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Inheritance of fatty acid content and related quality traits in groundnut, *Arachis hypogaea* L.

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Abstract

Groundnut is a rich source of edible oil. The fatty acid composition of the endogenous fats plays an important role in determining the shelf life, nutrition and flavor of groundnut. Gene action involved in the fatty acid composition (palmitic acid, stearic acid, oleic acid, linoleic acid, arachidic acid, eicosenoic acid, behenic acid and lignoceric acid) and quality parameters (Oleic/linoleic fatty acid ratio (O/L ratio), iodine value (IV), total saturated fatty acids, polyunsaturated / saturated fatty acid ratio (P/S)) and total long chain saturated fatty acids (TLCSFA)) were studied in three crosses in groundnut. Generation means analysis for all the traits indicated that additive and additive × additive gene actions played predominant role in controlling the fatty acid content and quality parameters. In addition to additive and additive × additive gene actions, dominance and additive × dominance gene action were also important in explaining variation for IV and P/S ratio. The choice of a suitable breeding procedure depends upon the relative magnitude of different gene effects and an understanding of the mode of inheritance of some complex quantitative characters. The additive and additive × additive components of genetic variation are fixable in groundnut. Oleic acid content, O/L ratio and IV are predominantly under the control of additive gene action; hence selection for these traits can be practiced in early generations.

Key words: Iodine value, O/L ratio, P/S fatty acid ratio, generation means analysis, gene action

Introduction

Groundnut (*Arachis hypogaea* L.) is the fourth most important source of edible oil and third most important source of vegetable protein in the world (FAO, 2007). About two-thirds of the produce is crushed for oil and the remaining one-third is used for confectionery purposes. Groundnut makes an important contribution to the human diet and its wide spread acceptability is attributed to its economic value to the industry and nutritional benefits to the consumers. The presence of groundnuts and its products in the diet reduces the risk of heart disease by 21% (O'Bryne *et al.*, 1997). A groundnut seed contains approximately 50% of its weight as oil. Oleic acid, a monounsaturated acid, and linoleic acid, a polyunsaturated fatty acid account for 75-80% of the total fatty acids in the groundnut oil (Mercer *et al.*, 1990; Ahmed and Young, 1982). The fatty acid composition of the endogenous fats plays an important role in determining the shelf life, nutrition and flavor of groundnut. Groundnut oil varies both in quantity and relative proportion of fatty acids. Although up to 12 fatty acids have been reported in groundnut, generally palmitic acid (16:0) constitutes nearly 10%, and the oleic (18:1) and linoleic acid (18:2) proportions together make up 80% of the fatty acid composition in groundnut (Ahmed and Young, 1982). Oleic (O)/linoleic acid (L) acid ratio and iodine value (IV) are both the indicators of stability and shelf life in groundnut products (James *et al.*, 1983; Branch *et al.*, 1990).

Earlier investigations indicated that the fatty acid content of groundnut is quantitatively inherited; predominance of additive gene action was reported by Khan *et al.* (1974); Moore and Knauft (1989); Mercer *et al.* (1990); Knauft *et al.* (1993); while significance of both additive and non-additive gene action was reported by Tai and Young (1975) and Bansal *et al.* (1992 and 1993). In two high oleic and low linoleic natural mutant breeding lines (Norden *et al.*, 1987), the genetic control of high O/L ratio was reported to be under the control of duplicate recessive alleles (Moore and Knauft, 1989) and in addition to these, there are modifiers and epistatic interactions governing the trait (Isleib *et al.*, 2006). The present study aims at providing a better understanding of the inheritance pattern and magnitude of gene action governing different fatty acid composition and quality related traits in three different crosses. This knowledge would further help in targeted breeding for different fatty acid content and in modifying the fatty acid composition suiting to different uses and needs.

