Correlation and path coefficient study of soybean yield and seed quality traits

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An experiment was conducted to evaluate the genotypic-phenotypic variability and environmental effect in 20 pure lines and varieties (PLV) of soybean, and observations were recorded on various characters affecting quality, such as palmitic, stearic, oleic, linoleic and linolenic acid, oil and protein content. High values of GCV and PCV were observed for features such as grain yield (14.89, 11.13) and oleic acid (13.13, 12.73) and linolenic acid (11.29, 10.33) content, which indicates the presence of high genetic variation. Analysis of phenotypic and genotypic correlation coefficients of quantitative characters and partitioning of the genotypic correlation to the grain revealed that the correlation coefficients of grain yield with oil content were positive and significant. The linolenic acid content showed the highest positive direct effect on grain yield. High heritability coupled with the high genetic advance observed for the traits and contents of oleic, linoleic, and linolenic acids indicates the presence of additive gene action and demands population improvement by selection.

Keywords: Genetic advance, Genetic variability, Heritability, Soybean, Yield traits.

1. INTRODUCTION

Studies on soybeans have shown that seed yield and quality vary considerably depending on the cultivar and growing conditions. Several studies have investigated the effect of year or location on the fatty acid content of soybean lines with different fatty acid profiles [1, 2]. According to the Turkish Food Codex (2014/53), the oil of common soybean consists of 8.0%-13.5% palmitic (16:0), 2.0%-5.4% stearic (18:0), 17.0%-30.0% oleic (18:1), 48.0%-59.0% linoleic (18:2), and 4.5%-11.0% linolenic acid (18:3) [3]. Variation in palmitic acid content in the low-palmitic-acid soybean lines is influenced by temperature, and the environmental impact is less severe than that observed for oleic acid content in soybean [4]. However, like the mid-oleic-acid soybean genotypes, reduced palmitic acid lines of soybean have been reported to suffer a decrease in yield [5]. Soybean oil contains approximately 8% of linolenic acid [6], which is an unstable fatty acid that can be easily oxidised; therefore, cross-breeding and genetic modification of soybeans have been developed to reduce linolenic acid levels, although linolenic acid are essential fatty acids regarding human health, and its amounts in soybean supply the daily linolenic acid intake requirement [7]. It is also important to remember that linolenic acid is converted into other biologically relevant long-chain polyunsaturated fatty acids by a sequential desaturation and elongation enzyme system [8]. Oleic acid is effective in reducing cholesterol levels and possesses antidiabetic and anti-inflammatory properties, and linoleic acid can improve insulin resistance and is also reported to lower blood pressure [9]. Soybean protein, comprising 40% of dry seed weight on average, is highly valued for food and feed because of

Table I - Cross name/parentage of soybean pure lines and varieties

Pure lines and varieties	Cross name / parentage	Days to maturity
KSUS 157[a*]	Umut2002 X Sprite87	99.50
KWD 60[a*]	Williams X Defiance	99.50
KKMA 118[a*]	Macon X Apollo	98.50
KAS 19-1[a*]	Sprite87 x Apollo	99.50
KSA-26[a*]	Sprite87 x Apollo	99.50
KA04-03-05[b*]	NE3297 X Apollo	105.70
KA04-06-01[b*]	Umut2002 X Sprite87	105.70
KA04-07-04[b*]	Defiance X Nazlıcan	106.00
SO10815[b*]	NE3399 X Ap2292	105.70
KA0405-02[b*]	Macon X Apollo	105.00
UMUT 2002[c**]	Unknown	98.50
ÇETİNBEY[a**]	Unknown	105.70
SA 88[d**]	Unknown	98.50
ATAEM 7[e**]	Unknown	97.50
ARISOY[f**]	Unknown	96.50
NOVA[g**]	Unknown	97.20
ÇU05-62[h*]	Turksoy[h**] X Prowar[**]	105.10
ÇU03-75-1[h*]	527[h*] X Prota[**]	103.30
ÇU04-07[h*]	Nazlıcan[h**] X JMS 2387[**]	101.00
ÇU04-122[h*]	Nazlıcan[h**] X JMS 2387[**]	103.00

