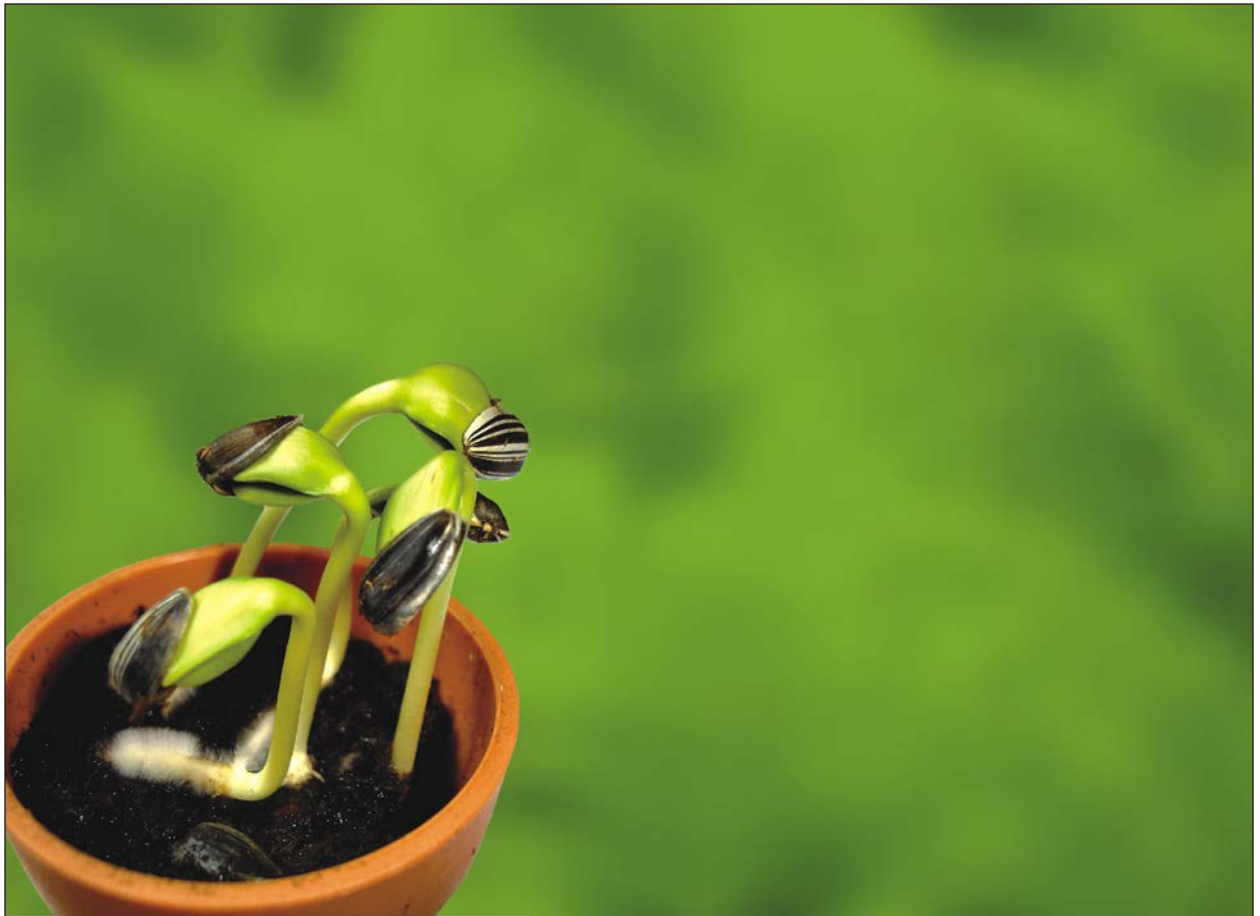




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Diallel Cross Analysis for Yield and its Related Traits in Some Genotypes of Flax (*Linum usitatissimum* L.)

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ABSTRACT

Six genotypes of flax representing different agronomic characters were crossed in a half-diallel model in 2009/2010 winter season. The six parents and their 15 F_1 crosses were evaluated in 2010/2011 and 2011/2012 seasons to study the combining ability and mode of gene action for yield and its components traits of flax. The results indicated clearly that mean squares of genotypes, general and specific combining ability were highly significant for all studied traits in both seasons and their combined data, except general combining ability for capsules No. plant⁻¹ in both seasons and No. of basal branches plant⁻¹ in the second season were insignificant. The GCA/SCA ratio was more than unity for days to the first flower, plant height and technical length, indicating that these traits are predominantly controlled by additive gene action. Whereas, GCA/SCA ratio was less than unity for No. of basal branches plant⁻¹, No. of capsules plant⁻¹, 1000-seed weight, seed yield plant⁻¹ and straw yield plant⁻¹, indicating that these traits are mainly controlled by non-additive gene action. The best general combiners were P1 (S2) for straw yield, plant height and technical length; P5 (Hermis) for seed and straw yields; P4 (Bleinka) for seed yield plant⁻¹ and 1000-seed weight. Eight crosses and nine crosses showed significant or highly significant and positive SCA effects for seed yield plant⁻¹ and straw yield plant⁻¹, respectively, indicating that these crosses were the best combinations for increasing seed and straw yields.