Material and methods

The experimental material consisted of parents, F_1, F_2 and back cross generations of three crosses, Cross 1 : ICGV 88438 × ICGV 88448 (ICGV 88438 is a large-seeded breeding line derived from two germplasm lines, GP NC 343 and NC 17367, and ICGV 88448 is a large-seeded interspecific derivative from a cross between *A. hypogaea* and *A. cardenesii,* developed at North Carolina State University); Cross 2 : ICGV 96234 × Hard Kernel Mutant (ICGV 96234 is a chemically (ethyl methyl sulphonate) induced mutant from ICGV 88448 developed at ICRISAT (Dwivedi *et al.*, 1998) with O/L ratio of >2.0 and Hard Kernel Mutant was isolated (Chandramouli and Kale, 1990) after 200 Gy treatment of TG 18A; and Cross 3: ICGV 96234 × JL 24 (JL 24, a selection from EC 94943 is a popular cultivar in India and is also known as Phule Pragati).

The experimental material (P_1, P_2, F_1, F_2, BC_1P_1 and BC_1P_2) in each cross was planted on 60 cm ridges in a Randomized Block Design with two replications during the 1999 rainy season in Alfisols at the International Crops Research Institute for the semi-Arid Tropics (ICRISAT, 17° 30′ N; 78° 16′ E; altitude 549 m), Patancheru. In each cross, two rows for each of the parents, a single row each for F_1, BC_1P_1 and BC_1P_2 and 20 rows for F_2, each of 4 m length, were grown. The distance between plants within a row was maintained at 10 cm with a uniform seed depth of 5 cm. The trial received 375 kg/ha of single super phosphate before sowing and was protected against foliar diseases and insect pests during the cropping period, and kept weed-free through manual weeding. Individual plants were harvested in each plot at the time of maturity. Five gram of sound mature kernels (8% seed moisture) from each plant in each generation was used for estimating the fatty acid content as per the procedure described by Mercer *et al.* (1990). From the fatty acid estimation, five quality parameters, iodine value (IV), oleic (O)/linoleic (L) fatty acid ratio, total saturated fatty acids (TSF), polyunsaturated (P)/saturated (S) fatty acid ratio, and total long chain fatty acids (TLCSF), were determined as described by Mozingo *et al.* (1988). The statistical analyses were performed using Genstat 8th Edition (GenStat, 2005). The means and variances from individual plant data on fatty acids and quality parameters were estimated for every generation and estimates of genetic effects were determined. A joint scaling test (Cavalli, 1952) was conducted to estimate the genetic components and digenic interaction among these components, *viz.*, *m* (mean), *d* (pooled additive effects), *h* (pooled dominance effects), *I* (the pooled additive × additive epistatic effects), *j* (the pooled additive × dominance effects) and *l* (the pooled dominance × dominance effects). Subsequently, the stepwise regression analysis was done to find the best fit model as per Torres *et al.* (1993). In addition to the three-parameter model, epistatic interactions were also studied to explain the variation. For this purpose, a six-parameter model was fitted to the generation means. This model was tested for goodness of fit by the chi-square test to determine if linkage in the higher order interactions was present (Mather and Jinks, 1982). Contribution made by each parameter in explaining the variation for a trait was calculated using the sum of squares.

Results and discussion

The quality of the edible groundnuts is principally due to the chemical composition of the oil, protein, and carbohydrate fractions of the seed. Since fatty acids make up the major portion of the weight of an oil molecule, the physical and chemical properties of the oil tend to be determined by the properties of the fatty acids which predominate in their makeup. Parents in all the three crosses differed significantly from each other for the palmitic, stearic, oleic and linoleic acids but variation between parents for arachidic, eicosenoic, behenic and lignoceric acid contents was non-significant. Significant differences were also observed between the parents in all the three crosses for O/L ratio, IV and TSF but the differences for P/S fatty acid ratio and TLCSF were non-significant (Table 1). The F_1 mean for all the traits except for behenic acid in ICGV 88438 × ICGV 88448 and ICGV 96234 × Hard Kernel Mutant fell between the two parents. The F_2 population in all the three crosses showed continuous variation in fatty acid content. Continuous variation for fatty acid content among the groundnut genotypes has been well documented (Khan *et al.*, 1974; Tai and Young, 1975; Norden *et al.*, 1987; Mercer *et al.*, 1990; Lopez *et al.*, 2001, 2002).

