP4	11.60	11.27	9.35	39.40	34.13	25.87	197.33	193.45	163.11	9.27	9.32	9.23
	P2xP5	13.47	10.84	11.03	44.14	46.08	35.27	205.58	202.83	161.15	9.08	9.03	9.13
	P2xP6	11.67	11.40	9.40	33.25	38.25	30.74	144.80	148.45	114.40	8.55	8.70	8.52
	P2xP7	9.08	9.02	8.41	33.77	34.21	29.30	165.97	160.57	128.77	7.99	7.78	7.95
	P2xP8	8.65	8.27	7.63	36.10	38.50	34.77	157.23	135.98	98.08	8.22	8.25	8.15
	P3xP4	9.53	8.95	7.47	37.86	39.40	30.14	141.04	139.21	104.26	8.18	8.33	8.03
	P3xP5	12.00	11.41	10.57	45.47	44.77	43.69	178.68	160.25	115.15	7.79	8.08	8.00
	P3xP6	10.78	9.70	8.38	44.49	43.97	34.17	132.42	121.55	82.63	8.22	8.47	8.23
	P3xP7	11.15	10.59	9.14	37.37	35.07	29.12	143.80	139.46	106.63	8.56	8.49	8.50
	P3xP8	11.25	10.81	10.21	37.00	38.63	31.78	134.47	153.31	103.60	8.83	8.84	8.80
	P4xP5	11.69	11.23	10.20	40.23	30.00	23.35	128.13	102.65	98.93	8.01	8.10	7.98
	P4xP6	11.63	11.43	10.02	48.40	51.85	44.68	221.07	182.57	137.98	8.67	8.70	8.63
	P4xP7	13.56	12.85	10.73	46.65	45.67	36.76	227.47	201.12	159.52	7.77	7.74	7.73
	P4xP8	9.87	9.20	8.68	38.30	38.11	29.59	167.14	162.21	127.23	8.19	8.11	8.20
	P5xP6	13.04	12.73	10.63	37.10	35.33	28.29	186.13	188.03	155.35	8.29	8.30	8.22
	P5xP7	13.77	12.76	11.72	42.57	40.76	32.30	151.23	144.70	108.50	8.53	8.46	8.60
	P5xP8	7.75	7.63	7.07	32.43	32.30	23.98	159.83	144.52	115.45	8.10	8.16	8.00
	P6xP7	12.59	12.55	10.77	37.96	35.87	30.21	224.12	209.37	175.82	8.19	8.23	8.16
	P6xP8	12.08	11.88	11.41	42.60	41.23	35.03	178.80	171.27	131.47	7.89	7.71	7.90
	P7xP8	12.10	12.08	10.96	35.46	34.23	25.85	205.06	197.55	167.70	7.64	7.70	7.72
Crosses mean		11.65	11.19	9.86	39.11	38.00	30.81	167.67	160.08	125.61	8.32	8.33	8.33
General mean		11.49	10.99	9.66	39.07	37.92	30.53	168.94	163.30	130.05	8.30	8.30	8.29
L.S.D. at 0.05		2.23	1.70	0.84	3.18	8.17	6.71	29.51	22.99	22.64	0.66	0.53	0.55
L.S.D. at 0.01		2.96	2.25	1.11	4.23	10.84	8.90	39.17	30.53	30.06	0.88	0.71	0.73

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Table 3 Continued:

Genotypes	Parents	1000-seed weight (g)			Oil percentage (%)			Harvest index (%)		
		F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
S. 2465/1/3	P1	8.28	8.43	7.75	40.95	40.55	40.02	27.35	27.92	24.84
Sakha 6	P2	8.52	8.84	7.95	38.04	38.40	37.72	29.58	26.78	28.55
S. 402/1	P3	9.80	9.49	9.19	37.75	37.44	37.09	25.83	26.33	26.96
Sakha 5	P4	9.67	9.33	9.29	44.76	44.85	44.28	30.18	30.11	31.65
Giza 11	P5	10.24	10.03	9.65	40.34	40.28	39.75	35.06	29.60	27.17
Sakha 2	P6	8.60	8.85	7.99	40.92	40.39	39.75	31.23	31.62	30.68
Giza 12	P7	9.20	10.34	8.67	38.13	38.08	37.50	28.20	29.05	30.27
Jowhar	P8	9.79	9.46	9.39	38.48	38.87	38.32	27.43	29.50	32.65
Parents mean		9.26	9.35	8.74	39.92	39.86	39.30	29.36	28.86	29.10
P1xP2		9.82	9.67	9.45	42.21	40.69	40.25	29.51	33.43	33.06
P1xP3		9.56	9.71	8.95	42.78	40.91	40.52	34.10	34.34	33.72
P1xP4		9.19	9.35	8.71	46.33	46.47	45.93	27.05	29.40	29.41
P1xP5		9.67	9.41	9.20	43.88	44.70	44.18	35.35	34.23	31.41
P1xP6		9.50	8.91	9.07	44.12	44.70	44.00	27.17	28.26	27.42
P1xP7		9.41	8.97	8.97	41.94	40.47	40.01	27.23	27.79	28.03
P1xP8		6.30	6.68	5.62	43.83	41.34	40.78	31.44	35.11	31.84
P2xP3		9.04	8.79	8.55	41.01	40.31	39.75	33.75	35.74	33.24
P2xP4		7.77	7.31	7.42	46.43	44.90	44.30	35.46	32.80	30.48
P2xP5		8.33	8.28	7.88	43.73	41.85	41.31	27.10	23.76	26.27
P2xP6		8.34	8.15	7.97	41.81	40.28	39.78	33.33	34.71	31.06
P2xP7		10.17	10.06	9.73	41.24	40.22	39.97	20.58	20.21	21.56
P2xP8		8.39	8.13	7.84	41.56	40.79	40.31	27.41	26.23	26.03
P3xP4		8.74	8.32	8.19	46.07	44.39	43.91	22.87	23.70	22.66
P3xP5		9.30	9.28	8.75	42.27	40.83	40.31	32.57	32.76	33.48
P3xP6		8.89	8.17	8.41	41.44	40.42	40.23	29.98	29.36	26.44
P3xP7		9.40	9.22	8.81	41.81	40.43	39.92	25.64	25.46	25.28
P3xP8		9.29	9.30	8.98	40.44	39.82	39.40	32.70	31.23	31.59
P4xP5		9.60	9.59	9.20	45.73	43.88	43.43	27.77	27.26	31.03
P4xP6		9.67	9.23	9.23	45.57	43.73	43.30	29.49	30.08	32.82
P4xP7		9.63	9.51	9.17	41.93	40.16	39.79	31.03	29.75	29.62
P4xP8		9.32	9.40	8.98	43.70	41.04	40.56	28.71	28.25	29.93
P5xP6		10.21	10.15	9.86	42.61	40.80	40.30	30.81	30.42	29.16
P5xP7		10.12	10.09	9.74	40.77	38.72	38.59	27.38	27.58	30.13
P5xP8		8.95	9.06	8.60	41.39	39.35	39.00	20.76	21.21	23.39
P6xP7		9.31	9.20	9.09	40.93	39.28	38.79	32.29	32.57	33.01
P6xP8		8.58	8.55	8.37	41.46	39.62	39.12	26.88	26.96	28.60
P7xP8		8.61	8.48	8.24	40.26	37.97	37.40	30.64	30.45	33.97
Crosses mean		9.11	8.96	8.68	42.76	41.36	40.90	29.25	29.39	29.45
General mean		9.15	9.05	8.69	42.13	41.03	40.54	29.27	29.28	29.37

L.S.D. at 0.05	0.66	0.68	0.65	0.99	1.06	1.02	4.25	4.95	2.43
L.S.D. at 0.01	0.87	0.90	0.86	1.31	1.40	1.35	5.64	6.57	3.22

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Analysis of combining ability variances for different traits

Griffing's 1956 Method 2 Model 1 was used to conduct the analysis of variance for combining ability. Table 4 shows how genetic variance is divided into general (GCA) and particular (SCA) combining abilities. While SCA variations are attributed to non-additive gene effects involving dominance and epistasis components of the genetic variation, GCA variances are typically assigned to additive and additive x additive gene effects. Table 4 shows how the genetic variance was divided into GCA and SCA variants for each characteristic. With the exception of GCA for technical stem length in F1 and fiber length in F2D2, general and specific combining ability mean squares were found to be highly significant for straw yield and its components in the F1, F2D1, and F2D2. This suggests the significance of both additive and non-additive gene effects in the expression of these traits. For straw yield/plant (except at F2D2), plant height (except at F1), fiber percentage, and fiber fineness, the ratios of GCA/SCA variances were more than unity in all studied environments, suggesting that additive gene effects primarily governed the inheritance of these features. Nonetheless, ratios for technical stem length, fiber yield/plant, and fiber length were less than unity in every case examined, indicating that non-additive gene effects were primarily responsible for these characteristics. In this regard, El-Farouk et al. (1998) discovered that the mean squares of variances due to general and specific combining ability were significant for straw yield, plant height, and technical stem length. He also demonstrated that additive gene effects were primarily responsible for the higher magnitude of variance due to general combining ability for straw yield, plant height, and technical stem length.