Key words: Flax, diallel analysis, combining ability, gene action

INTRODUCTION

Flax (*Linum usitatissimum* L.) is considered the most important past fiber crop in Egypt since several thousand years ago. Choice of parents for crossing is considered an important step in any plant breeding program aimed at improving yield and related attributes. Combining ability analysis is an important tool for the selection of desirable parents together with the information regarding to the nature and magnitude of gene effects controlling quantitative traits. It is important to accurately estimate the magnitude and relative proportion of the various components of genetic variance in order to understand the underlying type of gene action that controls the trait of interest, for example General Combining Ability (GCA) variance is a measure of additive effects of genes and of additive x additive epistatic interaction, while Specific Combining Ability (SCA) variance is measure of dominance and epistatic types of gene action. Many researchers studied the combining ability in flax, i.e., Patil *et al.* (1997), Foster *et al.* (1998), Abo El-Zahab and Abo-Kaied (2000), Abo-Kaied (2002) and El-Kady and Abo-Kaied (2010), they found that additive genetic variance had more important role in the inheritance of straw yield, plant height, technical stem length and 1000-seed weight. On the other hand, non-additive variance had an important role in the inheritance of No. of basal branches plant⁻¹, seed yield plant⁻¹ and capsules number

plant⁻¹ as reported by Shehata and Comstock (1971), Patil and Chopde (1981), Zahana (2006), Abo-Kaied *et al.* (2007) and El-Kady and Abo-Kaied (2009). While, Mishra *et al.* (2013) reported that GCA/SCA were less than 1 revealed the importance of non-additive gene action in the inheritance of all seed yield and its components traits.

Mohammadi *et al.* (2010) showed that additive gene actions had greater effects on inheritance of days to flowering, plant height, primary branches per plant and 1000-seed weight. However, number of capsules per plant was largely controlled by dominance genetic effects, whereas both additive and non-additive gene actions were important in genetic control of seed yield plant⁻¹. Therefore, the present investigation was designed to estimate the combining ability effects and the mode of gene action in the inheritance of some traits in six parental foreign flax genotypes and their 15 F₁ crosses during two growing seasons.

MATERIALS AND METHODS

The genetic materials used in this investigation as parents included six foreign genotypes of flax. The parent's names and their origin are presented in Table 1.

In 2009/2010 winter season, the six parental genotypes were sown at various dates in order to overcome the differences in flowering time. All possible cross combinations excluding reciprocals were made among the six genotypes, giving 15 F₁ crosses. The parents and their F₁ crosses were evaluated in the Farm of Agron, Department of Agronomy, Faculty of Agriculture, Mansoura University, Egypt during two growing seasons, 2010/2011 and 2011/2012. The experiments were laid out in a randomized complete block design with three replications. Each plot consisted of one row for parents and its F₁ crosses. Rows were 3 m long and spaced 20 cm apart. Single seeds were hand drilled at 5 cm spacing within row. All other cultural practices were applied as recommended for flax cultivation. At harvest, individual guarded plants were taken at random from each row; 10 plants from each parent and F₁ per replication for recording the studied traits.

Studied traits: Days to first flower (day), plant height (cm), technical length (cm), No. of basal branches plant⁻¹, No. of capsules plant⁻¹, 1000-seed weight (g), seed yield plant⁻¹ (g) and straw yield plant⁻¹ (g).

Statistical analysis: The data obtained for each trait was analyzed on plot mean basis in both parents and F₁ generation. All obtained data was subjected to the statistical analysis of the randomized complete block design to test the differences among various genotypes under each season according to Snedecor and Cochran (1980). Combined analysis was performed between the

Table 1: Flax genotypes names and their origin

Parent	Name	Origin (From imported)
P1	S ₂	India
P2	S ₅	India
P3	Escalina	Holland
P4	Bleinka	Holland
P5	Hermis	Belgicea
P6	Leflora	Island

Table 2: Analysis of variance from method 2 model 1 and expected mean squares for combining ability analysis

SV	df	MS	EMS
GCA	P-1	Mg	$\sigma^2_{e+(P+2)} (1/P-1) \sum g^2_i$
SCA	P (P-1)/2	Ms	$\sigma^2_{e+2/P} (P-1) \sum_i \sum_j S^2_{ij}$
Error	(r-1) (c-1)	Me	σ^2_e

Me: Error mean squares of the main randomized complete block design divided by number of replications (Me: Me/r), P: Number of parents

two seasons to indicate the seasonal year effects. Treatments were compared using the Least Significant Differences values (LSD) at 5% probability according to Gomez and Gomez (1984). An ordinary analysis using Griffing (1956) method 2 model 1 (fixed effects) was applied to estimate General Combining Ability (GCA) and Specific Combining Ability (SCA) effects, as shown in Table 2.

