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Gene Effects Controlling the Inheritance of Yield, Oil Content and Fatty Acid Composition of Flax (*Linum usitatissimum*, L.)

F.S. El-Nakhlawy
Department of Arid Land Agriculture, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz Univ., Jeddah, Saudi Arabia

Abstract. The present study aimed to estimate the type of gene action of the different flax traits including technical plant length, number of capsules/plant, seed yield/plant besides oil content and fatty acid composition of the oil from genetic study of six populations, *i.e.*, P_1, P_2, F_1, BC_1, BC_2 and F_2 of the cross between Egyptian cultivar, Giza-8 and the Netherlandish cultivar, Viking through 1998/1999 to 2002/2003 seasons at Alexandria, Egypt. Significant genetic variance were showed for the studied traits. Additive genetic variance contained the major component in the inheritance of seed yield and number of capsules/plant while both additive and dominance variance were significantly equal in technical plant length inheritance. Oil content and linolenic fatty acid were genetically controlled by additive gene effect while palmitic, stearic, oleic and linoleic acids are genetically controlled by dominance gene effect. Heritability estimates (broad-sense) were 91.72, 76.75, 71.33 and 87.97% for seed yield/plant, number of capsules/plant, technical plant length and oil content, respectively. For fatty acids, heritability estimates (broad-sense) were 69.40, 83.09, 92.80, 85.38 and 89.60%, respectively. In narrow-sense, heritability estimates were 83.65, 57.79, 37.28 and 75.00% for seed yield/plant, number of capsules/plant, technical plant length, and oil content, respectively, while for fatty acids composition were 22.70, 26.67, 32.04, 32.28 and 56.36% for palmitic, stearic, linoleic and linolenic acids respectively. As, for the predicted gain from selection, the values were 93.05, 35.95, 10.90, 10.32, 7.72, 90.01, 13.48, 11.04 and 25.52% for seed yield/plant number of capsules/plant, technical plant length, oil content, and fatty acids, *i.e.*, palmitic, stearic, oleic, linoleic and linolenic, respectively.

Keywords: Flax, Genetic variance, Additive, Dominance, Heritability, Gain from selection, Fatty acids.

Introduction

The genetic behavior and type of gene action controlling the agronomic characters of flax besides seed oil content and its fatty acid composition are of crucial importance to the breeder in achieving the suitable procedure for improvement of flax crop through increasing fiber and seed yields, oil content and modification the fatty acid ratios in the oil to be used as an edible oil. Few authors studied these points, El-Nakhlawy *et al.* (1983) recorded high additive genetic variances in three studied flax crosses for seed yield/plant which led to high values of heritability ratios. Hemker (1989) reported that vegetative traits were mostly controlled by additive gene action whereas dominance gene action had a major effect on reproductive characters. Khorgade, *et al.* (1992) found that additive genetic variation was important for expression of number of capsules/plant and seed yield/plant. Foster, *et al.* (1998) reported that dominance was high for plant height and seed weight, while 100-seed weight displayed no dominance at all. Heritability estimates were high for plant height and moderate for seed weight and straw weight. Popescu, *et al.* (1998) suggested that both additive and dominance effects were involved in the inheritance of fiber yield and fiber content. Heritability coefficients, in the narrow sense, were high. Khotilyova, *et al.* (1999) found that technical length genetically was controlled by additive gene action, but Sakovich (1999) found that over dominance controlled the technical length of the stem and number of seeds/capsules, while additive gene effects were noted in the inheritance of the number of capsules/plant. Significant and positive heterosis over the mid-parental value was recorded for oil content (11.20%) and protein content (20.16%). Payasi, *et al.* (2000) revealed high estimates of phenotypic and genotypic coefficient of variations for number of capsules/plant, also, high heritability estimates coupled with high genetic advance were recorded for fiber length and seed yield/plant. Polonetskaya, *et al.* (2000) reported that the flax yield and yield components were affected by genotype and genotype × environment interaction. El-Hariri *et al.* (2004a) stated that heritability values in broad-sense ranged between 60.93% for capsules/plant and 90.74% for seed index. El-Hariri, *et al.* (2004b) found high heritability estimates in broad-sense for technical stem length of flax.

Materials and Methods

The present study was carried out at the Agricultural Research Experiment Station, Faculty of Agriculture, Alexandria University, Egypt during 1998/1999, 1999/2000, 2000/2001 and 2001/2002 seasons. Chemical analysis for the determination of oil content and fatty acid composition of the extracted oil was done at 2002/2003 season. Two flax cultivars were chosen for the genetic studies, *i.e.* Giza-8 (P1) and Viking (P2) cultivars. The main characteristics of which are presented in Table 1.