% [a]These materials obtained from Bahri Dagdas International Agricultural Research Institute, [b]These materials obtained from Karadeniz Agricultural Research Institute, [c] These material obtained from Eagean Agricultural Research Institute, [d]These material obtained from Agrova Co., [e] These material obtained from Western Mediterranean Agricultural Research Institute, [f] These material obtained from Cukurova University, [g] These material obtained from May Co., [h] These materials obtained from Eastern Mediterranean Agricultural Research Institute, *These materials are Advanced Soybean Lines, **These materials are Registered soybean varieties

Table II - Temperature (°C) and precipitation (mm) climate data and long year averages for 2015 growing season

		April	May	June	July	August	September	October
Temparature (˚C)	2015	16.0	22.2	24.6	28.0	29.6	27.8	20.6
	Long Terms	17.5	21.7	25.6	28.0	28.4	25.8	21.2
Precipitation (mm)	2015	7.8	81.0	0	0	8.6	40.8	56.0
	Long Terms	51.2	47.3	20.5	6.3	5.6	17.9	42.0

its amino acid composition and high digestibility [10]. The success of soybean cultivation is attributed to the combination of its high protein (about 40%) and oil content (about 20%), together with satisfactory productivity levels for the grain in a range of soils and climatic conditions. Developing productive cultivars with significantly incremented protein and/or oil content is one of the main objectives of soybean breeding programs [11]. The protein and oil content of soybean grains involves quantitative genetic control and is influenced by the environment [12]. The existence of interactions between genotypes and environments (G x E) constitutes one of the main problems for breeding programs, be it at the selection stage or in the recommendation of cultivars. The importance of these interactions means that the breeder must evaluate their magnitude and significance, quantify their effects on breeding techniques and adopt procedures to minimise or take advantage of the interactions [13].

There are plenty of studies of the adaptability and stability of soybean genotypes for grain yield [14, 15, 16]. However, few of these analyses were performed for protein, oil, and fatty acid contents. Turkish studies on this matter often assessed a very small number of cultivars, with low protein or oil content, bringing small contributions to breeding programs.

The purpose of this study was to assess the character association and contribution towards the grain yield of pure lines and varieties and to find out the direct and indirect effect of protein and fatty acid components on grain yield with the help of path coefficient analysis.

2. MATERIALS AND METHODS

2.1. MATERIALS

This study was conducted as a second crop (June-October) condition as part of the national soybean breeding program carried out at the experimental farm of the Eastern Mediterranean Agricultural Research Institute (EMARI), Adana, Turkey, during the 2015 growing seasons. Pure lines with characteristics above those of the standard variety were selected in the breeding program every year. Cross names/parentages of soybean pure lines and varieties are given Table I. The soils belonging to the trial area are loamy and slightly alkaline, moderate in organic matter, poor in nitrogen and phosphorus but rich in potassium. On the other hand, temperature (°C) and precipitation (mm) climate data and long year averages for the 2015 growing season are given in Table II. Twenty soybean pure lines and commercial varieties were used as experimental material. Each PLV was planted in four rows 5 m long with 70 cm row spacing. Before sowing, seeds were inoculated with *Bradyrhizobium japonicum* bacteria, and sowing was performed by machine, with 200 kg ha^{-1} of DAP (36 kg ha^{-1} N, 92 kg ha^{-1} P) applied before planting. Weed control was performed twice by hand. After soybeans reached harvest maturity (R8 stage), soybean yield was determined by harvesting the centre two rows from each plot, and the yield was adjusted to a moisture content of 13%. A randomised complete block design with four replications was used.

2.2 METHODS

2.2.1. Crude Oil and Protein Analyses

Crude oil was extracted from aliquots with petroleum ether using a Soxhlet apparatus for 4 h and total nitrogen by the Kjeldahl method [17].

2.2.2. Fatty Acid Analysis

Fatty acid methyl esters were prepared via methylation of total lipids [3]. Methyl esters were separated by gas chromatography in an Agilent GC 7890A gas chromatograph equipped with a flame ionisation detector (FID) and a fused silica capillary column Agilent J&W GC Columns (100 m × 0.25 mm id, 0.25 µm film thickness, Part Number 112-88A7). The carrier gas flow (H^2) was 1.2, 30 mL min^{-1} N^2 and a minimum of 300 mL min^{-1} synthetic air (H^2). The sample splitting rate was 1:50. The samples (1 µL) were injected in triplicate. Peak areas were determined using an Agilent Chem Station B04.03. To identify fatty acids, the retention times were compared with those of standard methyl esters (Supelco 37 Component FAME Mix).

