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GENOTYPIC AND PHENOTYPIC VARIATIONS AND GENETIC GAIN IN FABA BEAN WITH INFLUENCE OF NANO-SILICON

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SUMMARY

The latest study aimed to evaluate the genotypes' genetic potential and estimate the genetic parameters for yield-related traits in two faba beans (*Vicia faba* L.) cultivars with the influence of nano-silicon different concentrations. The experiment comprised a randomized complete block design (RCBD) with a factorial arrangement of two factors and three replications. Faba bean cultivars (Turkish and Italian) were content in the main plots, while the subplots comprised nano silicon different levels (0, 1, and 2 ml L^{-1}). The analysis of variance exhibited significant differences between the cultivars for all studied traits. The superiority of the Turkish cultivar was remarkable for the pods per plant, seeds per pod, seed yield, and biological yield. The results showed that the phenotypic and genotypic variations were high for all traits at the nano silicon level of 2 ml L^{-1}). However, they decreased at the control treatment. Heritability (broad sense) was extremely high for all traits and nano-silicon concentrations, indicating that the variation among the cultivars was mainly genotypic. The genetic gain displayed the highest for the 100-seed weight while low for the rest of the yield-related traits in faba beans.

Keywords: Faba bean (*Vicia faba* L.), cultivars, nano-silicon concentrations, genotypic and phenotypic variations, heritability, genetic gain

Key findings: The study showed the superiority of the Turkish cultivar in yield characteristics and its components and was more responsive to foliar application of the nano-silicon. It indicates that the phenotypic variation between the cultivars was predominantly genetic.

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INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the valuable plants of the leguminous family, widespread in the world as a chief source of protein in various countries of Africa and Asia. Faba bean growing foremost serves to obtain soft and dry seeds, as it contributes significantly to a balanced diet given that it contains essential sources of vegetable protein (25%–40%), which are rich in amino acids (Alghamdi, 2009).

Faba bean yield suffers from a low productivity rate because of the deterioration of the genetic structure of local cultivars and perhaps environmental non-adaptation of the cultivars introduced in Iraq. The cultivars vary in their genetic and physiological composition, which makes them differ in growth behavior and yield-related traits according to prevailing environmental conditions and the nature of crop-growing operations (Atab *et al.*, 2023). The estimation of variation components by quantitative traits also plays a vital role in choosing the appropriate and effective method of genetic improvement (Mulualem *et al.*, 2013).

The genetic improvement of any desired trait depends mainly on the size and nature of the genetic variability and the percentage of inheritance of the desired traits (Shakarji, 2010), and the estimate of inheritance works as a guide in breeding methods (Abbadi and Al-Kamar, 2010). Different cultivars vary for various morphological and yield-related traits and one of the difficulties plant breeders face is the selection criteria. The choice of parents to know their genetic differences for most vital traits can serve as a criterion for selection (Bijan, 2022).

. Plant breeders should rely on quality-associated yield-related traits with better inheritance because the measured attribute is a quantitative one (Kalia and Sood, 2004).

Nutrients integrate with genetic structures and environments and play crucial roles in determining breeding methods to improve the genotypes adapted to particular plant nutrition conditions and the factors affecting plant growth and crop yield (Jasim *et al.*, 2018). Among the essential nutrient fertilizers for crop plants, the nano-silicon element is one of the rare nutrients that play a pivotal role in withstanding various types of environmental stresses, which increases the rate of photosynthesis and helps the plant to resist diseases and insect pests and, eventually, enhance its tolerance to environmental stress conditions (Atab, 2023).

The presented study will explore the phenotypic and genetic variations and genetic gain for yield-related components, which will be a forward step to infer their results in knowing the extent to which these cultivars respond to selection in breeding programs and improving the faba bean crop in the future. The latest study aimed to evaluate the genetic potential of faba bean cultivars under the influence of different concentrations of nano-silicon at the Babylon Governorate, Iraq. In addition, the study also sought to select the best-performing faba bean genotypes for productivity and quality-related parameters.

