Combining ability and heterosis for flax straw and seed yield components

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Abstract

Fifteen crosses generated from six diverse parents in half diallel mating design were evaluated in 2020/2021 season to estimate combining ability and heterosis in flax for improving yield and its various components. The analysis of data showed that variance due to genotypes, parents and crosses were highly significant, indicating sufficient variability existed in populations. Variance of parents vs. crosses as an indication to average heterosis was significant for all the studied traits except technical length and fibre percentage traits. The analysis for combining ability illustrated significant variance due to both general combining ability (GCA) and specific combining ability (SCA) for all the studied traits, indicating presence of both additive and non-additive gene actions in the expression for these traits. GCA/SCA ratio was more than unity for all studied traits except number of basal branches and number of capsules/plant traits, indicating that additive gene effects were more important than non-additive gene effects for control the inheritance of these traits. S.620/1/3 (P1) was good combiner for all studied traits and Sakha 3 (P2) and Belinka (P3) were good combiners for most of the studied traits. Six crosses were the good combination for the most of the studied traits and particularly three crosses (S. 620/1/3 x Sakha 3, S. 620/1/3 x Belinka and S. 620/1/3 x Sozana) exhibited positive significant heterosis for most of the studied traits. Therefore, good combiners and best crosses combinations can be used for improvement of yield and their components in the programs of flax breeding.

Key words: Flax, combining ability, heterosis, gene action

INTRODUCTION

Flax is fibre crop producing fibre from the plant stem and oil from seeds. Flax is cultivated in some countries for fibre only and in other countries for seed oil only. In Egypt, three types of flax coexist namely a fibre type, a seed oil type and a dual purpose type. The flax fibre is natural and is industrial processed for textiles production due to theirs fibre quality. Flax seed is commercially planted for seed production which is used to extract oil and a high protein livestock feed (Sankari, 2000; Kurt and Bazkurt 2006). In seeds of flax, there are very important compounds which have anticancer properties for human such as lignans (Westcott and Muri, 2003), acting as an antioxidant agent. Flax seed of provides up to 800 times higher lignans content than seeds of other crops (Jhala and Hall, 2010). Singh and Marker (2006) stated that the highly valued omega 3 fatty acid in flax oil is considered important to aid in reducing cholesterol.

Flax is a self-pollinated crop which is the only species in linaceae family with economic values (Tadesse *et al.*, 2010). Its genetic improvement need to be carried out through conventional breeding methods of selection and hybridization. Flax breeders need continually to improve yields of straw and seeds productivity alongside with their components by genetic improvement in breeding programs. The success of any breeding program depends on the choice of a suitable breeding methods and better genotypes which have high inheritance ability for all desirable traits to pass on progenies in their crosses. Hybridization techniques provide us with information regarding combining ability and nature of gene action. It is essential to determine the magnitude and inheritance of the components of genetic variance to understand the type of gene action which control the target traits. Diallel crosses have been utilized for estimation of the combining ability of parents and cross combinations. Combining ability helps the breeder to study and compare the better performance of the new genotypes in the combination of hybrids. Mahto and Rahman (1998) and Kumar *et al.* (2000) reported that combining ability analysis is crucial to obtain better parents with informations of nature and magnitude of gene effects which control yield traits of economic importance. The frequency of heterotic hybrids is higher for good general combining parents than for weak combining parents (Sahu *et al.*, 2013). Extremely important numbers for both combining capabilities were obtained by Mishra *et al.* (2013). Combining ability and gene action for desirable flax traits were previously estimated (Singh *et al.*, (2009); Pali and Mehta 2014; Kumar and Paul, 2015; Kumar *et al.* 2016; Singh *et al.* 2016; Mahawar *et al.*, 2021; Swetha *et al.*, 2021). Hybridization of two lines or genotypes produced superior F_1 hybrids which can raise the yield in this crop, this superiority referee to heterosis. Development of superior hybrids need to evaluate viable promising lines and their cross combinations for yield and as well as its components (Singh *et al.*, 2006). It is essential to have detailed information about the desirable hybrid combinations in any breeding program which can reflect a high degree of heterotic response for yield improvement and also other characteristics of flax. The target of heterosis analysis is to know the best combination of hybrids which give

