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DIALLEL CROSS ANALYSIS FOR COMBINING ABILITY IN SOME FLAX GENOTYPES

Maysa S. Abd AL-Sadek, Doaa I. Mahmoud and Abo El-Komsan, M. Sabah

Fiber Crops Research Department, Field Crops Research Institute, A.R.C, Giza, Egypt.

ABSTRACT

Knowledge of genetic behavior and type of gene action controlling target traits is a basic principle to design an appropriate breeding procedure for genetic improvement purposes, this study was carried out to estimate combining ability and nature of gene action for yield and its components in a flax. Six parents (P_1= S.1074, P_2 = Giza 12, P_3 = S.813/8/3, P_4= S.809/2, P_5= Sakha 3, and P6= Beraton) were crossed in diallel mating design excluding reciprocals to obtain 15 F_1 in season 2017/2018, in season 2018/2019, crossing among parents was carried out again in order to have more seeds for recording F_1 traits, in the same time F_1 plants were raised in breeding nursery and selfed to obtain F_2 seeds. Six parents and their 30 crosses (15$F_1$and 15F_2) were evaluated in a randomized complete block design with three replications in season2019/2020 at Giza research station, Giza Governorate. The analysis of variance showed significant differences among all genotypes, parents, crosses for all studied traits in F_1 and F_2 generations, except number of seeds per capsule for parents, fruiting zone length in F_1 for crosses. Mean squares due to GCA and SCA were significant for all studied traits, except fruiting zone length in F_1 and number of seeds per capsule in F_2 generation, indicating the importance of additive and non- additive genetic variances controlling studied traits. The ratio of GCA/SCA was greater than the unity for all studied traits, except straw yield/plant and no. of seeds/capsule in F_2. Giza 12 (P_2)showed high general combining ability for all traits under study, except for fiber percentage in F_2.Two cross (P_1×P_2,and P_2×P_5) exhibited significant and positive SCA effects for each of straw yield/plant (in F_1), plant height, and technical stem length in both generations, this cross included high x high general combiner parents for straw yield .Straw yield per plant was significantly and positively correlated with both of plant height and technical stem length, seed yield per plant exhibited highly significant and positive correlation with each of no. of capsules/ plant , 1000-seed weight. Therefore, the possibility of using the two traits (plant height and technical stem length) as selection criteria for improving straw yield per plant as well as using 1000-seed weight and number of capsules per plant as selection criteria for improving seed yield per plant.

Key words: ***Flax (Linum usitatissimum** L.**), Combining ability, GCA - SCA, Gene action, Correlation.***

INTRODUCTION

Flax is an oldest domesticated and economically important industrial crop which is being cultivated for seed and its fiber since centuries (Damania, 1997).It is also called flaxseed or linseed when it is used as oilseed and referred to as fiber flax or just flax (in Europe) when it is used for fiber (Vaisey-Genser and Morris, 2003). In Egypt, flax is cultivated as a dual purpose (seeds and fiber). The cultivated area through the last 20 years was decreased from 60.000 to 30.000 feddan (one fed = 4200 $m^{2)}$ due to the great competition of other economic winter crops resulting in a gap between production and consumption. Therefore, it is necessary to increase flax productivity per unit area which could be achieved by using high yielding and stable cultivars for straw and seed yields (Abd El Mohsen and Amein 2016).

The linseed oil is an important ingredient in the manufacture of currency papers, plastics, stickers, tarpaulins, soaps, paint, varnish, printing ink, linoleum and also is used in the animal care products, earthen floors, industrial lubricant, leather treatment, oil cloth particle detectors, textiles, wood preservation and seasoning of cookware (Asewar and Naaz, 2022).Linseed seed contains oil, ranging from 35 to 45% (Gaikwad, *et al* 2020).Oil is a great source for human nutrition, as a delivery of omega-3 (Swetha *et al* 2021),which constitutes up to 65% of total fatty acid composition in linseed oil (Worku *et al* 2015). Linseed is a rich source of vitamin B2, many essential minerals for human and animals (Goyal *et al* 2014). The oilcake remaining after the extraction of oil is a valuable source of nutrition for farm animals. This contains 36% of protein and fibers. Lignans are plant compounds which have inhibitor and steroid properties, every of which may facilitate decrease the danger of most cancers and enhance fitness. There is developing hobby in linseed incredible molecule and its fitness advantages. Flax-seed supplementation confirmed a bit discount in serum globulin entirely in individuals with a B.M.I (Body Mass Index) large than thirty (Swetha *et al* 2021).Fiber flax stem yields, fiber of good quality having high strength, non-elasticity, repeated flexibility, a low density etc. which make it very attractive and suitable use as a rope and thread that can be easily blended with cotton, hemp and jute to enhance its textiles properties (Chauhan *et al* 2009)and (Nirala *et al* 2018).

The genetic improvement of straw and seed yields and its components is one of the main objectives of flax breeding programs (Lay and Dybing, 1989), diallel mating design helps realizing the precise estimate of the combining ability of the parents and their by selecting superior parents as well as cross combinations.(Singh *et al* 2009). Success of program chiefly depends on combining ability of parents used in crossing program (Hallauer *et al* 2010). Combining ability provides an important tool for selection of desirable parents and to get required information regarding the nature of gene action controlling desirable trait (Sprague and Tatum, 1942). Combining ability, underlining the additive gene effects in governing plant height, capsules per plant, seed weight and seed yield in flax (Singh *et al* 2009). Griffing's methods of diallel analysis have been widely used to provide reliable information on the nature and magnitude of gene effects that contribute to the expression of quantitative traits and to help plant breeder select appropriate parents for hybridization and producing desirable transgressive segregants (Griffing, 1956) and (Shattuck *et al* 1993).