MATERIALS AND METHODS

The faba bean (*Vicia faba* L.) field experiment commenced during the winter of 2022–2023 at the Agricultural Research Station, Directorate of Agriculture, South Babylon Province, Iraq (latitude 32.40 North and longitude 44.39 East)***.*** Nano-silicon different concentrations treatment estimated genotypic and phenotypic variations, genetic gain, and the genetic potential of two bean cultivars. The experiment comprised a randomized complete block design (RCBD) with a factorial arrangement of two factors and three replications. The two bean cultivars (Turkish and Italian) became content in the main plots, with the nano-silicon concentrations (0, 1, and 2 ml L^{-1}) placed in the subplots. The experimental units totaled 18 (3 × 2 × 3).

The perpendicular soil plowing used the deep dump plow (30 cm), followed by soil smoothing and leveling with the laser leveling and opening of the main waterways by Fateh Al-Sawaqi. Later, soil division into three main sectors ensued, with a one-meter distance between the two. Planting proceeded by drilling the rows in its upper third with a 5-cm depth; then, placing two seeds in one drilling received covering with an appropriate layer of soil. Ten days after planting, the patching process continued for the non-germinating gore, and after two weeks of germination, the thinning process transpired by keeping one plant per hole. The seeds of the two faba bean cultivars' sowing occurred on November 1, 2022, in 4-m long rows, with a 25-cm and 70-cm distance between plant-to-plant and row-to-row, respectively (Atab *et al.*, 2023).

The field operations like irrigation, hoeing, and weeding proceeded according to the plant's needs. The addition of phosphate superphosphate fertilizer had the rate of P_2O_5 100 kg ha^{-1} (in one batch before planting) and nitrogen fertilizer (urea 46%) 100 kg N ha^{-1} in two batches (the first at planting and the second after one month from the first application). Irrigation also occurred per plant needs, with the bushes hoed manually Merhij and Al-Khafaji , 2023) The first spray of the nano-silicon happened at the beginning of flowering, with the second spray two weeks after the first spray during the flower phase completion. Spraying of bean plants progressed in the early morning by a dorsal sprayer with a capacity of 20 liters, adding a diffuser material to reduce the surface tension of the water, ensure complete wetness of leaves, and increase the efficiency of the spray solution in penetrating the outer surface of the plants.

Data recorded and statistical analysis

After the plants reached physiological maturity, the data recording on quantitative yield-related traits ensued for pods per plant, seeds per pod, 100-seed weight (g), seed yield (t/ha), and biological yield (t/ha). After collecting and tabulating the data for all the quantitative characteristics in the field experiment, the data analysis according to RCBD design used the statistical analysis program 12-Genstat-v. The different treatment means' further comparison and separation employed the least significant difference ($LSD_{0.05}$) test (Al-Rawi and Khalaf-Allah, 2000).

Genetic parameters

Genotypic, phenotypic, and environmental variances

The estimation for the genotypic, phenotypic, and environmental variations continued according to the method illustrated by Walter (1975) as follows:

$$\sigma_r^2 = \sigma_G^2 = \frac{Msg - Mse}{r}$$

$$\sigma_E^2 = Mse$$

$$\sigma_p^2 = \sigma_G^2 + \sigma_E^2$$

Where:

σ_G^2 : Genetic variance

σ_E^2 : Environmental variance

σ_p^2 **:** Phenotypic variance

Heritability and genetic gain

The heritability (broad sense) estimation employed the procedure by Hanson *et al.* (1956) as follows:

$$H_{B.S}^2 = \frac{\sigma_G^2}{\sigma_p^2} \times 100$$

Where:

$H_{B.S}^2$: Represents inheritance in the broad sense

σ_G^2 : Genetic variation of the trait

: σ_p^2 : Phenotypic variation of the trait

The expected genetic gain calculation is per the equation below.

$$G.A = K.H_{B.S.}^2\sigma_P$$

Where:

$G.A$: Represents the expected genetic gain

H^2 (B.S): Heritability in the broad sense

σ_P **:** Standard deviation of phenotypic variation

K : Selection intensity was equal to 2.06 (when selecting 5% of plants)

The adopted limits of the genetic gain values relied on Robinson *et al.* (1966), as follows: High (>30%), Medium (10%–30%), and Low (<10%).