Table 4: General and specific combining ability mean squares of parents and F1's as well as F2 over early (F2D1) and late (F2D2) sowing dates for studied traits in 8-parent half diallel crosses of flax

Source of variance	d.f	Seed yield per plant (g plant ⁻¹)			No. of fruiting branches per plant (branch plant ⁻¹)			No. of capsules per plant (Capsule plant ⁻¹)		
		F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
GCA	7	3.84**	2.25**	0.30**	20.66**	28.09**	26.83**	1860.08**	1476.48**	1193.85**
SCA	28	2.14**	2.28**	1.82**	12.89**	19.63**	21.33**	910.59**	816.72**	757.67**
Error	70	0.62	0.36	0.09	1.27	8.38	5.65	109.44	66.45	64.45
GCA/SCA		1.79	0.99	0.16	1.60	1.43	1.26	2.04	1.81	1.58

Source of variance	d.f	No. of seeds per capsule (Seeds capsule ⁻¹)			1000-seed weight (g)			Oil percentage (%)		
		F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
GCA	7	0.115	0.147**	0.12**	0.83**	0.98**	0.81**	15.77**	17.15**	16.73**
SCA	28	0.16**	0.17**	0.16**	0.57**	0.53**	0.63**	2.50**	1.99**	1.94**
Error	70	0.06	0.04	0.04	0.05	0.06	0.05	0.12	0.14	0.13
GCA/SCA		0.72	0.86	0.75	1.46	1.85	1.29	6.31	8.62	8.62

Source of variance	d.f	Harvest index %		
		F ₁	F ₂ D ₁	F ₂ D ₂
GCA	7	6.01*	8.50**	2.47**
SCA	28	15.41**	15.30**	12.89**
Error	70	2.27	3.08	0.74
GCA/SCA		0.39	0.56	0.19

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Estimates of general and specific combining ability effects:

Seed yield per plant (g plant⁻¹):

Estimates of GCA effects for seed yield/plant under different environments are presented in Table 5. Results indicate that the parents Giza 11, S. 2465/1/3 and Giza 12 showed highly significant positive GCA values under F1 and F2 at early (D1) and late (D2) sowing dates, respectively. Therefore, these parents appeared to be the best combiners for seed yield per plant under the mentioned environments which can be used as promising progenitors for high expression of yielding ability. On the other hand, the parents Jowhar under F1 and F2D1, Sakha 6 under F2D1 and Sakha 5 under F2D2 manifested highly significant negative GCA

effects. Thus, these parents seemed to be poor combiners for this trait under the mentioned environments. The SCA effects calculated for each cross are presented in Table 6. Nine crosses Viz., P1×P2, P1×P3, P1×P8, P2×P3, P3×P8, P4×P7, P5×P7, P6×P8 and P7×P8 exhibited highly significant positive SCA values under all respective environments. Therefore, these cross combinations are considered as good F1 and F2 hybrids for seed yield/plant under their respective environments. Out of these crosses, one cross (P5×P7) included high x high general combiner parents. In contrast, six crosses showed highly significant negative SCA effects under all environments. Therefore, these crosses are considered as poor cross combinations for seed yield/plant.

Table 5: Estimates of general combining ability (GCA) effects of parents and F₁'s as well as F₂ over early (F₂D₁) and late (F₂D₂) sowing dates for studied traits in 8-parent half diallel crosses of flax

Parents	Seed yield per plant (g plant ⁻¹)			No. of fruiting branches per plant (branch plant ⁻¹)			No. of capsules per plant (Capsule plant ⁻¹)			No. of seeds per capsule (Seeds capsule ⁻¹)		
	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
S. 2465/1/3 (P ₁)	0.28	0.58**	0.02	-1.48**	-2.39**	-2.72**	-10.32**	-7.14**	-6.33**	-0.01	-0.04	0.05
Sakha 6 (P ₂)	-0.16	-0.44*	-0.02	-0.89**	-1.06	-0.70	17.20**	16.78**	16.54**	0.14*	0.10	0.15*
S. 402/1 (P ₃)	-0.21	-0.07	-0.14	0.53	0.81	1.19	-22.40**	-17.82**	-17.51**	0.02	0.13*	0.04
Sakha 5 (P ₄)	-0.38	-0.12	-0.32**	1.71**	1.44	0.48	4.60	0.27	0.55	0.12	0.13*	0.09
Giza 11 (P ₅)	0.97**	0.34	0.11	1.33**	0.97	0.92	-13.00**	-14.19**	-10.04**	0.07	0.07	0.04
Sakha 2 (P ₆)	0.37	0.28	0.12	1.42**	2.54**	2.60**	9.35**	6.36**	3.08	-0.14	-0.13*	-0.13*
Giza 12 (P ₇)	0.24	0.29	0.25**	-0.58	-0.98	-0.75	4.64	4.89*	4.52	-0.07	-0.09	-0.09
Jowhar (P ₈)	-1.12**	-0.87**	-0.02	-2.03**	-1.33	-1.03	9.95**	10.86**	9.19**	-0.14	-	-
											0.16**	0.15**
gca(j)	0.23	0.18	0.09	0.33	0.86	0.70	3.09	2.41	2.37	0.07	0.06	0.06
Parents	1000-seed weight (g)			Oil percentage (%)			Harvest index (%)					
	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂			
S. 2465/1/3 (P ₁)	-0.23**	-0.19**	-0.27**	0.77**	1.11**	1.08**	0.31	1.49**	0.02			
Sakha 6 (P ₂)	-0.34**	-0.34**	-0.35**	-0.52**	-0.34**	-0.38**	0.28	-0.3	-0.56*			
S. 402/1 (P ₃)	0.15*	0.03	0.08	-0.80**	-0.72**	-0.67**	-0.02	0.18	-0.4			
Sakha 5 (P ₄)	0.10	-0.01	0.13	2.60**	2.50**	2.49**	-0.07	-0.2	0.49			
Giza 11 (P ₅)	0.44**	0.45**	0.43**	0.18	0.14	0.17	0.84	-0.71	-0.51*			
Sakha 2 (P ₆)	-0.06	-0.14	-0.02	0.05	0.04	0.01	0.89*	1.21*	0.55*			
Giza 12 (P ₇)	0.27**	0.48**	0.29**	-1.42**	-1.58**	-1.54**	-1.23**	-1.16*	-0.22			
Jowhar (P ₈)	-0.33**	-0.29**	-0.28**	-0.86**	-1.15**	-1.17**	-1.01*	-0.51	0.63*			
gca(j)	0.07	0.07	0.07	0.10	0.11	0.11	0.45	0.52	0.25			