Estimates of different genetic parameters and their significance in three crosses are presented in Table 2. Generation means analysis for all the quality traits indicated that additive gene action was the major component; while dominance and epistatic interactions were also significant for some traits. The oleic and linoleic acid contents were controlled by additive gene action (Table 2 and 3). The O/L ratio in all the three crosses was controlled by additive gene action (Table 2) and the direction of the gene effect was consistent towards increasing the O/L ratio. The additive effect accounted for 43%, 83% and 96%, respectively, of the total genetic variation in all three crosses. In ICGV 88438 × ICGV 88448, in addition to the additive effects, additive x additive epistatic interaction (accounting for 43%), which is genetically fixable in groundnut, was also significant (Table 3). The O/L ratio is a measure of oil stability and can be easily manipulated in a breeding program (Young and Waller, 1972; Tai, 1972; Khan *et al.*, 1974; Tai and Young, 1975; Worthington and Hammons, 1977). There is a negative correlation between the percentage of oleic and linoleic acids (Norden *et al.*, 1987; Moore and Knauft, 1989; Mercer *et al.*, 1990), since linoleic acid is produced from the conversion of oleic acid (Mozingo and Steele, 1982). Thus, selection for high O/L ratio is relatively straight forward because selection of genotypes with high oleic acid results in lower levels of linoleic acid. The quantitative inheritance of O/L ratio and presence of epistatic interactions was also confirmed by Khan *et al.* (1974); Tai and Young (1975); Moore and Knauft (1989) and Knauft *et al.*, 1993. High heritability estimates of the

O/L fatty acid ratio were also reported by Tai (1972). Increase in the oleic acid content is much easier to achieve using two high oleic fatty acid mutant lines where the trait is governed by two recessive genes (Norden *et al.*, 1987; Moore and Knauft, 1989; Isleib *et al.*, 2006). Since there is a positive correlation between the oil content and O/L ratio (Dwivedi *et al.*, 1993), it should be possible to improve oil content and oil stability (through O/L ratio) simultaneously.

Iodine reacts readily with the double bonds of oil/fat molecule and the quantity of iodine absorbed by oil is an index of its degree of unsaturation. Low iodine number implies the presence of few unsaturated bonds and hence low susceptibility to oxidative rancidity. Iodine value was predominantly under the control of additive gene action, which accounted for 90% and 98% of the genetic variance in crosses ICGV 96234 × Hard Kernel Mutant and ICGV 96234 × JL 24, respectively. In ICGV 88438 × ICGV 88448, along with additive gene action (accounting for 30% of the variation), additive × additive (accounting for 23%) and additive × dominance (accounting for 25%) interactions were also significant (Table 2 and 3). The direction of the additive genetic effects (-0.8 ± 0.14; -3.0 ± 0.40 and -3.6 ± 0.23) in all the three crosses was consistent towards decreasing the iodine number (Table 2). Higher O/L ratio and lower IV generally suggest better stability and longer shelf life of groundnut oil (Mercer *et al.*, 1990).

Groundnut storage qualities and nutritional quality are both dependent on the relative proportions of the saturated and unsaturated fatty acids that make up the oil. The total amount of unsaturation is inversely proportional to the keeping quality of the oil, oxidative rancidity increases with increased level of the polyunsaturated fatty acids which cause associated odours and flavors (St. Angelo and Ory, 1973). The P/S fatty acid ratio in crosses ICGV 96234 × Hard Kernel Mutant and ICGV 96234 × JL 24 was under the control of additive gene action (which accounted for 87% of the variation in ICGV 96234 × Hard Kernel Mutant and 96% in ICGV 96234 × JL 24). In ICGV 88438 × ICGV 88448, in addition to the additive gene action (contributing to 23% of genetic variation), dominance gene action (30%) and additive x dominance (26%) interaction were also significant (Table 2 and 3). Though the heritable additive genetic effects can be fixed in groundnut, variance due to dominance and their interaction effects cannot be exploited due to self pollinating nature of the crop.