2.2.3. Statistical Analyses

For each feature, variance analysis was estimated using the GLMUnivariate procedures of the IBM SPSS Statistical Program and variance components estimated using the REML method. Genotypic (σ^2_G) and phenotypic (σ^2_P) variants, heritability (h^2) [18] and phenotypic (PCV) and genotypic (GCV) coefficients of variation were calculated [19]. GCV and PCV coefficients were classified as low <10%; moderate 10%–20% and high >20% [20]. Heritability was sorted as low <30%; moderate 30%–60% and high >60% [21]. Genetic advances as percent of means (GAM) was rated as low (<10%), moderate (10%–20%) and high (>20%) [22]. Phenotypic and genotypic correlation coefficients were calculated [23]. Correlation test and path coefficients are shown in IBM SPSS Amos 22.

3. RESULTS AND DISCUSSION

The mean value of grain yield in the year 2015 is shown in Table III. The grain yield ranged from 325.45 to 551.62 (kg da^{-1}), and genotype 'CU-04-07' had the highest while 'KA04-03-05' had the lowest grain yield. Data on mean relative proportion of different fatty acids of 20 soybean PLV revealed significant genotypic variations for all the fatty acids (Tab. II). Palmitic acid content ranged from 10.37% to 12.14%, and the genotype 'SO10815' exhibited highest palmitic acid content. The highest and lowest stearic acid content had 3.65 (KA04-06-01) to 4.70% (CETINBEY), respectively. The oleic acid content ranged from 22.04 (CU-04-07) to 38.07% (KSA-26), whereas the linoleic acid content varied from 38.18 (KSA-26) to 51.85% (CU-04-07) with a mean value of 45.82%. The linolenic acid content among soybean PLV ranged from 4.48% to 6.61% and highest and lowest values were observed in 'CU-04-07' and 'KSA-26' respectively. The protein and oil content of soybean PLV varied from 34.81% to 40.60% and 22.02% to 24.28%, respectively. The mean sum of squares due to replication was non-significant for all the studied characters, while the variation due to PLV was significant for all the characters except protein content (Tab. IV).

3.1. ESTIMATION OF GENETIC VARIABILITY

The characters under investigation were analysed for genotypic variance (σ^2_G), phenotypic variance (σ^2_P), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (h^2) and genetic advance as percentage of the mean (Tab. V). In this investigation, genotypic variances had higher values than phenotypic variances, contrary to previous studies [24, 25, 26]. This indicates the effect of genetic variation. We observed a low range in PCV and GCV in previous studies [24, 25, 26]. Moderate GCV and PCV were observed for the traits grain yield, oleic acid and linolenic acid, and the contents of palmitic, stearic, and linoleic acids, oil and protein revealed low GCV and PCV. These results are lower than those of various other scientists [26, 27]. The reason for the different results obtained in this study may be the environment in which soybeans are grown in the temperate climate zone. High heritability coupled with

Table III - Mean values for grain yield, fatty acid composition(palmitic, stearic, oleic, linoleic and linolenic acid), oil and protein contents of soybean genotypes for various traits