Selection of superior segregants followed by the selection of the best ones are the basic tasks of any breeding process (Simmonds, 1989) to this aim the selection of the most valuable parental forms to achieve the crossing programme which will result in obtaining the best segregants is the first step of this process and on its accuracy there greatly depends on the success and efficiency of the whole program. This may be achieved on the basis of some objective criteria offered by the determination of the combining ability in parental forms used, (Popescu *et al* 1999).

Genetic studies on quantitative traits of flax including yield components have been reported by (Singh *et al* 2009) and (Sood *et al* 2007). Constant efforts to improve yield through hybridization and selection of the parents are important in crop improvement program.

The present study aimed to estimate the combining ability and the type of gene action for yield and yield components traits for six flax genotypes and their 15 crosses in $F_1$and F_2 generations, to select superior parents for producing favorable progenies in the breeding program.

MATERIALS AND METHODS

Plant materials and experimental design:

In the first season 2017/2018 six flax parents (S.1074=P_1, Giza 12 = P_2 , S.813/8/3=P_3, S.809/2=P_4, Sakha 3=P_5, Beraton=P_6) were crossed in all possible combinations using a diallel mating design excluding reciprocals to obtain15F_1hybrid seeds of flax at Giza Agricultural Research Station ARC, Egypt. In the second season 2018/2019, crossing among parents was carried out again in order to have more seeds for recording F_1 traits; in the same time F_1 plants were raised in breeding nursery and selfed to obtain F_2seeds. At the third season (2019/2020) F_1 and F_2generations as well as six parents were evaluated in a randomized complete block design with three replications, Plots of 6 m^2 (2m width × 3m length), each plot contains ten rows spacing of 20 cm row to row and 5 cm plant to plant each of (F_1, F_2 crosses and their parents) were planted. All recommended agronomic practices were adopted to raise a healthy crop. The data were recorded on ten randomly selected plants from each plot for straw yield and related characters,[plant height (cm),technical stem length (cm) and fruiting zone length (cm),seed yield and related characters, number of capsule per plant, number of seeds per capsule and 1000-seed weight (g) and technological characters (fiber and oil percentage).Oil percentage was determined by Soxhlet extraction apparatus according to the method described by AOAC (2000). Data were analysis of variance using plot means.

General (GCA) and specific (SCA) combining ability were calculated according to Griffing's method 2, model 1 (fixed effects). Forms of analysis for individual generation as given by Griffing (1956) were used for the combining ability analysis. General (GCA) and specific (SCA) combining ability were calculated according to Griffing's method 2, model 1 (fixed effects). Forms of analysis for individual generation as given by Griffing (1956) were used for the combining ability analysis. GCA/SCA ratio with its significant level was used as indicator for the relative importance (RI) of additive and non-additive effects.

Sources of different flax genotypes represent in Table 1, soil mechanical analysis, moisture constants and monthly average of temperature, relative humidity (RH) , pressure (P), wind speed and rain fall, in evaluation season 2019/2020 at Giza research station are shown in Table 2.

Table 1. Sources of different flax genotypes (dual purpose types D and fiber types F).

No	Genotypes	Pedigree	Type	Origin
P1	S.1074	Giza 12 × hybrid 1074	Dual	Local strain
P2	Giza 12	S.148/6/1 × S.2419/1	Dual	Local variety
P3	S.813/8/3	420/140/5/10 × Marlin	Dual	Local strain
P4	S.809/2	Giza 7 × Marlin	Fiber	Local strain
P5	Sakha 3	I.2569 × Belinka	Fiber	Local variety
P6	Beraton	Introduced from Holland	Fiber	Introduced from Holland

Table 2. Soil Mechanical analysis, moisture constants and monthly average of temperature, relative humidity (RH) , pressure (P), wind speed and rain fall, in evaluation season 2019/2020 at Giza research station.

Soil fraction	Content %	Depth Cm	Field capacity% (W/W)	Wilting point% (W/W)	Available moisture %	Bulk density g/cm
Coarse sand	2.91	0-15	41.90	18.60	23.24	1.20
Fine sand	13.04	15-30	33.70	17.50	16.18	1.20
Silt	30.51	30-45	28.40	16.90	11.44	1.20
Clay	53.18	45-60	28.10	16.50	11.51	1.30
Texture class	Clay					

Month	Temperature (°C)	RH (%)	Pressure (hPa)	Wind speed (m/s)	Rain fall (Kg/m^2)
November	24.61	50.64	998.51	2.56	23.28
December	20.36	50.46	999.66	1.70	1.14
January	14.01	63.39	1002.19	1.48	7.52
February	11.56	65.56	1004.80	1.98	7.52
March	13.27	61.93	1003.43	1.96	6.26
April	16.33	54.01	997.94	1.34	89.71
May	19.15	50.76	998.13	1.87	2.36

RESULTS AND DISCUSSION

Analysis of variances

The analysis of variance data in Table (3) revealed highly significant differences among all genotypes, parents and crosses for must quantitative traits under study, indicating the existence of wider variability across parental genotypes and the flax crosses. Variability among different flax genotypes for yield and its components was also reported by Abo-Kaied *et al (*2007), Abd Al-Sadek (2015) and Mahmoud *et al (*2021). Mean squares due to crosses were highly significant differences for all studied characters, except fruiting zone length in F_1. These results indicated wide genetic variability for all crosses studied. Parents exhibited significant differences for straw, seed yield/plant and related characters, except for no. of seeds/capsule in the two generations ($F_1$and F_2).

Table 3. Analysis of variance for diallel crosses for ten characters in flax.