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a high degree of heterobeltiosis and characterization of crosses for the purpose of economic exploitation (Sharma *et al*., 2005; Kumar *et al*. 2013a; Kumar *et al*. 2013b; Reddy *et al*.(2013; Pali and Mehta 2014; Kumar and Paul 2015) Kumar *et al*. 2016; Singh *et al*. 2016). The main objective of this investigation is to (1) determine the superior parents and cross combinations by using diallel cross system and (2) estimate combining ability and mode of gene action and heterosis in terms of yield and its components of six flax genotypes and their 15 F_1 hybrids to use in hybridization breeding program for improving flax yield.

MATERIALS AND METHODS

In the present study, six genotypes were evaluated to determine which one has the high ability for inheritance of all desirable traits to the progenies in their crosses in order to used them in hybridization breeding programs to improve flax traits. The genetic materials used for this investigation used six flax genotypes S. 620/1/3, Sakha 3, Belinka, Sozana, Beraton, and Gowhar which were crossed in all possible combinations using a diallel mating design (excluding reciprocals) to obtain 15 F_1 crosses of flax during 2019/2020 season at Giza Agricultural Research station, Agriculture Research Center, Egypt. The description of the genotypes is shown in Table 1.

In 2020/2021 season, 21 entries (6 parents and 15 F_1 crosses) were assessed in Ismailia Research Station, Ismailia Governorate (the soil is sandy, organic matter of 0.53%, available nitrogen in the soil was 7.19 ppm, EC. 0.15 and the value of pH was 7.44).

Three replications used to evaluate the experimental materials thorough a randomized complete block design. Each experimental plot included ten rows. Rows were three meters long and 20 cm apart, each genotype was planted in one row the distance between plants in each rows was 5 cm. Fertilization, weed control and other agronomic practices were done according recommendations for flax production.

The observations were noted on ten randomly chosen plants from each replication on the following traits (1) straw yield/plant (g), (2) plant height (cm), (3) technical stem length (cm), (4) number of basal branches/plant, (5) seed yield/plant (g), (6) number of capsules/plant, (7) number of seeds/capsule, (8) 1000 – seed weight (g) and (9) fibre percentage.

Statistical analysis

Griffing's (1956) method of diallel analysis provides important information on the nature and magnitude of the gene effects that contributes to select good parents for hybridization and producing desirable and good segregants to enhance and improve quantitative traits. Gene action is measured in terms of components of genetic variance or combining general ability variances effects (GCA) and specific combining ability variances (SCA) effects that were calculated using Griffing's (1956) Method 2 Model 1 for diallel analysis. The ratio of GCA/SCA was determined to evaluate the gene action in the inheritance of the studied traits. If the ratio is more than unity this means that the additive gene effects were more important than non-additive gene effects in the inheritance of the studied traits.

Effect of heterosis

Better-parent (B.P.) heterosis was calculated according to the following formula given by Bhatt (1971):

$$\text{Better parent heterosis} = \frac{\bar{F}_1 - \overline{B.P.}}{\overline{B.P.}} x100$$

Where:

$\bar{F}_1$= the mean of the first generation

$\overline{B.P.}$= the mean of the better parent.

RESULTS AND DISCUSSION

In this investigation, mean squares of the analysis of variance for nine studied traits of 21 flax genotypes (6 parents and 15 F_1 crosses) are shown in Table 2.