Pure lines and varieties	X1	X2	X3	X4	X5	X6	X7	X8
KSUS 157[a*]	448.50	10.90	4.15	25.39	49.47	6.32	23.13	40.38
KWD 60[a*]	430.20	11.67	4.52	29.87	44.86	5.55	23.11	37.61
KKMA 118[a*]	504.35	10.72	4.47	29.21	46.70	4.83	24.03	39.24
KAS 19-1[a*]	500.55	10.66	4.28	26.93	48.43	6.02	23.37	39.65
KSA-26[a*]	430.10	10.96	4.69	38.07	38.18	4.48	22.29	34.81
KA04-03-05[b*]	325.45	11.82	3.90	28.49	47.33	4.72	23.06	38.40
KA04-06-01[b*]	534.32	10.90	3.65	31.96	44.86	5.12	23.80	38.00
KA04-07-04[b*]	459.00	11.20	4.21	28.77	47.05	5.30	23.24	39.65
SO10815[b*]	506.65	12.14	4.41	27.55	46.85	5.43	24.18	37.91
KA0405-02[b*]	511.90	10.91	4.18	32.52	43.24	5.28	22.69	38.74
UMUT 2002[c**]	452.47	11.75	4.43	30.37	44.92	5.09	23.27	37.56
ÇETİNBEY[a**]	455.45	11.26	4.70	36.40	38.66	4.66	22.02	36.24
SA 88[d**]	449.42	11.85	4.53	27.42	45.95	5.25	23.14	38.49
ATAEM 7[e**]	450.37	10.98	4.31	29.79	45.70	4.97	22.87	38.85
ARISOY[f**]	487.60	10.43	4.15	27.69	48.43	5.25	24.28	38.46
NOVA[g**]	437.65	11.46	4.58	33.18	38.92	4.88	23.48	38.01
ÇU05-62[h*]	513.42	10.37	4.42	28.32	47.49	5.55	23.36	40.60
ÇU03-75-1[h*]	355.37	11.00	4.07	25.85	49.48	5.57	23.07	37.58
ÇU04-07[h*]	551.62	11.90	3.96	26.10	48.10	6.09	23.56	36.87
ÇU04-122[h*]	414.05	11.36	3.92	22.04	51.85	6.61	23.13	39.49
Range	318.50	2.61	1.32	17.74	18.87	2.64	3.63	8.49
Minimum	325.45	10.37	3.65	22.04	38.18	4.48	22.02	34.81
Maximum	551.62	12.14	4.70	38.07	51.85	6.61	24.28	40.60
Mean	460.92	11.21	4.28	29.30	45.82	5.35	23.26	38.33
CV(%)	9.89	2.37	3.08	3.23	3.16	4.55	2.25	2.75
ST ERROR	22.80	0.13	0.07	0.47	0.72	0.12	0.26	0.53

X1:Grain yield (kg da^{-1}), X2: Palmitic acid% , X3: Stearic acid%, X4: Oleic acid%, X5: Linoleic acid% , X6: Linolenic acid%, X7: Oil%, X8:Protein% [a]These materials obtained from Bahri Dagdas International Agricultural Research Institute, [b]These materials obtained from Karadeniz Agricultural Research Institute, [c] These material obtained from Eagean Agricultural Research Institute, [d]These material obtained from Agrova Co., [e] These material obtained from Western Mediterranean Agricultural Research Institute, [f] These material obtained from Cukurova University, [g] These material obtained from May Co., [h] These materials obtained from Eastern Mediterranean Agricultural Research Institute, *These materials are Advanced Soybean Lines, **These materials are Registered soybean varieties

high genetic advance observed for the contents of oleic, linoleic, and linolenic acids indicates a presence of additive gene action and offers the best possibility for improvement of these compounds by various selection methods. A characteristic with a high heritability and a high genetic advance is considered under the control of additive genes, which highlights the usefulness of plant selection based on phenotypic performance [28]. High heritability coupled with moderate genetic advance was observed for the contents of palmitic and stearic acid and indicates the presence of both additive and non-additive gene action for these traits. High heritability coupled with low genetic advance was found grain yield and oil and protein content, which clearly states the presence of non-additive gene action, and selection is not rewarding for these traits. These features may be useful for the improvement of heterosis breeding involving a population improvement exercise [29].

The estimated value of expected genetic advance expressed as a percentage of the mean ranged from 3.05% for oil content to 25.41% for oleic acid. With this range, a relatively high expected genetic advance was obtained from traits with high and moderate heritability but with a better genotypic coefficient of variation. In the present study, oleic acid gave high genetic advance as a percentage of the mean, while moderate genetic advance as a percentage of the mean was computed for stearic acid (11.94%), linoleic acid (15.04%), grain yield (17.13%) and linolenic acid (19.48%) [22]. This finding corresponded to the previous works for grain yield. [26, 30]. Generally, from this study, traits such as oleic acid have the potential to respond positively to selection because of their better broad sense heritability with relatively high genetic advance.

