Estimation of Some Genetic Parameters and Stability of Growth and Quality Traits for Six Soybean (Glycine max L. Merr) Cultivars under Nano-Phosphate Fertilizer Levels

Muhamed Auda Kalaf AL-Abody[1], Yaseen Obaid Noori Ahmed Sharif[2*], Mohammed Hussein Noor Al-Jana[3], Tariq Raad Thaer Al-Mafarji[4]

[1]Department of Field Crops, College of Agriculture, University of Basrah, Iraq, mohammad.kalaf@uobasrah.edu.iq, https://orcid.org/0000-0002-7380-5307
[2]Department of Field Crops, College of Agriculture, University of Kirkuk, Kirkuk, Iraq. yaseenobaidnoori@uokirkuk.edu.iq, https://orcid.org/0009-0001-2581-9448
[3]Department of Field Crops, College of Agriculture, AL-Muthanna University, AL-Muthanna, Iraq mohammad.noor@mu.edu.iq, https://orcid.org/0000-0002-4472-2158
[4]Department of Medicinal and Industrial Plants, College of Medicinal and Industrial Plants, University of Kirkuk, Kirkuk, Iraq, tariqraad@uokirkuk.edu.iq https://orcid.org/0009-0008-8131-682X

ABSTRACT
Background: Soybean productivity and seed quality are strongly influenced by genetic makeup and nutrient management. This study aimed to estimate genetic parameters and stability of six soybean (Glycine max L. Merr) cultivars and to evaluate their response to different levels of nano-phosphate fertilizer under field conditions.
Methods: A field experiment was conducted during the summer season of 2024 in northern Kirkuk Governorate. Six cultivars (Iman, Energy-2, Energy-3, Lee-74, Shaima, and Senaia-2) were evaluated under six nano-phosphate levels (0, 1000, 2000, 3000, 4000, and 5000 mg/kg). The experiment was arranged in a split-plot within a Randomized Complete Block Design (RCBD) with three replications. Genetic parameters including genotypic (σ^2G), environmental (σ^2E), and phenotypic (σ^2P) variances, broad-sense heritability (h^2_{bs}), stability analysis, and genetic correlation coefficients were estimated.
Results: Oil yield showed positive and highly significant genetic correlations with number of vegetative branches (0.938**), effective branches (0.528**), protein content (0.822**), protein yield (0.998**), and oil content (0.842**). Broad-sense heritability was high for most traits, reaching 70.04% for protein yield and 69.95% for oil yield, indicating predominance of genetic effects and effectiveness of selection. The highest genotypic and phenotypic variances were observed for number of leaves and effective branches. The cultivar Lee-74 (G4) recorded the highest protein and oil yields and was identified as the most genetically stable and high-performing cultivar.
Highest protein yield, and oil yield, were for Lee-74 (G4) cultivar which was identified as the genetically stable cultivar with high yield, representing the ideal cultivar for cultivation.

Keywords: Stability analysis, Genetic parameters, Growth and quality traits, Soybean cultivars, Nano-phosphate fertilizer

Introduction

One of the greatest significant crops in the Fabaceae family is the soybean (Glycine max L.). Widely grown in a variety of environments, it is utilized as a base ingredient for numerous sectors as well as for consumption by humans and animals, and is a rich source of high-quality protein and vegetable oil (Alshamary et al., 2025). Researchers have shown considerable interest in increasing soybean production and narrowing the gap between production and consumption by enhancing yield per unit area, particularly due to the numerous challenges faced by this crop, especially in Iraq, where farmers tend to reduce its cultivation (Al-Issawi and Al-Fahad, 2023).
Foliar supplying has been urged to play down contamination caused by synthetic fertilizers, (Hassan et al., 2019), therefore, it is crucial to use materials that build yield without hurting the surroundings, among that nano-phosphate fertilizers are thought-out highly potent. They are stated to be until three times extra efficient than regular fertilizers, that lowering the demand for chemical fertilizers. They also rapidly penetrate inside cells, are more absorbent by root, as well as transfer and assimilation inside plant (Morales-Diaz et al., 2017).
As a macronutrient, phosphorus is needed by crops and is necessary for physiological and metabolic functions of plant (Milic and Valizadeh, 2016).
Studying genetic stability is crucial for selecting cultivars with both stable genetics and high yield, enabling breeders to develop varieties capable of withstanding environmental variations and adverse conditions. Continuous analysis of genetic stability is necessary to identify soybean cultivars that maintain stable seed yield across different environments (Al-Obaidi & Al-Jubouri, 2023; Al-Mafarji et al., 2026).
Considering the limited studies on the stability analysis and some genetic parameters of growth and quality traits of soybean, and their response to six levels of nano-phosphate fertilizer, the present experiment was conducted.