RESULTS AND DISCUSSION

Analysis of variance for the studied traits under both seasons and their combined data are presented in Table 3. The results indicated clearly that mean squares of genotypes were highly significant for all studied traits in both seasons and their combined data. These results reflected an indication to the presence of real differences between the studied genotypes for these traits. General (GCA) and specific (SCA) combining ability mean squares presented in Table 3 were highly significant for all studied traits in both seasons and their combined data, except general combining ability for No. of capsules plant⁻¹ in both seasons and No. of basal branches plant⁻¹ in the second season were insignificant.

The GCA/SCA ratio was more than unity for each of days to first flower, plant height and technical length in both seasons and their combined data (Table 3), indicating that these traits are predominantly controlled by additive gene action. Therefore, it could be concluded that selection procedures based on the accumulation of additive gene effect would be more effective in the early segregating generations for improving these traits. These results are in general agreement with those previously reported by Foster *et al.* (1998), Abo El-Zahab and Abo-Kaied (2000), Abo-Kaied (2002), El-Kady and Abo-Kaied (2010) and Mohammadi *et al.* (2010). On the other hand, GCA/SCA ratio was less than unity for each of No. of basal branches plant⁻¹, No. of capsules plant⁻¹, 1000-seed weight, seed yield plant⁻¹ and straw yield plant⁻¹ traits in both seasons and their combined data (Table 3), indicating that these traits are mainly controlled by non-additive gene action. Therefore, it could be concluded that hybridization procedures based on dominance gene effect would be more effective for improving these traits. Similar results in general reported previously by Shehata and Comstock (1971), Patil and Chopde (1981), Zahana (2006), Abo-Kaied *et al.* (2007), El-Kady and Abo-Kaied (2009) and Mishra *et al.* (2013).

Mean performance of genotypes: Data in Table 4 indicated that the P4 (Bleinka) and crosses P2×P6, P3×P5 and P4×P5 were the earliest in flowering in both seasons and their combined data. P1 (S2) and P3 (Escalina) and crosses P1×3, P1×4 and P2×3 gave the highest values of plant height in both seasons and their combined data. The parent P1 (S2) and crosses P1×3 and P1×5 gave the highest values of technical length in both seasons and their combined data. Parents P4 (Bleinka) and P5 (Hermis) and crosses P2×4, P2×3, P1×3 and P5×6 gave the highest values for No. of basal branches plant⁻¹ in both seasons and their combined data. Parents P1 (S2) and P6 (Leflora) and

Table 3: Mean squares from analysis of variance, for general and specific combining abilities for all studied traits in the 1st and 2nd seasons and their combination

S.O.V	df		Days to first flower (day)			Plant height (cm)		
	Single	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Rep.	2	5	1.06	2.71	28.34	19.06	31.49	773.75
Genotypes	20	20	12.69**	11.21**	23.22**	211.80**	131.40**	318.10**
GCA	5	5	5.50**	5.63**	5.40**	120.74**	80.58**	95.13**
SCA	15	15	3.81**	3.10**	3.36**	53.88**	31.53**	38.97**
Error	40	100	0.11	0.10	0.06	6.97	3.98	3.03
GCA/SCA	-	-	1.44	1.82	1.61	2.24	2.56	2.44

S.O.V	df		Technical length (cm)			No. of basal branches plant ⁻¹		
	Single	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Rep.	2	5	6.49	10.11	135.60	0.57	0.05	3.46
Genotypes	20	20	166.50**	159.40**	324.70**	2.14**	1.25**	3.22**
GCA	5	5	108.12**	101.44**	104.68**	0.56**	0.18	0.34**
SCA	15	15	37.98**	37.01**	37.27**	0.77**	0.50**	0.60**
Error	40	100	5.47	3.79	1.89	0.21	0.11	0.07
GCA/SCA	-	-	2.85	2.74	2.81	0.73	0.36	0.57

S.O.V	df		No. of capsules plant ⁻¹			1000-seed weight (g)		
	Single	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Rep.	2	5	17.71	16.30	138.90	1.103	2.89	57.90
Genotypes	20	20	283.80**	242.00**	523.30**	59.95**	50.39**	103.40**
GCA	5	5	10.05	5.17	7.38**	15.76**	7.37**	9.79**
SCA	15	15	122.79**	105.85**	113.84**	21.39**	19.93**	19.71**
Error	40	100	4.21	3.99	1.72	0.02	0.25	0.29
GCA/SCA	-	-	0.08	0.05	0.06	0.74	0.37	0.50

S.O.V	df		Seed yield plant ⁻¹ (g)			Straw yield plant ⁻¹ (g)		
	Single	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Rep.	2	5	0.312	0.617	10.07	1.36	2.30	19.52
Genotypes	20	20	28.01**	22.68**	49.97**	100.40**	90.50**	190.60**
GCA	5	5	5.98**	5.81**	5.81**	26.63**	20.85**	23.63**
SCA	15	15	10.46**	8.14**	9.17**	35.76**	33.27**	34.47**
Error	40	100	0.00	0.03	0.30	0.15	0.11	0.07
GCA/SCA	-	-	0.57	0.71	0.63	0.74	0.63	0.69

*,**Significant at 0.05 and 0.01 levels of probability, respectively

crosses P2×4, P3×4, P1×5, P4×5 and P5×6 gave the highest values for No. of capsules plant⁻¹ in both seasons and their combined data. The parent P6 (Leflora) and cross P3×P6 gave the highest values of 1000-seed weight in both seasons and their combined data. The parent P5 (Hermis) and cross P4×5 gave the highest values for seed yield plant⁻¹ in both seasons and their combined data. The parents P1 (S2) and P2 (S5) and the crosses P1×2 and P4×5 gave the highest values of straw yield plant⁻¹ in both seasons and their combined data, as shown in Table 4.