Table IV - Analysis of variances for various traits in soybean genotypes

Sources of variation	X1	X2	X3	X4	X5	X6	X7	X8
Pure lines and varieties	12601.57**	1.05**	0.32**	56.50**	54.11**	1.28**	1.27**	7.67
Replications	1129.51	0.03	0.03	1.49	0.37	0.14	0.24	3.96
Error	2078.60	0.07	0.02	0.89	2.10	0.06	0.27	1.11

* ; ** and indicate significance at 0.05 and 0.01 probability levels, respectively. X1:Grain yield (kg/da), X2: Palmitic acid%, X3: Stearic acid%, X4: Oleic acid%, X5: Linoleic acid% , X6: Linolenic acid%, X7: Oil%, X8: Protein%

Table V - Components of variationforvarioustraits in soybeangenotypes

Components	X1	X2	X3	X4	X5	X6	X7	X8
σ_G^2	4709.34	0.32	0.09	14.79	15.10	0.36	0.52	2.75
σ_P^2	2630.74	0.25	0.08	13.90	13.00	0.31	0.25	1.64
GCV	14.89	5.02	7.13	13.13	8.48	11.29	3.11	4.33
PCV	11.13	4.42	6.43	12.73	7.87	10.33	2.14	3.34
h^2	0.56	0.78	0.81	**0.94**	0.86	0.84	0.48	0.60
GAM	17.13	8.03	11.94	25.41	15.04	19.48	3.05	5.31
CV(%)	9.89	2.37	3.08	3.23	3.16	4.55	2.25	2.75

σ_G^2=Genotipic Variance, σ_P^2=Phenotypic Variance,GCV=Genotypic Coefficient of Variation, PCV=Phenotypic Coefficient of Variation, h^2=Heritability, GAM:Genetic Advance as percent of Mean

X1:Grain yield(kg/da), X2: Palmitic acid% , X3: Stearic acid%, X4: Oleic acid%, X5: Linoleic acid%, X6: Linolenic acid%, X7: Oil%, X8:Protein%

3.2. CORRELATION OF COEFFICIENT ANALYSIS

The results regarding genotypic, phenotypic, and environmental correlation coefficients showed that the genotypic correlations of stearic, oleic, linoleic and linolenic acid and oil contents were higher than the phenotypic and environmental ones (Tab. VI). The environmental correlation coefficients were particularly important in stearic, oleic and linoleic acid and oil content, indicating a high environmental influence in this experiment. Grain yield was positively correlated with oil content at the genotypic level, but previous works found a significant negative correlation between grain yield and oil content [26, 31]. Palmitic acid was positively correlated with stearic acid content and negatively correlated with linolenic acid at the environmental level. A significant positive correlation was found between palmitic acid and protein at the phenotypic level in the previous study [32], but we found a correlation of these traits at the genotypic level. Stearic acid content was found to display a positive and significant correlation with oleic acid content, whereas it was found to be negatively and significantly correlated with linoleic acid, linolenic acid, and oil content at the phenotypic, genotypic and environmental levels. Plants high in stearic acid are more likely to contain oleic acid. Significant negative correlations between palmitic and stearic acid and between oleic and linoleic and linolenic acids, as well as a positive correlation between linoleic and linolenic acid, were observed at the genotypic level. These findings showed an agreement with other studies [33].

The association of oleic acid content was negative and significant with linoleic and linolenic acid, oil, and protein contents at the phenotypic and genotypic levels. La *et al.* [34] observed a nonsignificant correlation of oleic acid with yield, protein, and oil concentrations in the normal-oleic group whereas the high-oleic group was positively correlated with these traits. These correlations could be explained by the association of yield genes with genes related to high-oleic and high oil concentration. Linoleic and linolenic acid and oil content also affected oleic acid negatively at the environmental level. These results revealed that plants high in oleic acid have a low linoleic and environmental linolenic acid content. A highly significant positive correlation was observed between the linoleic acid and linolenic acid, oil, and protein content at the phenotypic and genotypic level. This showed that high linoleic PLV gave a high oil content. These results agree with the results of Hou *et al.,* [35] that demonstrated that environmental linolenic acid was vulnerable to environmental changes. The trend of the relationship of linolenic acid with protein content was positive and highly significant at both the genotypic and phenotypic levels. Therefore, selection based on this trait would be effective at increasing the protein content. We found that, in contrast to previous studies [36, 37, 38], oil content represented a significant positive correlation with protein content at the phenotypic level but showed a significant negative correlation with the environmental condition. Schwender et al. [39] studied the relationship between oil and protein content and suggested that a 1% reduction in to-