Materials And Methods

A field experiment was conducted in a northern Kirkuk Governorate, during the summer cropping season of 2024. The experiment aimed to analyze genetic stability and estimate some genetic parameters for growth and quality traits of six soybean (Glycine max L. Merr) cultivars (Iman, Energy-2, Energy-3, Lee-74, Shaima, and Senaia-2), to six levels of nano-phosphate fertilizer (0, 1000, 2000, 3000, 4000, and 5000 mg/kg),The experiment was arranged using a split-plot design within a Randomized Complete Block Design (R.C.B.D.) with three replications was used to set up the experiment. Plots were created in the field, with four rows in each experimental unit, with a row length of 3 m. Seeds were sown in rows spaced 70 cm apart, with 20 cm between hills. Planting was conducted on May 20, 2024. Irrigation was applied immediately after sowing, with subsequent irrigations given as needed. An amount of 200 kg N ha^{-1} (Ali, 2012), the nitrogen fertilizer was administered as urea (46% N) in two equal splits: once after planting and once at the start of blooming (Sharif et al., 2024a).According to Walter (1975) and Hanson et al. (1956), genetic factors such as genotypic variance (σ^2G), environmental variance (σ^2E), phenotypic variance (σ^2P), and broad-sense heritability ($h^2_{b.s}$ %) were calculated. number of vegetative branches per plant, number of effective branches per plant, protein yield (kg ha^{-1}), oil yield (kg ha^{-1}), protein content (%), and oil content (%) were the traits for which phenotypic and genotypic coefficients of variation were computed in accordance with Dudley and Moll (1969) and Burton (1952), respectively. According to Finlay and Wilkinson (1963), Eberhart and Russell (1966), Kang (1993), Wricke (1962), and the Geometric Adaptability Index (GAI), genetic stability study was conducted for the six soybean cultivars' seed production per plant, protein yield, and oil yield.

Results And Discussion

Analysis of variance

The results of Table (1) for the analysis of variance, represented by the mean squares of the Cultivars and Nano-phosphate fertilization of the soybean crop for the studied traits, show that there is a highly significant effect of the traits of the number of vegetative branches in the plant, the number of effective branches, the percentage of protein, the protein yield, and the content of oil. The oil yield. This is due to the difference of the Cultivars in the genetic factor. A highly significant effect was observed for the above traits; This is attributed to the role of nano-phosphate fertilizer in producing these highly significant effects. A highly significant effect was also found for the above traits due to the interaction between Cultivars and nano-phosphate fertilizer levels, Regarding the interaction between Cultivars and Nano-phosphate fertilization, it had a highly significant effect on the studied traits ,This is attributed to the interaction between Cultivars (genetic factors) and Nano-phosphate fertilization levels, which significantly influenced the studied traits(Zhang, 2017; Xu et al. ,2024)

Table 1. Analysis of variance(ANOVA) Traits of soybean as Affected by Treatments.

S.O.V	d.f	Traits					
		NVBPP	NEBPP	PC (%)	PY (kg ha^{-1})	OC (%)	OY (kgha^{-1})
Rep.	2	8.306	0.236	2.637	7980.984	0.447	1120.616
Nano-phosphate	5	456.470**	2.705**	85.742**	195850.078**	8.468**	31891.529**
Error (Nano-phosphate)	10	0.973	0.274	0.954	2182.700	0.0532	280.198
Cultivars	5	12.832**	4.753**	37.786**	83882.370**	3.208**	12854.026**
Nano-phosphate× Cultivars	25	0.930**	0.231**	2.206**	4771.553**	0.232**	754.172**
Error	60	0.265	0.092	0.904	1992.120	0.066	296.936
Total	107						

Abbreviations: SOV, source of variation; df, degrees of freedom; Rep., replication; NVBPP, Number of Vegetative Branches Per Plant; NEBPP, Number of Effective Branches Per Plant; PC, Protein Content (%); PY, Protein Yield (kg ha^{-1}); OC, Oil Content (%); OY, Oil Yield (kg ha^{-1}), *: significant at $p \leq 0.05$; **: significant at $p \leq 0.01$.

Number of vegetative branches per plant

The results in Table (2) indicate that the Lee-74 Cultivar exhibited the highest Number of vegetative branches per plant 29.07, while the Energy-2 Cultivar produced the fewest 26.52. This may be attributed to genetic differences between the Cultivars , consistent with the findings of (Ali ,2018; Sharif et al.,2026). The high level of nano - phosphate fertilizer 5000 mg/Kg resulted in the highest Number of vegetative branches per plant 35.42, while the treatment without the addition of 0 mg/Kg produced the fewest 21.61. This may be because the nature of nano-fertilizers, characterized by their small size and large surface area, facilitates their penetration into plant tissues and increases their absorption rates, thus stimulating plants to produce more vegetative branches. This aligns with the findings of reference missing. (Jamel et al., 2020; Alshamary, et al., 2025; Ali, et al., 2025. And Saleh, et al; 2026).

Table 2. Effect of Cultivars, levels of Nano-phosphate fertilizer and their interaction on the number of vegetative branches in the plant

Cultivars	Nano-Fertilization levels(mg/kg)						Cultivars Means
	0	1000	2000	3000	4000	5000	
Iman	21.94 qr	24.20 op	25.43 m	28.22 ij	30.42 fg	34.50 cd	**27.45 bc**
Energy-2	20.48 s	22.77 q	24.62 m-p	26.66 l	29.68 gh	34.94bcd	**26.52 d**

Energy-3	21.86 qr	23.71 p	25.36 mn	27.86 jk	31.21 f	35.22 bc	**27.53 b**
Lee-74	22.65 q	24.45 nop	27.12 kl	28.94 hi	32.91 e	38.38 a	**29.07 a**
Shaima	21.31 s	23.87 p	25.29 mn	28.22 ij	30.56 fg	35.44 b	**27.45 bc**
Senaia-2	21.40 r	23.80 p	24.93mno	28.39 ij	30.24 g	34.08 d	**27.14 c**
Fertilization Means	**21.61 f**	**23.80 e**	**25.46 d**	**28.05 c**	**30.84 b**	**35.42 a**	**x̅=27.53**

Means followed by the same letter(s) are not significantly different at the 5% probability level according to Duncan's Multiple Range Test (DMRT).

