Performance evaluation and genetic parameters of yield traits and their components in faba bean (Vicia faba L.) cultivars under the effect of potassium foliar application

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Abstract

The purpose of this research is to measure the impact of applying different levels of humic acid through foliar spray on the performance of six varieties of faba bean (Vicia faba L.), and to estimate some genetic parameters. This study was carried out on one of the fields belonging to the Kirkuk Irrigation Project in the growing season 2025–2026. The experiment was arranged according to the Split plot Design in RCBD with three repetitions. Main plots were comprised of three treatments (humic acid concentrations): (no spraying, 20 and 40 kg/ha). Sub plots were constituted of six faba beans genotypes (Syrian local large, Sciabola verde, Luz de otono, Aquadulce, Aqualogy, and Yildiz). Results indicated that significant differences have been recorded at 5% probability for genotypes, humic acid treatments, and their interactions concerning all examined traits. Genotype Aqualogy proved its supremacy over other tested genotypes in most characters due to high biological yield (535,735.14) and seed yield (141,031.17) without spraying, together with high genetic variance values. The highest values of genetic variance for biological yield (1,318,325.92) and seed yield (223,416.67) have been achieved due to spraying treatment with humic acid at 20 kg/ha. Thus, it can be concluded that this environment proved its efficiency for the implementation of breeding and selection programs in order to develop faba bean genotypes. Despite significant superiority of 40 kg/ha regarding the yield-related traits, genetic variance for seed yield has been recorded in the value of 473,685.65. All yield-related traits proved their strong broad-sense heritability in high ranges (88.27% number of seeds per pod; 93.16% seed yield; and 63.55% biological yield). Expected genetic advancement reached 18.38% and 16.40% for biological yield and seed yield, respectively, in the second environment, whereas in the first environment, it was 27.14% for number of seeds per pod.

Keywords: Faba bean, humic acid, genotypes, yield traits, genetic improvement.

ISSN 2072-3857

Introduction

Faba bean (Vicia faba L.) is categorized under the plant kingdom as a leguminous annual plant belonging to the family Fabaceae (1). It is also referred to as field bean, broad bean, fava bean, and horse bean. It has a nutritional value that consists of plant protein and dietary fibers, which enhance the functioning of the digestive system. Moreover, faba bean is a rich source of vitamin B9, which plays a key role in the process of formation of blood cells. Additionally, the crop is known for the presence of minerals like iron and magnesium together with bioactive phytochemicals, making it important for maintaining health (2). Faba beans are used for human and animal feed and in the production of diverse food items such as dried grains and pastes (3). This crop has a long history since it is one of the oldest crops grown by humans. It is believed that the faba bean originated in the Middle East before spreading to North Africa, Europe, and America (4). It is typically grown in the winter season in temperate climatic regions. The crops are tolerant to low temperatures provided that the soils are fertile and well-drained (1). Faba bean production in the world recorded a great rise in 2025 owing to the growing interests in proteins of plant origin and sustainable farming practices globally. The Asia-Pacific region has been among the regions with the highest faba bean production. Currently, the world's market capacity is estimated to be 86 million tons in 2022 and expected to rise to 111 million tons by 2028 (5). In 2025, the cultivated land for faba beans in Iraq stood at 1,661 kg per donum while the total production was approximately 28,181 tons. Even though the crop plays a significant role in the economy, there have been some challenges faced in its cultivation such as competition with other winter crops like wheat and barley, marketing problems, and lack of incentive prices (6). Many nations are trying to develop faba bean lines resistant to pathogens and high yields, together with the adoption of better agricultural practices and supporting farmers in their farming activities (7). One way of increasing crop productivity entails genetic studies and evaluation of adaptability to different environments (8). Genetic parameters help in knowing the inheritance of traits such as yield and quality together with environmental tolerance (9). This enables breeders to select the best lines of crops for breeding. Moreover, genetic studies assist in achieving food security through breeding of crops tolerant to climate change. It also helps in the preservation of genetic diversity in plants to achieve sustainable

ISSN 2072-3857

agriculture and economic development (9). Foliar application of humic acid has been one of the novel methods employed in improving the growth and productivity of various crops (10), including faba beans (Vicia faba L.). The application of humic acid increases the levels of chlorophyll content, leading to enhanced productivity by improving the photosynthesis process , In addition, the use of humic acid increases crop nutrients and improves crop quality. Some studies have shown that humic acid contributes to increasing crop resistance to various abiotic factors by activating antioxidants (11). Humic acid is known to increase water-use efficiency of crops, ensuring sustainability of crop production (12). Previous studies have confirmed the benefits associated with seed characteristics such as weight and size due to the application of humic acid, leading to improved crop quality (13). Therefore, humic acid application is an effective method that increases productivity and quality in crops, specifically faba beans (14).