Table 4: Mean performance of flax genotypes (parents and their 15 F₁ crosses) for all studied traits in the 1st and 2nd seasons and their combination

Genotypes	Days to first flower			Plant height (cm)			Technical length (cm)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
P1 (S2)	93.67	92.33	93.00	115.0	106.7	110.8	72.33	68.33	70.33
P2 (S5)	93.67	91.33	92.50	110.0	100.0	105.0	66.67	62.00	64.33
P3 (Escalina)	94.67	91.67	93.17	115.0	104.0	109.5	61.67	56.67	59.17
P4 (Bleinka)	89.67	87.67	88.67	100.0	91.7	95.8	51.67	48.67	50.17
P5 (Hermis)	92.33	89.67	91.00	116.7	98.3	107.5	63.33	58.00	60.67
P6 (Leflora)	94.00	91.33	92.67	100.0	95.0	97.5	58.33	53.33	55.83
P1×P2	93.67	92.67	93.17	118.3	110.0	114.2	69.33	62.67	66.00
P1×P3	89.33	87.67	88.50	127.7	116.7	122.2	76.67	71.67	74.17
P1×P4	93.33	91.67	92.50	126.7	118.3	122.5	75.67	72.00	73.83
P1×P5	92.33	90.33	91.33	125.0	111.7	118.3	76.67	71.67	74.17
P1×P6	93.67	91.67	92.67	121.7	106.7	114.2	75.00	70.00	72.50
P2×P3	90.67	89.67	90.17	128.3	111.7	120.0	73.33	69.67	71.50
P2×P4	90.33	88.67	89.50	117.0	103.3	110.2	70.00	66.00	68.00
P2×P5	91.67	88.33	90.00	114.7	101.7	108.2	70.00	66.67	68.33
P2×P6	89.33	86.67	88.00	113.3	101.7	107.5	61.67	56.67	59.17
P3×P4	89.33	87.33	88.33	125.0	111.7	118.3	75.00	70.00	72.50
P3×P5	88.67	87.33	88.00	113.3	102.3	107.8	71.67	66.67	69.17
P3×P6	94.33	91.33	92.83	111.7	103.3	107.5	63.33	59.67	61.50
P4×P5	88.67	87.33	88.00	122.7	106.0	114.3	63.33	58.67	61.00
P4×P6	91.67	89.33	90.50	108.3	101.7	105.0	63.33	58.33	60.83
P5×P6	93.33	91.00	92.17	105.0	103.3	104.2	53.33	53.33	53.33
LSD _{0.05}	0.95	0.90	0.71	7.54	5.70	4.88	6.68	5.57	3.85
LSD _{0.01}	1.27	1.21	0.94	10.09	7.63	6.46	8.94	7.45	5.10
Genotypes	No. of basal branches plant ⁻¹			No. of capsules plant ⁻¹			1000-Seed weight (g)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
P1 (S2)	4.333	3.33	3.833	38.33	33.33	35.83	27.03	23.67	25.35
P2 (S5)	3.667	3.00	3.333	23.33	19.67	21.50	25.00	23.00	24.00
P3 (Escalina)	3.333	3.00	3.167	31.67	26.67	29.17	28.80	25.33	27.07
P4 (Bleinka)	4.667	3.33	4.000	33.33	28.33	30.83	32.73	30.23	31.48
P5 (Hermis)	4.333	3.67	4.000	23.33	19.67	21.50	30.30	28.50	29.40
P6 (Leflora)	4.333	3.33	3.833	38.33	33.33	35.83	38.90	26.77	32.83
P1×P2	5.333	4.33	4.833	35.00	33.33	34.17	28.20	25.67	26.93
P1×P3	5.333	4.67	5.000	28.33	27.33	27.83	34.03	31.63	32.83
P1×P4	4.333	4.00	4.167	25.00	21.33	23.17	26.70	23.93	25.32
P1×P5	4.667	4.00	4.333	48.33	43.33	45.83	33.63	31.00	32.32
P1×P6	3.333	3.00	3.167	36.67	31.67	34.17	28.70	25.67	27.18
P2×P3	5.667	4.67	5.167	38.33	33.33	35.83	34.67	32.33	33.50
P2×P4	6.333	5.00	5.667	55.33	48.33	51.83	34.63	31.33	32.98
P2×P5	4.667	4.00	4.333	45.00	40.33	42.67	33.97	31.33	32.65
P2×P6	5.333	4.33	4.833	41.67	36.67	39.17	32.23	30.00	31.12
P3×P4	5.000	4.33	4.667	51.67	46.67	49.17	31.00	28.67	29.83
P3×P5	4.000	3.33	3.667	31.67	26.67	29.17	21.93	19.77	20.85