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Table 6: Estimates of specific combining ability (SCA) effects of F1's as well as F2's over early F2D1 and late F2D2 sowing dates for studied traits in 8-parent half diallel crosses of flax

Crosses	Seed yield/plant (g plant ⁻¹)			No. of fruiting branches/plant (Branches plant ⁻¹)			No. of capsules/plant (Capsule plant ⁻¹)			No. of seeds/capsule (Seed capsule ⁻¹)		
	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
P ₁ XP ₂	1.93**	2.68**	2.01**	2.61**	-0.57	-0.59	14.29**	20.16**	2.68**	-0.39**	-0.35**	-0.31**
P ₁ XP ₃	1.57**	2.02**	2.08**	-3.49**	-2.52*	-3.11**	17.62**	17.43**	2.02**	-0.10	0.02	-0.05
P ₁ XP ₄	-0.38	-1.07**	0.16	1.38**	3.19**	1.02	10.71*	14.48**	-1.07**	0.03	0.08	0.03
P ₁ XP ₅	0.04	0.11	0.28*	-0.72	0.12	0.54	-15.45**	-13.19**	1.11	0.50**	0.34**	0.55**
P ₁ XP ₆	-0.09	-0.63**	-0.69**	-3.01**	-3.07**	-1.93*	-17.20**	-29.42**	-0.63**	-0.26**	-0.57**	-0.23**
P ₁ XP ₇	-1.18**	-1.09**	-0.38**	3.06**	2.69*	3.67**	-14.20**	-11.70**	-1.09**	0.01	0.19*	-0.09
P ₁ XP ₈	1.75**	1.51**	0.39**	0.95*	-0.57	1.36	-35.80**	-34.17**	-31.03**	0.69**	0.75**	0.74**
P ₂ XP ₃	2.14**	2.39**	1.10**	0.56	-2.40*	-1.48	0.24	-2.82	-2.53	-0.09	-0.18*	0.01
P ₂ XP ₄	0.64*	0.83**	0.03	-0.49	-4.16**	-4.44**	6.61	13.10**	15.97**	0.71**	0.78**	0.70**
P ₂ XP ₅	1.16**	-0.05	1.28**	4.63**	8.26**	4.52**	32.45**	36.94**	24.60**	0.57**	0.56**	0.65**
P ₂ XP ₆	-0.04	0.57*	-0.35**	-6.34**	-1.15	-1.69	-50.67**	-37.99**	-35.27**	0.24*	0.43**	0.21**
P ₂ XP ₇	-2.50**	-1.82**	-1.47**	-3.83**	-1.67	0.22	-24.80**	-24.40**	-22.35**	-0.39**	-0.53**	-0.41**
P ₂ XP ₈	-1.57**	-1.42**	-1.99**	-0.04	2.97*	5.97**	-38.85**	-54.96**	-57.70**	-0.08	0.01	-0.14
P ₃ XP ₄	-1.38**	-1.86**	-1.73**	-3.45**	-0.77	-2.07*	-10.09*	-6.54*	-8.83**	-0.26**	-0.24**	-0.39**
P ₃ XP ₅	-0.26	0.14	0.94**	4.53**	5.07**	11.04**	45.15**	28.95**	12.65**	-0.59**	-0.43**	-0.37**
P ₃ XP ₆	-0.87**	-1.50**	-1.25**	3.47**	2.70*	-0.15	-23.46**	-30.29**	-32.99**	0.03	0.17*	0.03
P ₃ XP ₇	-0.38	-0.62*	-0.63**	-1.65**	-2.68*	-1.86	-7.37	-10.92**	-10.43**	0.30**	0.15	0.25**
P ₃ XP ₈	1.09**	0.75**	0.72**	-0.57	1.23	1.08	-22.02**	-3.04	-18.13**	0.65**	0.57**	0.62**
P ₄ XP ₅	-0.4	0.01	0.74**	-1.88**	-10.32**	-8.58**	-32.39**	-46.74**	-21.63**	-0.47**	-0.40**	-0.44**
P ₄ XP ₆	0.15	0.27	0.57**	6.20**	9.95**	11.06**	38.19**	12.64**	4.31	0.39**	0.40**	0.38**
P ₄ XP ₇	2.20**	1.69**	1.14**	6.46**	7.29**	6.50**	49.30**	32.66**	24.40**	-0.58**	-0.61**	-0.56**
P ₄ XP ₈	-0.13	-0.81**	-0.63**	-0.45	0.08	-0.39	-16.34**	-12.22**	-12.56**	-0.09	-0.16*	-0.03
P ₅ XP ₆	0.2	1.12**	0.74**	-4.72**	-6.09**	-5.76**	20.86**	32.55**	32.26**	0.06	0.06	0.02
P ₅ XP ₇	1.06**	1.14**	1.70**	2.75**	2.86*	1.6	-9.33*	-9.31**	-16.04**	0.23*	0.17*	0.36**
P ₅ XP ₈	-3.59**	-2.84**	-2.68**	-5.93**	-5.25**	-6.44**	-6.05	-15.46**	-13.75**	-0.13	-0.05	-0.18*
P ₆ XP ₇	0.48	0.99**	0.75**	-1.94**	-3.61**	-2.17*	41.21**	34.82**	38.18**	0.10	0.15*	0.09
P ₆ XP ₈	1.33**	1.47**	1.66**	4.15**	2.11	2.92**	-9.43*	-9.25**	-10.84**	-0.14	-0.30**	-0.11
P ₇ XP ₈	1.49**	1.67**	1.08**	-0.99*	-1.37	-2.91**	21.54**	18.50**	23.94**	-0.46**	-0.35**	-0.33**
sca(ii)	0.72	0.55	0.27	1.02	2.63	2.16	9.49	7.39	7.28	0.21	0.17	0.18
sca(ij)	0.31	0.24	0.12	0.45	1.14	0.94	4.13	3.22	3.17	0.09	0.07	0.08