Results indicated that the analysis of variance of genotypes, parents and crosses were highly significant for all the studied traits indicating that all entries (parents and crosses) showed wide genetic variability and the differences among all genotypes were significant. From the results in Table 2, significant mean squares due to parents vs crosses (P.vs. C.) are found for all the studied traits except technical length and fibre percentage traits. Variance of P. vs. C. is an indication of average heterosis thus, all the studied attributes except technical length and fibre % showed average heterosis among crosses. Mean squares of general combining ability (GCA) and specific combining ability (SCA) were highly significant for all studied traits (Table 2). Therefore, it appeared that the inheritance of these studied traits was controlled by

Table 1: The description and origin of six flax genotypes

Genotypes	Type	Pedigree	Origin
S.620/1/3	Fibre	S.422 x Giza 7	Local Strain
Sakha 3	Fibre	I. 2569 x Belinka	Local cultivar
Belinka	Fibre	Introduction from Netherlands	Netherlands
Sozana	Fibre	Introduction from Belgium	Belgium
Beraton2	Fibre	Introduction from Holland	Holland
Gawhar	Oil	Introduction from India	India

both additive and non-additive gene effects and the two type of gene action were very important for these traits. Comparable results were obtained by Bhateria *et al.* (2006), Mishra *et al.* (2013), Pali and Mehta (2014), Singh *et al.* (2016), Nirala *et al.* (2018), Swetha *et al.* (2021) and Prakashsinh *et al.* (2023).

The GCA variance was higher than the SCA variance and the ratio of GCA/SCA was greater than unity for all the studied attributes, except for the number of basal branches and number of capsules/plant traits (Table 2). Thus, results indicate that additive gene effects were more important than non-additive gene effects for the control of the inheritance of these traits. This type of gene action (additive effect) indicate that the selection should be effective in early segregation generations without much increase in the cost of production. Singh *et al.* (2008) revealed that the additive gene impact was more important than non-additive gene effect. Nirala *et al.* (2018) reported that additive genetic variance exceeded non-additive genetic variance for flax plant height and number of capsules per plant.

Combining ability effects

General combining ability (GCA) helps in the selection of parents which have high ability for inheritance of all desirable traits to the progenies in their crosses and use these parents in the hybridization programs to improve the target traits. General combining ability (GCA) effects of six parents in diallel mating design are shown in Table 3.

Results revealed that the strain 620/1/3 (P_1) showed high and positive general combining ability effects for all the studied traits, suggesting that this strain must be used as a good general combiner for improving these traits in flax breeding programs. The parent 2 (Sakha 3) exhibited significant and positive GCA effects for plant height, technical length, fibre percentage and number of seeds/capsule traits. Thus Sakha 3 (P_2) is considered as better combiner for these four traits. Belinka (P_3) was good general combiner for straw yield/plant, plant height, technical length, number of basal branches and number of capsules/plant traits. The fourth parent Sozana showed positive significant GCA effects for straw yield/plant, fibre percentage and number of seeds/capsules traits, therefore considered as a good combiner for these traits. Beraton 2 (P_5) and Gawhar (P_6) were good combiners for 1000-seed weight trait. In general and amongst the six parents, the strain 620/1/3 was the best combiner for improving straw, seed yields and its attributes. The two parents Sakha 3 (P_2) and Belinka (P_3) were the good combiners for plant height and technical length traits. Therefore, the three parents S.620/1/3 (P_1), Sakha 3 (P_2) and Belinka (P_3) with positive significant general combining ability could be used with flax hybridization program for improving the desirable traits.