SOV	df	Straw yield and related characters								
		Straw yield/plant (g)		Plant height (cm)		Technical stem length (cm)		Fruiting zone length		Fiber %
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
Reps.	2	0.030	0.025	101.675*	54.680	107.345*	28.250	8.880	6.970	0.595
Genotypes	20	0.412**	0.409**	998.238**	1054.310**	729.506**	829.950**	46.993**	73.350**	6.075**
Crosses	14	0.447**	0.449**	1057.409**	1113.396**	876.526**	975.197**	19.136	58.886*	4.979**
Parents	5	0.376**	0.376**	994.568**	994.568**	453.836**	453.836**	125.480**	125.480**	10.263**
P.vs.C	1	0.094**	0.007	188.097**	525.810**	49.566	677.057**	44.550	15.731	0.467
Error	40	0.011	0.015	24.789	18.785	30.274	20.066	18.887	27.441	0.305
SOV	df	Seed yield and related chrachcters								
		seed yield/plant (g)		No. of capsules/plant		No. of seeds /capsule		1000 - seed weight		Oil %
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
Reps.	2	0.055	0.070	2.130	1.390	0.385	1.945**	0.065	0.180	0.220
Genotypes	20	1.099**	1.273**	73.56**	86.011**	0.902**	1.313**	7.856**	8.170**	12.956**
Crosses	14	0.956**	1.200**	64.081**	81.873*	0.767**	1.038**	5.330**	5.756**	8.909**
Parents	5	1.694**	1.694**	114.799**	114.799**	0.164	0.164	16.073**	16.073**	26.182**
P.vs.C	1	0.138	0.194**	0.123	0.013	6.471**	10.909**	2.151**	2.460**	3.480*
Error	40	0.026	0.022	2.925	3.050	0.290	0.175	0.289	0.089	0.731

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

Mean squares due to parents *vs* crosses (P *vs* C) an indication of average heterosis among crosses were found to be highly significant for straw and seed yield/plant and their components with exception, fruiting zone length and number of capsules/plant in both generations, straw yield/plant and fiber percentage in F_2, technical stem length and seed yield/plant in F_1.

Results revealed highly significant mean squares due to general and specific combining ability (GCA and SCA) for all the characters under study, except no. of seeds /capsule in F_2 for GCA and fruiting zone length in F_1 for SCA.

Data presented in Table (4) indicate that both additive and non additive types of gene action were involved for the expression of these characters. Similar results are also reported by Mishra *et al (*2013), Pali and Mehta (2014) and Nirala *et al (*2018). Both general and specific combining ability played the important role in the expression for all traits. GCA variances were higher than SCA variances for all traits which indicated the predominance of the additive gene effects for these traits.

Table 4. Analysis of variance and estimates of components of variance for combining ability for ten characters in flax.

SOV	df	Straw yield and related chrachcters								
		Straw yield/plant (g)		Plant height (cm)		Technical stem length (cm)		Fruiting zone length (cm)		Fiber %
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
GCA	5	0.336 **	0.102 **	843.342 **	883.205 **	561.816 **	576.218 **	38.984 **	42.404 **	4.655 **
SCA	15	0.071 **	0.147 **	162.545 **	174.180 **	136.953 **	176.794 **	7.891	18.477 *	1.147 **
Error	40	0.005	0.007	8.263	6.262	10.091	6.688	6.296	9.147	0.102
GCA/SCA		4.709	0.698	5.188	5.071	4.102	3.259	4.940	2.294	4.065
SOV	df	Seed yield and related chrachcters								
		seed yield/plant (g)		No. of capsules/plant		No. of seeds /capsule		1000 seed weight		Oil %
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
GCA	5	1.314 **	1.380 **	84.242 **	95.168 **	0.350 **	0.134	8.710 **	9.120 **	10.764 **
SCA	15	0.051 **	0.105 **	4.614 **	6.505 **	0.284 **	0.539 **	0.588 **	0.591 **	2.171 **
Error	40	0.009	0.007	0.975	1.017	0.097	0.058	0.096	0.030	0.244
GCA/SCA		25.895	13.066	18.257	14.630	1.232	0.250	14.808	15.434	4. 959

*** and ** = Significant at 0.05 and 0.01 levels, respectively**

GCA/SCA ratio was less than1.0 for straw yield/plant and no. of seeds/capsule in F_2indicatingsuperiority of non-additive gene effects over additive genetic effects. This ratio was greater than 1.0 for all characters, except straw yield/plant and no. of seeds/capsule in F_2, indicating the superiority of additive gene action compared to non-additive gene action involved in the genetic control of these traits. Therefore, selection should be possible within this F_2 and subsequent generation for these traits. Similar results were recorded by Abo-Kaied *et al* (2008). Kumar *et al*(2013), Abdel-Moneam (2014) Abd Al-Sadek (2015), Abd El-Haleem and Abd Al-Sadek (2015), Nirala *et al* (2018), and Mahmoud *et al* (2021).

Combining ability effects

General combining ability (GCA) effects.

A selection of good parent for crosses influences the success in flax crop improvement program. Hence, the combining ability analysis serve as an important role for selection of parents with the highest breeding value. The parents with high general combining ability effects may be used for the improvement of individual traits. The combining ability analysis was performed to obtain information on the parent selection. The estimates of GCA effects are presented in Table (5). Data revealed that P_2 (Giza 12) showed high general combining ability effects for all characters under study, except fiber percentage trait in F_2.The second high combiner parent was P_1 (S. 1074) for 6 characters (plant height, technical stem length ,seed yield/plant and no. of capsules/plant)in both generations,(straw yield/plant in F_1 and oil percentage in F_2), suggesting the importance role of these two parents (P_1 and P_2) for increasing plant height , technical stem length and no. of capsules,P_2 (Giza12) for improvement for straw yield/plant and seed yield/plant in flax breeding programs. Also, P_5 (Sakha 3) showed highly significant and positive GCA effects for plant height, technical stem length in F_1 and F_2, straw yield/plant and fruiting stem length in F_1 and fiber percentage in F_2. This result indicates the preponderance of additive and additive x additive gene effects (Griffing, 1956 and Sprague1942).Whereas, P_6exhibited significant but negative GCA effects, except fiber percentage in F_2.This result indicated the preponderance of dominance gene effects. Since the genetic improvement of seed yield and its components is a major goal of any flax breeding program, these genotypes can be used in recombination breeding program to accumulate their favorable genes responsible for increasing straw and seed yield characters.

