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Original Research Article

Genetic Analysis of Oil and Protein Contents in Groundnut (*Arachis hypogaea* L.)

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Abstract

Eight groundnut genotypes were crossed in half diallel fashion without reciprocals to study the combining ability, gene action, heterosis, character association and path coefficient analysis in respect of oil and protein content. The mean squares due to gca and sca variances were significant for both oil and protein content. The magnitude of mean squares due to gca was more than that of sca for both the characters in kharif, 2009. In rabi, 2009 mean square due to gca was greater than that of sca for oil content. The F_1, TIR-25 × K-1375 recorded the highest significant positive relative heterosis, heterobeltiosis and JL-220 × K-1375 showed significant standard heterosis during *kharif*. In *rabi*, the F_1, JL-220 × K-1375 recorded highest significant relative heterosis, ICGV-91114 × ICGV-99029 had exhibited highest significant positive heterobeltiosis, and JL-220 × TCGS-647 significant standard heterosis with positive inbreeding depression indicating the importance of additive gene action in expression of this character. Low to moderate heritability values and low genetic advance as per cent of mean were obtained for both oil and protein content indicating the preponderance of non-additive gene action in inheritance of these characters. The relationship between oil and protein contents was negative non significant in parents but significant positive association in F_1s and negative significant association in F_2 generation. The path analysis revealed that during kharif and rabi, in F_1generation, the oil content had a positive indirect effect through protein content.

Keywords

Character association
Combining ability
Genetic variability
Groundnut
Heterosis
Path analysis

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the chief sources of vegetable oils extensively used for cooking purposes around the world. In Indian cultivated groundnut varieties it ranges from 47 to 54.6% (Bishi et al., 2013). Likewise, the protein content in groundnut kernels varies from 22-36% depending on cultivar, location, season, seed maturity and agronomic practices. Average protein content is higher than that of eggs, dairy products, meat and fish and the digestibility of groundnut protein is very high (Singh and Singh, 1991). Kernel protein is an important factor affecting seed quality and thus a key determinant of both end use and market value in confectionery groundnut (Wang et al., 2011 and Atasie et al., 2009). The nuts are crushed to remove the kernels that provide digestible protein, cooking oil, a significant source of animal feed and important raw materials for many industrials products (Jambunathan et al., 1985). Peanut kernels are eaten fresh or roasted, used in cookery, confectionery, and about 47% of the produce is crushed for edible oil (Jambunathan et al., 1985; Rajgopal et al., 2000; Wang et al., 2001).

The groundnut seeds are particularly valued for its protein content, which is well balanced and thus constitute a nutritious food for growing children and pregnant women (Atasie et al., 2009; Ajay et al., 2012). Peanut oil is high in energy, has very good lipid profile with saturated, monounsaturated and polyunsaturated fats in healthy proportions (Ajay et al., 2012). Information on the genetic control of these traits is important for initiating a breeding programme. Therefore, the present investigation was taken up to study the genetic nature of oil and protein content in groundnut.

Materials and methods

The material for the present study comprised of parents, F_1 and F_2 generations of crosses involving eight parents *viz.*, Tirupati-4, TIR-25, ICGV-91114, TCGS-584, JL-220, ICGV-99029, K-1375 and TCGS-647. Eight parents were crossed in a half-diallel manner to generate 28 crosses during *rabi* 2008. One more set of F_1s were produced during *kharif* 2009 for conducting simultaneous evaluation of F_1 and F_2 generations during *rabi* 2009. Emasculation and pollinations were done as per the procedure outlined by Norden (1973).

Experiment – 1

Twenty eight F_1s along with eight parents were sown in a Randomised Block Design (RBD) with three replications during *kharif* 2009. Each parent was sown in 3 rows of 3 m length while F_1s were raised in a single row of 3 m length. All the 28 treatments were allotted at random to the experimental plots in each replication. Observations were recorded on ten random plants in each treatment per replication.

Experiment -2

Twenty eight F_1s (generated during *kharif* 2009), as well as their F_2 populations (obtained from experiment 1) along with their eight parents were grown in a RBD with 3 replications during *rabi* 2009. All the 64 treatments were randomized in each replication. Each F_1 was raised in a single row of 3 m length while parents and F_2s were raised in 3 rows of 3 m length. Ten random plants per replication were sampled in case of parents and F_1s, while 20 plants per replication were tagged at random in each F_2 population for recording observations.

The experiment was conducted in a red sandy loam soil with a neutral pH, low in organic carbon. Recommended agronomic and plant protection measures were adopted for the conduct of experiment. The data were recorded for oil per cent and protein per cent.

Statistical analysis

The data collected on sampled plants in all the entries in different replications were averaged (replication wise) and mean values were subjected for statistical analysis. The combining ability analysis was carried out according to Model I and Method II of Griffing (1956). The fixed effect model (Model I) was considered to be more appropriate in the present investigation since the study was restricted to the parents and direct crosses only. By taking square roots of the variances, the corresponding standard errors required for testing were obtained.