TABLE 1. The pedigree of the genotypes used in the study.

Genotype	Source	Main characters			
		Seed yield kg/ha	Total plant length (cm)	No. of days to flowering	Oil content (%)
Giza-8	Egypt	1800	95.71	109.76	38.10
Viking	Netherland	921	103.93	113.33	23.41

Propagation of the two cultivars was made during 1998/1999 season to obtain pure-selfed seeds from each cultivar to be used as parent. The artificial crossing between the two cultivars was done in 1999/2000 season. In 2000/2001 season the parents and F_1 seeds were grown and backcrosses between F_1 and both parents were made. In 2002/2002 season, the parents, F_1, F_2, BC_1 and BC_2 seeds were grown in a randomized complete block design with three replicates. Each replicate consisted of the following number of rows for each population:

Population	P_1	P_2	F_1	BC_1	BC_2	F_2
No. of rows	3	3	3	5	5	10

The row was 210cm long and 20cm apart. In each row 20 seeds were hand-sown at 10cm spacing. The recommended cultural practices of flax were followed during the growing seasons.

Data were recorded for each individual plant for the following characters: technical plant length (cm), number of capsules/plant, seed weight/plant (g), seed oil percentage for each plant using Soxhlet instrument according to A.O.A.C. (1984). Oil content of each plant was analyzed for fatty acids composition, *i.e.* palmitic acid, stearic acid (saturated F.A.) and olic acid, linoleic acid and linolenic acid (unsaturated fatty acids) using gas chromatograghy according to Radwam (1978) and Patterson (1989). The obtained results were statistically analyzed according to Steel and Torrie (1980).

Genetic Analysis

Estimation of type of gene action was carried out using the procedures described by Mather and Jinks (1971). Variances within P_1, P_2, F_1, BC_1, BC_2 and F_2 were calculated and partitioned into environmental and genotypic variances.

Genotypic variance was partitioned into additive genetic variance and dominance genetic variance according to Mather and Jinks (1971).

Heritability estimates were calculated in both broad and narrow senses. The predicted genetic gain from selection was calculated upon selecting the highest 5% of the population as given by Lush (1948).

Results and Discussion

Data presented in Table 2 show the mean values and genotypic coefficients (G.C.V.) of seed weight/plant, number of capsules/plant and technical plant length (the main plant part producing flax fibers) of the six population. The presented results show that the highest seed weight/plant was given by the F_2 population (5.36g) followed by BC_2 population (5.07g) while the lowest seed weight/plant was from P_1 (Viking) population (2.59g), but F_1 population mean was almost in the middle between P_1 and P_2. Genotypic coefficients of variation ranged from 41.92% in BC up to 51.72% in F_2 population.

Table 2. Generation means ($\overline{X}$) and genotypic coefficients of variability (G.C.V.) for seed weight/plant (g), number of capsules/plant, and technical plant length (cm) of flax for (Viking × Giza-8) cross.

Character	Statistic	P_1	P_2	F_1	BC_1	BC_2	F_2
Seed weight/plant (g)	$\overline{X}$	2.59	4.96	3.38	3.63	5.07	5.36
	G.C.V.	–	–	–	41.92	84.50	51.72
No. of capsules/plant	$\overline{X}$	79.30	100.6	101.2	88.4	106.3	105.9
	G.C.V.	–	–	–	20.74	23.84	26.46
Technical plant length	$\overline{X}$	73.23	46.18	59.06	67.21	52.93	63.85
	G.C.V.	–	–	–	11.76	9.28	11.99

With respect to the number of capsules/plant, BC_2 and F_2 population produced the highest values (106.30 and 105.90, respectively), while F_1 population plants were around the same number of capsules/plant of P_2 population (Giza-8), (101.20 and 100.60, respectively). F_2 population had the highest G.C.V. (26.46%) followed by BC_2 (23.84%), then BC_1 (20.74%) as shown in Table 2. Means of technical plant length of the six populations as presented in Table 2 demonstrates that Viking parent had the tallest plants (73.23cm) and the other parent (Giza-8) was the shortest in technical plant length (46.18cm) while the F_1 population plants were around the middle between the two parents. The segregated generations had G.C.V. value ranging from 11.99% in F_2 to 9.28% in BC_2 populations.

Means and genotypic coefficient of variability values of oil content (%) and fatty acid composition percentage are presented in Table 3. The presented data reveal that Giza-8 (P_2) seeds had 37.12% oil and Viking (P_1) seeds had 23.39%, while F_1 seed oil content was 31.80%. The F_2 seed oil content was 39.04% almost equal to BC_2 (39.07%). F_2 and BC_1 populations had the same (6.26%) G.C.V., while the G.C.V. value of BC_2 was 5.04%.