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Table 6 Continued:

Crosses	1000-seed weight (g)			Oil percentage (%)			Harvest index (%)		
	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂	F ₁	F ₂ D ₁	F ₂ D ₂
P ₁ XP ₂	1.24**	1.14**	1.38**	-0.18	-1.11**	-1.00**	-0.35	2.96**	4.22**
P ₁ XP ₃	0.49**	0.81**	0.45**	0.67**	-0.51**	-0.44**	4.54**	3.39**	4.72**
P ₁ XP ₄	0.18	0.49**	0.17	0.81**	1.82**	1.81**	-2.46**	-1.16	-0.48
P ₁ XP ₅	0.32**	0.10	0.35**	0.79**	2.41**	2.38**	4.93**	4.17**	2.53**
P ₁ XP ₆	0.65**	0.19*	0.68**	1.15**	2.53**	2.37**	-3.31**	-3.72**	-2.53**
P ₁ XP ₇	0.22*	-0.37**	0.26**	0.45**	-0.09	-0.07	-1.13	-1.82**	-1.14**
P ₁ XP ₈	-2.28**	-1.89**	-2.51**	1.78**	0.36*	0.32*	2.86**	4.85**	1.82**
P ₂ XP ₃	0.08	0.04	0.13	0.18	0.35*	0.25	4.21**	6.59**	4.83**
P ₂ XP ₄	-1.13**	-1.40**	-1.05**	2.21**	1.71**	1.65**	5.98**	4.04**	1.17**
P ₂ XP ₅	-0.91**	-0.88**	-0.90**	1.93**	1.02**	0.97**	-3.30**	-4.50**	-2.04**
P ₂ XP ₆	-0.40**	-0.43**	-0.35**	0.14	-0.45**	-0.40**	2.88**	4.53**	1.69**
P ₂ XP ₇	1.09**	0.87**	1.10**	1.04**	1.11**	1.35**	-7.75**	-7.60**	-7.04**
P ₂ XP ₈	-0.09	-0.29**	-0.22*	0.80**	1.26**	1.31**	-1.15	-2.23**	-3.42**
P ₃ XP ₄	-0.65**	-0.76**	-0.71**	2.13**	1.58**	1.54**	-6.32**	-5.55**	-6.80**
P ₃ XP ₅	-0.43**	-0.25*	-0.45**	0.75**	0.38*	0.26	2.47**	4.01**	5.02**
P ₃ XP ₆	-0.35**	-0.77**	-0.34**	0.05	0.08	0.34*	-0.16	-1.30	-3.08**
P ₃ XP ₇	-0.17	-0.34**	-0.25**	1.88**	1.71**	1.59**	-2.38**	-2.83**	-3.47**
P ₃ XP ₈	0.32**	0.51**	0.49**	-0.04	0.68**	0.69**	4.45**	2.29**	1.99**
P ₄ XP ₅	-0.08	0.10	-0.05	0.81**	0.20	0.23	-2.27**	-1.11	1.68**
P ₄ XP ₆	0.49**	0.32**	0.43**	0.78**	0.16	0.25	-0.61	-0.21	2.41**
P ₄ XP ₇	0.11	-0.01	0.07	-1.40**	-1.79**	-1.70**	3.05**	1.83**	-0.02
P ₄ XP ₈	0.41**	0.65**	0.45**	-0.18	-1.33**	-1.31**	0.52	-0.32	-0.56
P ₅ XP ₆	0.69**	0.79**	0.76**	0.24	-0.41**	-0.43**	-0.20	0.64	-0.25
P ₅ XP ₇	0.27**	0.11	0.33**	-0.14	-0.87**	-0.58**	-1.51*	0.17	1.49**
P ₅ XP ₈	-0.30**	-0.15	-0.24*	-0.07	-0.67**	-0.55**	-8.34**	-6.86**	-6.09**
P ₆ XP ₇	-0.05	-0.19*	0.14	0.15	-0.20	-0.23	3.35**	3.24**	3.31**
P ₆ XP ₈	-0.17	-0.07	-0.02	0.13	-0.29	-0.27	-2.28**	-3.02**	-1.96**
P ₇ XP ₈	-0.48**	-0.75**	-0.46**	0.40**	-0.32*	-0.43**	3.60**	2.83**	4.19**
sca(ii)	0.21	0.22	0.21	0.31	0.34	0.33	1.36	1.59	0.78
sca(ij)	0.09	0.09	0.09	0.13	0.15	0.14	0.59	0.69	0.34

* and ** Denote significant differences at 0.05 and 0.01 levels, respectively.

Number of fruiting branches per plant (branch plant⁻¹)