Table 4: Continue

P3×P6	3.000	3.00	3.000	45.00	40.00	42.50	37.87	35.27	36.57
P4×P5	5.000	4.33	4.667	48.33	43.33	45.83	34.80	32.12	33.46
P4×P6	4.000	3.67	3.833	25.00	21.67	23.33	34.13	32.27	33.20
P5×P6	5.333	4.67	5.000	48.33	43.33	45.83	24.73	22.73	23.73
LSD _{0.05}	1.32	0.92	0.74	5.86	5.71	3.68	0.38	1.44	1.50
LSD _{0.01}	1.76	1.24	0.98	7.85	7.64	4.87	0.51	1.92	1.98
Seed yield plant ⁻¹ (g)				Straw yield plant ⁻¹ (g)					
Genotypes	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination			
P1 (S2)	6.15	5.10	5.62	21.69	19.49	20.59			
P2 (S5)	6.94	6.10	6.52	17.37	15.38	16.38			
P3 (Escalina)	6.51	5.36	5.93	12.66	11.27	11.96			
P4 (Bleinka)	7.34	7.38	7.36	13.81	12.61	13.21			
P5 (Hermis)	9.96	8.86	9.41	15.48	13.96	14.72			
P6 (Leflora)	7.78	6.32	7.05	14.99	14.28	14.63			
P1×P2	11.96	10.22	11.09	32.63	30.51	31.57			
P1×P3	11.54	10.03	10.79	24.69	22.35	23.52			
P1×P4	8.84	7.53	8.18	25.16	22.93	24.05			
P1×P5	11.66	10.20	10.93	28.67	26.52	27.60			
P1×P6	9.23	8.13	8.68	21.72	20.22	20.97			
P2×P3	14.24	12.80	13.52	21.65	20.21	20.93			
P2×P4	14.56	12.47	13.51	20.38	19.30	19.84			
P2×P5	10.81	9.40	10.11	18.50	17.43	17.96			
P2×P6	9.49	8.30	8.90	17.63	16.53	17.08			
P3×P4	9.83	8.15	8.99	24.36	22.32	23.34			
P3×P5	11.79	10.50	11.14	23.81	21.62	22.71			
P3×P6	13.15	11.23	12.19	25.86	24.08	24.97			
P4×P5	17.91	15.76	16.83	33.60	31.82	32.71			
P4×P6	9.30	10.28	9.79	15.81	14.42	15.12			
P5×P6	14.50	13.31	13.90	22.66	20.33	21.49			
LSD _{0.05}	0.17	0.48	0.49	1.12	0.94	0.71			
LSD _{0.01}	0.22	0.64	0.64	1.50	1.26	0.94			

Estimates of General Combining Ability effects (GCA): Data in Table 5 indicated that the parents P4 (Bleinka) and P5 (Hermis) showed high significant and negative GCA effects for days to the first flower in both seasons and their combined, indicating that these parents could be considered as good combiners for earliness. For plant height and technical length, P1 (S2) and P3 (Escalina) showed high significant and positive GCA effects in both seasons and their combined, indicating that these parents could be considered as good combiners for tallness of plant height and technical length. For No. of basal branches plant⁻¹, P2 (S5) gave significant and highly significant positive GCA effects in the first season and combined, respectively, indicating that this parent could be considered as good combiner for this trait. For No. of capsules plant⁻¹, P4 (Bleinka) and P6 (Leflora) showed significant positive GCA effects in combined data, indicating that these parents could be considered as good combiners for this trait. For 1000-seed weight, P4 (Bleinka) gave highly significant positive GCA effects in the two seasons and combined, indicating that this parent could be considered as good general combiner for increasing the weight of seeds. For seed yield plant⁻¹, P4 (Bleinka) and P5 (Hermis) showed high significant and positive GCA effects in both seasons and

Table 5: Estimates of GCA effects of six parents flax genotypes for studied the traits in the 1st and 2nd seasons and their combination