Specific combining ability (SCA) effects

Gene action refers to the behavior or mode of expression of genes in a genetic population. General combining ability refers to additive gene action but specific combining ability refers to non-additive gene action which included dominance and epistatic effects. The crosses with high and positive specific combining ability were very important for improving the desirable traits and

Table 2: Mean squares from analysis of variance for half diallel crosses of six parents of flax for nine studied traits

SOV	df	Straw yield/ plant (g)	Plant height (cm)	Technical length (cm)	Number of basal branches	Fiber %	Seed yield/ plant (g)	No. of capsules/ plant	No. of seeds/ capsule	1000 seed weight (g)
Reps.	2	0.0255	15.664*	8.849	0.021	0.006	0.052	46.892**	0.174	0.006
Genotypes	20	2.6303**	264.404**	194.833**	0.531**	4.134**	1.740**	157.372**	1.935**	3.219**
Parents(P)	5	1.0500**	147.073**	244.226**	0.383**	5.148**	0.686**	78.779**	1.524**	3.849**
Crosses(C)	14	1.8756**	287.551**	191.054**	0.613**	4.065**	1.325**	142.013**	2.159**	1.013**
P.vs.C.	1	21.0981**	526.994**	0.785	0.125*	0.025	12.823**	765.361**	0.843*	30.956**
Error	40	0.0667	4.423	5.919	0.025	0.008	0.048	6.112	0.117	0.009
GCA	5	1.213**	205.64**	165.349**	0.159**	4.393**	0.821**	52.173**	0.702**	1.559**
SCA	15	0.765**	48.97**	31.476**	0.183**	0.373**	0.499**	52.552**	0.626**	0.911**
Error	40	0.022	1.474	1.973	0.0084	0.0029	0.0161	2.0373	0.0392	0.0033
GCA/SCA		1.587	4.199	5.253	0.869	11.778	1.645	0.993	1.121	1.711

** and ** = significant at 0.05 and 0.01 levels, respectively.*

Table 3: Estimates of general combining ability effects for different traits studied in flax

Parents	Straw yield/ plant (g)	Plant height (cm)	Technical length (cm)	Number of basal branches	Fiber %	Seed yield/ plant (g)	No. of capsules/ plant	No. of seeds/ capsule	1000 seed weight (g)
S.620/1/3(P1)	0.5486**	6.1429**	4.0504**	0.1340**	0.6789**	0.5814**	3.2312**	0.3657**	0.5278**
Sakha 3 (P2)	-0.0706	3.0242**	2.8054**	0.0282	0.7547**	-0.2040**	-2.3871**	0.2403**	-0.4239**
Belinka(P3)	0.1194*	2.9008**	3.9883**	0.0753*	0.0022	-0.0232	2.1542**	-1.1214	-0.0618**
Sozana (P4)	0.1653**	-1.4033**	-0.5283	0.0386	0.2614**	0.0601	-0.4967	0.1578*	-0.5597**
Beraton (P5)	-0.1368**	-2.6496**	-2.9588**	-0.2714**	-0.5274**	-0.0599	0.8050	-0.3443**	0.0786**
Gawhar (P6)	-0.6260**	-8.0150**	-7.3571**	0.0047	-1.1699**	-0.3544**	-3.3067**	-0.2981**	0.4390**
L.SD 5%	0.135	1.097	1.270	0.083	0.048	0.114	1.290	0.179	0.052