Estimates of general combining ability (GCA) effects for No. of fruiting branches/plant are recorded in Table 5. Results indicated that the variety Sakha 2 showed high significant positive general combining ability values under all studied environments (F₁, F₂D₁ and F₂D₂), while Sakha 5 and Giza 11 observed high significant positive general combining ability values under F₁ only. Therefore, it could be concluded that these parents appeared to be the best combiner for No. of fruiting branches/plant. Contrary, the line- parent S. 2465/1/3 manifested highly significant negative (GCA) effects under different environments, while Sakha 6 and Jowhar observed highly significant negative (GCA) effects under F₁ only for No. of fruiting branches/plant. Therefore, these parents behaved as the poor combiners for No. of fruiting branches/plant.

Estimates of specific combining ability (SCA) effects for No. of fruiting branches/plant are recorded in Table 6. Data showed that the five out of 28 crosses; P1×P7, P2×P5, P3×P5, P4×P6 and P4×P7 had highly significant positive (SCA) effects under all studied environments. Therefore, these crosses were considered as the best F1 and F2 cross combinations for No. of fruiting branches/plant. Out of these crosses, one cross (P4×P6) included high x high general combiner parents. These parents and crosses can be used as useful genetic materials for improving No. of fruiting branches/plant in flax under various environmental studied. Contrary, six crosses exhibited highly significant negative SCA values under different environments. Therefore, these crosses behaved as the poor combiners for No. of fruiting branches/plant.

Number of capsules per plant (capsule plant⁻¹)

Concerning No. of capsules/plant, results in Table 5 revealed that highly significant positive GCA effects were detected for the two parents; Sakha 6 and Jowhar in the F1 and F2 at early and late sowing dates, as well as Sakha 2 in the F1 and F2D1 and Giza 12 in the F2D1. Therefore, it could be concluded that these parents appeared to be good combiner for no. of capsules/plant under their respective environments. On the other side, the three parents, S. 2465/1/3, S. 402/1 and Giza 11 Estimates of registered highly significant negative GCA effects under different environments. Therefore, it could be concluded that these parents appeared to be poor combiners for No. of capsules/plant under all respective environments.