Heterosis over mid parent (relative heterosis) better parent (heterobeltiosis) and standard parent (standard heterosis) in F_1 generation and inbreeding depression from F_1 to F_2 in each cross were estimated for vegetative characters using standard formulae. The phenotypic and genotypic coefficients of variations were computed according to Burton (1952). The heritability in broad sense was computed as suggested by Allard (1960) and genetic advance as percentage of mean as per Johnson et al. (1955). Genotypic and phenotypic correlation coefficients were calculated among the genotypes using the formulae suggested by Al-Jibouri et al. (1958). Path coefficient analysis was carried out by using phenotypic and genotypic correlation coefficients as per the method suggested by Dewey and Lu (1959).

Results and discussion

The analysis of variance for oil and protein contents for parents and F_1s (kharif, 2009); parents and F_1s (rabi, 2009) and parents and F_2s (rabi, 2009) are furnished in Table 1. During rabi, 2009 significant difference was observed for oil content only among eight parents, twenty eight F_1 s and F_2s.

Table 1. Analysis of variance (Mean squares) for oil and protein content in groundnut.

Character	Kharif 2009		Rabi 2009			
	8 parents and 28 F_1s		8 parents and 28 F_1s		8 parents and 28 F_2 s	
	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
Replications (d.f. = 2)	0.1285	0.2782	0.2648	0.1949	0.2196	0.0043
Treatments (d.f. = 35)	0.9304**	0.1891*	0.6814**	0.1127	06207**	0.1490
Error (d.f. = 70)	0.3995	0.1145	0.1560	0.0804	0.1253	0.0996

* Significant at 5 % level; ** Significant at 1 % level.

Per Se Performance

Parents and F_1s (*Kharif*, 2009)

The mean oil content ranged from 47.57% (TCGS-647) to 47.93% (K-1375) among the parents with a mean of 47.70 %. Three parents had higher oil content than parental mean. Among F_1s, JL-220 x TCGS-647 recorded the minimum (45.37%), while ICGV-91114 × K-1375 recorded maximum (48.07%) oil content with a general mean of 47.35%. Seventeen crosses exceeded the general mean of F_1s.

The protein content ranged from 26.03 (ICGV-99029) to 26.40% (ICGV-91114) among the parents with a mean of 26.22 %. Four parents had higher protein per cent than parental mean. Among F_1s, Tirupati-4 × TIR-25 recorded the minimum (25.63%), while TCGS-584 × K-1375 recorded maximum (26.73%) protein per cent with a general mean of 26.26%. Seventeen crosses exceeded the general mean of F_1s (Table 2).

Parents, F_1s and F_2s (*Rabi*, 2009)

Among parents, TCGS-647 recorded the lower mean oil content (46.83%) and TIR-25 exhibited the highest (48.31%). Six parental genotypes exhibited more mean oil content than parental general mean (47.77%). Among the F_1s, it ranged from 46.37% (ICGV-99029 × TCGS-647) to 48.47% (TIR-25 × JL-220) and fifteen F_1s exceeded the general mean (47.63%) of F_1s. Mean oil content ranged from 46.80% to 48.40% among the F_2 s with a general mean value of 47.63%. K-1375 × TCGS-647 and TIR-25 × ICGV-91114 recorded the lowest (46.0%) and highest (48.40%) mean oil content respectively. F_2 populations derived from fifteen crosses had higher oil per cent than general mean of F_2 populations.

The protein content, among the parental genotype, K-1375 (25.73%) recorded the lowest and JL-220 the highest protein content (26.30%) with the general mean of 26.16%. Six parents had higher protein content than parental mean. Protein content ranged from 26.07% to 26.67% among the F_1s with a general mean of 26.41%, which was surpassed by thirteen F_1s. The F_1, JL-220 × TCGS-647 had the highest protein content (26.67%) and it was lowest (26.07%) in TPT-4 × TIR-25. protein content ranged from 26.03% to 26.73% with overall mean of 26.45% in F_2 generation. Seventeen F_2 populations mean exceeded the mean protein content (26.45%). JL-220 × TCGS-647 recorded the highest protein content (26.73%). F_2 population viz., ICGV-91114 X TCGS-584 registered the lowest harvest index (26.03%).

The parental genotype, K-1375 exhibited the highest *per se* performance for oil per cent during kharif. The parent, JL-220 recorded the highest *per se* performance for protein per cent during rabi. Among the F_1s, ICGV-91114 × K-1375 for oil per cent showed the highest *per se* performance during kharif.

Table 2. ***Per se*** **performance for oil per cent and protein content in groundnut.**