Palmitic, stearic, arachidic, behenic and lignoceric acids together form the total saturated fatty (TSF) acids in groundnut. The TSF and individual saturated fatty acids were under the control of additive gene effects in all the three crosses (Table 2 and 3). The direction of the effects was consistently towards decreasing the TSF, which is a desirable quality trait. The later three saturated fatty acids are the undesirable long chain saturated fatty acids (LCSFA) (20-24 carbons: arachidic, behenic and lignoceric acids) (Treadwell *et al.*, 1983). These fatty acids have been shown to comprise 4-9% of the total composition (Worthington and Hammons, 1977). These LCSFA together and also individually were controlled by additive gene action and additive × additive interactions in all the three crosses. In addition to the above gene actions, for arachidic acid in ICGV 88438 × ICGV 88448 and behenic acid in ICGV 96234 × Hard Kernel Mutant, dominance × dominance type of epistatic interactions were also significant (Table 2 and 3).

Significant positive correlations also have been reported between the arachidic and behenic acids (Dwivedi *et al.*, 1993). The additive × additive interaction for LCSFA was also reported by Upadhyaya and Nigam (1999). Eicosenoic acid content was under the control of additive × additive and dominance × dominance type of inter-allelic interactions in ICGV 88438 × ICGV 88448, while the former was predominant in ICGV 96234 × Hard Kernel Mutant, only additive interaction was predominant in ICGV 96234 × JL 24. Presence of inter-allelic additive × dominance interactions could be specific to ICGV 88438 × ICGV 88448 (Table 2). As LCSFA are not desirable for health, genotypes with less content of these would be preferred.

The fatty acid composition and content in groundnut is influenced by environment, season and also the location and geographic area of production in addition to planting date, market grade and genotype (Mohamed-Som, 1984; Mozingo and Steele, 1982; Mozingo *et al.*, 1988, Treadwell *et al.*, 1983, Young and Worthington, 1974). Bovi (1982) observed a negative correlation between IV and soil temperature and suggested that the chemical composition of groundnut oil could be altered by adjusting the planting date. Environment was found to interact more strongly with epistatic interaction than with the additive or dominance gene action (Upadhyaya and Nigam, 1999). As this study was conducted only in one season, it does not account for genotype x environment interaction.

In a self pollinating crop, the additive and additive × additive genetic variance can be fixed in homozygous cultivars by following appropriate selection strategies. As oleic acid content, O/L ratio and IV are predominantly under the control of additive gene action, the selection for these traits can be practiced in early generations. Where additive × additive interactions are predominant, large populations should be carried forward to later generations to allow favorable combinations to come in a homozygous state before practicing selection.

Table 1 **Means and standard errors (SE) of fatty acid contents and quality traits in parents, their F_1, F_2, B_1 (F_1 x P_1) and B_2 (F_1 x P_2) in three different crosses**