SCA effects are illustrated in Table 6. The results display those nine hybrids (P1×P2, P1×P3, P1×P4, P2×P5, P3×P5, P4×P7, P5×P6, P6×P7 and P7×P8) exhibited highly significant positive SCA values under all environments. Therefore, these crosses were considered as the best F1 and F2 cross combinations for No. of capsules/plant. Out of these crosses, two crosses; P1×P3 and P3×P5 included high x high general combiner parents, while three crosses; P1×P2, P2×P5 and P5×P6 included high x low general combiner parents. These crosses can be used as useful genetic materials for improving No. of capsules/plant in flax under various environmental studied. Contrarily, thirteen crosses exhibited high significant negative SCA values under different environments. Therefore, these crosses behaved as the poor combiners for No. of capsules/plant.

Number of seeds per capsule (seed capsule⁻¹)

Regarding No. of seeds/capsule, results in Table 5 show that significant positive general combining ability effects were detected for Sakha 6 in the F1 hybrid and F2 at late sowing date (D2) and S. 402/1 and Sakha 5 in the F2 at early sowing date (D1) which considered the best combiners for No. of seeds/capsule under their respective environments. On the other hand, two parents; Jowhar and Sakha 2 registered highly significant negative GCA effects under F2D1 and F2D2, thus these parents seemed to be poor combiners for this trait under their respective environments.

Estimates of specific combining ability effects for No. of seeds/plant are illustrated in Table 6. The data indicate that eight crosses; P1×P5, P1×P8, P2×P4, P2×P5, P2×P6, P3×P8, P4×P6 and P5×P7 exhibited highly significant positive SCA effects under all studied environments. As a result, in their particular settings, these crossings are thought to be the greatest hybrids for this characteristic. These crosses can be utilized as valuable genetic resources to increase the number of flax seeds/plants under different environmental conditions. One of these crosses, i.e., P2×P4 included high x high general combiner parents while, three crosses, i.e., P2×P6, P3×P8 and P4×P6 involved high x low general combiner parents for no. of seed/plant. contrarily, eight crosses; P1×P2, P1×P6, P2×P7, P3×P4, P3×P5, P4×P5, P4×P7 and P7×P8 display highly significant negative SCA effects under all studied environments (F1, F2D1 and F2D2). Therefore, these crosses are considered as poor hybrid combinations for No. of seeds/plant under their respective environments.

1000 seed weight (g)

Thousands of seed weight estimate of general combining ability effects for each parent are presented in Table 5. The results indicated that the parents; Giza 11 and Giza12 observed highly significant positive GCA values under all studied environments, while the line parent S. 402/1 showed significant positive GCA value under F1 hybrid only. Thus, these parents are considered as good combiners for this trait under respective environments. On the other hand, the three parents; S. 2465/1/3, Sakha 6 and Jowhar had highly significant negative GCA effects under all respective environments. Therefore, these parents behaved as poor combiners for this trait under their respective environments.

Estimates of specific combining ability effects are presented in Table 6 for 1000-seed weight show that the eight crosses; P1×P2, P1×P3, P1×P6, P2×P7, P3×P8, P4×P6, P4×P8 and P5×P6 manifested highly significant positive SCA values under all environments. Therefore, these crosses are considered as the good hybrids for this trait under their respective environments. These crosses can be used as useful genetic materials for improving 1000-seed weight in flax under various environmental studied. Three of these crosses, i.e., P1×P3, P2×P7 and P3×P8 involved high x low general combiner parents while one cross; P1×P2 included low x low general combiner parents for 1000-seed weight. Contrary, eight crosses; P1×P8, P2×P4, P2×P5, P2×P6, P3×P4, P3×P5, P3×P6 and P7×P8 exhibited highly significant negative SCA values under all respective environments. Thus, these hybrids are considered as poor cross combinations for 1000-seed weight under their respective environments.

Oil percentage (%)

Estimates of general combining ability (GCA) effects for oil percentage are recorded in Table 5. Results indicated that S. 2465/1/3 and Sakha 5 parents showed high significant positive general combining ability values under all studied environments. Therefore, it could be concluded that this parents appeared to be the best combiner for oil percentage. These parents could be used as promising progenitors for high expression of oil percentage. Contrary, the parents; Sakha 6, S. 402/1, Giza 12 and Jowhar observed highly significant negative general combining ability values under all respective environments. Therefore, these parents behaved as the poor combiners for oil percentage.