Table 3. Generation means ($\overline{X}$) and genotypic coefficients of variability (G.C.V.) for oil content (%), and fatty acids composition of flax oil (%) for (Viking × Giza-8) cross.

Character	Statistic	P_1	P_2	F_1	BC_1	BC_2	F_2
Oil content (%)	$\overline{X}$	23.39	7.12	31.80	27.64	39.07	39.04
	G.C.V.	–	–	–	6.26	5.04	6.26
Saturated fatty acids							
Palmitic	$\overline{X}$	2.27	5.91	3.57	2.44	3.01	2.01
	G.C.V.	–	–	–	5.79	11.01	14.07
Stearic	$\overline{X}$	7.42	12.36	10.77	6.00	7.49	7.37
	G.C.V.	–	–	–	13.44	15.46	14.80
Unsaturated fatty acids							
Oleic	$\overline{X}$	29.92	22.17	26.12	26.44	24.62	26.24
	G.C.V.	–	–	–	18.22	17.21	19.10
Linoleic	$\overline{X}$	13.04	18.35	14.65	15.063	19.49	16.79
	G.C.V.	–	–	–	12.01	15.01	16.44
Linolenic	$\overline{X}$	47.35	41.21	44.89	47.45	19.67	22.12
	G.C.V.	–	–	–	16.76	18.24	20.93

Concerning fatty acid composition, data in Table 3 show that the saturated fatty acid, palmitic acid, percentages in Giza-8 (P_2) and Viking (P_1) were 5.90 and 2.27%, respectively and F_1 contained 3.57% palmitic acid but the oil produced from F_2 population contained 2.01% less than both BC_1 (2.44%) and BC_2 (3.01%) whereas G.C.V. values were highest in F_2 (14.07%) and lowest in BC_1 (5.79%). The other saturated fatty acid, stearic acid, percentages were highest in Giza-8 (P_2) (12.36%) followed by F_1 (10.77%), BC_2 (7.49%) and Viking P_1 (7.42%). G.C.V. values ranged from 13.44% in BC_1 to 14.80% in F_2.

As for unsaturated fatty acids, oleic, linoleic and linolenic fatty acids, the mean values for the six populations revealed that Viking (P_1) was the highest population in oleic acid (29.92%) and the other parent had 22.17% oleic acid while F_1 population produced oil containing 26.12% oleic acid. F_2 and BC_1 populations were almost equal to F_1 in oleic acid constituent but the BC_2 population had 24.62% oleic acid. F_2 population had the highest variation (G.C.V. = 19.10%) followed by BC_1 (18.32%) then BC_2 (17.21%). Giza-8 (P_2) had 18.35% linoleic acid while Viking (P_1) had 13.04% linoleic acid and F_1 had 14.65% linoleic acid. On the other hand linoleic acid ranged in the segregating generations from 19.49% in BC_2 to 15.63% in BC_1 while in F_2 was 16.79% with G.C.V. 18.41%. The highest unsaturated fatty acid, linolenic acid, content was shown in Viking (P_1) and BC_1, with values 47.35% and 47.45%, respectively, while the lowest value was presented in F_2 population (22.12%). G.C.V. values ranged from 20.93% in F_2 population down to 16.76% in BC_1 population, as shown in Table 3.

Data of environmental and genotypic variances, besides the ratios of additive variance and dominance variance to the genetic variance for seed weight/plant, number of capsules/plant and technical plant length are presented in Table 4. The data reveal highly significant genetic variances for the previous characters. By partitioning the genetic variance to its components, *i.e.* additive and dominance genetic variances, the obtained results revealed that additive genetic variance contributed with the major component in the genetic variances in seed weight (91%) and number of capsules/plant (75%), while the ratios of additive and dominance variance were almost equal in technical plant length (52 and 48%, respectively). The results clarify that the additive effects are predominating in the control of seed yield/plant and number of capsules/plant, while technical plant length is genetically controlled by both additive and dominance gene effects. The previous results are confirmed with the results obtained by Hemker (1989), Khorgade, *et al.* (1992) who reported that additive genetic variance was important for expression of capsules/plant and seed yield/plant. Also, El-Nakhlawy, *et al.* (1983) concluded that the number of capsules and seed weight/plant are genetically controlled by additive gene effects while technical plant length is controlled by additive and additive × additive gene effects. The same results were also obtained by Hemker (1989) and Sakovich (1999).