Table 5. General combining ability (GCA) effects of parents for ten characters in flax.

Straw yield and related characters										
Parents	Straw yield/plant (g)		Plant height (cm)		Technical stem length (cm)		Fruiting zone length		Fiber%
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
S.1074	0.074**	-0.011	3.079**	3.452**	3.633**	3.162**	-0.553	0.137	-0.223*
Giza 12	0.300**	0.210**	14.545**	15.474**	11.372**	11.562**	3.173**	3.759**	0.097
S.813/8/3	-0.260**	-0.099**	-13.460**	-13.809**	-11.653**	-11.257**	-1.896*	-2.705**	-0.965**
S.809/2	-0.191**	-0.012**	-9.465**	-9.319**	-7.849**	-8.583**	-1. 616	-0. 889	-0.610**
Sakha 3	0.079**	-0.100**	5.910**	4.772**	3.542**	3.781**	2.368**	1.297	1.078**
Beraton	-0.019	0.011	-0.609	-0.570	0.866	1.335	-1.475	-1.600	0.623**
SE (gi)	0.02	0.02	0.93	0.81	1.03	0.83	0.81	0.98	0.10
SE(gi-gj)	0.03	0.06	1.44	1.25	1.59	1.29	1.25	1.51	0.16
LSD 0.05	0.061	0.072	2.905	2.529	3.210	3.613	2.536	3.056	0.322
0.01	0.082	0.097	3.886	3.383	4.295	3.496	3.392	4.089	0.431
r	0.976**	0.763**	0.982**	0.985**	0.985**	0.987**	0.950**	0.914**	0.936**
Seed yield and related characters									
Parents	seed yield/plant (g)		No. of capsules/plant		No. of seeds/capsule		1000 seed weight		Oil%
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
S.1074	1.580**	0.165**	2.274**	2.748**	0.107	-0.126	-0.074	0.042	0.728**
Giza 12	0.546**	0.564**	3.810**	3.891**	0.235*	0.180*	1.335**	1.371**	1.543**
S.813/8/3	0.197**	0.234**	1.380**	1.848**	0.148	0.021	0.730**	0.759**	0.429*
S.809/2	0.053	-0.001	0.393	-0.349	-0.008	0.099	0.431**	0328**	-0.009
Sakha 3	-0.470**	-0.480**	-3.786**	-4.334**	-0.324**	-0.013	-1.157**	-1.192**	-1.431**
Beraton	-0.485**	-0.482**	-4.071**	-3.804**	-0.158	-0.160*	-1.264**	-1.309**	-1.259**
SE (gi)	0.03	0.03	0.32	0.33	0.10	0.08	0.10	0.06	0.16
SE(gi-gj)	0.05	0.05	0.49	0.50	0.16	0.12	0.16	0.09	0.25
LSD 0.05	0.093	0.087	0.998	1.019	0.314	0.244	0.314	0.174	0.499
0.01	0.125	0.116	1.335	1.363	0.420	0.326	0.420	0.233	0.667
r	0.994**	0.987**	0.954**	0.961**	0.869**	0.659*	0.993**	0.989**	0.943**

r = the simple correlation between GCA effects and parent means

The simple correlation between GCA effects and parental means for straw and seed yield and its components were significant and positive in all characters in F_1 and F_2 (Table 5).These results indicated that the parents showing higher mean performance proved to be the highest general combiners for these traits. Therefore, high mean performance of the parents could be transferred to crosses in such cases.

Specific combining ability (SCA) effects

The SCA value represents the dominance and epistatic interactions which are non-fixable and related to heterosis (Griffing 1956). Both or one of parents involved in the crosses with high SCA values could be successfully exploited in varietal improvement program and expected to give superior transgressive segregants (Kumar *et al* 1994, Nie *et al* 1991, Mishra and Rai 1996 , Singh *et al* 2016 and Nirala *et al* 2018). Specific combining ability effects for straw and seed yield and related characters are presented in Table (6). Significant and positive SCA effects were found in 11 crosses out of the 15 F_1 and F_2crosses. Five crosses showed significant and positive SCA effects in straw yield/plant (1×2, 2×5 and 4×6) crosses in F_1, (1×3, 2×4 and 4×6) crosses in F_2. High SCA effects in the desirable direction for both plant height and technical length were found in (1×2, 2×5, 4×6 and 5×6) in F_1 and F_2 generations, except cross (3×4) in F_1 and the cross (5×6) in F_2 for plant height. On the other hand we noticed the highest significant SCA effects in a positive direction for seed yield per plant in the crosses (1×2 and 2×3) in both generations, (5×6) cross in F_2. The crosses also exhibited significant and positive SCA effects for no of capsules/plant (1×2) in F_2, (2×3) in both generations,(2×5) in F_1 for the same character. Also three crosses showed high SCA effects in no of seed per capsules(1×2) in F_1 and (4×5 and 5×6) in F_2.The results revealed that five crosses (1×2, 1×5, 2×3, 3×5 and 3×6) exhibited significant values for 1000 seed- weight in F_1 and F_2 generations, except one cross (4×5) in F_2.One cross (P_4×P_6) had low × low general combiner parents for straw yield and related characters, might produce transgressive segregants in later generations (Langham, 1961 and Mishra and Rai, 1996) and help breaking undesirable linkage. This result indicates the potential for exploiting hybrid vigor in the breeding program. Out of 15 crosses, five crosses, gave a highly significant SCA effected (1×2, 1×6, 3×4, 3×6 and 4×6) in F_2 for fiber percentage and four crosses give significant and positive SCA gene action(1×2, 3×6, 4×5 and 5×6) in oil percentage also in F_2. In general, one cross (P_1×P_2) exhibited significant and positive SCA effects for straw, seed yield and its components. This cross (P_1×P_2) involved high × high and high × low general combiners for these traits.