related to heterosis. Specific combining ability impacts in 15 F_1 hybrids for nine traits of flax are showed in table 4. The results showed that eight crosses exhibited specific combining ability for straw yield/plant trait (P_1 x P_3, P_1 x P_4, P_1 x P_5, P_2 x P_3, P_2 x P_4, P_2 x P_6, P_3 x P_4 and P_3 x P_5 Crosses). Regarding plant height trait, seven crosses (P_1 x P_2, P_1 x P_3, P_1 x P_4, P_2 x P_3, P_2 x P_4, P_3 x P_6 and P_5 x P_6) showed significant and positive specific combining ability impacts. Six crosses (P_1x P_2, P_1 x P_3, P_2 x P_3, P_2 x P_6, P_3 x P_6 and P_5 x P_6) were found to be the best specific combinations for technical length trait. Thus, these crosses were the best for high technical length. Concerning the number of basal branches trait, four crosses (P_1 x P_4, P_1 x P_5, P_2 x P_6 and P_3 x P_4) exhibited positive significant SCA effects and four crosses (P_3 x P_6, P_4 x P_5, P_4 x P_6 and P_5 x P_6) showed negative significant SCA effects and would be good combinations for non-branching trait which is very important for fibre quality trait. With regard to fibre percentage trait, six crosses (P_1 x P_3, P_1 x P_4, P_2 x P_3, P_2 x P_4, P_4 x P_6 and P_5 x P_6) recorded positive significant SCA effects, indicating that these crosses were the good combinations for fibre percentage trait, thus, we may use these crosses for improving fibre percentage trait. For seed yield/plant trait, ten crosses (P_1 x P_2, P_1 x P_4, P_1 x P_5, P_1 x P_6, P_2 x P_4, P_2 x P_5, P_2 x P_6, P_3 x P_4, P_3 x P_5 and P_4 x P_5) were the best combinations for improving seed yield/plant which gave positive significant SCA effects. Among 15 crosses, eight crosses (P_1 x P_2, P_1 x P_3, P_1 x P_4, P_1 x P_5, P_2 x P_4, P_2 x P_6, P_3 x P_4 and P_3 x P_5) showed positive significant SCA effects for number of capsules/ plant trait. Regarding number of seeds/capsule trait six crosses (P_1 x P_2, P_1 x P_3, P_1 x P_4, P_2 x P_6, P_4 x P_5 and P_4 x P_6) recorded significant and positive SCA impacts.

Eleven crosses (P_1 x P_3, P_1 x P_5, P_2 x P_3, P_2 x P_4, P_2 x P_5, P_3 x P_4, P_3 x P_5, P_3 x P_6, P_4 x P_5, P_4 x P_6 and P_5 x P_6) exhibited positive significant SCA effects for 1000-seeds weight trait. These good combinations of the nine traits considered very important in flax breeding programs for improving straw and seed yields.

Mean performance of parents and crosses

Mean performance of six parents and 15 crosses for nine flax traits are stated in Table 5. The best parent S. 620/1/3 recorded the highest values of straw yield/plant, plant height, technical length, fibre percentage and seed yield/plant traits and recorded the less number of basal branches. This parent is the best general combiner for all the studied traits. The parent Sakha 3 recorded high values of plant height and fibre percentage. The parent Beraton 2 ranked the second in straw yield/plant and number of capsules/plant traits, while Sozana ranked the second in technical length and number of seeds/capsule. From Table 5, data illustrated that the highest mean value of the good three crosses for nine studied traits were as follows: with regard to straw yield/plant, the good three crosses which recorded the highest values of this trait were P_1 x P_4, P_1 x P_3 and P_1 x P_5. For plant height, trait the crosses P_1 x P_3, P_1 x P_2 and P_2 x P_3 showed the highest plant height. From the 15 F_1 crosses, the three crosses P_1 x P_2, P_1 x P_3 and P_2 x P_3 recorded the highest values of technical length trait.

For low number of basal branches trait, the best three crosses were P_1x P_5, P_2 x P_6 and P_1 x P_2. For fibre percentage the good crosses were P_2 x P_4, P_2 x P_3 and P_1 x P_3. Regarding seed yield/plant trait, the crosses P_1 x p_5, P_1 x P_6 and P_1 x P_4 exhibited the highest values of seed yield/plant. The best three crosses for number of capsules/plant trait were P_1 x P_3, P_3 x P_5 and P_1 x P_4 while, for number of seeds/capsule they were P_2 x P_6, P_1 x P_2 and P_1 x P_4 crosses. For low 1000-seed weight, the three crosses P_2 x P_4, P_2 x P_3 and P_1 x P_4 were the good crosses. In general, the cross P_1 x P_4 ranked first for straw yield/ plant trait and ranked third for seed yield/plant, number of capsules/plant and number of seeds/capsule. The cross P_1 x P_3 ranked first in plant height trait and number of capsules/plant and second in straw yield/plant and technical length traits. Based on these results, the best crosses were P_1 x P_2, P_1 x P_3, P_1 x P_4, P_1 x P_5, P_2 x P_3 and P_2 x P_4 thus it could be concluded that these six crosses would