Table VI - Phenotypic correlation (rp); Genotypic correlation coefficient (rg)and Simple correlation (r)coefficients between yield componentns in soybean genotypes

		X2	X3	X4	X5	X6	X7	X8
X1	rg	-0.24	0.01	0.07	-0.04	0.17	0.52*	0.11
	rp	-0.22	-0.04	0.04	-0.01	0.15	0.23	0.18
	re	-0.19	-0.13	-0.08	0.09	0.14	-0.08	0.28
	r	-0.23	-0.01	0.06	-0.02	0.16	0.41*	0.13
X2	rg		0.02	-0.10	-0.06	0.04	-0.03	-0.41*
	rp		0.13	-0.07	-0.11	-0.10	-0.01	-0.26
	re		0.59*	0.09	-0.33	-0.69*	0.05	0.06
	r		0.05	-0.09	-0.07	-0.01	-0.02	-0.36*
X3	rg			0.53**	-0.62**	-0.42**	-0.33**	-0.36*
	rp			0.52**	-0.61**	-0.48**	-0.32**	-0.18
	re			0.56**	-0.54**	-0.78**	-0.38**	0.27
	r			0.52**	-0.62**	-0.44**	-0.32**	-0.30
X4	rg				-0.96**	-0.81**	-0.51**	-0.70**
	rp				-0.93**	-0.79**	-0.44**	-0.49**
	re				-0.70**	-0.70**	-0.56**	0.23
	r				-0.96**	-0.81**	-0.48**	-0.63**
X5	rg					0.75**	0.53**	0.73**
	rp					0.73**	0.42**	0.48**
	re					0.63**	0.29	-0.19
	r					0.74**	0.48**	0.65**
X6	rg						0.22	0.57**
	rp						0.23	0.35**
	re						0.29	-0.23
	r						0.22	0.50**
X7	rg							0.57**
	rp							0.05
	re							-0.54**
	r							0.37**

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).
X1:Grain yield(kg/da), X2: Palmitic acid%, X3: Stearic acid%, X4: Oleic acid%, X5: Linoleic acid%, X6: Linolenic acid%, X7: Oil%, X8:Protein%

tal oil content would lead to a 2% increase in total protein content. Thus, the regulation of carbon flux during embryogenesis is shifted toward one or the other, which is impacted by both genetics and the environment, although strong metabolic links between oil and storage protein synthesis are not apparent. Generally, single cross and rapid back cross breeding is used in soybean breeding. The parents may be useful sources of alleles which do not exhibit the usual pleiotropic effects of low seed oil and high seed protein.

3.3. PATH CO-EFFICIENT ANALYSIS

In this investigation, grain yield was considered as a resultant variable, and palmitic, stearic, oleic, linoleic and linolenic acid and oil and protein content were causal (independent) variables. The cause and effect relationship between grain yield and quality characteristics is presented in Table VII.

Palmitic acid registered a high negative direct effect (-3.25) on grain yield (Tab. VI). The indirect effect of this trait on yield via stearic acid (0.05) and oleic acid (0.01) was positive but small in magnitude. The indirect effect of this character on grain linolenic acid (-0.13) was negative. The negative direct effect was counterbalanced by the considerable indirect positive effects of linolenic acid (0.62), oil (0.78) and protein content (2.03), making the total correlation between yield and palmitic acid positive but low (0.11).

Stearic acid (%) showed a negative direct effect (-0.21) on grain yield. The indirect effect of palmitic acid via this trait was positive and high, whereas the indirect effect of oleic acid (0.01) and oil content (0.17) was small. On the other hand, the indirect effect of linoleic and linolenic acid, oil and protein content were negative.