Table 6. Specific combining ability (SCA) effects of the crosses for ten characters in flax.

Straw yield and related characters									
Crosses	Straw yield/plant (g)		Plant height (cm)		Technical stem length (cm)		Fruiting zone length (cm)		Fiber%
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
1X2	0.525 **	-0.136 *	24.333 **	21.294 **	23.084 **	21.139 **	1.249	0.242	1.422 **
1X3	-0.018	0.644 **	0.571	1.457	0.003	0.522	0.568	1.066	-0.773 **
1X4	-0.055	-0382 **	-2.821	-4.845 *	-2.735	-3.949	-0.086	-0.765	-0.555
1X5	-0.315 **	-0.275 **	-15.923 **	-14.276 **	-15.506 **	-18.568 **	-0.417	3.964	0.311
1X6	-0.046 **	0.056	-2.037	-1.641	-2.240	-5.982 *	0.203	4.013	0.945 **
2X3	-0.302 **	-0.114	-15.232 **	-14.858 **	-12.054 **	-12.008 **	-3.178	-2.719	-0.562
2X4	-0.337 **	0.593 **	-16.967 **	-17.111 **	-13.821 **	-15.007 **	-3.146	-1.973	0.152
2X5	0.439 **	-0.146 *	20.501 **	23.506**	21.574 **	21.187 **	-1.073	1.992	-0.308
2X6	-0.403 **	-0.479 **	-19.036 **	-19.141 **	-13.806 **	-17.134 **	-5.230 *	-2.334	-2.594 **
3X4	0.077	0.013	3.888	5.094 *	-0.559	0.742	4.447	4.483	0.642 *
3X5	-0.148 **	0.110	-5.764 *	-14.577 **	-6.194 *	-10.721 **	0.429	-4.183	-1.193 **
3X6	-0.030	-0.271 **	-1.488	-0.210	-0.787	-4.460	-.701	3.922	0.858 **
4X5	0.037	-0.212 **	0.591	0.037	0.888	-5.659 *	0.294	5.369	-0.148
4X6	0. 146 **	0.730 **	7.334 **	5.763 *	6.995 *	4.140 *	0.339	1.295	1.043 **
5X6	0.064	-0.030	5.656 *	2.147	6.744 *	14.659 **	-1.088	-9.631	-0.058
SE (Sij)	0.05	0.06	2.55	2.22	2.82	2.29	2.22	2.68	0.28
SE(Sij-Sik)	0.08	0.09	3.80	3.31	4.20	3.42	3.32	4.00	0.42
LSD 0.05 0.01	0.162 0.216	0.191 0.256	7.685 10.282	6.690 8.951	8.493 11.363	6.914 9.251	6.708 8.975	8.086 10.818	0.853 1.141
r	0.779*	0.937**	0.761*	0.764*	0.822*	0.836*	0.385	0.793*	0.711

Table 6. Cont.

Crosses	Seed yield/plant (g)		No. of capsules/plant		No. of seeds/capsule		1000 seed- weight		Oil%
	Seed yield and related characters								
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
1X2	0.475**	0.435**	1.393	1.967*	0.619*	0.180	0.869**	1.110**	3.185**
1X3	-0.230**	-.237**	-0.091	-0.885	0.111	-0.028	-1.362**	-0.839**	0.219
1X4	0.043	-0.018	0.573	0.518	-0.119	-0.219	0.170	-0.047	-0.154
1X5	-0.152	-0.015	-1.835*	-0.266	-0.517	-0.540*	0.635*	0.828**	0.772
1X6	-0.313**	-0.339**	-3.532**	-2.796**	-0.498	-1.032**	-0.095	-0.330*	-0.140
2X3	0.270**	0.716**	3.366**	6.647**	-0.822**	-0.121	0.646*	0.666**	-0.956*
2X4	-0.166*	-.231**	0.180	-0.908	-0.272	0.041	-0.635*	-0.774**	-2.502**
2X5	-0.118	-0.429**	2.169*	-0.856	-0.030	-0.742**	-0.830**	-1.012**	-0.850
2X6	-0.237**	-0.224**	-0.389	0.328	-0.341	-0.727**	-0.237	0.008	-1.135*
3X4	-0.264**	-0.425**	-3.277**	-4.054**	0.150	-0.298	-0.340	-0.476**	0.599
3X5	-0.008	-0.090	-0.975	-0.533	-0.298	-0.900**	1.145**	0.943**	-0.763
3X6	0.096	0.023	-0.596	-0.741	0.175	-0.148	1.195**	1.146**	0.892*
4X5	0.043	0.122	1.049	0.119	-0.413	0.441*	0.374	0.532**	1.088*
4X6	-0.021	-0.058	-0.132	-0.118	-0.239	-0.825**	0.291	0.256	0.297
5X6	0.136	0.245**	1.677	1.560	-0.457	0.970**	-0.074	-0.138	1.679**
SE (Sij)	0.08	0.08	0.88	0.89	0.28	0.21	0.28	0.15	0.44
SE(Sij-Sik)	0.12	0. 11	1.31	1.33	0.41	0.32	0.41	0.23	0.65
LSD 0.05	0.247	0.229	2.640	2.696	0.831	0.645	0.830	0.461	1.319
LSD 0.01	0.330	0.307	3.532	3.607	1.112	0.863	1.111	0.617	1.765
r	0.535	0.633	0.566	0.643	0.887*	0.965**	0.388	0.406	0.617

r = the simple correlation between SCA effects and crosses means.

Therefore, this cross is likely to give good segregates for these traits if the allelic genetic systems are present in good combination and epistatic effects present in the crosses act in the same direction as to maximize the desirable characteristics.