Number of effective branches per plant

The results in Table (3) show that the Lee-74 Cultivar produced the highest number of effective branches per plant 5.05, while the Energy-2 Cultivar produced the lowest number of effective branches per plant 3.49. This may be due to the genetic nature of each studied Cultivar , which is consistent with the findings of (Xu et al. ,2024 ; Sharif et al., 2026).The two levels of nano-phosphate fertilizer 4000 , 5000 mg/Kg recorded the highest number of effective branches 4.84 and 4.87, respectively, with no significant difference between them. The treatment without the addition produced the lowest number of effective branches for this trait 3.90 . This may be due to the role of nano materials in activating the transport system in phloem tissues, thus helping to transport manufactured nutrients from their source to the downstream end. This is consistent with the findings of (Al-Obaidi, 2021 ; Ali, et al., 2025).The Lee-74 Cultivar , at nano-phosphate fertilizer levels of 4000 and 5000 mg/Kg, exhibited the highest average number of branches 5.84 and 6.16 per plant, respectively, with no significant difference between them. Conversely, the Energy-2 Cultivar, at nano-phosphate fertilizer levels of 1000 and 0 mg/Kg, showed the lowest number of branches (3.45 and 3.46 per plant, respectively.

Table 3. Effect of Cultivars, levels of Nano-phosphate fertilizer, and their interaction on the number of effective branches in the plant

Cultivars	**Nano-Fertilization levels(mg/kg)**						**Cultivars Means**
	0	**1000**	**2000**	**3000**	**4000**	**5000**	
Iman	3.93 h-l	4.66 b-f	4.77 b-e	4.44 c-h	4.98 bc	4.91 bcd	**4.61b**
Energy-2	3.46 lm	3.45 lm	3.60 kl	3.01 m	3.74 jkl	3.67 jkl	**3.49 c**
Energy-3	4.03 g-l	4.50 b-h	4.64 b-f	4.03 g-l	4.82 b-e	5.06 b	**4.51 b**
Lee-74	4.03 g-l	4.64 b-f	4.75 b-e	4.91 bcd	5.84 a	6.16 a	**5.05 a**
Shaima	3.84 i-l	4.25 e-j	4.61 b-g	4.37 d-i	4.79 b-e	4.70 b-f	**4.42 b**
Senaia-2	4.13 f-k	4.60 b-g	4.66 b-f	3.94 h-l	4.85 b-e	4.74 b-e	**4.48 b**
Fertilization Means	**3.90 c**	**4.35 b**	**4.50 ab**	**4.11 bc**	**4.84 a**	**4.87 a**	**x̅=4.43**

Protein content (%):

The results in Table (4) show that the Lee-74 Cultivar was superior in giving the highest protein content, which reached 41.22%, while the Energy-2 Cultivar gave the lowest protein content, which reached 36.74%. The reason is due to the genetic variation of the Cultivar, and this is consistent with what (Ali, 2018 ; Al-Ajili, 2023) The 5000 mg/Kg nano-phosphate fertilizer level recorded the highest protein content 41.87%, while the 1000 , 0 mg/Kg treatment gave the lowest protein content 36.17% and 36.83%, respectively, with no statistically significant difference between them. This may be due to the role of nano-phosphate fertilizer and its effect on qualitative traits. This is consistent with the findings of (Kalyanee et al., 2024), where the Lee-74 Cultivar , at both levels of 5000 mg/Kg nano-phosphate fertilizer, gave the highest average for this trait 44.77%, while the Energy-2 Cultivar, at the 0 mg/Kg nano-phosphate fertilizer level, gave the lowest protein percentage 32.58%.

Table 4. Effect of Cultivars, levels of Nano-phosphate fertilizer, and their interaction on protein content(%)

Cultivars	**Nano-Fertilization levels(mg/kg)**						**Cultivars Means**
	0	**1000**	**2000**	**3000**	**4000**	**5000**	
Iman	37.11 jkl	37.62 i-l	38.18 h-k	39.74 e-h	40.11 c-f	40.84 c-f	**38.93 b**
Energy-2	32.58 n	34.81 m	36.58 kl	36.66 jkl	38.44 g-k	41.39 c-f	**36.74 d**
Energy-3	36.94 jkl	36.65 jkl	38.05 h-k	39.02 ghi	41.58 cd	42.26 bc	**39.08 b**
Lee-74	38.50 g-j	38.10 h-k	41.51 cde	41.14 c-f	43.31 ab	44.77 a	**41.22 a**
Shaima	35.87 im	36.97 jkl	37.90 h-k	39.73 e-h	40.06 d-g	42.24 bc	**38.79 bc**
Senaia-2	36.05 im	36.83 jkl	37.19 jkl	40.07 d-g	39.59 fgh	39.73e-h	**38.24 c**
Fertilization Means	**36.17 e**	**36.83 e**	**38.23 d**	**39.39 c**	**40.51 b**	**41.87 a**	**x̅=38.84**

Protein yield (kg ha^{-1})

The results in Table (5) confirm the superiority of the Lee-74 Cultivar, which yielded the highest protein yield 1065.08 kg ha^{-1}, while the Energy-2 Cultivar yielded the lowest (855.68 kg ha^{-1}). This is attributed to the genetic variation between the varieties, which aligns with the findings of (Sharif et al. ,2026; Hasan et al. 2026). The high level of nano-phosphate fertilizer 5000 mg/Kg resulted in the highest protein yield 1096.79 kg ha^{-1}, while the 1000 , 0 mg/kg treatment yielded the lowest protein content 850.15 and 827.83 kg ha^{-1}. This may be due to the role of nano-phosphate fertilizer in increasing seed yield, which is consistent with the findings of (Kalyanee et al.,2024). At the 5000 mg/Kg nano-phosphate fertilizer level, the Lee-74 Cultivar yielded the highest protein yield. 1237.26 kg ha^{-1} while the Energy-2 variety, at the nano-phosphate fertilizer level of 0 mg/Kg, gave the lowest protein yield of 698.03 kg ha^{-1}