Referring to the oil content and its components of saturated and unsaturated fatty acids, data in Table 5 show that oil content and all fatty acids constituents were genetically controlled with significant values. Additive gene effects were the main components in the genetic variance and the main type of gene action in the inheritance of both oil content and linolenic acid, while, the other unsaturated fatty acids besides the saturated fatty acids were genetically controlled mainly by dominance gene effects with values of 65%, 62%, 68% and 69% for linoleic, oleic, stearic and palimitic acid, respectively. These results are generally in agreement with the results of El-Nakhawy, *et al.* (1983) and Hemker

(1989). This is very important for the flax breeder to use the hybridization methods to improve the linoleic and oleic acid contents in linseed oil allowing its utilization as an edible oil for humans.

TABLE 4. Environmental variance $\left(\sigma_e^2\right)$, genotypic variance $\left(\sigma_g^2\right)$ and the ratios of additive $\left(\sigma_D^2\right)$ and dominance $\left(\sigma_H^2\right)$ variances to the genotypic variance of seed weight/ plant (g), number of capsules/plant and technical plant length (cm) of flax for (Viking × Giza-8) cross.

Character	Environmental variance $\left(\sigma_e^2\right)$,	Genotypic variance $\left(\sigma_g^2\right)$	$\frac{\sigma_D^2}{\sigma_g^2}$	$\frac{\sigma_H^2}{\sigma_g^2}$
Seed weight/plant (g)	0.69	7.68**	0.91	0.19
No. of capsules/plant	237.82	785.02**	0.75	0.25
Technical plant length (cm)	23.57	58.64**	0.52	0.48

**Significant at 0.01 level of probability.

TABLE 5. Environmental variance $\left(\sigma_e^2\right)$, genotypic variance $\left(\sigma_g^2\right)$ and the ratios of additive $\left(\sigma_D^2\right)$ and dominance $\left(\sigma_H^2\right)$ variances to the genotypic variance of oil content (%) and fatty acid composition of flax for (Viking × Giza-8) cross.

Character	Environmental variance $\left(\sigma_e^2\right)$,	Genotypic variance $\left(\sigma_g^2\right)$	$\frac{\sigma_D^2}{\sigma_g^2}$	$\frac{\sigma_H^2}{\sigma_g^2}$
Oil content (%)	0.82	5.98**	0.85	0.15
Saturated fatty acids				
Palmitic	0.03	0.08**	0.31	0.69
Stearic	0.24	1.18**	0.32	0.68
Unsaturated fatty acids				
Oleic	1.95	25.13**	0.35	0.65
Linoleic	1.30	7.59**	0.38	0.62
Linolenic	11.19	96.39**	0.63	0.37

**Significant at 0.01 level of probability.

The obtained results of the heritability estimates in broad and narrow senses for the studied characters are presented in Table 6. Heritability estimates in broad-sense for seed weight/plant, number of capsules/plant and technical plant length were more than 71% with 91.72% for seed weight/plant. These results are confirmed with the results reported by E-Hariri, *et al.* (2004a,b). In narrow sense, heritability values were 83.65%, 57.79% and 37.28% for seed weight/plant, number of capsules/plant and technical plant length, respectively. As for heritability values of oil content and its fatty acids constituents, data in Table 6 show that oil content and its fatty acids composition were highly heritable with values more than 83% except for palmitic acid 69.40%. In narrow sense heritability value was also high in oil content (75%) due to the highest genetically effect of additive gene action (85%), but for fatty acids low narrow-sense heritability values were detected except for linolenic acid due to the low values of the additive variance contribution in the total genetic variance of these fatty acids as shown in Table 5. These results are similar to results obtained by Foster, *et al.* (1998).

Table 6. Heritability estimates in broad and narrow senses and the predicted gain from selection upon selecting the highest five percentage in F_2 generation for (Viking × Giza-8) cross.

Character	Mean	Heritability		G %
		Broad-sense	Narrow-sense	
Seed weight/plant (g)	5.36	91.72	83.65	93.05
No. of capsules/plant	105.90	76.75	57.79	35.95
Technical plant length (cm)	63.85	71.33	37.28	10.90
Oil content (%)	39.04	87.97	75.00	10.32
Fatty acids (%)				
Saturated Fatty acids:				
Palmitic	2.01	69.40	22.70	7.72
Stearic	7.37	83.09	26.67	9.01
Unsaturated Fatty acids:				
Oleic	26.24	92.80	32.64	13.48
Linoleic	16.79	85.38	32.28	11.04
Linolenic	46.89	89.60	56.36	25.52

Values of predicted gain from selection of the studied traits (Table 6) reveal that selection the highest 5% of the F_2 population may improve seed yield by 93.05%, technical plant length by 10.90% and oil content by 10.32%. As for fatty acid composition, the obtained data show that selection of the highest 5% in the fatty acid constituents may increase them by 7.22, 9.01, 13.48, 11.04 and 25.52% for palmitic, stearic, oleic, linoleic and linolenic acid, respectively. These results are confirmed with the results obtained by El-Nakhlawy, *et al.* (1983) and Foster, *et al.* (1998).