The correlation between cross means and their SCA values (Table 6) was significant and positive in nine crosses with ten characters indicating that high performing crosses are high specific combinations. Therefore, the choice of promising cross combination would be based on SCA effects. This results in agreement with. EL-Kady and Abo-Kaied, (2010), Mohammadi *et al* (2010) and Mahmoud *et al (*2021).

Mean performance and ranks of straw and seed yields for 36 flax genotypes.

Mean performance for parents

Data in Table (7) represent average of (straw and seed) yields and related characters ranks for 6 flax parents and their crosses in F_1 and F_2.

Table 7. Mean performances of 36 flax genotypes (6) parents, 15 F_1 and 15 F_2 crosses) for straw, seed yield and their components and technological characters.

Straw yield and related characters										
Genotypes	Straw yield/plant (g)		Plant height (cm)		Technical stem length (cm)		Fruiting zone length		Fiber%	
P1	2.14	c	106.47	c	93.54	b	12.93	d	16.52	d
P2	2.68	a	134.67	a	107.83	a	26.83	a	18.78	c
P3	1.73	d	84.47	f	74.25	f	10.22	f	16.23	e
P4	1.72	e	87.43	e	76.50	e	10.94	e	15.86	f
P5	2.20	b	111.67	b	90.91	c	20.76	b	20.50	a
P6	2.14	c	105.94	d	90.86	d	15.09	c	18.79	b
Parents. Mean	2.10		105.11		88.98		16.13		17.78	

Straw yield and related characters									
Crosses	Straw yield/plant (g)		Plant height (cm)		Technical stem length (cm)		Fruiting zone length		Fiber %
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
1X2	2.94 a	2.18 d	144.33 a	140.72 b	125.67 a	119.66 b	18.67 b	21.06 d	18.94 c
1X3	1.84 i	2.65 c	92.57 j	91.64 i	79.65 i	76.23 g	12.92 j	15.42 k	15.68 o
1X4	1.87 h	1.71 o	93.17 i	89.83 j	80.63 h	74.43 h	12.54 l	15.40 l	16.26 l
1X5	1.90 g	1.73 n	95.44 h	94.49 h	79.25 i	72.17 j	16.20 c	22.32 c	18.81 d
1X6	2.05 d	2.17 e	02.81 d	101.78 d	89.84 d	82.31 d	12.97 i	19.47 e	18.99 b
2X3	1.78 k	2.12 f	88.23 m	87.35 l	75.33 l	72.09 k	12.90 k	15.25 m	16.21 m
2X4	1.81 j	2.91 a	90.49 k	89.59 k	77.28 j	71.77 l	13.21 h	17.82 f	17.28 i
2X5	2.88 b	2.08 g	143.33 b	144.29 a	124.07 b	120.33 a	19.27 a	23.97 a	18.51 f
2X6	1.92 f	1.86 k	97.28 g	96.30 f	86.01 f	79.56 f	11.27 n	16.74 h	15.77 n
3X4	1.67 m	2.02 i	83.34 o	82.51 n	67.61 n	64.70 o	15.26 e	17.81 g	16.71 j
3X5	1.73 l	2.03 h	89.06 l	76.93 o	73.36 m	65.60 n	15.70 d	11.33 n	16.56 k
3X6	1.73 l	1.76 m	86.82 n	85.95 m	76.09 k	69.42 m	10.73 o	16.54 i	18.16 g
4X5	1.98 e	1.80 l	99.41 f	96.03 g	84.16 g	73.33 i	15.26 f	22.70 b	17.96 h
4X6	1.98 e	2.85 b	99.64 e	96.41 e	87.59 e	80.69 e	12.05 m	15.73 j	18.70 e
5X6	2.18 c	2.00 j	113.33 c	106.89 c	98.73 c	103.57 c	14.60 g	6.99 o	19.29 a
Mean	2.02	2.12	101.28	98.71	87.02	81.72	14.27	17.24	17.59
G. Mean	2.04	2.11	102.38	100.54	87.58	83.80	14.80	16.92	17.64
LSD 0.05	0.133	0.188	6.630	5.772	7.327	5.964	5.788	6.976	0.741

Table 7. Cont.

Seed yield and related characters					
Genotypes	Seed yield/plant (g)	No. of capsules/plant	No. of seeds /capsule	1000- seed weight	Oil %
P1	1.76 c	24.69 a	8.59 d	8.37 d	37.92 d
P2	2.34 a	22.66 b	9.07 a	11.39 a	42.62 a
P3	1.82 b	21.94 c	8.81 b	9.45 c	39.27 b
P4	1.65 d	19.99 d	8.65 c	9.56 b	38.73 c
P5	0.47 f	9.78 f	8.38 f	5.69 e	34.58 f
P6	0.56 e	11.74 e	8.58 e	5.56 f	35.09 e
Mean	1.43	18.47	8.68	8.337	38.04