Table 4: Specific combining ability effects for nine traits studied in flax crosses

Crosses	Straw yield/ plant (g)	Plant height (cm)	Technical length (cm)	Number of basal branches	Fiber %	Seed yield/ plant (g)	No. of capsules/ plant	No. of seeds/ capsule	1000 seed weight (g)
P1 x P2	0.1942	6.6843**	3.5951**	0.2124*	0.0151	0.4937**	7.2754**	0.4986**	0.0550
P1 x P3	0.5975**	7.3243**	3.0422*	0.1620	0.8176**	0.0929	4.6308**	0.5003**	0.2996**
P1 x P4	0.8983**	9.3118**	-0.1245	0.1286	0.4118**	0.3596**	7.0449**	0.4678**	-0.1192**
P1 x P5	0.7838**	-0.5019	-1.6674	0.7820**	-0.4961**	0.5962**	5.4766**	-0.0201	0.6225**
P1 x P6	-0.0771	-4.9232**	-6.4190**	0.1286	-0.1503**	0.8208**	1.5183	-0.5597**	0.0088
P2 x P3	0.5400**	8.4798**	3.2705*	0.1445	0.7585**	-0.5917**	0.7858	-0.4710*	0.1712**
P2 x P4	0.8908**	4.5073**	1.5772	-0.0189	0.5893**	0.2850*	3.3366*	-1.8668**	0.6258**
P2 x P5	-0.1337	-6.9098**	-6.2057**	0.0278	-0.0186	0.4317**	0.7049	-0.6047**	0.7775**
P2 x P6	1.3221**	-1.3944	5.2560**	0.3845**	-0.3628**	0.6429**	3.9633**	1.1824**	-0.0896
P3 x P4	0.5242**	0.1373	-0.6157	0.2307**	-0.8349**	0.2542*	6.7620**	-0.7551**	0.5104**
P3 x P5	0.4363**	1.9702	-0.0720	0.0707	-0.8095**	0.9542**	6.8637**	0.2736	0.5721**
P3 x P6	0.2488	2.9823**	3.2130*	-0.3960**	-0.6470**	-0.2046	-8.6913**	-0.2293	1.1550**
P4 x P5	-0.0196	-5.7957**	-6.6753**	-0.6026**	-0.3520**	0.4175**	0.1379	0.5811**	0.8833**
P4 x P6	-0.3438*	-4.0569**	-8.9503**	-0.2326**	0.4339**	0.1954	0.9729	0.5949**	1.0696**
P5 x P6	-0.3717**	9.6227**	9.7168**	-0.5993**	0.8360**	-0.4679**	-7.7155**	-0.6897**	0.1079*
LSD 5%	0.370	3.010	3.486	0.228	0.133	0.315	3.540	0.491	0.143

be a valuable in flax breeding program to improve straw, seed yields and its components. These crosses included one or two general combiners parents which is very important in improving flax breeding programs.

Heterosis effects

Hybridization of two genotypes produce superior crosses which can raise the yield, this superiority refers to heterosis. The target of heterosis analysis is to find the best combinations of hybrids with a high degree of heterobltiosis and commercial exploitation. The heterosis is essential for increasing the productivity of crops without much increase in the cost of production. Results of heterosis percentage relative to better parent (BP) for straw, seed yields and their components are showed in Table 6. From the 15F$_1$ crosses, three crosses P$_1$ x P$_2$, P$_1$ x P$_3$ and P$_1$ x P$_4$ exhibited positive significant heterosis relative to better parent for straw yield/plant, plant height, fibre percentage, seed yield/plant and number of capsules/ plant traits. Therefore, these three crosses were very important for improving straw and seed yield/plant in flax breeding programs. Percentage of heterosis relative to better parent were significant and positive in eleven and eight crosses in straw yield/plant and plant height traits, respectively. Only one crosses P$_2$ x P$_3$ showed positive significant heterosis for technical length trait. The low number of basal branches was a desirable trait. Thus, negative heterosis was important for this trait. Five crosses showed negative heterosis for number of