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الفعل الجيني المتحكم في وراثة المحصول ومحتوى الزيت ومكوناته من الأحماض الدهنية في الكتان

فتحي سعد النخلاوي

قسم زراعة المناطق الجافة ، كلية الأرصاد والبيئة وزراعة المناطق الجافة

جامعة الملك عبد العزيز ، جـــدة - المملكة العربية السعودية

المستخلص. أجريت هذه الدراسة بهدف تقدير نوعية الفعل الجيني المتحكم في وراثة الصفات التالية للكتان: محصول البذور/ نبات، وعدد الثمار/ نبات، والطول الفعال للنبات، بالإضافة إلى نسبة الزيت بالبذور والأحماض الدهنية المكونة لهذا الزيت، وهي البالمتيك والاستياريك والأولييك واللينولييك واللينولينيك وذلك من خلال دراسة وراثية على ستة عشائر، تم تكوينها من التهجين بين الصنف المصري: جيزة - ٨ والصنف الهولندي فايكينج Viking، وهي عشائر الأب الأول، والأب الثاني، والجيل الأول، والهجين الرجعي الأول، والهجين الرجعي الثاني، والجيل الثاني خلال السنوات من ١٩٩٨/ ١٩٩٩م وحتى ٢٠٠٢/ ٢٠٠٣م في الإسكندرية - جمهورية مصر العربية. وقد أوضحت نتائج البحث أن التباينات الوراثية كانت معنوية لجميع الصفات التي درست، والتباين الوراثي المضيف كون الجزء الأكبر من التباين الوراثي، وكان له الفعل الأكبر في وراثة محصول البذور/ نبات، وعدد الثمار/ نبات، في حين أن صفة الطول الفعال للنبات تحكم في وراثتها كلٌ من الفعل الوراثي المضيف، والفعل الوراثي السيادي. وقد تحكم الفعل الوراثي المضيف في وراثة نسبة الزيت وكذلك الحامض الدهني لينولينيك، في حين أن الفعل الوراثي السيادي كان الأكثر تأثيراً في التحكم في وراثة الأحماض الدهنية البالمتيك والاستياريك والأولييك واللينولييك.

وكانت قيم درجة التوريث بمعناها الواسع لصفات محصول البذور/ نبات، عدد الثمار/ نبات، والطول الفعال للنبات، ونسبة الزيت ٧٢,٩١٪، و٧٥,٧٦٪، و٣٣,٧١٪، و٩٧,٨٧٪ على الترتيب، في

حين كانت للأحماض الدهنية ٤٠ , ٦٩٪، و٩٠ , ٨٣٪، و٨٠ , ٩٢٪، و٣٨ , ٨٥٪، و٦٠ , ٨٩٪ لأحماض البالمتيك، والاستياريك، والأولييك، واللينولييك ، واللنيولينيك على الترتيب. بينما كانت درجة التوريث بمعناها الضيق كالأتي: ٦٥ , ٨٣٪، و٧٩ , ٥٧٪، و٢٨ , ٣٧٪، و٧٥٪ لصفات محصول البذور/ نبات، عدد الثمار/ نبات، الطول الفعال للنبات، ونسبة الزيت على التوالي، بينما كانت للأحماض الدهنية كالآتي: ٧٠ , ٢٢٪، و٦٧ , ٢٦٪، و٦٤ , ٣٢٪، و٢٨ , ٣٢٪، و٣٦ , ٥٦٪ لأحماض البالمتيك ، والاستياريك ، والأولييك ، واللينولييك واللينولينيك على الترتيب.

وكانت القيم المتنبأ بها للعائد المتوقع نتيجة للانتخاب هي: ٠٥ , ٩٣٪، و ٩٥ , ٣٥٪، و ٩٠ , ١٠٪، و ٣٢ , ١٠٪، و ٧٢ , ٧٪، و ٠١ , ٩٪، و ٤٨ , ١٣٪، و ٠٤ , ١١٪، و٥٣ , ٢٥٪ لصفات محصول البذور/ نبات، وعدد الثمار/ نبات، والطول الفعال للنبات، ونسبة الزيت والأحماض الدهنية البالمتيك والاستياريك والأولييك واللينولييك واللينولينيك على التوالي.