Parents/crosses	Kharif 2009		Rabi 2009			
	8 parents and 28 F_1s		8 parents and 28 F_1s		8 parents and 28 F_2 s	
	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
Parents						
TPT-4	47.63	26.20	48.03	26.20	-	-
TIR-25	47.67	26.30	48.31	26.17	-	-
ICGV-91114	47.63	26.40	47.68	26.17	-	-
TCGS-584	47.73	26.23	47.90	26.27	-	-
JL-220	47.80	26.27	47.96	26.30	-	-
ICGV-99029	47.60	26.03	47.93	26.13	-	-
K-1375	47.93	26.03	47.83	25.73	-	-
TCGS-647	47.57	26.33	46.83	26.30	-	-
Crosses						
TPT-4 × TPT-25	47.57	25.63	47.93	26.07	47.77	26.30
TPT-4 × ICGV-91114	47.93	26.27	47.83	26.53	47.80	26.63
TPT-4 × TCGS-584	47.37	25.93	47.37	26.50	47.80	26.40
TPT-4 × JL-220	47.97	25.77	47.53	26.50	47.77	26.57
TPT-4 × ICGV-99029	47.77	26.47	47.33	26.50	47.30	26.70
TPT-4 × K-1375	47.73	26.47	47.50	26.53	47.90	26.10
TPT-4 × TCGS-647	47.80	26.20	47.70	26.60	46.97	26.57
TIR-25 × ICGV-91114	47.73	26.00	48.10	26.33	48.40	26.47
TIR-25 × TCGS-584	47.53	26.33	48.17	26.30	48.10	26.47
TIR-25 × JL-220	47.93	26.13	48.47	26.17	48.10	26.40
TIR-25 × ICGV-99029	46.87	26.37	47.70	26.43	47.70	26.37
TIR-25 × K-1375	47.67	26.33	48.10	26.30	48.37	26.23
TIR-25 × TCGS-647	47.43	26.37	47.87	26.23	47.87	26.10
ICGV-91114 × TCGS-584	47.50	26.10	47.63	26.30	47.87	26.03
ICGV-91114 × JL-220	47.20	26.63	47.73	26.30	47.50	26.63
ICGV-91114 × ICGV-99029	47.67	26.27	47.50	26.57	47.33	26.60
ICGV-91114 × K-1375	48.07	26.23	46.40	26.37	47.53	26.60
ICGV-91114 × TCGS-647	47.00	26.43	47.37	26.60	47.40	26.73
TCGS-584 × JL-220	47.90	26.40	47.97	26.37	48.07	26.53
TCGS-584 × ICGV-99029	47.53	26.70	47.67	26.57	47.47	26.50
TCGS-584 × K-1375	47.63	26.73	47.90	26.40	47.47	26.40
TCGS-584 × TCGS-647	47.20	26.60	47.63	26.57	46.97	26.40
JL-220 × ICGV-99029	46.83	26.40	47.60	26.30	47.83	26.50
JL-220 × K-1375	47.10	26.23	47.83	26.60	48.13	26.47
JL-220 × TCGS-647	45.37	26.33	47.80	26.67	46.93	26.73
ICGV-99029 × K-1375	46.73	25.80	46.97	26.37	47.20	26.57
ICGV-99029 × TCGS-647	46.33	25.93	46.37	26.10	47.40	26.53
K-1375 × TCGS-647	46.37	26.43	47.77	26.37	46.80	26.20
Mean of parents	47.70	26.22	47.77	26.16	-	-
Range among parents	47.57-47.93	26.03 -26.40	46.83-48.31	25.73-26.30	-	-
Mean of F_1s	47.35	26.26	47.63	26.41	-	-
Range among F_1s	45.37-48.07	25.63-26.73	46.37-48.47	26.07-26.67	-	-
Mean of F_2 s	-	-	-	-	47.63	26.45
Range among F_2s	-	-	-	-	46.80-48.40	26.03-26.73
CD at 5% level	1.03	0.55	0.64	0.46	0.65	0.51

Combining ability

Combining ability was studied for oil and protein content in 8 parents and 28 F_1s both in kharif, 2009 and in rabi, 2009 and are presented below (Tables 3, 4 and 5).

The analysis of variance for combining ability of 8 parents and 28 F_1s for both rabi and kharif seasons are presented in Table 3. Mean squares due to gca and sca variances were significant for both oil and protein content. The magnitude of mean squares due to gca was more than that of sca for both the characters in kharif, 2009. In rabi, 2009 mean square due to gca was greater than that of sca for oil content. The estimates of variance component suggested that the estimates of sca variance components were larger than the estimates of gca variance components for both the characters in kharif. In rabi also estimates of sca variance component was larger than estimates of gca variance component for both the characters.

Table 3. Analysis of variance for combining ability for oil per cent and protein content in groundnut.

Source	d.f.	Kharif 2009		Rabi 2009	
		8 parents and 28 F_1s		8 parents and 28 F_1s	
		Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
Gca	7	0.87**	0.09*	0.56**	0.03
Sca	28	0.17	0.06	0.15**	0.04
Error	70	0.13	0.04	0.05	0.02
Var. (gca)		0.01	0.00	0.01	0.00
Var. (sca)		0.14	0.04	0.05	0.03

* Significant at 5 % level ** Significant at 1 % level

The estimates of general combining ability (gca) effects of the eight parents and specific combining ability (sca) effects of 28 crosses for oil and protein content in kharif (2009) and rabi (2009) are presented in Tables 4 and 5.

Kharif, 2009

The gca effects for oil content ranged from –0.54 (TCGS-647) to 0.25 (TIR-25.) Significant and positive gca effects were observed in TIR-25 (0.25), Tirupati-4 (0.24) and JL-220 (0.22), while ICGV-99029 (-0.32), and TCGS-647 (-0.54) have showed significant negative gca effects. The Estimates of sca effects for oil content ranged from –1.19 (ICGV99029 × TCGS-647) to 0.66 (TIR-25 × TCGS-647). Only one F_1 viz., TIR-25-6 × TCGS-647 recorded positive significant sca effects and one F_1 exhibited significant negative sca effects (Table 4).

