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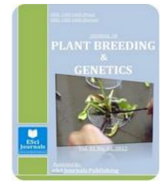

ASSOCIATION OF AGRO-MORPHOLOGICAL AND OIL TRAITS IN GROUNDNUT (ARACHIS HYPOGAEA L.) CULTIVARS

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A B S T R A C T

The associations between the traits of interest in plant breeding are commonly evaluated by means of phenotypic, genotypic and environmental correlations, and through path coefficient analysis that shows direct and indirect cause and effect relationship. Sixteen groundnut genotypes (including local check) were evaluated for quantitative parameters. The crop was sown during 2015 wet season across four locations in Ethiopia. The experiment was laid out in Randomized Complete Block Design (RCBD) with two replications. The results indicated that genotypic correlations were higher than the phenotypic and environmental ones. The grain yield (kg/ha) has presented positive and significant genetic correlation with PWP, SWP and 100SW. Genetic correlations of oil content with agro-morphological traits and oil quality parameters were shown that oil content was significant and positively correlated with pod weight per plant (PWP) and seed weight per plant (SWP) showing that possibility of indirect selection for oil content through these traits. The path analysis based on genotypic correlation in the present study was shown that selection for oil content trait is effective through OY, GY, NMP and NSPOD. Furthermore, the path analysis has shown that breeding for high O/L ratio can be conducted through selection for AGBP, NSPOD, NSP, oil content, TPUS/TS or oleic acid traits; likewise breeding for oil yield (OY) can be conducted via selection for oil content, NSP, AGBP, NBP or TPUS/TS.

Keywords: Genetic correlation, PWP, Oil content, Grain yield, Oil quality, Iodine value, OY, O/L ratio.

INTRODUCTION

The plant breeder's role in identifying the individual crops that simultaneously meet the desirable traits is not easy, because several of these traits are positive or negatively associated. The associations between the traits of interest in plant breeding are evaluated by means of phenotypic, genotypic and environmental correlations. Phenotypic correlations are directly estimated from the mean phenotypic values in the field, being, therefore, the result of genetic and environmental causes. The genotypic correlation, contrastingly, corresponds to the genetic part of the phenotypic correlation and is used to guide breeding programs because of its heritable nature (Hallauer *et al.*, 2010; Falconer and Mackay, 1996; Cruz, 2001). However, the correlation coefficients, nonetheless their high utility in the quantification of the size and direction of factors or effects in the determination of complex characters, offer only relative importance of the direct and indirect effects of these factors. Solution raised for this limitation is to perform a path analysis because it unfolds the estimated correlations into direct and indirect effects (Falconer and Mackay, 1996). Considering such justifications, this research was planned to identify traits that contribute to grain yield, oil content, oil yield and oil quality in groundnut so as to be used as selection criteria in breeding programs of this crop and to meet the demands of the producers and the agro-industry sector.

MATERIALS AND METHODS

The experiment was carried out across four locations

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viz Fedis, Mechara (Eastern Ethiopia), Pawe and Guba (locations in Western Ethiopia) in 2015 growing season under rainfed condition. The experimental materials consisted of sixteen groundnut genotypes including local variables and varieties which were released by Ethiopian Institute of Agricultural Research (EIAR) from 1976 to 2012 and Haramaya University. Before starting laboratory experiment moisture content of seeds was reduced to 5%. Total lipid from the seed sample was quantitatively extracted, according to the method of Folch *et al.* (1957). Iodine value was determined with the Hanus method (Baur and Ensminger, 1977). Fatty acids were transesterified to form methyl esters using 0.5 N NaOH in methanol and 14 % BF_3 in methanol (Slover and Lanza, 1979). FAMEs from fat were quantified using a Varian 430 flame ionization GC, with a fused silica capillary column, Chrompack CPSIL 88 (100 m length, 0.25 mm ID, 0.2µm film thicknesses). Galaxy Chromatography Software recorded the chromatograms.