The direct effect of the amount of oleic acid was positive (0.70). The negative indirect effect via palmitic acid (-0.02) and stearic acid (-0.01) were, however,

Table VII - Direct (Bold) and Indirect Effects of 7 characters (Independentvariables) on GrainYield (DependentVariable) in 20 lines of soybean

	Palmitic acid (A)	Stearic acid (B)	Oleic acid (C)	Linoleic acid (D)	Linolenic acid (E)	Oil content (F)	Protein content (G)	r_g
A	**-3.25**	0.05	0.01	0.62	-0.13	0.78	2. 03	0.11
B	0.77	**-0.21**	0.01	-0.81	-0.22	0.17	-0.13	-0.41
C	-0.02	-0.01	**0.70**	4. 45	-2. 25	-1. 98	-1. 26	-0.36
D	-0.24	0.02	0.37	**8.44**	-3. 47	-3. 85	-1. 97	-0.70**
E	0.12	0.01	-0.43	-8.14	**3.60**	3. 54	2. 04	0.73**
F	-0.54	-0.01	-0.29	-6.86	2.69	**4.73**	0.85	0.57*
G	-1.71	0.01	-0.23	-4.30	1.90	1.04	**3.86**	0.57*

Resıdue = -0.3305; ** Significant at 1% level

exceptionally low. The total correlation for this trait was insignificant and negative (-0.36), which was mainly due to the indirect negative contribution of linolenic acid, oil, and protein content. The high indirect effect of linoleic acid was positive.

The direct effect of linoleic acid on grain yield (8.44) was positive. Here, the direct effect of linoleic acid was positive, but the total correlation value was significant and negative, these were due to the considerable negative indirect effects of linolenic acid (-3.47), oil (-3.85) and protein content (-1.97) via these traits.

Linolenic acid had the highest positive direct effect (3.60) on grain yield. A small and negligible negative indirect effect of this trait on yield was registered through oleic acid. The relatively high and positive correlation between linolenic acid and grain yield (0.73) was largely due to the highest positive direct effect and positive indirect effect through oil and protein content (Tab. VII). The result revealed that direct selection for this trait to improve grain yield was highly effective as it furnished the highest direct contribution towards yield.

Oil content showed a positive direct effect (4.73) on yield. The character showed a considerable indirect positive effect on grain yield through linolenic acid. Palmitic, oleic, and linoleic acids had a considerable negative indirect effect via oil content on yield. The total correlation was significant and positive (0.57).

The direct effect of protein content was positive (3.86). The indirect effect found via linolenic acid and oil content on grain yield. On the other hand, the indirect effects of linolenic acid and oil content were positive and considerable; consequently, the total correlation was positive and significant (0.57).

4. CONCLUSION

This study identified the existence of adequate genetic variability among 20 tested PLV for grain yield and quality characteristics. The PLV 'CU-04-07' showed the highest grain yield, significantly above the rest of the PLV. Oleic, linoleic, and linolenic acids displayed high heritability coupled with high genetic advance, which indicates the presence of additive gene action and demands population improvement by selection. Grain yield was significantly and positively correlated with oil content at the genotypic level. Highly significant and positive inter-character associations at both the genotypic and phenotypic levels were obtained between linoleic acid and linolenic acid, oil and protein content. These results indicated that plants high in oil and protein have a high linoleic acid and linolenic acid content. Stearic acid and oleic acid showed highly significant negative correlations with oil content at the genotypic, phenotypic, and environmental levels. Thus, a correlation study revealed that a selection based on linoleic and linolenic acid would be effective in increasing oil content, whereas stearic and oleic acid (%) had negative effects on this trait.

The results of path coefficient analysis revealed that linoleic acid had the highest positive direct (8.44) effect on grain yield, followed by oil content (4.73), protein content (3.86) and oleic acid (0.70). These results indicate that a direct selection based on these characters would be effective for yield improvement. Linolenic acid content had a considerable positive indirect effect via oil content. The indirect effect of oil content via oleic acid (-1.98) and linoleic acid (-3.85) were considerable and negative. The residual effect was -0.3305, which indicated that some other characters were responsible for the contribution to grain yield but not taken into consideration in this investigation. Hence, the information generated from this study can be helpful for the soybean breeder to exploit genetic parameters for future soybean breeding programs.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest

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