	ICGV 88438 (P_1) x ICGV 88448 (P_2)	ICGV 96234 (P_1) x Hard Kernel Mutant (P_2)	ICGV 96234 (P_1) x JL 24 (P_2)
Traits	Mean ± SE	Mean ± SE	Mean ± SE
(1)	(2)	(3)	(4)
Palmitic acid			
P_1	9.95 ± 0.06	9.94±0.11	10.29±0.15
P_2	11.21 ± 0.27	13.96±0.14	12.86±0.11
F_1	10.50 ± 0.13	12.19±0.21	11.93±0.21
B_1	8.92 ± 0.25	11.02±0.20	10.94±0.11
B_2	10.42 ± 0.14	11.17±0.24	12.10±0.22
F_2	10.11±0.06	11.39±0.08	11.97±0.08
Stearic acid			
P_1	3.13±0.20	3.31±0.20	2.60±0.13
P_2	2.90±0.17	2.23±0.13	3.05±0.17
F_1	3.08±0.18	3.10±0.18	3.24±0.23
B_1	3.23±0.23	2.96±0.25	3.29±0.27
B_2	3.15±0.20	2.67±0.17	3.55±0.21
F_2	3.02±0.06	2.60±0.04	3.09±0.06
Oleic acid			
P_1	53.13±0.29	53.25±0.46	53.09±0.61
P_2	49.77±1.28	41.36±1.15	37.47±0.26
F_1	51.65±0.54	43.46±0.57	44.15±0.97
B_1	52.68±0.93	49.00±0.72	46.69±0.58
B_2	52.01±0.59	47.27±0.94	40.84±0.97
F_2	52.34±0.25	48.21±0.22	43.68±0.37
Linoleic acid			
P_1	26.08±0.34	25.27±0.26	26.04±0.42
P_2	28.74±0.73	34.68±0.98	38.02±0.28
F_1	27.31±0.34	32.82±0.47	32.70±0.73
B_1	26.76±0.58	28.60±0.40	30.48±0.47
B_2	26.51±0.36	30.36±0.89	34.88±0.82
F_2	26.44±0.17	29.71±0.16	32.64±0.30
Arachidic acid			
P_1	1.49±0.06	1.58±0.04	1.40±0.05
P_2	1.42±0.06	1.16±0.06	1.44±0.07
F_1	1.49±0.05	1.53±0.07	1.45±0.06
B_1	1.66±0.07	1.48±0.07	1.49±0.06
B_2	1.56±0.06	1.38±0.07	1.57±0.06
F_2	1.53±0.02	1.30±0.02	1.49±0.02
Eicosenoic acid			
P_1	1.19±0.04	1.20±0.05	1.31±0.04
P_2	1.11±0.05	1.13±0.04	1.07±0.04
F_1	1.12±0.04	1.03±0.03	1.11±0.03
B_1	1.12±0.03	1.19±0.04	1.23±0.03
B_2	1.17±0.03	1.23±0.03	1.05±0.04
F_2	1.19±0.01	1.22±0.01	1.15±0.01