Table 5: Mean performance of six parents and 15 F$_1$ Crosses for nine studied traits in flax

Genotypes	Straw yield/ plant (g)	Plant height (cm)	Technical length (cm)	Number of basal branches	Fiber %	Seed yield/ plant (g)	No. of capsules / plant	No. of seeds/ capsule	1000 seed weight (g)
P1 (S.620/1/3)	4.73	80.92	51.22	1.55	19.15	3.33	48.59	8.25	8.32
P2 (Sakha 3)	3.28	77.94	44.20	1.67	19.11	2.31	42.29	9.07	6.08
P3 (Belinka)	3.89	72.93	45.89	2.03	18.45	3.05	54.23	8.06	6.22
P4 (Sozana)	4.18	72.72	48.67	2.31	18.49	2.71	44.78	8.76	5.09
P5 (Beraton)	4.21	73.09	38.87	1.60	17.46	2.26	53.98	7.50	6.38
P6 (Gawhar)	3.18	60.43	25.50	2.33	15.70	2.15	53.46	7.22	7.45
P1 x P2	5.50	93.43	52.78	2.36	19.54	4.22	63.22	9.07	7.86
P1 x P3	6.09	93.95	53.41	2.36	19.59	4.00	65.12	8.71	8.47
P1 x P4	6.44	91.63	45.73	2.29	19.45	4.35	64.88	8.95	7.55
P1 x P5	6.02	80.57	41.76	2.63	17.75	4.46	64.61	7.98	8.93
P1 x P6	4.67	70.78	32.61	2.24	17.45	4.40	56.54	7.47	8.67
P2 x P3	5.42	91.98	52.39	2.23	19.61	2.53	55.65	7.61	7.39
P2 x P4	5.81	83.71	46.19	2.03	19.70	3.49	55.55	6.49	7.34
P2 x P5	4.49	71.04	35.97	1.77	18.30	3.52	54.22	7.25	8.13
P2 x P6	5.45	71.19	43.04	2.39	17.32	3.43	53.37	9.09	7.63
P3 x P4	5.64	79.21	45.18	2.33	17.52	3.64	63.52	7.24	7.59
P3 x P5	5.25	79.80	43.29	1.86	16.76	4.22	64.92	7.77	8.29
P3 x P6	4.57	75.45	42.18	1.66	16.28	2.77	45.26	7.31	9.23
P4 x P5	4.84	67.73	32.17	1.15	17.48	3.76	55.54	8.36	8.10
P4 x P6	4.02	64.10	25.50	1.79	17.62	3.25	52.27	8.42	8.65
P5 x P6	3.69	76.54	41.73	1.11	17.23	2.47	44.88	6.63	8.33
Grand Mean	4.83	77.58	42.33	1.98	18.09	3.35	55.10	7.96	7.70
LSD 5%	0.417	3.40	3.93	0.26	0.15	0.335	4.00	0.55	0.161