RESULTS AND DISCUSSION

Pods per plant

The faba bean cultivars and nano-silicon concentrations revealed significant differences for pods per plant (Table 1). The Turkish cultivar achieved the highest rate for the number of pods per plant (10.12) compared with the Italian cultivar obtaining the lowest number (8.11). Nano-silicon concentration (2 ml L^{-1}) significantly performed better and, on average, showed the most number of pods per plant (13.07), followed by nano-silicon concentration (1 ml L^{-1} with 7.90 pods/plant); however, the control treatment provided the lowest average at 5.61 pods/plant. In the case of genotype by nano-silicon interactions, the Turkish cultivar with nano-silicon concentration of 2 ml/L produced the optimum number of pods per plant (14.87) versus the Italian and Turkish cultivars with control treatments of nano-silicon recording with the least values for the said trait (5.57 and 6.32, respectively).

Seeds per pod

Faba bean cultivars and nano-silicon levels remarkably influenced the seeds per pod, exhibiting considerable differences for the said trait (Table 2). The results further enunciated that the Turkish cultivar appeared substantially superior for the number of seeds per pod (4.06) than the Italian cultivar, which achieved the lowest rate for the attribute (3.93). Likewise, the results showed a meaningful effect of the nano-silicon on the number of seeds per pod, with its highest level (2 ml/L) producing the maximum number of seeds per pod (4.86), followed by its low level (1 ml/L at 3.44) compared to the control treatment, giving the lowest rate (3.07 seeds/pod). On interactions of faba bean cultivars and nano-silicon, the Turkish cultivar with nano-silicon concentration (2 ml/L) showed an enhanced number of seeds per pod (5.44) compared to the Italian and Turkish cultivars with controlled treatments of nano-silicon, recording the minimum values for seeds per pod (3.03 and 3.10, respectively).

Table *1*. Effect of cultivars and nano-silicon on the pods per plant in faba beans.

Cultivars	Nano-silicon (ml/L)			Means
	0	1	2	
Turkish	6.32	9.17	14.87	10.12
Italian	5.57	7.493	11.28	8.11
Means	5.61	7.90	13.07	
$LSD_{0.05}$ Cultivars: 0.321, Nano-silicon: 0.278, V × S: 0.556				

Table *2*. Effect of cultivars and nano-silicon on the seeds per pod in broad beans.

Cultivars	Nano-silicon (ml/L)			Means
	0	1	2	
Turkish	3.10	3.64	5.44	4.06
Italian	3.03	3.74	5.01	3.93
Means	3.07	3.44	4.86	
$LSD_{0.05}$ Cultivars: 0.158, Nano-silicon: 0.137, V × S: 0.274				

Table 3. Effect of cultivars and nano-silicon on the 100-seed weight in broad beans.

Cultivars	Nano-silicon (ml/L)			Means (g)
	0	1	2	
Turkish	113.68	120.96	129.03	121.22
Italian	91.16	106.57	138.99	112.24
Means (g)	100.55	113.90	135.02	
$LSD_{0.05}$ Cultivars: 2.300, Nano-silicon: 1.992, V × S: 3.984				

Table 4. Effect of cultivars and nano-silicon on the seed yield in broad beans.

Cultivars	Nano-silicon (ml/L)			Means (t/ha)
	0	1	2	
Turkish	0.638	1.154	2.983	1.592
Italian	0.439	0.856	2.246	1.180
Means (t/ha)	0.501	0.898	2.451	
$LSD_{0.05}$ Cultivars: 0.063, Nano-silicon: 0.055, V × S: 0.110				

Table 5. Effect of cultivars and nano-silicon on the biological yield in broad beans.