The estimated genetic $r_{g(xy)}$ and phenotypic $r_{p(xy)}$ correlations between traits x and y (Holland *et al.*, 2010) are given by:

$$E\,(MSPV) = \sigma_{exey} + r\,\sigma_{gxgy}\ ;\ E\,(MSPe) = \sigma_{exey}$$

$$\sigma_{gxgy} = \frac{MSPv - MSPgxe}{re}$$

$$r_{g(xy)} = \frac{Gcov_{xy}}{\sqrt{(GV_x \cdot GV_y)}}$$

Where, σ2g(x,y) or σ_{gxgy} = genetic covariance of traits x and y; $r_{g(xy)}$= genetic correlation; $GCOV_{XY}$ = Genotypic covariance between traits X and Y; GV_X = Genotypic variance of X, GV_Y = Genotypic variance of Y. Confidence intervals for genetic correlation coefficients are constructed as $r \pm z_{(0.05)}\sigma_e$, where $z_{(0.05)}$ is the value from the standardized normal distribution table at p=0.05 and σ_e is the standardized error correlation coefficient. Estimated correlation coefficients were regarded as significantly different from zero if their 95% confidence intervals did not include zero (Holland, 2006).

Path coefficient analysis: The direct and indirect effect of traits on agronomically important trait was analyzed through path coefficient analysis. This analysis was computed as suggested by Dewey and Lu (1959) with the following formula**:**

$$rij = Pij + \Sigma rikpkj$$

Where: rij= mutual association between the independent (i) and dependent character (j) as measured by the correlation coefficient. Pij= component of direct effects of independent character (i) and dependent character (j) as measured by the path coefficient and, **Σ**rikpkj= summation of components of an indirect effect of a given independent character (i) on the given dependent character (j) via all other independent characters (k). The residual effect will be estimated by the formula:

$$\sqrt{1 - R^2}$$

Where: $R^2 = \sum P_{ij} * r_{ij}$

p*ij*=component of direct effects of the independent character (i) and dependent character (j) as it has been measured by the path coefficient; r_{ij}= mutual association between the independent character (i) and dependent character (j) as it was measured by the correlation coefficient. The phenotypic and genetic covariance and correlation coefficients and path coefficient analyses among pairs of traits were computed across locations using SAS version 9.2 CANDISC and IML procedures (SAS, 2011).

RESULT AND DISCUSSION

The genetic correlation for fatty acid compositions (Table 1) was shown that no significant correlation was observed for oil content with fatty acid contents and oil quality parameters and also with grain yield. Mercer *et al.* (1990) has also suggested that fatty acid composition should not affect the oil content of the seed. Oleic acid was significantly and positively correlated with TMUS, TUS and O/L ratio. However, oleic acid was significantly and negatively correlated with linoleic and palmitic acids, suggesting that it probably raise oleic acid content while lowering linoleic and palmitic acid contents. The highest significant negative correlation was noted for oleic and linoleic acids (r: -0.97). Grain yield was significant and positively correlated only with arachidic acid and oil yield, but negative and significantly correlated with linoleic acid.

The negative relationship between palmitic acid and oleic acid was likely due to an increased rate of palmitic acid elongation to stearic acid with rapid desaturation to oleic acid via delta-9 desaturase (Groff *et al.*, 1996).

Table 1. Genetic correlation of grain yield with % oil content and fatty acids evaluated for 16 groundnut varieties across four locations.