Behenic acid			
P_1	3.68±0.06	3.83±0.06	3.77±0.14
P_2	3.61±0.23	3.81±0.14	4.42±0.07
F_1	3.73±0.09	4.21±0.13	4.09±0.09
B_1	3.93±0.11	4.16±0.10	4.26±0.10
B_2	3.88±0.08	4.05±0.09	4.40±0.09
F_2	3.94±0.04	3.83±0.03	4.35±0.04
Lignoceric acid			
P_1	1.30±0.10	1.59±0.06	1.46±0.16
P_2	1.23±0.10	1.65±0.07	1.68±0.10
F_1	1.07±0.07	1.65±0.03	1.42±0.09
B_1	1.60±0.04	1.61±0.05	1.61±0.10
B_2	1.28±0.07	1.80±0.05	1.60±0.06
F_2	1.46±0.02	1.71±0.01	1.64±0.03
O / L ratio			
P_1	2.04±0.04	2.11±0.04	2.05±0.06
P_2	1.75±0.08	1.21±0.08	0.99±0.01
F_1	1.90±0.04	1.33±0.03	1.38±0.07
B_1	2.00±0.07	1.73±0.05	1.54±0.04
B_2	1.98±0.05	1.60±0.08	1.20±0.06
F_2	2.01±0.02	1.64±0.02	1.37±0.03
Iodine value (IV)			
P_1	91.80±0.41	90.51±0.28	91.80±0.28
P_2	93.46±0.23	96.53±0.71	98.92±0.34
F_1	92.61±0.32	95.04±0.55	95.49±0.55
B_1	92.55±0.43	92.62±0.32	6.33±0.43
B_2	91.57±0.26	94.20±0.79	96.36±0.66
F_2	91.74±0.14	93.87±0.14	95.00±0.22
Total saturated fatty acids (TSF)			
P_1	19.55±0.19	20.25±0.29	19.52±0.24
P_2	20.37±0.56	22.81±0.25	23.45±0.18
F_1	19.87±0.32	22.69±0.38	22.13±0.33
B_1	19.34±0.46	21.23±0.43	21.58±0.27
B_2	20.30±0.29	21.06±0.26	23.21±0.30
F_2	20.06±0.11	20.83±0.10	22.54±0.13
Polyunsaturated / Saturated fatty acid ratio (P/S)			
P_1	1.34±0.03	1.25±0.02	1.33±0.02
P_2	1.41±0.01	1.52±0.03	1.62±0.02
F_1	1.41±0.01	1.45±0.03	1.48±0.03
B_1	1.39±0.03	1.35±0.02	1.42±0.03
B_2	1.31±0.02	1.44±0.04	1.50±0.03
F_2	1.32±0.01	1.43±0.01	1.45±0.01
Total long chain saturated fatty acid (TLCSF)			
P_1	6.47±0.11	7.00±0.11	6.63±0.24
P_2	6.26±0.27	6.62±0.15	7.54±0.09
F_1	6.28±0.12	7.39±0.18	6.95±0.15
B_1	7.19±0.18	7.25±0.17	7.35±0.18
B_2	6.72±0.13	7.23±0.13	7.57±0.14
F_2	6.93±0.06	6.85±0.04	7.47±0.06

IV = (%oleic acid)(0.8601)+(%linoleic acid)(1.7321)+(%eicosenoic acid)(0.7854); TSF = palmitic acid + stearic acid + arachidic acid + behenic acid + lignoceric acid; P/S = linoleic acid / TSF; TLCSF = arachidic acid + Behenic acid + lignoceric acid

Table 2 Estimates of different genetic parameters using six parameter model for different fatty acid content in cross 1: ICGV 88438 x ICGV 88448; 2 : ICGV 96234 x Hard Kernel Mutant and cross 3 : ICGV 96234 x JL 24