Table 4. Estimates of general combining ability effects for oil per cent and protein content in groundnut.

Source	d.f.	Kharif 2009		Rabi 2009	
		Parents			
		Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
TPT-4	7	0.24*	-0.03	0.03	0.05
TIR-25	28	0.25*	-0.16**	0.40**	-0.10*
ICGV-91114	70	0.16	-0.01	-0.10	0.02
TCGS-584		0.07	-0.003	0.12	0.04
JL-220		0.22*	0.13*	0.19**	0.03
ICGV-99029		-0.32**	0.08	-0.20**	-0.01
K-1375		-0.09	-0.07	-0.08	-0.01
TCGS-647		-0.54**	0.07	-0.35**	0.06

* Significant at 5 % level; ** Significant at 1 % level.

The gca effects for protein content ranged from –0.16 (TIR-25) to 0.13 (JL-220). Significant and positive gca effects were observed in JL-220 (0.13) while TIR-25 (-0.16) had showed significant negative gca effects. Estimates of sca effects for protein per cent ranged from –0.46 (TIR-25 × JL-220) to 0.45 (TIR-25 × K-

1375). Only two F_1s viz., TIR- TIR-25-6 × K-1375 and JL-220 × K-1375 recorded positive significant sca effects and one F_1 exhibited significant negative sca effects (Table 5).

Table 5. Estimates of specific combining ability effects for oil per cent and protein content in groundnut.

Crosses	Kharif 2009		Rabi 2009	
	28 F_1s			
	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
TPT-4 × TPT-25	-0.25	0.24	-0.16	-0.23
TPT-4 × ICGV-91114	-0.19	0.18	0.24	0.12
TPT-4 × TCGS-584	-0.00	0.01	-0.44*	0.07
TPT-4 × JL-220	-0.09	-0.09	-0.35	0.07
TPT-4 × ICGV-99029	0.26	-0.27	-0.16	0.11
TPT-4 × K-1375	0.36	-0.12	-0.11	0.21
TPT-4 × TCGS-647	0.44	0.04	0.36	0.15
TIR-25 × ICGV-91114	0.09	0.18	0.14	0.07
TIR-25 × TCGS-584	-0.39	-0.16	-0.01	0.01
TIR-25 × JL-220	0.06	-0.46*	0.22	-0.12
TIR-25 × ICGV-99029	0.41	0.29	-0.17	0.19
TIR-25 × K-1375	0.14	0.45*	0.12	0.13
TIR-25 × TCGS-647	0.66*	0.04	0.16	-0.07
ICGV-91114 × TCGS-584	-0.13	0.09	-0.05	-0.10
ICGV-91114 × JL-220	0.12	-0.25	-0.01	-0.10
ICGV-91114 × ICGV-99029	-0.40	0.04	0.14	0.21
ICGV-91114 × K-1375	0.17	0.16	-1.08**	0.08
ICGV-91114 × TCGS-647	0.38	0.05	0.16	0.18
TCGS-584 × JL-220	-0.52	0.25	-0.00	-0.05
TCGS-584 × ICGV-99029	0.49	-0.07	0.08	0.19
TCGS-584 × K-1375	0.66	0.05	0.20	0.09
TCGS-584 × TCGS-647	0.04	0.11	0.20	0.12
JL-220 × ICGV-99029	0.21	0.23	-0.05	-0.08
JL-220 × K-1375	0.07	0.42*	0.07	0.29*
JL-220 × TCGS-647	0.09	0.14	0.30	0.23
ICGV-99029 × K-1375	0.09	-0.03	-0.42*	0.10
ICGV-99029 × TCGS-647	-1.19**	-0.17	-0.75**	-0.30*
K-1375 × TCGS-647	-0.46	-0.32	0.54*	0.04
SE (Sij)	0.37	0.20	0.23	0.16

* Significant at 5 % level; ** Significant at 1 % level.

Rabi, 2009

The gca effects for oil content ranged from –0.35 (TCGS-647) to 0.40 (TIR-25). Significant and positive gca effects were observed in TIR-25 (0.40) and JL-220 (0.19) while ICGV-99029 (-0.20) and TCGS-647 (-0.35) have showed significant negative gca effects. The estimates of sca effects for oil content ranged from –1.08 ICGV-91114 × TCGS-647) to 054 (ICGV-99029 × TCGS-647). Only one F_1 *viz.*, ICGV-99029 × TCGS-647 recorded positive significant sca effect and four F_1s exhibited significant negative sca effects.

The gca effects for protein content ranged from –0.10 (TIR-25) to 0.06 (TCGS-647). None of the parents recorded significant gca effects. Significant and negative gca effect was observed in TIR-25 (0.10). The estimates of sca effects for protein content ranged from -0.30 (ICGV-99029 x TCGS-647) to 0.29 (JL-220 × K-1375). Only one F_1 viz., JL-220 × K-1375 recorded positive significant sca effect and one F_1 exhibited significant negative sca effect.