Specific combining ability effects calculated for each cross regarding oil percentage are presented in Table 6. The data observed that 16, 13 and 12 out of 28 crosses had highly significant positive SCA effects under all studied environments, ranging from 0.40 for the cross (P7×P8), 0.35 for the cross (P2×P3) and 0.32 for the cross (P1×P8) to 2.21 for the cross (P2×P4), 2.53 for the cross (P1×P6) and 2.38 for the cross (P1×P5) under F1, F2D1 and F2D2, respectively. Ten crosses; P1×P4, P1×P5, P1×P6, P1×P8, P2×P4, P2×P5, P2×P7, P2×P8, P3×P4 and P3×P7 showed highly significant positive SCA effects under all respective environments. Therefore, all these cross combinations are considered as good F1 and F2 hybrids for this trait under their respective environments. One of these crosses P1×P4, involved high x high general combiner parents while, three crosses; P1×P8, P2×P4 and P3×P4 included high x low general combiner parents and three crosses; P2×P7, P2×P8 and P3×P7 included low x low general combiner parents for oil percentage. On the other side, 1, 9 and 9 out of 28 crosses showed highly significant negative SCA effects in the F1, F2D1 and F2D2, respectively. One cross showed highly significant negative SCA effects under all studied environments. Thus, these crosses are considered as poor cross combinations for oil percentage.

Harvest index (100%)

Concerning harvest index, results in Table 5 reveal that significant positive GCA effects were detected for Sakha 2 in the F1 and F2 (at early and late sowing dates), while significant positive GCA effects were found for S. 2465/1/3 under F2D1 and Jowhar under F2D2. Therefore, it could be concluded that these parents appeared to be good combiner for harvest index under their respective environments. On the other side, the parents, Giza 12 under F1 and F2D1, Jowhar under F1 and Sakha 6 and Giza 11 under F2D2 registered significant negative GCA effects under their respective environments. Therefore, it could be concluded that these parents appeared to be poor combiner oil percentage.

Estimates of SCA effects for harvest index are illustrated in Table 6. The results display that ten; P1×P3, P1×P5, P1×P8, P2×P3, P2×P4, P2×P6, P3×P5, P3×P8, P6×P7 and P7×P8 hybrids exhibited highly significant positive SCA values under all studied environments. Therefore, these crosses were considered as the best F1 and F2 cross combinations for harvest index. These crosses can be used as useful genetic materials for improving harvest index in flax under various environmental studied. Out of these crosses, one cross; P2×P6 included high x high general combiner parents, while two crosses; P6×P7 and P6×P7 included high x low and low x low general combiner parents, respectively. Contrary, seven crosses exhibited high significant negative SCA values under different environments. Therefore, these crosses behaved as the poor combiners for harvest index.

In this connection, similar results for general and specific combining ability were recorded by many investigators likes, Popescu et al (1999), Bhatia et al (2006), Mohammadi et al (2010), Sood et al (2011), Pali & Mehta (2014), Abd Al-Sadek (2015), Kumar et al (2016), Singh et al (2016a), El-Refaie & Hussein (2017) and Naik (2017). Amein (2016) recorded that combining ability variances in F1 and F2 generations were highly significant for seed yield/plant, No. of capsules/plant and oil%, indicating the importance of additive and non-additive genetic variances in determining the performance of these traits. Since the ratio of GCA/SCA exceeded the unity, suggesting that additive was much larger and more important than non-additive gene effects in the inheritance of these traits. Data indicated great and significant genotypic differences in studied traits. According to Singh et al. (2016b), there have been notable variations in yield and related features in the F1 and F2 generations for both the specific combining ability (SCA) effects among the hybrids and the general combining ability (GCA) effects among the parents.

For yield and associated attributes, the GCA and SCA components of variance were significant. The predominance of additive gene action for the traits under study was indicated by the fact that the amount of GCA variance was greater than SCA. With the exception of seed weight in the F1 generation and oil percentage in the F2 generation, the GCA:SCA ratio showed that additive gene effects predominated in both generations. According to Kumar et al. (2017), dominance and epistasis gene action make up non-additive genetic variance, while additive gene action causes additive genetic variance. The mean squares of the general combining ability (GCA), specific combining ability (SCA) in the F1 and F2 hybrids were statistically significant for No. of capsules/plant, No. of seeds/capsule, 1000-seed weight, seed yield/plant and oil% in F₁ and F₂ generations.

Conclusions

Delaying sowing date caused a reduction in all studied traits of parents and crosses in F2, indicating that the delay in the planting date has a detrimental effect on studied traits. General and specific combining ability mean squares were highly significant for seed yield per plant and their related characters in F1, F2D1 and F2D2, indicating the importance of both additive and non-additive gene effects in the expression of seed yield and its components. Results showed that the parents Giza 11, Sakha 6, Sakha 2, S. 2465/1/3 and Sakha 5 appeared to be the best general combiner for one or more from studied traits under all respective environments. Some of the crosses exhibited highly significant and positive SCA effects included high x high and high x low general combiner parents, suggesting that the breeding procedures utilize both additive and non-additive genetic variances would be more effective useful for improvement of seed yield and its components of flax.

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