Traits	Days to first flower			Plant height (cm)			Technical length (cm)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Parents									
P1 (S2)	0.86**	1.29**	1.08**	4.69**	5.18**	4.94**	5.90**	5.69**	5.80**
P2 (S5)	0.03	0.04	0.03	-0.01	-0.86	-0.44	0.86	0.82	0.84
P3 (Escalina)	-0.14	-0.21*	-0.17*	3.03**	2.31**	2.67**	1.57*	1.49*	1.53**
P4 (Bleinka)	-1.26**	-1.08**	-1.17**	-1.51	-1.36*	-1.44*	-2.51**	-2.10**	-2.31**
P5 (Hermis)	-0.43**	-0.58**	-0.51**	0.28	-1.69*	-0.71	-1.14	-1.18	-1.16**
P6 (Leflora)	0.94**	0.54**	0.74**	-6.47**	-3.57**	-5.02**	-4.68**	-4.72**	-4.70**
LSD _{0.05} (gi) ¹	0.22	0.21	0.16	1.72	1.30	1.11	1.53	1.27	0.87
LSD _{0.01} (gi)	0.29	0.28	0.22	2.30	1.74	1.47	2.04	1.70	1.16
LSD _{0.05} (gi-gj) ²	0.34	0.32	0.25	2.67	2.02	1.72	2.36	1.97	1.37
LSD _{0.01} (gi-gj)	0.45	0.42	0.33	3.57	2.70	2.28	3.16	2.63	1.87
Traits	No. of basal branches plant ⁻¹			No. of capsules plant ⁻¹			1000-seed weight (g)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Parents									
P1 (S2)	-0.04	-0.42**	-0.04	-1.75*	-1.14	-1.44**	-1.58**	-1.48**	-1.53**
P2 (S5)	0.33*	0.17	0.25**	-0.25	-0.18	-0.22	-0.54**	-0.05	-0.29
P3 (Escalina)	-0.29	-0.13	-0.21**	-0.71	-0.68	-0.69	-0.11**	0.16	0.02
P4 (Bleinka)	0.25	0.13	0.19*	1.00	0.65	0.83*	1.09**	1.46**	1.28**
P5 (Hermis)	0.04	0.08	0.06	0.54	0.44	0.49	-1.04**	-0.39*	-0.72**
P6 (Leflora)	-0.29	-0.21*	0.25**	1.17	0.90	1.03*	2.18**	0.30	1.24**
LSD _{0.05} (gi) ¹	0.30	0.21	0.16	1.33	1.29	0.83	0.08	0.32	0.34
LSD _{0.01} (gi)	0.40	0.28	0.21	1.78	1.73	1.10	0.11	0.43	0.45
LSD _{0.05} (gi - gj) ²	0.47	0.33	0.26	2.08	2.02	1.31	0.14	0.51	0.54
LSD _{0.01} (gi - gj)	0.62	0.44	0.34	2.79	2.70	1.73	0.19	0.68	0.73
Traits	Seed yield plant ⁻¹ (g)			Straw yield plant ⁻¹ (g)					
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination			
Parents									
P1 (S2)	-1.12**	-1.19**	-1.15**	3.15**	2.79**	2.79**			
P2 (S5)	0.06**	-0.05	0.002	-0.69**	-0.56**	-0.62**			
P3 (Escalina)	-0.12**	-0.30**	-0.21**	-0.67**	-0.76**	-0.71**			
P4 (Bleinka)	0.08**	0.39**	0.24**	-0.51**	-0.40**	-0.46**			
P5 (Hermis)	1.51**	1.38**	1.45**	0.89**	0.80**	0.85**			
P6 (Leflora)	-0.41**	-0.24**	-0.32**	-2.17**	-1.88**	-2.03**			
LSD _{0.05} (gi)	0.04	0.11	0.11	0.25	0.21	0.16			
LSD _{0.01} (gi)	0.05	0.15	0.15	0.34	0.29	0.22			
LSD _{0.05} (gi-gj) ²	0.06	0.17	0.17	0.39	0.33	0.25			
LSD _{0.01} (gi-gj)	0.08	0.22	0.23	0.53	0.45	0.33			

*, **Significant at 0.05 and 0.01 level of probability, respectively, ¹Least significant difference for a GCA effect, ²Least significant difference for the difference between estimates of GCA effects

their combined, indicating that these parents could be considered as good combiners for increasing seed yield. While for straw yield plant⁻¹, P1 (S2) and P5 (Hermis) showed high significant and positive GCA effects in both seasons and their combined, indicating that these parents could be considered as good combiners for increasing straw yield. So, these parents could be used as parents for the development of desirable hybrids. These results are in agreement with those obtained by Abo El-Zahab and Abo-Kaied (2000), Abo-Kaied (2002), Zahana (2006), Abo-Kaied *et al.* (2007),

Table 6: Estimates of SCA effects of 15 F₁ single crosses flax genotypes for the studied traits in 1st and 2nd seasons and their combination