Objectives : This study aims to evaluate the performance of six faba bean genotypes, and to investigate the effect of foliar application of different concentrations of humic acid on the growth and productivity of faba bean. And estimate of some genetic parameters, heritability broad sence and expected genetic advance.

Materials and Methods

Experimental Site and Field Preparation

The experiment was carried out in one of the farmers' fields of the Kirkuk Irrigation Project during the summer season 2025-2026. The soil in the field was prepared through double plowing using a chisel plow in two perpendicular directions and followed by leveling and smoothing of soil to achieve proper conditions for planting and good growth. The triple super phosphate fertilizer (P_2O_5) fertilizer was used as phosphorus fertilizer with a rate of 200 kg ha-1. Urea (46% N) was used as nitrogen fertilizer with a rate of 200 kg ha-1(15). The urea was applied in two equal applications, where the first dose was applied at planting while the second, after one month of planting. Split-plot design was used in a randomized complete block design (RCBD) with three replications. The main plots in each replication were related to the foliar application of humic acid in three concentrations (16). Each replication had 18 experimental units to which the interaction between the two studied factors was assigned randomly. Each main plot was divided into six subplots, while genotypes were randomly distributed within the subplots (17). There were

ISSN 2072-3857

four rows in each experimental unit, with 0.70 m spacing between rows and 0.25 m spacing between hills in each row. Spacing of 1m between experimental units and between main plots and blocks was ensured to maintain sufficient space for different treatments. 2-3 seeds were sown on each hill, which were later thinned to one plant per hill two weeks after emergence.

The studied characteristics were:

1. Number of pods per plant: Average number of pods per plant.
2. Number of seeds per pod: Number of seeds per plant divided by number of pods per plant.
3. 100 seeds weight (g): Random sampling of one hundred seeds from each experimental unit and measuring their weights using sensitive balances.
4. Seeds yield (kg ha-1): Harvesting plants in two central rows in each experimental unit. Drying, threshing and cleaning of seeds of ten sampled plants were done and their total weights were measured and converted to standard moisture percentage of 15%.
5. Biological yield (kg ha-1): It is the total dry weight of the plant including pods from ground level up to the top of the plant for ten plants from the two central rows.

Statistical and Genetic Analysis

The experimental data were statistically analyzed according to a randomized complete block design (RCBD) with a split-plot arrangement. Means were compared using Duncan's Multiple Range Test at the appropriate probability level, employing the SAS software package (18). Genetic analyses were also performed using the **GENES** software (16), following the procedures described by (19), as outlined below:

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. Phenotypic, Genotypic, and Environmental Variances and Coefficients of Variation

The three types of variances were estimated according to the method described by (20) at each level of potassium application, as follows:

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$\sigma_P{}^2 = {}^2\sigma_E + {}^2\sigma_G$ ‘ $\sigma_E{}^2 = \frac{Mse}{r}$ ‘$\sigma_G{}^2 = \frac{\text{Msg}-\text{Mse}}{\text{r}}$

where:
σP2\sigma_P^2σP2 = phenotypic variance,
σG2\sigma_G^2σG2 = genotypic variance,
σE2\sigma_E^2σE2 = environmental variance,
MSgMSgMSg = mean square of genotypes,
MSeMSeMSe = error mean square,
rrr = number of replications.

The phenotypic and genotypic coefficients of variation were calculated according to the method described by (21) . Values less than 10% were considered low, values between 10–30% moderate, and values greater than 30% high (22), as follows:

$$G.C.V\,\% = \frac{\sigma_G}{X^-} \times 100$$

$$P.C.V\,\% = \frac{\sigma_P}{X^-} \times 100$$

where:
PCV = phenotypic coefficient of variation,
GCV = genotypic coefficient of variation,
σP\sigma_PσP = phenotypic standard deviation,
σG\sigma_GσG = genotypic standard deviation,
X‾\bar{X}X‾ = overall mean of the trait.

Broad-Sense Heritability and Expected Genetic Advance

Broad-sense heritability (HB.S2H^2_{B.S}HB.S2) was estimated according to the method of (23), where values less than 40% were considered low, values between 40–60% moderate, and values greater than 60% high:

$$H^2{}_{B.S} = \frac{\sigma_G{}^2}{\sigma_P{}^2}$$

ISSN 2072-3857

The expected genetic advance (GA) was estimated based on the limits proposed by (24), where values less than 10% were considered low, 10–30% moderate, and more than 30% high, as reported by (25), using the following equation:

$$G.A = K. \times H^2_{B.\,s.} \times \sigma P$$

where:
GA = expected genetic advance,
K = selection intensity constant (1.40 at 20% selection intensity),
HB.S2H^2_{B.S}HB.S2 = broad-sense heritability,
σP\sigma_PσP = phenotypic standard deviation of the trait.