Table 5. Effect of Cultivars and levels of Nano-phosphate fertilizer and the interaction between them on protein yield (kg ha^{-1})

Cultivars	Nano-Fertilization levels(mg/kg)						Cultivars Means
	0	1000	2000	3000	4000	5000	
Iman	863.2k-n	886.0 j-n	914.8h-l	989.8 e-h	1007.4d-g	1045.2c-f	**951.06 b**
Energy-2	698.0 p	758.4op	837.6lmn	841.4k-n	925.7g-k	1072.9cde	**855.68 d**
Energy-3	856.1k-n	842.4k-n	906.5hl	953.6g-j	1083.0cd	1118.8bc	**960.07 b**
Lee-74	927.9g-k	909.9hl	1080.1cd	1060.4c-f	1175.8ab	1237.3a	**1065.08 a**
Shaima	807.4no	855.3k-n	899.7im	988.5e-h	1005.3d-g	1118.0 bc	**945.71 bc**
Senaia-2	814.4mno	849.6k-n	866.3k-n	1005.6d-g	981.6f-i	988.6e-h	**917.68 c**
Fertilization Means	**827.83 e**	**850.15 e**	**917.51 d**	**973.20 c**	**1029.80 b**	**1096.79 a**	**x̅=949.21**

Oil content (%):

The results in Table (6) show that the Lee-74 Cultivar was superior in giving the highest content of oil, which reached 19.96%, while the Energy-2 Cultivar gave the lowest content of oil, which reached 18.69%. The reason is due to the genetic nature of the variety, and this is consistent with what(Ali, 2018) concluded The level of nano-phosphate fertilizer 5000 mg/Kg recorded the highest oil content of 20.22% between them, while the treatment 0 , 1000 mg/Kg gave the lowest oil content of 18.48 and 18.57% respectively, with no significant difference between them. This is consistent with what was found by (Kalyanee et al., 2024). The Lee-74 Cultivar at the level of nano-phosphate fertilizer 5000 mg/Kg gave the highest average for this trait of 21.70%, while the Energy-2 variety at the level of nano-phosphate fertilizer 0 mg/Kg gave the lowest oil content of 17.91%

Table 6. Effect of Cultivars and levels of Nano-phosphate fertilizer and the interaction between them. Oil content (%).

Cultivars	Nano-Fertilization levels(mg/kg)						Cultivars Means
	0	1000	2000	3000	4000	5000	
Iman	18.64 n-r	18.77m-r	18.89 k-p	19.28 g-l	19.55 e-i	19.75 c-f	**19.15 bc**
Energy-2	17.91 t	18.06 ts	18.48 p-s	18.50 o-s	19.18h-m	19.97 cde	**18.69 d**
Energy-3	18.60 o-r	18.53 o-s	18.85 l-q	19.10 i-n	19.94 c-f	20.11 cd	**19.19 b**
Lee-74	19.00 j-o	18.90 k-p	19.73 d-g	19.64 d-h	20.79 b	21.70 a	**19.96 a**
Shaima	18.33 rst	18.61 n-r	18.82 l-r	19.28 g-l	19.62 e-h	20.22 c	**19.15 bc**
Senaia-2	18.37 qrs	18.57 o-r	18.64 n-r	19.37 g-k	19.46 f-j	19.54 e-i	**18.99 c**
Fertilization Means	**18.48 e**	**18.57 e**	**18.90 d**	**19.20 c**	**19.76 b**	**20.22 a**	**x̅=19.19**

Oil yield (kg ha^{-1})

The results in Table (7) confirm the superiority of the Lee-74 Cultivar, which yielded the highest oil yield 515.51 kg ha^{-1}, while the Energy-2 Cultivar yielded the lowest oil yield 434.17 kg ha^{-1}. This difference is attributed to genetic variations among the Cultivars, consistent with the findings of(Saqib et al.,2025).The high level of nano-phosphate fertilizer 5000 mg/Kg resulted in the highest oil yield 529.56 kg ha^{-1}, while the 0 and 1000 mg/Kg treatment yielded the lowest oil yield (422.17 kg ha^{-1} and 428.56 kg ha^{-1}. This may be due to the role of nano-phosphate fertilizer in increasing seed yield, consistent with the findings of (Kalyanee et al., 2024 ;Saqib et al.,2025).The Cultivar Lee-74, at both levels of nano-phosphate fertilizer 5000 mg/Kg, produced the highest oil yield 599.75 kg ha^{-1}, while the Energy-2 Cultivar, at the nano-phosphate fertilizer level 0 mg/Kg, produced the lowest oil yield 383.93 kg ha^{-1}

Table 7. Effect of Cultivars and levels of Nnano-phosphate fertilizer and the interaction between them on oil yield (kg ha^{-1})