Traits	Days to first flower			Plant height (cm)			Technical length (cm)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Crosses									
P1×P2	0.95**	1.57**	1.26**	-2.32	0.65	-0.83	-4.69*	-6.58**	-5.63**
P1×P3	-3.21**	-3.18**	-3.20**	3.98	4.15*	4.06**	1.94	1.76	1.85
P1×P4	1.91**	1.70**	1.80**	7.52**	9.48**	8.50**	5.02*	5.67**	5.35**
P1×P5	0.08	-0.14	-0.03	4.06	3.15	3.60*	4.65*	4.42*	4.54**
P1×P6	0.04	0.07	0.05	7.48**	0.02	3.75*	6.52**	6.30**	6.41**
P2×P3	-1.05**	0.07	-0.49*	9.35**	5.19**	7.27**	3.65	4.63*	4.14**
P2×P4	-0.26	-0.05	-0.16	2.56	0.52	1.54	4.40*	4.55*	4.47**
P2×P5	0.24	-0.89**	-0.32	-1.57	-0.81	-1.19	3.02	4.30*	3.66**
P2×P6	-3.46**	-3.68**	-3.57**	3.85	1.07	2.46	-1.77	-2.16	-1.96
P3×P4	-1.09**	-1.14**	-1.11**	7.52**	5.69**	6.60**	8.69**	7.88**	8.29**
P3×P5	-2.59**	-1.64**	-2.11**	-5.94*	-3.31	-4.63**	3.98	3.63*	3.81**
P3×P6	1.70**	1.24**	1.47**	-0.86	-0.44	-0.65	-0.81	0.17	-0.32
P4×P5	-1.46**	-0.76**	-1.11**	7.94**	4.02*	5.98**	-0.27	-0.79	-0.53
P4×P6	0.16	0.11	0.14	0.35	1.57	0.96	3.27	2.42	2.85*
P5×P6	0.99**	1.28**	1.14**	-4.77*	3.57	-0.60	-8.10**	-6.83**	-7.46**
LSD _{0.05}	0.59	0.57	0.44	4.73	3.58	3.05	4.18	3.50	2.42
LSD _{0.01} (Sij)	0.78	0.76	0.58	6.33	4.79	4.04	5.60	4.68	3.20
LSD _{0.05} (Sij-Sik) ²	0.89	0.85	0.67	7.05	5.34	4.56	6.24	5.21	3.61
LSD _{0.01} (Sij - Sik)	1.19	1.14	0.89	9.44	7.14	6.04	8.36	6.98	4.92
LSD _{0.05} (Sij - Skl) ³	0.83	0.79	0.61	6.53	4.93	4.22	5.78	4.83	3.33
LSD _{0.01} (Sij-Skl)	1.11	1.05	0.81	8.73	6.60	5.59	7.73	6.46	4.41
Traits	No. of basal branches plant ⁻¹			No. of capsules plant ⁻¹			1000-seed weight (g)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
Crosses									
P1×P2	0.47	0.35	0.41	-0.71	1.40	0.34	-0.82**	-0.96*	-0.89
P1×P3	1.10*	0.98**	1.04**	-6.92**	-4.10*	-5.51**	4.59**	4.80**	4.69**
P1×P4	-0.45	0.06	-0.19	-11.96**	-11.43**	-11.70**	-3.95**	-4.20**	-4.08**
P1×P5	0.10	0.10	0.10	11.83**	10.77**	11.30**	5.12**	4.72**	4.92**
P1×P6	-0.90*	-0.61*	-0.76**	-0.46	-1.35	-0.91	-3.04**	-1.31**	-2.17**
P2×P3	1.05*	0.77*	0.91**	1.58	0.94	1.26	4.17**	4.07**	4.12**
P2×P4	1.18**	0.85**	1.01**	16.87**	14.61**	15.74**	2.94**	1.77**	2.35**
P2×P5	-0.28	-0.11	-0.19	6.99**	6.82**	6.90**	4.40**	3.62**	4.01**
P2×P6	0.72	0.52	0.62**	3.04	2.69	2.86*	-0.55**	1.60**	0.52
P3×P4	0.47	0.48	0.47*	13.66**	13.44**	13.55**	-1.12**	-1.11*	-1.12*
P3×P5	-0.32	-0.48	-0.40	-5.88**	-6.35**	-6.12**	-8.06**	-8.15**	-8.11**
P3×P6	-0.99*	-0.52	-0.76**	6.83**	6.52**	6.68**	4.65**	6.66**	5.66**
P4×P5	0.14	0.27	0.20	9.08**	8.98**	9.03**	3.61**	2.89**	3.25**
P4×P6	-0.53	-0.11	-0.32	-14.88**	-13.14**	-14.01**	-0.29*	2.35**	1.03*
P5×P6	1.01**	0.93**	0.97**	8.91**	8.73**	8.82**	-7.55**	-5.33**	-6.44**
LSD _{0.05} (Sij) ¹	0.83	0.59	0.46	3.68	3.58	2.30	0.24	0.91	0.93
LSD _{0.01} (Sij)	1.11	0.78	0.60	4.92	4.79	3.05	0.32	1.22	1.23
LSD _{0.05} (Sij-Sik) ²	1.23	0.87	0.69	5.48	5.34	3.43	0.36	1.33	1.41
LSD _{0.01} (Sij-Sik)	1.65	1.16	0.92	7.33	7.14	4.54	0.49	1.78	1.92
LSD _{0.05} (Sij-Skl) ³	1.13	0.81	0.63	5.07	4.95	3.19	0.32	1.25	1.29
LSD _{0.01} (Sij-Skl)	1.51	1.08	0.84	6.79	6.62	4.23	0.43	1.68	1.71