The expected genetic advance as a percentage of the mean (EGA%) was calculated according to the method of (26):

$$E.G.A = \frac{G.A}{X^-} \times 100$$

where:
EGA (%) = expected genetic advance as a percentage of the trait mean,
GA = genetic advance,
X¯\bar{X}X¯ = overall mean of the trait.

Results and Discussion

Evaluation of Genotypes, Humic Acid Spraying, and Their Interaction on the Studied Traits

From the analysis of variance results shown in Table (1), it was clear that the mean squares of humic acid application, genotypes, and the interaction between genotypes and humic acid application were significantly affected at a probability level of 5%. The differences between genotypes of faba beans were significant. Differences are due to considerable variability that exists among the genotypes and influences how they respond to environmental factors and agricultural operations carried out on the land. Genetic differences are the major source of such variability as they affect growth and yield of crops. It shows the ability of genotypes to express their potential productivity under identical environmental conditions (27). With regards to humic acid application, its effect was highly significant as it was evident from results obtained. It shows the importance of the chemical compound in ensuring physiological

ISSN 2072-3857

development of crops, and subsequently improvement in productivity and yield of crops. It is used in increasing photosynthetic efficiency of plants, their water balance, and nutrient uptake capability (28). All of which improve yields by improving pod number and seed weight. Significant interaction between genotypes and humic acid application levels indicates differences in responses of genotypes to changes in humic acid applications. It implies that interaction of environmental and genetic factors played an important role in defining traits considered in the study. A particular genotype can produce better yield than other genotypes using specific concentration of humic acid (19). It emphasizes the importance of careful selection of genotypes and appropriate fertilization programs to increase yield and quality of crops produced. It also points out the importance of genotype-by-environment interactions in creating sustainable agriculture production system (29).

Table 1. Analysis of variance (ANOVA) for the studied traits.

Harvest Index (%)	Biological Yield (kg ha⁻¹)	Seed Yield (kg ha⁻¹)	100-Seed Weight (g)	Seeds / Pod	Pods / Plant	d.f	Source of Variation
26,255,586,710	14,439,177.9	2,042,309.17	385.33	6.54	64.58	2	Replications
3.29**	94,533,059.8**	48,470,928.07**	1,998.62**	45.12**	768.66**	2	Humic Acid
7,142,925,297.1	1,019,614.1	454,594.97	10.24	0.44	6.66	4	Error A
30,849,468,206**	22,005,694.4**	4,738,569.13**	462.16**	10.63**	112.34**	5	Genotypes
9,829,741,031.7**	260,220.4**	284,615.19**	9.59**	0.29**	9.59**	10	Humic Acid × Genotypes
2,908,508,265.8	520,696.0	143,148.4	27.59	0.35	14.95	30	Error B

Number of Pods per Plant

As can be seen from Table (2), the studied genotypes were significantly different in terms of pod quantity per plant. The Aqualogy variety had the greatest number of pods (24.55 pods per plant), while the variety Luz de Otoño had the lowest value (13.64 pods per plant). The high level of

ISSN 2072-3857

reproduction in the Aqualogy variety may be explained by the involvement of genetic mechanisms in the regulation and development of reproductive organs. In this case, one of the key components is leaf number, which has a direct impact on pod formation. Pod number is an important characteristic that can indicate the potential ability of seeds production. It is associated with the reproductive capacity of the plant due to flower formation and fertilization. The process involves many genes responsible for reproductive development, including genes regulating flowering induction and fertilization. The presence of advantageous genotypes with a set of genes that can contribute to an increase in the rate of flowers forming and their fertilization may lead to an increase in pod numbers. At the same time, there are some genotypes that can more effectively use favorable environmental conditions for pod formation such as nutrition and fertilization. These results correlate with those provided by (30). Speaking about humic acid treatment, the highest pod quantity was observed in plants receiving the 20 kg ha^{-1} concentration of humic acid (26.78 pods). The lowest number of pods was found in the untreated control (0 kg ha^{-1}) group (13.73 pods). As mentioned above, one of the main effects of humic acid is associated with the stimulation of physiological processes such as photosynthesis and translocation of nutrients and sugars in the plants' tissue. As a result, there is the improvement of flower formation and fertilization, and more flowers will be formed as pods. In addition, humic acid allows plants to survive under adverse environmental conditions such as drought or bad weather, contributing to the increased number of pods. Thus, the appropriate concentration of humic acid helps to increase the amount of fertilized flowers, which results in enhanced productivity (31). When it comes to the genotype x humic acid interaction, the maximum pod quantity was found in the group where the Aqualogy genotype was combined with 20 kg ha^{-1} humic acid treatment (32.40 pods), while the minimum value was found in the Luz de Otoño x 0 kg ha^{-1} group (10.43 pods). One reason that explains these results is that genetic mechanisms are strongly influenced by environmental factors. It should be noted that Aqualogy genotype had good resistance to environmental factors as well as high capacity for fertilization. Under the combined effect of genotype and humic acid treatment, physiological and metabolic processes in the plant were stimulated, leading to better flower fertilization and greater pod formation (29).