Cultivars	Nano-Fertilization levels(mg/kg)						Cultivars Means
	0	1000	2000	3000	4000	5000	
Iman	433.43 m-q	442.28 l-q	452.03 j-o	480.18 g-k	491.15 d-h	505.51 c-g	**467.42 bc**
Energy-2	383.93 s	393.48 Rs	423.26 o-r	424.64 n-r	461.87 h-m	517.88 cde	**434.17 d**
Energy-3	430.60	425.61	449.25	466.83	519.56	532.60	**470.74 b**

	m-q	n-q	k-o	h-l	cd	C	
Lee-74	458.00 i-n	450.96 j-o	513.47 c-f	506.27 c-g	564.62 b	599.75 A	**515.51 a**
Shaima	412.15 qrs	430.64 m-q	446.69 l-p	479.79 g-k	492.40 d-h	535.30 C	**466.16 bc**
Senaia-2	414.93 pqr	428.43 m-q	434.16 l-q	486.12 e-i	482.49 f-j	486.37 e-i	**455.41 c**
Fertilization Means	**422.17 e**	**428.56 e**	**453.14 d**	**473.97 c**	**502.01 b**	**529.56 a**	**$\bar{x}$=468.23**

Variances, heritability, and coefficients of variation

The findings in Table 8 show that for every trait under study, the genotypic variance (σ^2G) values were greater than the related environmental variances (σ^2E), underscoring the important role that genetic determinants play in the manifestation of these attributes. The interplay of environmental factors, especially the use of nano-phosphate fertilizer, and genetic factors is responsible for the significant genotypic variance. These results corroborate those of Dutta et al. (2021) and Al-Mafarji & Al-Jubouri (2023a).

The genotypic variance values for growth traits vegetative branches number, effective branches, content of protein, yield of protein, content of oil, and oil yield were, 1.04725, 0.388417, 3.0735, 6824.188, 0.261833, and 1046.424, respectively. These results indicate high genetic stability and a strong influence of genes controlling these traits, resulting in high Genetic variation values .The environmental variances for the same traits were 0.265712, 0.09218, 0.9043, 1992.12, 0.06642, and 296.9365, respectively. The interaction of Genetic variation × Environmental variation 0.221667, 0.046333, 0.434, 926.4777, 0.055333, 152.412 respectively. The corresponding phenotypic variances (σ^2P) were 1.533917, 0.52675, 4.4115, 9742.785, 0.383167, and 1495.772 respectively

Broad-sense heritability ($h^2_{b.s}$ %) for the studied traits was high, with values of 68.27, 73.74, 69.67, 70.04, 68.33, and 69.95% for vegetative branches number, effective branches number, content of protein, yield of protein, content of oil, besides yield of oil, respectively. The characteristics are mostly under genetic domination, accompanied by slightest impact of environmental due to great heritability principles AL-Asadi and AL-Abody, (2025) and Hindi et al. (2026b).

The (PCV) attitudes was above (GCV), displaying few environmental effect on characteristic. The GCV and PCV values for the intentional characteristics Protein yield (kg ha^{-1}) were 8.702884and 10.39871% and Oil yield (kg ha^{-1})were 6.908673 and 8.259875%, respectively. Verma et al. (2021); Sharif et al. (2024b) and Madab et al., (2025) and Hindi et al. (2026a).Genetic determinants have more powerful effect than environmental determinants due to great heritability principles noticed for most characters, and election established these characteristics suit to cause speedy genetic upgrade. active branches number achieved best genotypic plus phenotypic variances, these characteristics are forceful nominees for pick in soybean breeding programs.

Table 8. Estimation of genotypic (σ^2G), environmental (σ^2E), and phenotypic (σ^2P) variances, broad-sense heritability ($h^2_{b.s}$ %), and coefficients of genotypic (GCV%) and phenotypic variation (PCV%) for the studied soybean traits

Genetic Parameters	**Traits**					
	NVBPP	NEBPP	PC (%)	PY (kg ha^{-1})	OC (%)	OY (kgha^{-1})
σ^2G	1.04725 ± 0.170995	0.388417 ± 0.063337	3.0735 ± 0.503525	6824.188 ± 1117.791	0.261833 ± 0.042749	1046.424 ± 171.2889
σ^2E	0.265712 ± 0.018692	0.09218 ± 0.006489	0.9043 ± 0.063763	1992.12 ± 140.5133	0.06642 ± 0.004655	296.9365 ± 20.94425
$\sigma^2G×E$	0.221667 ± 0.03185	0.046333 ± 0.008054	0.434 ± 0.077079	926.4777 ± 166.9625	0.055333 ± 0.007945	152.412 ± 26.27426
σ^2P	1.533917	0.52675	4.4115	9742.785	0.383167	1495.772
h^2bs (%)	68.27	73.74	69.67	70.04	68.33	69.95
GCV (%)	3.717226	14.06842	4.513749	8.702884	2.666475	6.908673
PCV (%)	4.498779	16.38319	5.407717	10.39871	3.225662	8.259875

Stability Analysis

The results bestowed in Table 9 imply cultivar G4 showed the highest YI for protein, and oil, with values of 1065.081 kg ha^{-1}, and 515.511 kg ha^{-1}, individually. Differences in the genetic composition of the cultivars could be the reason (Akbar et al., 2021;Al-Jubouri et al., 2024; AL-Asadi and AL-Abody, 2025).Based on genetic stability analysis, G4 was identified as the genetically stable cultivar with high yield (the ideal cultivar). Using the Finlay and Wilkinson (1963) method, G4 exhibited regression coefficients (bi) of 0.991, and 0.978 for protein, and oil, individually. These results are consistent with those of Zhang et al. (2017), Akbar et al. (2021), Soriano et al. (2023), According to Eberhart and Russell (1966), G4 showed high stability and high yield, with deviation from regression (s^2di) values of 136.670, and 16.069 for protein, and oil, respectively. These findings agree with Soriano et al. (2023), Akbar et al. (2021).G4 is ultimate constant and important-yielding cultivar according to Wricke (1962), the Wi were 1969.017, and 279.701 for protein, and oil, individually Mesfin and Tulu (2024),.GAI of 1058.363 for protein, and 512.787 for oil yield which recognized G4 as the most genetically stable.(YSI), G4 was ultimate constant cultivar established Kang's (1993), with YSI of 5, and 4 for protein, and oil, individually. The ideal cultivar is outlined as one that integrates great yield accompanying genetic stability, that confirming G4 as the excellent genotype Yan and Kang (2003) and Akbar et al., (2021)