Trait	Oil	IV	Pal	Ste	Oleic	Lin	Arach	Eico	Beh	Lig	TS	TMUS	TUS	TPUS/TS	O/L	OY	GY
Oil	1.0	-0.15	-0.02	0.33	0.01	-0.06	0.32	-0.34	0.03	-0.23	0.19	-0.014	-0.19	-0.24	-0.01	0.34	0.24
IV		1.00	0.57*	-0.3	-0.80**	0.92**	-0.49	-0.03	-0.5	-0.05	0.07	-0.77**	-0.07	0.92**	-0.86**	-0.66**	-0.66**
Pal			1.00	0.1	-0.80**	0.76**	-0.06	-0.60*	-0.33	-0.62*	0.63**	-0.82**	-0.63**	0.27	-0.79**	-0.29	-0.29
Ste				1.00	-0.22	0.03	0.96**	-0.78**	0.36	-0.53*	0.78**	-0.27	-0.78**	-0.56*	-0.12	0.44	0.43
Oleic					1.00	-0.97**	-0.05	0.49	0.16	0.38	-0.65**	1.00**	0.65**	-0.53*	0.98**	0.40	0.40
Lin						1.00	-0.17	-0.35	-0.32	-0.28	0.44	-0.96**	-0.45	0.71**	-0.98**	-0.53*	-0.53*
Arach							1.00	-0.64**	0.58*	-0.41	0.71**	-0.1	-0.71**	-0.71**	0.07	0.53*	0.52
Eico								1.00	0.09	0.85**	-0.83**	0.55*	0.83**	0.3	0.42	-0.21	-0.19
Beh									1.00	0.14	0.32	0.16	-0.32	-0.54*	0.26	0.32	0.32
Lig										1.00	-0.63*	0.43	0.63*	0.22	0.36	0.01	0.03
TS											1.00	-0.68**	-1.00**	-0.31	-0.54*	0.18	0.17
TMUS												1.00	0.68**	-0.48	0.97**	0.37	0.37
TUS													1.00	0.31	0.54*	-0.18	-0.18
TPUS/TS														1.00	-0.62*	-0.69**	-0.69**
O/L															1.00	0.43	0.44
OY																1.00	0.99**
GY																	1.00

Where IV: iodine value; Pal; palmitic; Ste:steric acid; Lin: Linoleic acid; Arach: Arachidic acid; Eico:Eicosenoic acid; Beh: Behenic acid; Lig: Lignoceric acid; TS: total saturated fatty acids; TMUS: total monounsaturated fatty acids; TPUS: total polyunsaturated fatty acids; TUS: total unsaturated fatty acids; TPUS/TS: total polyunsaturated to total saturated fatty acids; O/L: oleic to linoleic acid ratio; GY: grain yield ($kgha^{-1}$); OY: oil yield ($kgha^{-1}$.

An inverse relationship between linoleic acid, O/L ratio confirmed earlier reports by Braddock *et al.* (1995) and O'Keefe *et al.* (1993).

Genetic correlation of oil content with agro-morphological and oil quality traits evaluated for 16 groundnut genotypes across four locations as shown in Table 2. Oil content was significant and positively correlated with pod weight per plant (PWP) and seed weight per plant (SWP) showing that the possibility of indirect selection for oil content through PWP and SWP. Grain yield was significant and positively correlated with SWP, 100SW and OY. Similarly, OY was significant and positively correlated with SWP, 100SW and GY. Low oil quality traits like linoleic acid and TPUS were significant and positively correlated with NSPOD and TPUS/TS, but significant and negatively correlated with grain yield. High oil quality traits like oleic acid and O/L ratio which indicate presence of monounsaturated fatty acids (responsible for oil stability or long shelf life due to reduced oxidation) were found to be positive and significantly correlated with NBP and AGBP indicating possibility of breeding for oil content trait via indirect selection through highly heritable traits. These results were in agreement with those of Shobhakruparani (1999) and Nagda *et al.* (2001) for days to 50 per cent flowering, Kumar *et al.* (1998), Sangha and Sandhu (1970) for oil yield, Abhay *et al.* (2002), Venkataramana (2001) for kernel yield.

Table 2. Genetic correlation of major agro-morphological and oil traits.

Trait	NBP	NMP	AGBP	PWP	SWP	100SW	NSP	NSPOD	Oleic	TPUS	O/L	Oil	TPUS/TS	Linoleic	GY	OY
NBP	1.00	0.34	0.78**	0.39	0.31	0.41	0.17	-0.86**	0.91**	-0.86**	0.88**	0.14	-0.39	-0.86**	0.36	0.37
NMP		1.00	0.25	0.60*	0.37	-0.33	0.51*	-0.60*	0.27	-0.12	0.12	0.31	0.28	-0.12	-0.09	-0.06
AGBP			1.00	0.12	0.08	0.14	0.05	-0.75**	0.73**	-0.64**	0.70**	0.03	-0.1	-0.64	0.09	0.10
PWP				1.00	0.80**	0.37	0.10	-0.44	0.23	-0.23	0.14	0.67**	-0.18	-0.23	0.44	0.49
SWP					1.00	0.51*	-0.26	-0.39	0.36	-0.4	0.31	0.62**	-0.44	-0.40	0.64**	0.68**
100SW						1.00	-0.44	-0.21	0.43	-0.60**	0.51	0.23	-0.84	-0.61**	0.85**	0.85**
NSP							1.00	-0.22	-0.001	0.14	-0.11	-0.23	0.54*	0.14	-0.27	-0.30
NSPOD								1.00	-0.84**	0.77**	-0.76**	-0.28	0.29	0.77**	-0.32	-0.35
Oleic									1.00	-0.97**	0.98**	0.01	-0.53	-0.97**	0.4	0.40
TPUS										1.00	-0.98**	-0.06	0.71**	1.00**	-0.53*	-0.53*
O/L											1.00	-0.005	-0.62**	-0.98**	0.44	0.43
Oil												1.00	-0.24	-0.06	0.24	0.34
TPUS/TS													1.00	0.71**	-0.69**	-0.69**
Linoleic														1.00	-0.53*	-0.53*
GY															1.00	0.99**
OY																1.00