Table 6: Heterosis relative to better parent (BP) for nine studied trait of flax

Crosses	Straw yield/ plant (g)	Plant height (cm)	Technical length (cm)	Number of basal branches	Fiber %	Seed yield/ plant (g)	No. of capsules/ plant	No. of seeds/ capsule	1000 seed weight (g)
P1 x P2	16.36**	15.46**	3.05	41.60**	2.04**	26.73**	30.11**	-0.07	-5.57**
P1 x P3	28.91**	16.10**	4.28	16.09*	2.29**	20.12**	20.07**	5.53	1.72
P1 x P4	36.25**	13.24**	-10.72**	-1.01	1.53**	30.63**	33.52**	2.13	-9.29**
P1 x P5	27.43**	-0.43	-18.47**	64.03**	-7.33**	34.13**	19.71**	-3.47	7.29**
P1 x P6	-1.13	-12.52**	-36.34**	-3.86	-8.87**	32.03**	5.76	-9.45**	4.24**
P2 x P3	39.13**	18.01**	14.18**	10.02**	2.59**	-17.05**	2.62	-16.13**	18.69**
P2 x P4	38.96**	7.39**	-5.10	-11.97*	3.07**	28.62**	23.51**	-28.43**	20.71**
P2 x P5	6.66	-8.85**	-18.61**	6.20	-4.24**	52.24**	0.46	-20.06**	27.55**
P2 x P6	66.26**	-8.66**	-2.62	2.57	-9.40**	49.63**	-0.17	0.15	2.32**
P3 x P4	34.74**	8.61**	-7.18	0.86	-5.24**	19.34**	17.12	-17.37**	21.96**
P3 x P5	24.72**	9.18**	-5.66	-8.37	-9.19**	38.36**	19.71**	-3.59	30.01**
P3 x P6	17.38**	3.45	-8.09	-28.85**	-11.79**	-9.29	-16.55**	-9.26**	23.88**
P4 x P5	14.97**	-7.33**	-33.90**	-50.22**	-5.49**	38.82**	2.91	-4.67	27.08**
P4 x P6	-3.82	-11.85**	-47.61**	-23.43**	-4.72**	19.78**	-2.23	-3.99	16.05**
P5 x P6	-12.20*	4.72*	7.37	-52.43**	-1.29**	8.98	-16.85**	-11.64**	11.72**

basal branches trait. Regarding fibre percentage, five crosses showed positive significant heterosis. For seed yield/plant from 15F_1 crosses, 12 crosses showed positive significant heterosis, thus these crosses are important for improving seed yield/plant in flax. Six and twelve crosses exhibited positive significant heterosis for number of capsules/plant and 1000-seed weight traits, respectively.

These crosses, which showed positive significant heterosis, were very important for improving productivity of straw and seed yields of flax in plant breeding programs. Desirable heterosis was obtained by several researchers for flax traits (Singh *et al.* 2009, Reddy *et al.* 2013, Mishra *et al.* 2013, Kumar *et al.* 2013a, Kumar *et al.* 2013b, Pali and Mehta 2014 and Kumar *et al.* 2016).

CONCLUSION

From the results of the present investigation, it appeared that the inheritance of studied traits were controlled by both additive and non-additive gene effects. Thus, the two types of gene action were important for the studied traits. The additive gene effects were more important than non-additive gene effects for control the inheritance of studied traits, except for number of basal branches and number of capsules/plant traits. Therefore, selection should be effective in early segregating generations. From the investigation results, the parent S.620/1/3 was the best general combiner for all studied traits and Sakha 3 was good combiner for plant height, technical length, fibre percentage and number of seeds/capsule traits. Belinka (P_3) was good general combiner for straw yield/plant, plant height, technical length, number of basal branches and number of capsules/plant traits. Thus, we recommend the use these three parents S. 620/1/3, Sakha 3 and Belinka in flax hybridization breeding programs to improve yield of flax. Six crosses P_1 x P_2 , P_1 x P_3, P_1 x P_4, P_1 x P_5, P_2 x P_3 and P_2 x P_4 were the best combination of the most of the studied traits and considered very important for improving flax traits. Three crosses P_1 x P_2, P_1 x P_3 and P_1 x P_4 showed significant heterosis for straw yield/plant, plant height, fibre percentage, seed yield/plant and number of capsules/plant traits. Therefore, these crosses are important for improving flax traits in breeding programs.

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