Seed yield and related characters									
Crosses	Seed yield/plant (g)		No. of capsules/plant		No. of seeds /capsule		1000 seed-weight		Oil %
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_2
1X2	2.54 a	2.51 b	25.87 b	27.07 b	9.14 a	8.26 d	10.76 b	11.17 b	43.86 a
1X3	1.49 e	1.51 d	21.96 d	22.17 c	8.54 b	7.89 f	7.92 m	8.61 i	39.78 b
1X4	1.61 d	1.49 e	21.64 e	21.38 d	8.16 e	7.78 h	9.16 g	8.97 g	38.97 e
1X5	0.90 m	1.02 i	15.05 k	16.61 h	7.44 m	7.34 k	8.03 k	8.33 j	38.48 f
1X6	0.72 n	0.69 n	13.07 n	14.61 l	7.63 l	6.70 o	7.20 n	7.05 n	37.74 i
2X3	2.37 b	2.86 a	26.95 a	30.85 a	7.74 i	8.10 e	11.34 a	11.45 a	39.42 d
2X4	1.79 c	1.68 c	22.78 c	21.10 e	8.13 f	8.34 c	9.76 c	9.58 c	37.44 l
2X5	1.32 g	1.00 k	20.59 f	17.16 g	8.06 g	7.45 j	7.98 l	7.82 m	37.67 j
2X6	1.18 h	1.21 f	17.75 g	18.88 f	7.91 h	7.31 l	8.46 h	8.72 h	37.56 k
3X4	1.35 f	1.15 g	16.89 h	15.91 i	8.47 c	7.85 g	9.45 d	9.26 d	39.43 c
3X5	1.08 j	1.01 j	15.02 l	15.45 k	7.70 j	7.13 n	9.35 e	9.16 f	36.64 n
3X6	1.17 i	1.12 h	15.11 j	15.77 j	8.34 d	7.74 i	9.29 f	9.25 e	38.47 g
4X5	0.99 k	0.99 l	16.05 i	13.90 n	7.43 n	8.55 b	8.28 i	8.32 k	38.06 h
4X6	0.91 l	0.81 m	14.59 m	14.19 m	7.68 k	7.14 m	8.09 j	7.92 l	37.44 l
5X6	0.54 o	0.63 o	12.22 o	11.89 o	7.24 o	8.82 a	6.13 o	6.01 o	37.40 m
Means	1.33	1.31	18.37	18.46	7.97	7.76	8.75	8.77	38.56
G. Means	1.36	1.35	18.40	18.46	8.17	8.02	8.63	8.65	38.41
LSD 0.05	0.231	0.188	2.279	2.326	0.717	0.549	0.717	0.399	1.138

Mean performance varied among 6 parents and two generations (F_1 and F_2) in all characters under study. Data showed that cultivar Giza 12, P_2 (dual purpose type) ranked the first in mean performance for straw yield and related characters, followed by Sakha 3, P_5 (fiber type) ranked second for all traits except technical stem length, followed by S.1074; P_1(dual purpose type) came third in straw yield/plant and related trials, except technical stem length ranked second and came the third in fruiting zone length, followed by Beraton (P_6) an introduction variety (fiber type) ranked third in straw yield/plant and fruiting zone length , fourth in plant height and technical stem length. At the last rank came (P_4) S.809/2, followed by the dual purpose (P_3) S.813/8/3, respectively.

Concerning seed yield/plant, P_2followed by P_3 and P_1, respectively was superior than most of other genotypes as well as the three parents (P_4, P_6 and P_5). Also, four parents (P_1, P_2, P_3 and P_4) followed by $P_6$and P_5, respectively for no. of capsules/plant, (P_2, P_3 and P_4) followed by (P_1, P_6 and P_5) for no of seed/capsule and oil percentage, (P_2,P_4 and P_3) followed by (P_1,P_5 and P_6) in seed index. These results indicated that the P_2 dual purpose cultivar had high yielding potentiality for straw, seed yield/plant and other related characters under study. Similar results were reported by Abo-Kaied *et al* (2008), Mohammadi *et al* (2010), Abd-Moneam (2014) Vikas and Mehta (2014), Sedhom (2016), Sayed *et al* (2019) and Mahmoud *et al* (2021)

Mean performance for crosses

The mean performance of the tested 15 crosses in the two generations (F_1 and F_2) is presented in Table (7).For straw yield/plant, plant height, technical stem length, seed yield/plant, no. of seeds/capsule and oil percentage revealed that the best cross was $P_1 \times P_2$ (in F_1) and ranked first in these traits, but ranked second in plant height/plant, technical stem length, and seed yield/plant (in F_2),tacked the same ranked in no of capsule/plant and 1000 seed-weight in the two generation ($F_1$and F_2) and the fruiting zone length in F_1. The cross $P_2 \times P_5$ possessed the highest plant height and technical stem length (in F_2) and exhibited the first rank in fruiting zone length in the two generations. While the cross P_5 xP_6possessed the highest number of seeds/capsule and fiber percentage. Cross $P_2 \times P_4$ ranked third in seed yield/plant in the two generations (F_1 and F_2), no. of capsule/plant in (F_1), no of seed/capsule in (F_2) and 1000-seed weight in (F_1 and F_2).These genotypes can be used in recombination breeding programs to accumulate their favorable genes responsible for increasing seed yield in promising pure lines, when recorded the first in straw yield/plant in (F_2). The remaining twelve flax genotypes laid intermediate position between the highest and the lowest crosses. We can conclude that mean performance for straw yield/plant, seed yield/plant and its components of 30 genotypes in the two successive generations (F_1, and F_2) ,four crosses($P_1 \times P_2$, $P_2 \times P_4$, $P_2 \times P_5$ and $P_5 \times P_6$) were superior to the other studied crosses in straw yield/plant, seed yield /plant and related characters in most cases. These results indicated that the three crosses ($P_1 \times P_2$, $P_2 \times P_4$ and $P_2 \times P_5$) exhibiting high parent superiority or were approaching the mean performance of the higher parent and exhibited positive and significant SCA effects across generations, probably their variance may be due to the fixed gene effects, could be successfully used for the development of high yielding pure breeding lines. The cross ($P_5 \times P_6$) may be also promising in flax breeding programs to selection for fiber percentage. Similar results were reported by Abo-Kaied *et al* (2008), Sayed *et al (*2019) and Mahmoud *et al (*2021).

Correlation analysis

Data presented in Table (8) for correlation coefficient values among all studied traits showed that straw yield per plant was significantly and positively correlated with both of plant height and technical stem length.

Table 8. Phenotypic correlation coefficients among straw, seed and their component traits across 36 flax genotypes (data of combined analysis).