NBP: number of primary branches per plant; NMP: number of mature pods per plant; AGBP: above ground biomass per plant; PWP: pod weight per plant; SWP: seed weight per plant; 100SW:100 seed weight; NSP: number of seeds per plant; NSPOD: number of seeds per pod; TPUS: total polyunsaturated fatty acids; TPUS/TS: total polyunsaturated to saturated fatty acids ratio; GY: grain yield; OY: oil yield.

Since the correlation coefficient does not provide the true relationship amongst traits. The total genotypic correlation coefficients were further partitioned into direct and indirect effects at the genotypic level. The path analysis of oil content for agro-morphological and oil traits was shown in Table 3. In this case, in the path analysis of oil content for genetic correlations, the direct effect of the PWP trait on the oil content was smaller than the indirect effect of NMP, OY, GY and NSPOD on oil content through PWP; in this case, the correlation value is attributed to the indirect effect of the NMP, OY, GY and NSPOD traits. In this situation, the causal indirect effect is considered for the selection processes. In a similar manner, the direct effect of SWP on oil content was also smaller than the indirect effects. Therefore, the Significant and positive genotypic correlation coefficient between SWP and oil content is explained in a larger proportion by indirect effects of OY and GY than for the direct effects of the SWP trait on oil content; this indicates that the significant and direct correlation between SWP and oil content is due, in large proportion, to the indirect influence of OY, GY, NMP and NSPOD traits.

The path analysis based on genotypic correlation in the present study was shown that breeding for oil content trait is effective through selection for high OY, GY, NMP and NSPOD.

Table 3. Path coefficient analysis for genotypic correlations of oil content on agromorphological and oil traits, direct effect (bold) diagonal, indirect effects (off diagonal).

Trait	NBP	NMP	AGBP	PWP	SWP	100SW	NSP	NSPOD	Oleic	O/L	TPUS/TS	Linoleic	GY	OY	Oil (corrl)
PWP	-0.14	0.23	-0.04	**7.22E-05**	-0.28	0.02	0.13	0.14	-0.01	0.0003	0.04	-0.04	0.31	0.33	0.67**
SWP	-0.11	0.14	-0.03	0.002	**-0.01**	0.03	-0.35	0.12	-0.01	0.001	0.10	-0.06	0.44	0.44	0.62**
R^2=0.88; h^2=0.12															

The coefficient of determination (R^2) in the path analysis of oil content for genotypic correlation indicates that 88% of the oil content variability was explained by the variables which is a good fit for the model and shows the importance of the explaining variables in the oil content definition.

Estimation of direct and indirect effects of oil traits in groundnut is rarely found. However, direct and indirect effects of various quantitative traits on yield and oil content have been reported by many researchers: Tuncturk and Çiftçi (2007), Marjanović-Jeromela *et al.* (2008) on *Brassica* species, and Baig (2017) on Soybean traits.

The path analysis of genetic correlation of O/L ratio on agro-morphological and oil traits was shown in Table 4. In this case, in the path analysis for genetic correlations, the direct effect of NBP trait on O/L ratio was smaller than the indirect effect of AGBP, NSPOD and oleic acid traits on O/L ratio; in this case, the significant correlation value between NBP and O/L ratio was attributed to the indirect effects of AGBP, NSPOD and oleic acid traits. That is breeding for high oil quality can be effective through indirect selection for high AGBP, NSPOD and oleic acid. In the path analysis of AGBP on O/L ratio, the direct effect of AGBP on O/L ratio was smaller than the indirect effects of NSPOD and oleic acid on the O/L ratio; in this case, the significant and positive correlation value between AGBP and O/L ratio is attributed to the indirect effects of NSPOD and oleic acid traits.