Table 6: Continue

Traits	Seed yield plant ⁻¹ (g)			Straw yield plant ⁻¹ (g)		
	1 st season	2 nd season	Combination	1 st season	2 nd season	Combination
P1×P2	2.38**	2.06**	2.22**	8.59**	8.39**	8.49**
P1×P3	2.14**	2.12**	2.13**	0.63	0.44	0.53*
P1×P4	-0.76**	-1.07**	-0.92**	0.95**	0.66*	0.80**
P1×P5	0.63**	0.60**	0.61**	3.05**	3.04**	3.05**
P1×P6	0.12*	0.16	0.14	-0.84*	-0.58	-0.71**
P2×P3	3.66**	3.75**	3.71**	1.43**	1.64**	1.54**
P2×P4	3.79**	2.73**	3.26**	0.01	0.37	0.19
P2×P5	-1.40**	-1.33**	-1.37**	-3.28**	-2.70**	-2.99**
P2×P6	-0.80**	-0.81**	-0.80**	-1.09**	-0.91**	-1.00**
P3×P4	-0.79**	-1.35**	-1.06**	3.96**	3.59**	3.78**
P3×P5	-0.25**	0.01	-0.12	2.01**	1.69**	1.85**
P3×P6	3.03**	2.37**	2.70**	7.13**	6.84**	6.98**
P4×P5	5.68**	4.58**	5.13**	11.64**	11.53**	11.58**
P4×P6	-1.01**	0.73**	-0.14	-3.08**	-3.19**	-3.13**
P5×P6	2.75**	2.76**	2.76**	2.36**	1.52**	1.94**
LSD _{0.05} (Sij) ¹	0.10	0.30	0.30	0.71	0.59	0.46
LSD _{0.01} (Sij)	0.14	0.41	0.39	0.95	0.78	0.60
LSD _{0.05} (Sij-Sik) ²	0.15	0.44	0.46	1.05	0.89	0.67
LSD _{0.01} (Sij-Sik)	0.20	0.59	0.60	1.41	1.19	0.89
LSD _{0.05} (Sij-Skl) ³	0.14	0.40	0.42	0.97	0.81	0.61
LSD _{0.01} (Sij-Skl)	0.19	0.54	0.55	1.30	1.08	0.81

*,**Significant at 0.05 and 0.01 level of probability, respectively, ¹Least significant difference for a SCA effect, ²Least significant difference for the difference between two SCA effects for a common parent, ³Least significant difference for the difference between two SCA effects for a non-common parent

El-Kady and Abo-Kaied (2009), El-Kady and Abo-Kaied (2010) and Mishra *et al.* (2013), where they observed significant and positive and negative GCA effects for these traits in their respective studies.

Once the best combiners are identified, they can be crossed together to obtain the promising hybrid combinations. In recurrent selection schemes, parents possessing high combining ability can be intercrossed to accumulate desirable alleles within base populations (Christie and Shattuck, 1992).

Estimates of Specific Combining Ability effects (SCA): Data in Table 6 indicated that, five crosses i.e., P1×P3, P2×P6, P3×P4, P3×P5 and P4×P5 showed high significant and negative SCA effects (desirable direction) for days to first flower trait in both seasons and their combined, indicating that these crosses were the best combinations for earliness. For plant height, four crosses viz., P1×P4, P2×P3, P3×P4 and P4×P5 showed significant or highly significant and positive SCA effects (desirable direction) in both seasons and their combined indicating that these crosses were the best combinations for tallness. For technical length, crosses P1×P4, P1×P5, P1×P6, P2×P4 and P3×P4 gave significant or highly significant and positive SCA effects in both seasons and their combined, indicating that these crosses were the best combinations for this trait. For No. of basal branches plant⁻¹, four crosses i.e., P1×P3, P2×P3, P2×P4 and P5×P6 showed significant or highly significant and positive SCA effects in both seasons and their combined indicating that these

crosses were the best combinations for this trait. For No. of capsules plant⁻¹, seven crosses i.e., P1×P5, P2×P4, P2×P5, P3×P4, P3×P6, P4×P5 and P5×P6 gave highly significant and positive SCA effects in both seasons and their combined indicating that these crosses were the best combinations for this trait. For 1000-seed weight, seven crosses viz., P1×P3, P1×P5, P2×P3, P2×P4, P2×P5, P3×P6 and P4×P5 gave highly significant and positive SCA effects in both seasons and their combined indicating that these crosses were the best combinations for increasing the weight of seeds. For seed yield plant⁻¹, eight crosses i.e., P1×P2, P1×P3, P1×P5, P2×P3, P2×P4, P3×P6, P4×P5 and P5×P6 showed highly significant and positive SCA effects in both seasons and their combined indicating that these crosses were the best combinations for increasing seed yield. For straw yield plant⁻¹, nine crosses viz., P1×P2, P1×P4, P1×P5, P2×P3, P3×P4, P3×P5, P3×P6, P4×P5 and P5×P6 showed significant or highly significant and positive SCA effects in both seasons and their combined, indicating that these crosses were the best combinations for increasing straw yield. It is worthy to note that most of superior F₁ crosses in their SCA effects for seed and straw yields and most of yield components traits include at least one of their parents of high GCA effects for the same traits. These results are in general agreement with those previously reported by Abo El-Zahab and Abo-Kaied (2000), Abo-Kaied (2002), Zahana (2006), Abo-Kaied *et al.* (2007), El-Kady and Abo-Kaied (2009), El-Kady and Abo-Kaied (2010) and Mishra *et al.* (2013), where they observed significant positive and negative SCA effects for these traits in their respective studies.

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