Trait	Mean (m)	additive (d)	dominance (h)	additive x additive (I)	additive x dominance (j)	dominance x dominance (l)
Palmitic acid						
Cross 1	11.8±0.65**	-0.6±0.14**	-5.5±1.89*	-1.2±0.63	-1.2±0.66	4.2±1.27**
Cross 2	13.1±0.59**	-2.0±0.11**	-5.4±2.06*	-1.1±0.71	3.5±0.68**	4.1±1.43
Cross 3	13.5±0.57**	-1.3±0.09**	-4.5±1.59*	-1.9±0.56**	0.4±0.51	2.9±0.65*
Stearic acid						
Cross 1	2.6±0.67**	0.1±0.009	1.2±1.95	0.4±0.66	-0.3±0.65	-0.8±1.34
Cross 2	2.3±0.59**	0.6±0.11**	0.4±1.73	0.4±0.58	-0.2±0.59	0.1±1.22
Cross 3	1.7±0.69*	-0.2±0.10*	4.2±2.02*	1.2±0.69*	0.06±0.67	-2.6±1.40*
Oleic acid						
Cross 1	50.2±2.64**	1.7±0.68	7.3±7.68	1.2±2.55	-0.6±2.74	-5.9±5.18
Cross 2	47.9±2.69**	5.9±0.61**	4.8±7.86	-0.6±2.62	-7.6±2.76*	-8.7±5.37
Cross 3	44.5±2.73**	7.8±0.32**	-2.9±7.56	0.8±2.71	-4.3±2.36	2.6±5.23
Linoleic acid						
Cross 1	27.6±1.62**	-1.3±0.39**	-4.5±4.64	-0.2±1.57	2.0±1.63	4.2±3.12
Cross 2	30.0±2.14**	-4.7±0.51**	-4.2±6.30	-0.02±0.08	4.8±2.23	7.3±4.33
Cross 3	32.1±2.28**	-5.9±0.26**	1.6±6.37	-0.1±2.27	3.4±2.01	-0.1±4.36
Arachidic acid						
Cross 1	1.2±0.21**	0.04±0.03	1.05±0.59	0.3±0.20	0.08±0.19	-0.8±0.14
Cross 2	1.04±0.19**	0.2±0.03**	0.6±0.57	0.3±0.19	-0.1±0.19	-0.3±0.40
Cross 3	1.3±0.18**	-0.02±0.02	0.6±0.53	0.1±0.18	-0.08±0.17	-0.5±0.36
Eicosenoic acid						
Cross 1	1.3±0.09**	0.04±0.03	-0.4±0.29	-0.2±0.09*	-0.2±0.10	0.1±0.21
Cross 2	1.1±0.12**	0.04±0.03	0.4±0.33	0.03±0.11	-0.2±0.12	-0.5±0.23*
Cross 3	1.2±0.10**	0.1±0.02**	-0.2±0.28	-0.03±0.09	0.08±0.09	0.06±0.19
Behenic acid						
Cross 1	3.9±0.35**	0.04±0.12	0.1±0.99	-0.3±0.32	-0.2±0.38	-0.4±0.68
Cross 2	2.9±0.29**	0.01±0.07	2.8±0.87**	0.9±0.29**	0.3±0.29	-1.7±0.64*
Cross 3	4.2±0.32**	-0.3±0.06**	0.7±0.89	-0.1±0.31	0.4±0.29	-0.8±0.60
Lignoceric acid						
Cross 1	1.5±0.15**	0.04±0.03	0.3±0.43	-0.2±0.15	0.4±0.15*	-0.6±0.28*
Cross 2	1.5±0.12**	-0.03±0.03	0.6±0.34	0.1±0.12	-0.4±0.12*	-0.4±0.23
Cross 3	1.6±0.12**	-0.1±0.03**	0.2±0.34	-0.05±0.12	0.18±0.11	-0.3±0.23
O/L ratio						
Cross 1	1.9±0.20**	0.2±0.04**	0.6±0.58	0.02±0.19	-0.1±0.20	-0.5±0.39
Cross 2	1.6±0.21**	0.5±0.04**	0.3±0.62	0.04±0.21	-0.6±0.21*	-0.60±0.42
Cross 3	1.5±0.18**	0.5±0.03**	-0.4±0.51	0.20±0.02	-0.4±0.17*	0.3±0.35
Iodine value (IV)						
Cross 1	92.0±1.20**	-0.8±0.14**	-1.7±3.41	0.6±1.19	2.9±1.10*	2.4±2.32
Cross 2	94.1±1.78**	-3.0±0.40**	-2.8±5.23	-0.6±1.74	1.7±1.83	4.8±3.65
Cross 3	94.8±1.87**	-3.6±0.23**	0.1±5.27	0.6±1.85	2.2±1.69	0.6±3.59
TSF						
Cross 1	21.0±1.33**	-0.4±0.29	-2.9±3.88	-1.1±1.29	-1.3±1.36	1.7±2.65
Cross 2	20.9±1.08**	-1.3±0.18**	-0.9±3.16	0.7±1.07	3.1±1.06*	1.9±2.19
Cross 3	22.3±0.94**	-1.9±0.14**	1.2±2.58	-0.8±0.93	0.9±0.82	-1.4±1.78
P/S ratio						
Cross 1	1.3±0.08**	-0.0±0.01**	-0.02±0.24	0.06±0.08	0.2±0.08	0.1±0.16
Cross 2	1.4±0.09**	-0.1±0.02**	-0.1±0.29	-0.04±0.09	0.01±0.09	0.2±0.20
Cross 3	1.4±0.09**	-0.2±0.01**	0.03±0.28	0.05±0.09	0.1±0.09	0.03±0.19
TLCSF						
Cross 1	6.6±0.53**	0.1±0.15	1.5±1.52	-0.3±0.51	0.3±0.55	-1.9±1.02
Cross 2	5.4±0.46**	0.2±0.08*	4.0±1.35*	1.4±0.46*	-0.2±0.45	-2.3±0.97*
Cross 3	7.1±0.48**	-0.5±0.08**	1.5±1.33	-0.04±0.47	0.5±0.43	-1.6±0.91