Table 9. Mean grain yield and estimates of stability parameters for protein yield, and oil yield of six soybean cultivars across six environments

protein yield (Kg ha $^{-1}$)						
Genotype	**Y1 (Seed yield)**	**bi (Finlay & Wilkinson, 1963)**	**S^2di (Eberhart & Russell, 1966)**	**Wi (Wricke, 1962)**	**GAI**	**YSI (Kang, 1993)**
G1	951.058	1.275	357.047	5970.579	948.711	8
G2	855.684	1.226	1283.597	11912.982	847.513	11
G3	960.068	0.710	334.980	3968.994	954.319	10
G4	1065.081	0.991	136.670	1969.017	1058.363	5
G5	945.714	1.287	734.234	7931.218	940.106	8
G6	917.682	1.210	847.207	8010.161	914.497	7
oil yield (Kg ha $^{-1}$)						
G1	467.429	1.259	50.268	806.783	466.682	7
G2	434.176	1.356	180.067	1904.474	431.941	10
G3	470.741	0.705	20.695	425.355	468.951	9
G4	515.511	0.978	16.069	279.701	512.787	4
G5	466.163	1.261	75.188	1047.357	464.364	7
G6	455.415	1.141	112.818	1821.103	454.411	5

YI: mean yield over all environments; bi: regression coefficient; s^2di: deviation from regression; Wi: Wricke's stability; index; GAI: Geometric Adaptability Index; YSI: Kang's yield stability index.

Genetic Correlation Analysis

The results presented in Table 10 indicates that the values of the genetic correlation coefficients showed a positive and highly significant correlation between the number of vegetative branches and the number of effective branches, reaching (0.510**). A positive and highly significant correlation was also observed between the protein content and the number of vegetative branches and the number of effective branches, reaching (0.843** and 0.644**) respectively. A positive and highly significant correlation was also observed between the protein yield and the number of vegetative branches, the number of effective branches, and the protein content, reaching (0.940**, 0.545**, and 0.849**) respectively. A positive and highly significant correlation was also found between the oil percentage and the number of vegetative branches, the number of effective branches, the protein content, and the protein yield, reaching (0.878**, 0.651**, 0.958**, and 0.857**) respectively. There is a positive and highly significant correlation between oil yield and the number of vegetative branches, the number of effective branches, the protein content, the protein yield, and the oil content, which were (0.938, 0.528, 0.822, 0.998, and 0.842) respectively. These genetic correlations indicate the degree of linkage among genes controlling specific traits and their effect on other related traits. Pleiotropy, relation of genes, or evolutionary connections with yield parts, on account of indirect belongings of gene performance may shape genetic correlations (Dutta et al., (2021), Verma et al. (2021), Al-Mafarji and Al-Jubouri (2023b), Alizawee et al. (2025), and Mahmood et al. (2025).

Table 10. Genetic correlation coefficients among the studied traits of soybean

Traits	**NVBPP**	**NEBPP**	**PC (%)**	**PY (kg ha^{-1})**	**OC(%)**
NVBPP					
NEBPP	0.510**				
PC (%)	0.843**	0.644**			
PY (kg ha^{-1})	0.940**	0.545**	0.849**		
OC(%)	0.878**	0.651**	0.958**	0.857**	
OY (kgha^{-1})	0.938**	0.528**	0.822**	0.998**	0.842**

Correlation is significant at the 0.01 level (**) and at the 0.05 level (*).

Conclusions

The results pointed out protein yield showed a firm and positive correlation accompanying content of protein. Oil yield revealed firm and highly significant positive correlation alongside content of protein, yield of protein, and content of oil. The broad-sense heritability was great for most of characteristics, displaying that genetic effects were too effective than environmental, and propounding that pick for previous characteristics manage result in fast genetic progress.

The best genetic and phenotypic variance was noticed for protein yield, and oil yield, making these characteristics encouraging applicants for selection in soybean programs of breeding. Lee-74 (G4) presented the best protein yield, and oil yield, in addition to genetic stability. The practiced genetic stability analysis ways were useful side to side various environments in recognizing genotypes accompanying great yield besides stable performance.