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Table (2). Mean Effect of Genotypes, Humic Acid, and Their Interactions on Number of Pods per Plant				
Mean Effect of Genotypes	Humic Acid 40 kg/ha	Humic Acid 20 kg/ha	Humic Acid 0 kg/ha	Genotype
20.35b	21.06cde	26.13abc	13.86efg	Syrian Local Large
20.41b	19.30c-f	28.16ab	13.76efg	Sciabola Verde
13.64c	13.53fg	16.96d-g	10.43g	Luz de Otono
20.46b	19.56c-f	28.73ab	13.10fg	Aquadulce
24.55a	23.80bcd	32.40a	17.46d-g	Aqualogy
20.87ab	20.56c-f	28.30ab	13.76efg	Yildiz
—	19.63b	26.78a	13.73c	Mean Effect of Humic Acid

Number of Seeds per Pod

From the results shown in Table (3), there were significant differences among the genotypes in terms of the number of seeds per pod. Among the different genotypes used in this experiment, the genotype Yildiz had the highest number of seeds (6.90) while Aquadulce had the lowest number (3.46) of seeds per pod. In this case, the best performance of genotype Yildiz could be attributed to the presence of certain genes that govern reproductive development in this particular genotype. There are specific genes that determine the number of seeds formed in each pod and those genes could be responsible for higher performance of Yildiz in forming more seeds per pod. Also, there are some genotypes that have the ability to increase their seed formation due to effective pollination and fertilization. Apart from that, there are many other factors that influence this character including efficient nutrient acquisition, efficient allocation of nutrients in seed formation, genes governing pod size and adaptation to environmental condition (32). Hence, genetic improvements in faba beans can lead to the better formation of seeds per pod. The effect of different concentrations of Humic Acid applied to the leaves on the number of seeds per pod was also highly significant.

Among different concentrations, the highest number of seeds was observed at 20 kg ha^{-1} (6.81) while the lowest number of seeds was obtained in the absence of the Humic Acid (control, 3.65). In this experiment, it was proved that humic acid helps plants in flower formation, fertilization, photosynthetic activities, root development and makes them resistant to water deficiency. Besides, humic acid is involved in osmoregulation which increases the utilization of water and nutrients. All these factors make plants produce more seeds hence increase productivity of faba bean crop (33). There was also a significant effect of interaction between genotypes and different concentrations of Humic Acid in producing seeds. The genotype Yildiz having 20 kg ha^{-1} Humic Acid produced the highest number of seeds per pod (9.00) while Aquadulce without any humic acid (0 kg ha^{-1}) produced the lowest number of seeds (1.90). The reason for this result could be the ability of genotype Yildiz to utilize humic acid which helps in the process of nutrients acquisition and enhances physiological activities involved in flower formation, seed development in the pod and photosynthesis. On the other hand, low number of seeds per pod in Aquadulce under no humic acid condition can be linked to the absence of stimulation in physiological and nutritional activities which reduces the rate of nutrients acquisition and formation of seeds (34).

Table (3). Mean Effect of Genotypes, Humic Acid, and Their Interactions on Number of Seeds per Pod

Mean Effect of Genotypes	Humic Acid 40 kg/ha	Humic Acid 20 kg/ha	Humic Acid 0 kg/ha	Genotype
5.22b	5.23d	6.53bc	3.90ef	Syrian Local Large
5.25b	5.10d	7.00b	3.86ef	Sciabola Verde
5.23b	5.40d	6.63bc	3.66f	Luz de Otono
3.46c	3.30f	5.20d	1.90g	Aquadulce
5.32b	5.56cd	6.53bc	3.66f	Aqualogy
6.90a	6.80b	9.00a	4.90de	Yildiz
—	5.23b	6.81a	3.65c	Mean Effect of Humic Acid