IV = (%oleic acid)(0.8601)+(%linoleic acid)(1.7321)+(%eicosenoic acid)(0.7854); TSF = palmitic acid + stearic acid + arachidic acid + behenic acid + lignoceric acid; P/S = linoleic acid / TSF; TLCSF = arachidic acid + Behenic acid + lignoceric acid ; ** - significant at 1% and * - significant at 5% level

Table 3 Per cent phenotypic variation explained for each trait in cross 1: ICGV 88438 x ICGV 88448; Cross 2 : ICGV 96234 x Hard Kernel Mutant and cross 3 : ICGV 96234 x JL 24

Trait	d	h	I	j	l
Palmitic acid					
Cross 1	44.76	2.93	28.06	-	23.00
Cross 2	88.91	2.63	-	5.08	1.85
Cross 3	92.97	2.24	2.22	-	2.50
Stearic acid					
Cross 1	55.77	-	-	24.18	15.46
Cross 2	88.51	-	-	-	-
Cross 3	63.05	23.96	-	-	-
Oleic acid					
Cross 1	74.69	-	13.66	-	-
Cross 2	83.05	-	-	2.50	-
Cross 3	97.77	-	-	-	-
Linoleic acid					
Cross 1	43.83	-	31.67	14.52	-
Cross 2	91.09	-	-	0.51	-
Cross 3	98.77	-	-	-	-
Arachidic acid					
Cross 1	-	33.95	-	-	35.68
Cross 2	87.76	-	-	-	-
Cross 3	1.93	41.96	-	-	-
Eicosenoic acid					
Cross 1	-	-	54.62	37.90	-
Cross 2	-	-	55.63	-	-
Cross 3	88.49	-	-	-	-
Behenic acid					
Cross 1	35.27	-	60.78	-	-
Cross 2	-	9.53	27.82	-	57.83
Cross 3	53.88	-	-	-	-
Lignoceric acid					
Cross 1	-	25.29	54.93	8.06	3.47
Cross 2	40.12	-	-	23.66	-
Cross 3	41.18	-	37.19	-	-
O/L ratio					
Cross 1	43.37	-	43.08	-	-
Cross 2	83.43	-	-	1.50	-
Cross 3	96.34	-	-	1.31	-
Iodine value					
Cross 1	29.70	-	22.87	25.43	-
Cross 2	90.91	-	-	-	-
Cross 3	98.69	-	-	-	-
TSF					
Cross 1	91.63	-	-	-	-
Cross 2	67.80	-	-	14.97	-
Cross 3	84.89	-	-	-	-
P/S ratio					
Cross 1	23.16	30.36	-	26.03	-
Cross 2	87.28	-	-	-	-
Cross 3	96.32	-	-	-	-
TLCSFA					
Cross 1	-	-	85.15	-	-
Cross 2	20.26	9.47	27.59	-	36.57
Cross 3	55.62	-	-	-	-

Iodine number (IV)= (%oleic acid)(0.8601) + (%linoleic acid)(1.7321)+(%eicosenoic acid)(0.7854); Total Saturated Fatty acids (TSF) = palmitic acid + stearic acid + arachidic acid + behenic acid + lignoceric acid; Polyunsaturated / Saturated fatty acids ratio (P/S) = linoleic acid / TSF; Total long chain saturated fatty acids (TLCSF) = arachidic acid + Behenic acid + lignoceric acid

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