The parent, TIR-25 (both seasons), TPT-4 (*kharif*) and JL-220 (*rabi*) appeared to be good general combiners for oil per cent. TIR-25 × TCGS-647 (*kharif*) and K-1375 × TCGS-647 (*rabi*) were the best superior combinations for oil content. These findings suggest that epistasis may be responsible for manifestation of this character. Estimates of gca and sca components of variances revealed the importance of additive gene action in *rabi* and non-additive gene action in *kharif*. Layrisse et al. (1980), Basu et al. (1986), Skyes and Michaels (1986), Bansal et al. (1992) reported additive gene action for oil per cent. Contrary to this several studies reported non-additive gene action for oil per cent (Basu et al. (1987), Makne and Bhale (1987), Francis and Ramalingam (1999), Varman (2000) and Ali et al. (2001), Venkateswarlu et al. (2007), and Ganesan et al. (2010).

Only one parental genotype, JL-220 was identified as best general combiner for protein content. Jl-220 × K-1375 (both seasons) and TIR-25 × K-1375 (*rabi*) were considered to be good specific combiners for protein content. A perusal of results of combining ability analysis indicated considerable non-additive gene action in the inheritance of oil and protein content. The non-fixable dominance deviation and epistatic effects are likely to hinder improvement through simple pedigree selection, which is commonly followed in groundnut. Under such situations, breeding procedures have to be amended suitably by postponing the selection to later generations (Baker, 1968).

Heterosis and inbreeding depression

Heterosis or hybrid vigour is measured as an increase or decrease of a trait over better parent (heterobeltiosis), mid-parental value (relative heterosis) and standard parent (standard heterosis), and inbreeding depression for oil content and protein content are computed and presented in Table 6.

Kharif, 2009

The F_1s recorded minimum and maximum relative heterosis for oil content areICGV-99029 × TCGS-647 (-2.65) and TCGS-584 × KK-1375 (2.02), respectively. Two F_1s registered significant positive heterosis and one F_1 showed significant negative heterosis (Table 6). Heterosis over better parent for oil content ranged from -3.13 (ICGV-99029 × TCGS-647) to 1.19 (TCGS-584 × K-1375). Twelve F_1s recorded significant positive heterosis while sixteen F_1s exhibited significant and negative heterosis (Table 6). Standard heterosis ranged from –4.76 (ICGV-99029 × TCGS-647) to 0.91 (TCGS-584 × K-1375). None of the F_1 recorded significant positive heterosis over standard parent. Two F_1 s recorded significant negative heterosis over standard parent for oil content.

Heterosis over better parent for protein content ranged from -1.89 (K-1375 × TCGS-647) to 2.58 (TIR-25 x K-1375). Fourteen F_1s recorded significant positive heterosis while fourteen F_1s exhibited significant and negative heterosis (Table 6). The F_1s recorded minimum and maximum relative heterosis are K-1375 × TCGS-647 (-0.70) and TIR-25 × K-1375 (2.92), respectively. Seven F_1s registered significant positive heterosis .Standard heterosis ranged from –1.65 (TIR-25 × JL-220) to 2.04 (Jl-220 × TCGS-647). Three F_1s recorded significant positive heterosis over standard parent. Only one F_1s recorded significant negative heterosis over standard parent for protein content.

Rabi, 2009

For oil content, the F_1s namely, ICGV-99029 × TCGS-647 recorded the lowest (-3.27) and the highest heterosis was observed in TIR-25 × JL-220 (0.32) over better parent respectively. Significant positive heterobeltiosis was observed in three F_1s. As many as twenty five F_1s exhibited significant negative heterobeltiosis. Relative heterosis ranged from -2.84 (ICGV-91114 × K-1375) to 1.30 (K-1375 × TCGS-647). Five F_1s exhibited significant positive relative heterosis. Eight F_1s exhibited significant negative relative heterosis. Standard heterosis ranged from -3.47 (ICGV-99029 × TCGS-647) to 0.90 (TIR-25 × JL-220). Only one F1 recorded significant positive heterosis over standard parent. Inbreeding depression for oil content ranged from –2.44 (ICGV-91114 × K-1375) to 2.02 (K-1375 × TCGS-647). Six crosses recorded significant positive inbreeding depression. Seven F_2s exhibited significant negative inbreeding depression. Nine and six F_2s showed non-significant positive and negative inbreeding depression, respectively.

Table 6. Estimates of heterosis and inbreeding depression for oil per cent and protein content in groundnut.