References

1. Akbar, M. R., Purwoko, B. S., Dewi, I. S., Suwarno, W. B., & Sugiyanta. (2021). Genotype × environment interaction and stability analysis for high yielding doubled haploid lines of lowland rice. Turkish Journal of Field Crops, 26(2), 218–225.
2. Al-Ajili, B. F. A. A. (2023). Estimation of stability under water stress and salicylate treatments for genotypes of soybean (Glycine max L.) (Master's thesis, University of Tikrit, College of Agriculture
3. Al-Asadi, E. Q. A., & Al-Abody, M. A. K. (2025). Genetic parameters of different oat genotypes using cluster analysis. SABRAO Journal of Breeding and Genetics, 57(1), 86–93.
4. Ali, A.H., Sharif, Y.O.N.A., Raheem, A.H., Hussein, A.A.K. and Al-Mafarji, T.R.T. (2025). The Effect of Phosphorus Levels on Growth and Yield Components in Sunflower (Helianthus annuus L.). Agricultural Science Digest. 1-6. doi:10.18805/ag.DF-771.
5. Ali, N. D. S. (2012). Fertilizer technologies and their uses. University House for Authoring, Publishing and Translation, University of Baghdad, College of Agriculture.
6. Ali, S. H. M. (2018). Effect of the distance between the lines and plants in the growth and yield of three soybean varieties (Glycine max L. Merrill),M.Sc. , University of Kirkuk, College of Agriculture.
7. Al-Issawi, A. M., & Al-Fahad, A. C. (2023). Effect of foliar application of glutathione on viability and vigor of sorghum seeds affected by heat stress. In IOP Conference Series: Earth and Environmental Science, 1252(1), 1–10.
8. Alizawee, M. R. M., Ahmed, H. S., Mohammad, M. I., Al-Ani, S. H. I., Al-Hadidi, R. M. F., & Al-Mafarji, T. R. T. (2025). Analysis of correlation and coefficient for seven flax varieties by two types of sprinkler heads system. IOP Conference Series: Earth and Environmental Science, 1549, 012136.
9. Al-Jubouri, R. M. A., Mohammed, M. I., & Al-Mafarji, T. R. T. (2024). Genetic Analysis of Heterosis and some Genetic Parameters of Half Diallel Crosses in Maize (Zea mays L.). IOP Conference Series: Earth and Environmental Science, 1371(5).
10. Al-Mafarji, T. R. T., & Al-Jubouri, J. M. A. (2023a). Combining Ability and Gene Action of Half Diallel Crosses in Bread Wheat (Triticum aestivum L.). IOP Conference Series: Earth and Environmental Science, 1262(5).
11. Al-Mafarji, T. R. T., & Al-Jubouri, J. M. A. (2023b). Heterosis, correlations and path analysis of grain yield components in bread wheat (Triticum aestivum L.). Kirkuk University Journal for Agricultural Sciences, 14(3), 34–46.
12. Al-Mafarji, T. R. T., Al-Jubouri, J. M. A., & Kanbar, A. (2024). Estimate Combining Ability and Gene Action of Yield, and Some Qualitative Traits of Bread Wheat Genotypes. (Triticum aestivum L.) of Half-Diallel Crosses. Tikrit Journal for Agricultural Sciences, 24(3), 182–196.
13. Al-Mafarji, T., Abdullah, R., Zabin, K., & Hasan, S. (2026). Genetic Variability and Stability of Grain Yield and Related Traits in Barley Genotypes Across Three Seasons Using Eberhart–Russell and GGE-Biplot Analyses. Egyptian Journal of Agronomy, 48(2), 751-765.
14. Al-Obaidi, A. H. S. H. (2021). Effect of pre-soaking technique of bread wheat grains with nano-fertilizer, polyamide, and gibberellin on growth, yield, and its components , M.Sc. College of Agriculture and Forestry, University of Mosul, Iraq.
15. Al-Obaidi, O. N. J., & Al-Jubouri, J. M. A. (2023). Stability study of cotton genotypes cultivated in different environments. In IOP Conference Series: Earth and Environmental Science (Vol. 1158, No. 6, p. 062030). IOP Publishing.
16. Alshamary, W. F. A., Sharif, Y. O. N. A., Noori, N. E., & Kahlel, A.-M. S. (2025). Effect of Moisture Depletion Rate and Irrigation Water Depth on the Productivity and Water Use Efficiency of Soybean Crop (Glycine max L.) Merr. under Drip Irrigation and Fixed Sprinkler Irrigation Systems. Agricultural Science Digest, 45(2), 222–227.
17. Burton, G. W. (1952). Quantitative inheritance in grasses. Proceedings of the Sixth International Grassland Congress, 1, 277–288.
18. Dudley, J. W., & Moll, R. H. (1969). Interpretations and use of estimates of heritability and genetic variances in plant breeding. Crop Science, 9, 257–262.
19. Dutta, P., Goswami, P. K., & Borah, M. (2021). Assessment of genetic variability, heritability and genetic advance in soybean [Glycine max (L.) Merril] genotypes. Electronic Journal of Plant Breeding, 12(4), 1461–1465.
20. Eberhart, S. A., & Russell, W. A. (1966). Stability parameters for comparing varieties. Crop Science, 6, 36–40.
21. Finlay, K. W., & Wilkinson, G. N. (1963). The analysis of adaptation in a plant-breeding programme. Australian Journal of Agricultural Research, 14(6), 742–754.
22. Hanson, C. H., Robinson, H. F., & Comstock, R. E. (1956). Biometrical studies of yield in segregating populations of Korean lespedeza. Agronomy Journal, 48(6), 268–272.
23. Hindi, H., Madab, D., Sharif, Y., & Al-Mafarji, T. (2026a). Effect of Boron Spraying on Flour Quality Traits of Bread Wheat (Triticum aestivum L.) Genotypes and Estimation of Their Genetic Parameters. Egyptian Journal of Agronomy, 48(1), 175-184.
24. Hindi, H. A., Faisal, L. N., Sharif, Y. O. N. A., & Al-Mafarji, T. R. T. (2026b). Performance evaluation, estimation of genetic and phenotypic correlation coefficients, and path coefficient analysis of quantitative traits in triticale genotypes grown under different seeding rates. Pakistan Journal of Agricultural Research, 39(1), 77–88.
25. Hasan, S. A., Abdullah, R. M., Jaber, H. A., & Al-Mafarji, T. R. T. (2026). Genetic diversity of oat (Avena sativa L.) genotypes under different concentrations of potassium. SABRAO J. Breed. Genet. 58 (1) 285-293.
26. Jamel, F. A., Al-Abody, M. A. K., and Al-Hilfi, S. K. J. (2020). Effect of different levels of nitrogen and phosphorus fertilizers on growth of fenugreek. Diyala Journal of Agricultural Sciences, 12 (Special Issue), 315. ISSN 2073-9524
27. Kalyanee, G., Sajid, M., Bhoyar, S. M., Age, A. B., Moharil, M. P., and Jadhav, A. C. (2024). Assessing Efficiency of nano phosphorus on soybean. International Journal of Chemical and Biochemical Sciences, 8(11), Article 3011.