Characters	Straw yield/ Plant (g)	Plant height (cm)	Technical stem length	Fruiting zone length (cm)	Seed yield/ plant (g)	Number of capsules/ plant	Number of seeds/ capsule
Plant height (cm)	0.554**						
Technical length(cm)	0.521**	0.972**					
Fruiting zone length (cm)	0.363*	0.545**	0.335*				
Seed yield/plant (g)	0.174	0.152	0.136	0.100			
Number of capsules/plant	0.167	0.131	0.127	0.042	0.956**		
Number of seeds/capsule	0.120	0.214	0.259	-0.050	0.457**	0.328*	
1000- seed weight	0.020	-0.054	-0.104	0.129	0.885**	0.794**	0.244

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

Also, plant height exhibited high positive correlation with technical stem length. On the other hand, seed yield per plant exhibited highly significant and positive correlation with each of no. of capsules, no of seeds/capsule and 1000-seed weight. Therefore, their is a possibility of using the two traits (plant height and technical stem length) as selection criteria for improving straw yield per plant as well as, using 1000-seed weight and number of capsules per plant as selection indices for improving seed yield per plant. It can be concluded that the association results in this study could help the flax breeders to the possibility of selection among flax genotypes which are characterized by highly technical length for and high seed yield. These results are in agreement with those obtained by Paul *et al (*2016), Paul and Chopra (2017), Patial *et al (*2018) and El-shimy *et al (*2019).

CONCLUSION

Overall, significant genetic variations were observed for the traits investigated in this study. Significant GCA and SCA effects for the studied traits imply the role of both additive and non-additive gene actions in the genetic control of all the studied traits. The ratios of GCA/SCA exhibited the higher contribution of additive gene effects to the inheritance of plant height, technical stem length, no. of capsule/plant, no. of seeds/capsule and 1000-seeds weight. The preponderance of additive gene action in explaining genetic variations in these characters indicates the possibility for their genetic improvement through accumulating favorable alleles from parents with high GCA values in the target genotype using appropriate methods such as diallel selective mating for selection of these traits. Since genetic improvement of straw, seed yield and its components is a major goal of any flax breeding program, the association results in this study helped the flax breeders to the possibility of selection of genotypes for superiority in straw and seed yield and related characters.

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تحليل القدره على الأئتلاف للهجن التبادليه لبعض التراكيب الوراثيه فى الكتان

مايسة سعيد عبد الصادق، دعاء إسماعيل محمود و صباح محمد أبو القمصان

قسم بحوث محاصيل الألياف – معهد بحوث المحاصيل الحقلية – مركز البحوث الزراعية – الجيزة – مصر

إن معرفة السلوك الجينى ونوع فعل الجين الذى يتحكم فى الصفات المستهدفه إجراء أساسى فى التربيه بغرض التحسين الوراثى ,أجريت هذه الدراسه لتقدير القدرة على الأئتلاف وطبيعه الفعل الجيني على المحصول ومكوناته فى الكتان.حيث تم التهجين بين ستة أباء (الاب الأول سلاله ١٠٧٤ , الاب الثانى جيزه ١٢ , الأب الثالث سلاله ٣/٨/٨١٣ , الأب الرابع سلاله ٢/٨٠٩ , الأب الخامس الصنف سخا٣ , الأب السادس بريتون) بأستخدام نظام الهجن نصف الدائريه بدون الهجن العكسيه لإنتاج بذره الجيل الأول موسم ٢٠١٨/٢٠١٧ وفى موسم ٢٠١٩/٢٠١٨ تم تكرار التهجين بين الأباء للحصول على المزيد من البذور لتسجيل صفات الجيل الأول, وفى نفس الوقت تم زراعه نباتات الجيل الأول للحصول على بذرة الجيل الثانى. تم تقييم السته أباء و٣٠ هجين (١٥هجين فى الجيل الأول و ١٥ هجين فى الجيل الثانى) فى تصميم القطاعات الكامله العشوائيه ذات الثلاث مكررات فى موسم ٢٠٢٠/٢٠١٩ بمحطه البحوث الزراعيه بالجيزة – مصر. أظهرتحليل التباين على معنويه الإختلافات بين التراكيب الوراثيه وكل من الأباء والهجن لكل الصفات تحت الدراسه فى الجيل الأول والثانى فيما عدا صفه عدد البذور بالكبسوله بالنسبه للأباء.وصفه طول المنطقه الثمريه فى الجيل الأول , كان تباين القدره العامه والخاصه على الإئتلاف معنوى لكل الصفات التى تم دراستها فيما عدا عدد البذور بالكبسوله فى الجيل الثانى ويدل ذلك على أهميه فعل الجين المضيف وغير المضيف فى وراثه هذه الصفات.كانت النسبه بين القدره العامه والقدرة الخاصه على الإئتلاف أكبر من الواحد لكل الصفات المدروسه فيما عدا صفه محصول القش للنبات وعدد البذور بالكبسوله فى الجيل الثانى. الأب الثانى جيزة ١٢ كان أفضل الأباء فى القدرة العامه على التألف لكل الصفات تحت الدراسه فيما عدا صفه النسبه المئويه للألياف فى كلا من الجيل الأول والثانى, كما أظهر الهجينين ١×٢ و٢×٥ قدرة إئتلافيه خاصه فى صفه محصول القش لكل نبات والطول الكلى والطول الفعال ونسبه الألياف فى الجيل الأول هذان الهجينان كان أبواهما ذو قدره ائتلافيه عامه عاليه فى صفه محصول القش لكل نبات. أظهرت نتائج الإرتباط أن هناك أرتباط معنوى موجب بين صفه محصول القش/نبات والطول الفعال والطول الكلى وطول المنطقه الثمريه و كذلك وجد إرتباط موجب ومعنوى بين صفه محصول البذرة لكل نبات وعدد الكبسولات لكل نبات وعدد البذور بالكبسوله مما يدل على أن هذة الصفات فعاله عند الأنتخاب لصفات القش والبذور فى برامج التربيه.

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