Crosses	Oil content (%)						Inbreeding depression (%)	Protein content (%)						Inbreeding depression (%)
	Heterosis (%)							Heterosis (%)						
	Kharif, 2009			*Rabi* 2009				*Kharif*, 2009			*Rabi*, 2009			
	>MP	>BP	>SP	>MP	>BP	>SP		>MP	>BP	>SP	>MP	>BP	>SP	
TPT-4 × TPT-25	0.14	0.07**	0.07	-0.49	-0.78**	-0.21	0.35	1.48*	0.38**	0.38	-0.45	-0.51**	-0.51	-0.90
TPT-4 × ICGV-91114	-0.10	-0.21**	0.00	-0.05	-0.42**	-0.42	0.07	1.15	0.76**	0.76	1.34**	1.27**	1.27*	-0.38
TPT-4 × TCGS-584	0.35	0.21**	0.21	-1.25**	-1.39**	-1.39**	-0.91	0.32	0.13**	0.13	1.02*	0.89**	1.15*	0.38
TPT-4 × JL-220	0.07	-0.21**	0.35	-0.96*	-1.04**	-1.04**	-0.49	-0.13	-0.51**	0.25	0.95	0.76**	1.15*	-0.25
TPT-4 × ICGV-99029	0.78	-0.07**	-0.07	-1.35**	-1.46**	-1.46**	0.07	-1.01	-1.39**	-0.64	1.27*	1.15**	1.15*	-0.75
TPT-4 × K-1375	1.59*	0.63**	0.63	-0.90*	-1.11**	-1.11**	-0.84	0.13	-0.64**	-0.64	2.18**	1.27**	1.27*	1.63
TPT-4 × TCGS-647	1.21	-0.14**	-0.14	0.94*	-0.69**	-0.69	1.54	0.06	-0.38**	0.51	1.33**	1.15**	1.53**	0.13
TIR-25 × ICGV-91114	0.59	0.42**	0.63	0.22	-0.43**	0.14	-0.62	1.74**	1.03**	0.25	0.64	0.64**	0.51	-0.51
TIR-25 × TCGS-584	-0.35	-0.42**	-0.56	0.13	-0.30**	0.28	0.14	0.26	-0.64**	-1.02	0.32	0.13**	0.38	-0.63
TIR-25 × JL-220	0.49	0.14**	0.70	0.69	0.32**	0.90*	0.76	-0.96	-2.40**	-1.65**	-0.25	-0.51**	-0.13	-0.89
TIR-25 × ICGV-99029	1.20	0.42**	0.28	-0.88*	-1.26**	-0.69	0.00	1.73**	0.25**	1.02	1.08*	1.02**	0.89	0.25
TIR-25 × K-1375	1.24	0.35**	0.21	0.06	-0.43**	0.14	-0.55	2.92**	2.58**	1.02	1.35**	0.51**	0.38	0.25
TIR-25 × TCGS-647	1.77**	0.49**	0.35	1.00*	-0.92**	-0.35	0.00	0.64	-0.88**	0.00	-0.00	-0.25**	0.13	0.51
ICGV-91114 × TCGS-584	-0.18	-0.42**	-0.21	-0.32	-0.56**	-0.83*	-0.49	1.09	0.89**	0.51	0.32	0.13**	0.38	1.01
ICGV-91114 × JL-220	0.24	0.07**	0.63	-0.17	-0.47**	-0.62	0.49	-0.25	-1.01**	-0.25	0.25	-0.00**	0.38	-1.27
ICGV-91114 × ICGV-99029	-0.88	-1.82**	-1.61	-0.64	-0.90**	-1.11**	0.35	0.64	-0.13**	0.64	1.59**	1.53**	1.40**	-0.13
ICGV-91114 × K-1375	0.92	-0.14**	0.07	-2.84**	-2.10**	-3.40**	-2.44	1.67**	1.28**	0.51	1.61**	0.76**	0.64	-0.88
ICGV-91114 × TCGS-647	0.81	-0.63**	-0.42	0.62	-0.65**	-1.39**	-0.07	0.57	-0.25**	0.64	1.40**	1.14**	1.53**	-0.50
TCGS-584 × JL-220	-1.05	-1.46**	-0.91	0.08	0.02**	-0.14	-0.21	1.46*	0.88**	1.65**	0.32	0.25**	0.64	-0.63
TCGS-584 × ICGV-99029	1.06	0.35**	0.07	-0.52	-0.56**	-0.76	0.42	0.06	-0.51**	0.25	1.40**	1.14**	1.40**	0.25
TCGS-584 × K-1375	2.02	1.19**	0.91	0.07	0.00**	-0.28	0.90	1.09	0.51**	0.13	1.54**	0.51**	0.76	0.00
TCGS-584 × TCGS-647	0.14	-1.05**	-1.33	0.94*	-0.56**	-0.83*	1.40	0.63	0.00**	0.89	1.08*	1.01**	1.40**	0.63
JL-220 × ICGV-99029	0.35	-0.77**	-0.21	-0.72	-0.74**	-0.90*	-0.49	1.14	1.14**	1.91**	0.32	-0.00**	0.38	-0.76
JL-220 × K-1375	0.67	-0.56**	0.00	-0.13	-0.26**	-0.42	-0.63	2.43**	1.26**	2.04**	2.24**	1.14**	1.53**	0.50
JL-220 × TCGS-647	0.14	-1.46**	-0.91	1.24**	-0.33**	-0.46	1.81	0.69	0.63**	1.53*	1.39**	1.39**	1.78**	-0.25
ICGV-99029 × K-1375	0.68	0.57**	-1.12	1.91**	-2.02**	-2.22**	-0.50	0.51	-0.63**	0.13	1.67**	0.89**	0.64	-0.76
ICGV-99029 × TCGS-647	-2.65**	-3.13**	-4.76**	-1.78**	-3.27**	-3.47**	-2.23	-0.69	-0.76**	0.13	-0.45	-0.76**	-0.38	-1.66
K-1375 × TCGS-647	-0.47	-0.86**	-2.73**	1.30**	-0.14**	-0.56	2.02	-0.70	-1.89**	-1.02	1.36**	0.25**	0.64	0.63
S.E.	0.45	0.52	0.52	0.28	0.32	0.32	0.34	0.24	0.28	0.28	0.19	0.22	0.22	0.23

* Significant at 5% level; MP = Mid-parent; ** Significant at 1% level; BP = Better parent; SP = Standard parent

Table 7. Estimates of genetic parameters for oil per cent and protein content in groundnut.