Cultivars	Nano-silicon (ml/L)			Means (t/ha)
	0	1	2	
Turkish	1.603	2.387	5.595	3.195
Italian	0.904	1.690	3.831	2.142
Means (tons/ha)	1.174	1.927	4.428	
$LSD_{0.05}$ Cultivars: 2.045, Nano-silicon: 1.771, V × S: 3.542				

100-seed weight

The faba bean cultivars and nano-silicon levels exhibited significant differences for the 100-seed weight (Table 3). On average, the Turkish cultivar achieved considerable superiority in the 100-seed at 121.22 g compared with the Italian bean cultivar, providing the lowest 100-seed weight at 112.24 g. As for nano-silicon, the concentration of 2 ml/L reached the highest average in 100-seed weight (135.02 g) versus the comparison treatment with the lowest value (100.55 g). In the case of faba bean cultivars by nano-silicon interactions, the Italian cultivar with a nano-silicon concentration of 2 ml/L produced the maximum 100-seed weight (138.99 g) compared with the Italian and Turkish faba bean cultivars with control treatments of the nano-silicon displaying the minimum 100-seed weight (91.16 and 113.68 g, respectively).

Seed yield

The results revealed that faba bean cultivars and nano-silicon concentrations markedly affected seed yield (t/ha) (Table 4). The Turkish cultivar achieved the highest average seed yield (1.592 t/ha) compared with the Italian cultivar, which attained the lowest total yield (1.180 t/ha). On the nano-silicon treatments, the nano-silicon concentration (2 ml\L) notably produced a higher seed yield (2.451 t\ha), and the lowest averages came from the nano-silicon concentration (1 ml/liter) and the control treatment (0.898 and 0.501 t/ha, respectively). In interactions of genotype by nano-silicon, the Turkish cultivar with nano-silicon concentration (2 ml\L) produced the highest seed yield (2.983 t\ha) compared with the Turkish and Italian cultivars with control treatments of nano-silicon, recording the lowest values for the said trait (0.638 and 0.439 t/ha, respectively).

Biological yield

The outcomes showed prominent differences in faba bean cultivars and nano-silicon concentrations for the biological yield (Table 5). The Turkish cultivar acquired the highest biological yield (3.195 t/ha) compared with the

Italian cultivar, which gained the lowest (2.142 t/ha). The nano-silicon higher concentration (2 ml/L) showed considerably enhanced biological yield (4.428 t/ha) versus the nano-silicon lower level (1 ml/L) and the check, achieving the lowest biological yield rates (1.927 and 1.174 t/ha, respectively). In the interaction of faba bean cultivars by nano-silicon concentrations, the Turkish cultivar with a nano-silicon concentration of 2 ml/L produced the utmost biological yield (5.595 t/ha) compared with the Turkish and Italian cultivars with control treatments of the nano-silicon providing the lowest biological yield (1.603 and 0.904 tons/ha, respectively).

The results enunciated that the variations among the faba bean genotypes for yield-contributing traits and seed yield might be due to their genetic makeup and the existing environmental conditions, which also have a considerable impact on the genotypes' performance (Kalia and Sood, 2004; Shakarji, 2010). In most crop plants, seed yield is the primary goal, a complex quantitative trait controlled by numerous genetic factors, environmental influences, growing conditions, and these interactions (Atab, 2023). Nano-silicon also contributes to enhancing the seed yield and its components. Silicon improves the activity of photosynthesis and its efficiency in plants and, eventually, increases the dry matter, with these factors associated with the efficiency of transporting nutrients to other parts of the crop plant (Behailu *et al*., 2018). Findings showed the plants with the most seeds filled in the pods increased 100-seed weight, leading to a high seed yield (Jawahar and Vaiyapuri, 2010).

Genetic parameters

The findings showed the values of genotypic, phenotypic, and environmental variations of the studied traits under the influence of different concentrations of nano-silicon (Table 6). It was evident that the higher values of genetic variation are due to the phenotypic variation than the environmental variation of studied traits. The said presentation also provides evidence that the genotype genetic makeup is vital in expressing traits, and it offers an opportunity for plant breeders to select effectively (Mulualem *et al.*, 2013). Therefore, the genotypic differences for the most valuable characteristics can become a criterion for selection (Kalia and Sood, 2004; Merhij and Al-Khafaji, 2023).