28. Kang, M. S. (1993). Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. Agronomy Journal, 85, 754–757.
29. Madab, D. S., Hindi, H. A., Sharif, Y. O. N. A., & Al-Mafarji, T. R. T. (2025). Nature in inheritance of yield and its components in different mating designs of cotton genotypes (Gossypium hirsutum L.). Natural and Engineering Sciences, 10(2), 495–509.
30. Mahmood, E. T., Al-Mafarji, T. R. T., AL-Ethawi, M. B., Ahmed, K. K., Al-Ani, S. H. I., & Korolev, K. P. (2025). Correlation analysis of growth, yield, and quality traits in maize (Zea mays L.) hybrids under different plant densities. IOP Conference Series: Earth and Environmental Science, 1538(1), 012041.
31. Mesfin, A., & Tulu, L. (2024). Genotype × environment interaction and stability analysis of soybean (Glycine max L.) genotypes using AMMI and other stability methods in Western Ethiopia. Jimma University Institutional Repository.
32. Milic, D., & Valizadeh, M. (2016). Role of phosphorus in regulating plant growth under field conditions. Journal of Plant Nutrition, 39(7), 1005–1017.
33. Morales-Diaz, H. O., Ortega, A. M., Juárez, G. P., Cadenas, S. M., González, A., & Benavides-Mendoza, A. (2017). Application of nanoelements in plant nutrition and its impact in ecosystems. Advances in Natural Sciences: Nanoscience and Nanotechnology, 8, 13.
34. Saleh, A. A., Sharif, Y. O. N. A., Raheem, A. H. (2026). Abscisic Acid Exogenous Spraying to Improve Sorghum (Sorghum bicolor (L.) Moench) Genotypes for Tolerance to Abiotic Stress. Pertanika Journal of Tropical Agricultural Science, 49 (2): 863 - 879.
35. Saqib, A., Manuja, S., Kumar, N., Sharma, R. P., Mujayed, B. A., Thakur, D., and Mridula. (2025). Effect of nitrogen and phosphorus levels and Nano-DAP application on growth and yield of soybean (Glycine max (L). Merr.). Himachal Journal of Agricultural Research 51(1): 88-93.
36. Sharif, Y. O. N. A., Al-Mafrajy, A. S. H., & Albarzenje, Z. M. M. (2024a). Evaluation of the Effectiveness of 2.4-D 72% Herbicide in Combating Weedy Leaves Associated with Different Varieties of Forage Sorghum (Sorghum bicolor L.) and Its Effect on Growth Characteristics. IOP Conference Series: Earth and Environmental Science, 1371(5).
37. Sharif, Y. O. N. A., Madab, D. S., & Hindi, H. A. (2024b). Estimation of path analysis and genetic parameters for sorghum (Sorghum bicolor (L.) Moench) varieties in different environments. IOP Conference Series: Earth and Environmental Science, 1371(5), 1–8.
38. Sharif, Y.O.N.A., AL-Abody, M.A.K., Muhammad, S.T. and Al-Mafarji, T.R.T. (2026). Genetic Parameters and Stability of Soybean [Glycine max (L.) Merr.] Cultivars under Nano-phosphorus Foliar Fertilization Levels. Indian Journal of Agricultural Research, 1–7.
39. Soriano, J. M., Malosetti, M., Roselló, M., Sillero, J. C., Royo, C., & Casas, A. M. (2023). Multi-environment grain yield and quality trait performance in Mediterranean durum wheat. European Journal of Agronomy, 145, 126774.
40. Verma, V., Shrivastava, M. K., Mehra, S., Amrate, P. K., & Yadav, R. B. (2021). Estimation of genetic parameters for yield-associated traits and principal component in advanced breeding lines of soybean (Glycine max (L.) Merrill). International Journal of Current Microbiology and Applied Sciences, 10(1), 2704–2710.
41. Walter, A. B. (1975). Manual of quantitative genetics (3rd ed.). Washington State University Press, USA. (Cited by Al-Haza’a, 2001)
42. Wilkinson, G. N. (1963). The analysis of adaptation in a plant-breeding programme. Australian Journal of Agricultural Research, 14(6), 742–754.
43. Wricke, G. (1962). Über eine Methode zur Erfassung der ökologischen Streubreite in Feldversuchen. Zeitschrift für Pflanzenzüchtung, 47, 92–96.
44. Xu, L.-W., Pang, J., Turner, N. C., Lambers, H., and He, J. (2024). Genotypic differences in soybean (Glycine max L.) in yield response to phosphorus fertilizer are associated with difference in biomass and phosphorus content. Field Crops Research, 302, 109079. https://doi.org/10.1016/j.fcr.2023.109079
45. Zhang, H., Berger, J. D., & Milroy, S. P. (2017). Yield stability and adaptability of canola (Brassica napus L.) in Western Australia. Euphytica, 213(12), 288.