Genetic parameter	*Kharif* 2009		*Rabi* 2009			
	28 F_1s		28 F_1s		28 F_2s	
	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
Mean	47.35	26.26	47.63	26.41	47.63	26.45
Phenotypic co-efficient of variation	1.65	1.34	1.23	1.02	1.13	1.19
Genotypic co-efficient of variation	0.86	0.48	0.80	0.15	0.76	0.24
H (BS)	27.06	12.70	42.96	2.24	45.63	3.91
GA	0.44	0.09	0.52	0.01	0.50	0.03
GAM	0.93	0.34	1.08	0.05	1.06	0.10

Table 8. Comparative statement based on estimates of different genetic parameters for oil per cent and protein content in groundnut.

Character	*Kharif* 2009		*Rabi* 2009			
	F_1 generation		F_1 generation		F_2 generation	
	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
Genetic parameters	Low h^2(b) and low GAM	Low h^2(b) and low GAM	Moderate h^2(b) and low GAM	Low h^2 (b) and low GAM	Moderate h^2(b) and low GAM	Low h^2(b) and low GAM
Gene effects	Non-additive	Non- additive	Non-additive	Non-additive	Non-additive	Non-additive
Influence of environment	high	high	Low	Low	High	High

Table 9. Phenotypic (P) and genotypic (G) correlation coefficients among oil and protein content in groundnut.

Character		*Kharif* 2009		*Rabi* 2009		
		Parents	F_1 generation	Parents	F_1 generation	F_2 generation
		Protein content (%)	Protein content (%)	Protein content (%)	Protein content (%)	Protein content (%)
Oil content (%)	P	-0.0438	-0.1289	-0.1735	-0.1487	-0.2219
	G	-0.5681	0.2852	-0.2952	0.4640*	-0.9240**

* Significant at 5% level, ** Significant at 1% level

Table 10. Changes in character association from parents to F_1s(kharif 2009) and from parents to F_1 to F_2 generations during *rabi*, 2009 for oil and protein content in groundnut

Association between the character	*Kharif* 2009		*Rabi* 2009		
	Association in parents	Association in F_1s	Association in parents	Association in F_1s	Association in F_2 s
Oil content with					
Protein content (%)	Negative non-significant	Positive non-significant	Negative non-significant	Positive significant	Negative significant

Table 11. Path coefficients for oil and protein content in groundnut.

Character		*Kharif* 2009				*Rabi* 2009					
		Parents		F_1 generation		Parents		F_1 generation		F_2 generation	
		Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
Oil content (%)	P	**-0.5075**	0.0126	**-0.0242**	0.0001	**-0.2264**	0.0070	**-0.0561**	-0.0079	**0.0118**	-0.0279
	G	**0.0426**	-0.0137	-0.0309	-0.0016	**0.0226**	0.0200	**-0.6998**	-0.0457	**0.8512**	-0.2145
Protein content (%)	P	**0.0222**	**-0.2885**	0.0031	**-0.0010**	-0.0183	**0.5913**	0.0083	**0.0529**	-0.0026	**0.1258**
	G	**-0.0242**	**0.0242**	-0.0088	**-0.0055**	0.1078	**0.1223**	-0.3247	**-0.0986**	-0.7865	**0.2321**

* Significant at 5% level of probability; Diagonal values (Bold): Direct effects; ** Significant at 1% level of probability.

Seventeen F_1s exhibited significant positive relative heterosis for protein content. Standard heterosis ranged from –0.38 (ICGV-99029 × TCGS-647) to 1.78 (JL-220 × TCGS-647). Twelve F_1s recorded significant heterosis over standard parent. The lowest heterobeltiosis was observed in F1, ICGV-99029 × TCGS-647 (-0.76), while the highest in F1, ICGV-91114 × ICGV-99029 (1.53). As many as twenty two F1s recorded significant positive heterobeltiosis. Significant negative heterobeltiosis was observed in six F_1s. Relative heterosis ranged from -0.45 (TPT-4 × TIR-25 and ICGV-99029 × TCGS-647) to 2.24 (JL-220 × K-1375).The F_2s, ICGV-99029 × TCGS-647 (-1.66) and TPT-4 × K-1375 (1.63) exhibited the minimum and maximum inbreeding depression respectively. Two F_2s recorded significant positive inbreeding depression while significant negative inbreeding depression was observed in eight F_2s. Nine and ten F_2s registered non-significant negative and positive inbreeding depression for protein content respectively.