Table 6. Genotypic and phenotypic variations and heritability ratios for various traits of broad beans under the influence nano-silicon concentrations.

Variations	Nano-Silicon	Pods/plant	Seeds/pod	100-seed weight (g)	Seed yield (t/ha)	Biological yield (t/ha)
Genotypic variation	0	6.77	1.89	2094.7	0.061	0.369
	1	13.44	2.43	2653.85	0.203	0.892
	2	35.82	4.88	3663.7	1.29	4.40
Phenotypic contrast	0	6.86	1.90	2097.0	0.062	0.373
	1	13.51	2.46	2664.0	0.205	0.902
	2	35.88	4.91	3665.2	1.30	4.43
Environmental variation	0	0.0846	0.0107	2.2710	0.0004	0.0039
	1	0.0655	0.0219	10.176	0.002	0.009
	2	0.0657	0.0297	1.513	0.005	0.0312
Heritability (broad sense)	0	98.76	99.43	99.89	99.23	98.94
	1	99.51	99.10	99.61	98.96	98.99
	2	99.81	99.39	99.95	99.54	99.29
Genetic gain	0	5.3	2.8	99.23	0.51	1.4
	1	7.53	3.2	105.91	0.92	1.9
	2	12.31	4.5	124.66	2.33	4.30

According to the results, the values of genetic variation were high with the influence of the nano-silicon concentration (2 ml/L) on the traits pods per plant, seeds per pod, 100-seed weight, seed yield, and biological yield, amounting to 35.82, 4.88, 3663.7, 1.29, and 4.40, respectively. However, by comparing with the control treatment, the values of the genetic variation for the said trait were least (6.77, 1.89, 2094.7, 0.061, and 0.369, respectively). It indicates more prominent variations between genotypes with a high nano-silicon concentration. The nature of genetic variability and the percentage of inheritance of the desired traits are essential in improving the genotypes (Abbadi and Al-Kamar, 2010; Shakarji, 2010).

About the phenotypic variation, the variations among the genotype plants cultivated under the nano-silicon concentration (2 ml/L) revealed that genotypic and phenotypic variations were more reflective in the heritability (broad sense). However, the heritability was highest in the nano-silicon (2 ml/L) compared with the control treatment, in which heritability significantly decreased. The results further indicated the better role of the genetic variation than the phenotypic variation. The faba bean plant expresses the traits from genetic structures and environmental influences and their interactions (Sahuke, 2006). The results in the phenotypic form, expressing these differences in variations, were consistent with past findings studying the genetic diversity of Ethiopian faba bean (*Vicia faba* L.) varieties (Behailu *et al*., 2018). Likewise, it could be due to additional and non-additional effects of genes in controlling the inheritance of these features in *Vicia faba* L. (Abbadi and Al-Kamar, 2010; Hussein *et al*., 2024).

The presented study also indicated the inheritance ratios with different rates for varying yield-contributing traits. These can benefit quantitative traits' genetic improvement and help enhance genetic resources. The inheritance ratios can also facilitate improving these traits through intensive selection (Mather and Jinks, 1982). The values of the expected genetic advance, as proposed by Robinson *et al.* (1966), with a nano-silicon concentration of 2 ml/L, the highest values were evident for pods per plant (12.31) and 100-seed weight (124.66), while low for the number of seeds per pod, seed yield, and biological yield (4.5, 2.23, and 4.30, respectively). However, for pods per plant, seeds per pod, 100-seed weight, seed yield, and biological yield with the control treatment, extremely minimum values of the genetic gain were 5.3, 2.8, 99.32, 0.51, and 1.4, respectively.

CONCLUSIONS

The results revealed that faba bean cultivars alone and with the influence of nano-silicon concentrations significantly differed in the seed yield and its contributing traits. The high concentration of nano-silicon (2 ml/L) increased the seed yield and its components compared with the control treatment. The utmost values of the phenotypic and genotypic variations also emerged for most traits. The faba bean Turkish cultivar performed better for yield-related characteristics and has a scope for further improvement with the influence of nano-silicon under existing environmental conditions.

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