Table 4. Path coefficient analysis for genotypic correlations of O/L ratio on agro-morphological and oil traits, direct effect (bold) diagonal, indirect effects (off-diagonal).

Trait	NBP	NMP	AGBP	PWP	SWP	100SW	NSP	NSPOD	GY	OY	Oil	TPUS/TS	Linoleic	Oleic	O/L
NBP	**-0.06**	-0.03	0.80	-0.13	-0.09	-0.03	-0.06	0.23	-0.07	-0.06	0.07	0.07	0.02	0.18	0.88**
AGBP	-2.01	-0.18	**0.03**	-0.38	-0.22	-0.09	-0.17	2.02	-0.18	-0.16	0.12	0.18	0.18	1.39	0.70**
100SW	-0.68	0.15	0.90	-0.78	-0.92	**-0.003**	0.98	0.36	-1.10	-0.85	0.69	1.01	0.11	0.52	0.51*
NSPOD	0.02	0.004	-0.07	0.01	0.01	0.001	0.01	**-0.72**	0.01	0.01	-0.01	-0.005	-0.002	-0.02	-0.76**
TPUSTS	0.01	-0.002	-0.01	0.005	0.01	0.004	-0.01	-0.01	0.01	0.01	-0.01	**-0.61**	-0.002	-0.01	-0.62**
Linoleic	0.34	0.01	-1.00	0.11	0.17	0.06	-0.08	-0.32	0.17	0.13	-0.04	-0.21	**-0.01**	-0.28	-0.98**
Oleic	-0.43	-0.04	1.35	-0.13	-0.19	-0.05	0.0003	0.41	-0.15	-0.11	0.01	0.18	0.05	**0.03**	0.98**
R^2=0.92; h^2=0.08															

NMP: number of mature pods per plant; NBP: number of primary branches per plant; AGBP: above ground biomass per plant; PWP: pod weight per plant; SWP: seed weight per plant; NSP: number of seeds per plant; 100SW:100 seed weight; NSPOD: number of seeds per pod; IV: iodine value; TPUS/TS: total polyunsaturated to saturated fatty acids; O/L: oleic to linoleic acids ratio;GY: grain yield; OY: oil yield.

In the path analysis of 100SW on O/L ratio, the direct effect of 100SW on O/L ratio was smaller than the indirect effects of TPUS/TS, NSP, AGBP and oil content on O/L ratio; in this case, the significant and positive correlation value between 100SW and O/L ratio is attributed to the indirect effects of TPUS/TS, NSP, AGBP and oil content on O/L ratio traits.

Similarly, in the path analysis of oleic acid on O/L ratio, the direct effect of oleic acid on O/L ratio was smaller than the indirect effects of AGBP and NSPOD on O/L ratio; in this case, the significant and positive correlation value between oleic acid and O/L ratio is attributed to the indirect effects of AGBP and NSPOD traits. The path analysis has shown that breeding for high O/L ratio can be conducted through selection for AGBP, NSPOD, NSP, oil content, TPUS/TS and oleic acid traits. The coefficient of determination (R^2) in the path analysis for genotypic correlation indicates that 92% of the O/L ratio variability was explained by the variables which are a good fit for the model and shows the importance of the explaining variables in the O/L ratio. Few reports are available about the direct and indirect effects of various oil quality traits. Chauhan *et al.* (2008) who reported high to moderate negative effects of palmitic, stearic, oleic, linoleic, linolenic and eicosenoic on erucic acid in Indian mustard varieties, and Siddiqui *et al.* (2016) who reported the direct and indirect effect of various quantitative traits on oil quality traits in linseed.