Out of twenty eight F_1s, only two F_1s (TIR-25 × TCGS-647 and TPT-4 × K-1375) and twelve F_1s exhibited significant positive heterosis over mid-parent and better parent, respectively for oil content during *kharif*. None of the F_1 recorded significant standard heterosis in desirable direction in *kharif*. Five F_1s and two F_1s recorded the highest significant positive heterosis over mid-parent and better parent during *rabi*. The F_1, TIR-25 × TCGS-647 exhibited highest positive and significant heterosis over mid-parent in both *kharif* and *rabi* seasons coupled with low positive inbreeding depression, indicating the importance of additive gene action for this character. The results of Mahesh Kumar (1981), Makne and Bhale (1991), Jayalakshmi et al. (2000) , Vinit Vyas Nagda and Sharma (2001) and Li et al. (2009) further confirm these findings.

Significant positive relative heterosis for protein content was observed in seven F_1s, heterobeltiosis in fourteen F_1s and standard heterosis in four F_1s during *kharif*. The F_1, TIR-25 × K-1375 recorded the highest significant positive relative heterosis, heterobeltiosis and JL-220 × K-1375 showed significant standard heterosis during *kharif* (Table 6). In *rabi*, seventeen, twenty two and twelve F_1s expressed significant positive heterosis over mid-parent, better parent and standard parent. The F_1, JL-220 x K-1375 recorded highest significant relative heterosis, ICGV-91114 × ICGV-99029 had exhibited highest significant positive heterobeltiosis, and JL-220 × TCGS-647 significant standard heterosis with positive inbreeding depression indicating the importance of additive gene action in expression of this character. Earlier Nagda and Sharma (2001) reported for protein content.From the forgoing discussion it can be concluded that the crosses during *rabi*, recorded significant standard heterosis for TIR-25 × JL-220 for oil content, JL-220 × TCGS-647 for protein content.

Variability, heritability and genetic advance

Genetic parameters in F_1 (kharif, 2009), F_1 and F_2 (rabi, 2009) generation as phenotypic and genotypic coefficients of variation, heritability in broad sense, genetic advance and genetic advance as per cent of mean for oil and protein content were furnished in Tables 7 and 8. The phenotypic co-efficient of variation was higher than genotypic co-efficient of variation for oil and protein content indicating the influence of environment in F_1 (kharif, 2009), F_1 and F_2 (rabi, 2009) generations.

During kharif 2009, in F_1 generation, low values of genotypic coefficient of variation, low phenotypic coefficient of variation, low heritability and low genetic advance expressed as per cent of population mean for oil and protein content. During rabi 2009, low genotypic coefficient of variation, low phenotypic coefficient of variation, moderate heritability and low genetic advance expressed as per cent of population mean for oil content and low genotypic coefficient of variation, low phenotypic coefficient of variation, low heritability and low genetic advance expressed as per cent of population mean for protein content in F_1 generation and in F_2 generation, low genotypic coefficient of variation, low phenotypic coefficient of variation were observed for oil and protein content but moderate heritability for oil content.The information on these genetic parameters is of much use for planning breeding strategies in selection of desirable crosses.

In the present studies it was revealed that low to moderate heritability values and low genetic advance as per cent of mean were obtained for both oil and protein content indicating the preponderance of non-additive gene action in inheritance of these characters (Table 8). Hence, selection for these characters is not effective in early segregating generations and has to be carried in later generations. Earlier Noubissie et al. (2012) reported low values of PCV and GCV and moderate heritability in groundnut.

Character association

Correlation coefficients at phenotypic (r_p) and genotypic level (r_g) were worked out between pairs of characters under study in parents, F_1 (kharif, 2009; rabi 2009) and F_2 (rabi, 2009) generations and are furnished in Table 9. In general, the genotypic correlations between oil and protein contents were higher in magnitude than the corresponding phenotypic correlations.

During kharif 2009, the correlation coefficients among the parents were worked-out for oil and protein in parents evaluated during kharif 2009 is furnished in Table 9. Oil per cent showed non-significant and negative association with protein per cent and in F_1 generation, it showed positive association with protein content. During rabi, 2009, oil content among the parents established a non-significant and negative association with protein content and in F_1 generation, oil per cent expressed significant and positive association with protein per cent (r_g = 0.4640). In F_2 generation, oil content expressed significant and negative association with protein per cent (r_g = -0.9240).

The relationship between oil and protein contents was negative non significant in parents but significant positive association in F_1s and negative significant association in F_2 generation (Table 10). Earlier Parmar et al. (2000) reported that oil and protein content showed a strong negative relationship indicating that selection for low oil content should result in higher protein content.

Path coefficients

The phenotypic and genotypic path coefficients for oil and protein contents in parents, F_1s and F_2s were given in Table 11(kharif, 2009 and rabi, 2009). Though, values of both phenotypic and genotypic path coefficients were furnished in tables, but these results were presented based on phenotypic path coefficients.

During kharif 2009, among the parents, protein content exhibited positive indirect effect through oil content. In F_1 Generation, the oil content had a positive indirect effect through protein content. During rabi 2009 among the parents, oil content had positive indirect effect through protein content. In F_1 generation, oil per cent had a negative indirect effect through protein per cent and in F_2generation; it had a negative indirect effect through protein content. These results were confirmed with the findings of Gomes et al. (2005) and Giri et al. (2009).

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