From the path analysis for genotypic correlation of OY with agro-morphological and oil traits (Table 5), it was revealed that small positive direct effect was observed for most of the traits that could be due to a weaker correlation of causative traits on OY (the effect). The indirect effect of SWP mainly through oil content and NSP was found to be greater than a direct effect of SWP on OY, indicating indirect selection of high oil yielding genotype(s) through oil content and NSP might have been effective; however, both oil content and NSP have low heritability and low genetic advance. Hence, indirect selection through such low heritable trait might not be effective. The indirect effect of 100SW mainly through NSP, oil content, AGBP, NBP and TPUS/TS was found to be greater than the direct effect of 100SW on OY, indicating indirect selection of high oil yielding genotype(s) is effective through AGBP, NBP and TPUS/TS. The direct effect of the GY on the OY is less than the indirect effect of GY through NSP, oil content, TPUS/TS, and AGBP; in this case, the significant and positive correlation between GY and OY is attributed to the indirect effect of the NSP, oil content, TPUS/TS, and AGBP traits on OY.

Table 5. Path coefficient analysis for genotypic correlations of oil yield (kg/ha) on agro-morphological and oil traits, direct effect (bold) diagonal, indirect effects (off diagonal).

Trait	NBP	NMP	AGBP	PWP	SWP	100SW	NSP	NSPOD	Oleic	O/L	Oil	TPUS/TS	Linoleic	GY	OY
SWP	0.19	-0.70	0.46	-3.11	**-0.09**	-1.48	1.55	0.13	0.30	0.19	6.22	0.28	0.09	-3.43	0.68**
100SW	0.53	1.33	1.74	-3.14	-3.50	**-0.04**	5.55	0.15	0.77	0.66	4.92	1.14	0.28	-9.84	0.85**
TPUS/TS	-0.01	-0.01	-0.02	0.02	0.04	0.06	-0.08	-0.002	-0.01	-0.01	-0.06	**-0.69**	-0.004	0.10	-0.69**
Linoleic	-0.27	0.12	-1.93	0.46	0.66	0.91	-0.44	-0.13	-0.42	-0.30	-0.30	-0.24	**-0.01**	1.48	-0.53*
GY	40.32	31.64	94.30	-320.0	-377.8	-459.6	293.6	19.69	63.0	48.88	440.87	81.43	21.6	**-0.001**	0.99**
R^2=0.99; h^2=-0.01															

NMP: number of mature pods per plant; NBP: number of primary branches per plant; AGBP: above ground biomass per plant; PWP: pod weight per plant; SWP: seed weight per plant; NSP: number of seeds per plant; 100SW:100 seed weight; NSPOD: number of seeds per pod; IV: iodine value; TPUS/TS: total polyunsaturated to saturated fatty acids; O/L: oleic to linoleic acids ratio;GY: grain yield; OY: oil yield.

The path analysis of genetic correlation in the present study was shown that breeding for oil yield (OY) can be conducted via selection for AGBP, NBP and TPUS/TS. The determination coefficient (R^2) in the path analysis for genotypic correlation of OY with agro-morphological and oil traits indicate that 99% of the OY variability was explained by those traits which is a good fit for the model and shows the importance of the explaining variables in the OY case. These findings were in accordance with Adeyanju *et al.* (2010) who reported direct and indirect effects of various oil traits on oil yield.

CONCLUSION

The biochemical analysis of oil traits will have a greater contribution to the future groundnut breeding program in Ethiopia. The present study has found that stearic acid, arachidic acid, eicosenoic acid, lignoceric acid, O/L ratio, palmitic acid, oleic acid, linoleic acid, behenic acid, total saturated fatty acids (TS), total monounsaturated fatty acids (TMUS), total polyunsaturated fatty acids (TPUS), TPUS/TS, TUS/TS and OY were more variable traits among evaluated genotypes. These traits have potential inbreeding groundnut for oil traits. However, low genetic variability for oil content and total unsaturated fatty acids (TUS) and iodine value was observed indicating that breeding for oil content should follow indirect selection through other traits due to low genetic advance for oil content trait. The present study has identified the possibility of breeding of groundnut for grain yield, high oil content, oil yield and oil quality through direct and indirect selection for agro-morphological and oil traits. This study has also shown that breeding for biochemical oil traits can be conducted through selection for agro-morphological traits with low cost. Breeding for low heritable traits like oil content and oil quality traits require systematic handling of traits via indirect selection through highly heritable traits.

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