100-Seed Weight (g)

ISSN 2072-3857

From the results shown in table (4), it is clear that there exist significant differences between the studied genotypes in terms of their 100-seed weight. The genotype Aqualogy showed the maximum weight at 154.98 g, while Sciabola verde gave the minimum value at 133.35 g. (Several explanations can be given to explain why) Aqualogy has performed better than other genotypes in this parameter, because of Aqualogy took more time to mature physiologically, hence giving more weight to the seeds. And, Aqualogy had large leaf area that favored seed development by facilitating efficient transfer of assimilates to sinks in seeds hence seed weight. Besides, genetic influence should not be left out. Genes determining the seed development and seed size are responsible for the final seed size. Genotypes that produce bigger seeds and effectively store nutrients in them give more weight (35). In addition, application of humic acid significantly affected 100-seed weight. Humic acid at 40 kg ha^{-1} gave the maximum weight (154.08 g), while the minimum weight (133.02 g) was recorded where humic acid was not applied (0 kg ha^{-1}). Such improvement can be attributed to its influence on plants and seed development. The application enhances photosynthesis, sugar translocation, and water balance in plants, thus giving bigger seeds. In addition, humic acid increases cell wall strength and improves plant adaptation to environmental stresses, thus giving improved seed growth, development, and final seed size (36). Lastly, the interaction between genotype and humic acid concentration was highly significant. The interaction between Aqualogy and 40 kg ha^{-1} humic acid gave the highest 100-seed weight (165.33 g), while that of Sciabola verde and 0 kg ha^{-1} humic acid gave the lowest weight (121.20 g). Such superiority can be attributed to the positive effect of interaction between genotype and environment. In this case, genotype possessed genes that increased seed size and seed weight, and under favorable humic acid concentrations, physiological processes like photosynthesis, nutrient and water uptake, and assimilation were further improved, thus giving higher seed weight. Interaction leads to improvements in seed quality and quantity, hence positive effect on faba bean yield (2).

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Table (4). Mean Effect of Genotypes, Humic Acid, and Their Interactions on 100-Seed Weight (g)				
Mean (Effect of Genotypes)	Humic Acid 40 kg/ha	Humic Acid 20 kg/ha	Humic Acid 0 kg/ha	Genotype
146.25b	158.16ab	144.56def	136.03fgh	Syrian Local Large
133.35d	144.63def	134.23gh	121.20i	Sciabola Verde
142.56bc	153.26bcd	144.80def	129.63hi	Luz de Otono
140.13c	148.20cde	141.80def	130.40hi	Aquadulce
154.98a	165.33a	154.83bc	144.80def	Aqualogy
145.03bc	154.93bc	144.10def	136.06fgh	Yildiz
	154.08a	144.05b	133.02c	Mean (Effect of Humic Acid)

Seed Yield (kg ha^{-1})

Based on the results obtained in Table (5), there were significant variations among the tested genotypes regarding seed yield. As observed, the genotype Aqualogy performed the best with 4619.1 kg ha^{-1} seed yield, while the Sciabola verde genotype showed the worst performance with a low seed yield of 2340.0 kg ha^{-1}. The excellent performance of the genotype Aqualogy can be due to the high mean of yield components traits of this genotype. (When the above-mentioned genetic traits are combined with modern farming approaches such as soil fertilization, the crop yield improves significantly (37). These findings coincide with those of other researches carried out by (29)). Application of foliar humic acid to plants had a considerable impact on seed yield. The highest seed yield was obtained when the concentration of humic acid was 40 kg ha^{-1} (4892.4 kg ha^{-1}), whereas the lowest yield was obtained when humic acid was not applied (control with 0 kg ha^{-1} yield rate of 1634.9 kg ha^{-1}). These results were due to the role of humic acid in promoting growth and increasing yield production by increasing photosynthetic processes, carbohydrates transport, water balance regulation, nutrient absorption, root growth, flowering, and pod formation. All these parameters contribute to an increase in the number of pods and their sizes, and, therefore, lead to a higher yield (36). An interaction between genotype and humic acid concentration had a significant effect on seed yield. The highest yield was achieved when the genotype Aqualogy was treated with 40 kg ha^{-1} of humic acid (6410.6 kg ha^{-1} yield rate). On the contrary, the poorest yield was obtained in case of Sciabola verde genotype with 0 kg ha^{-1} of humic acid (yield rate of 1094.4 kg ha^{-1}). These results might be due to the fact that genotype Aqualogy has the highest ability to absorb humic acid that facilitates overall plant growth, photosynthesis efficiency, flowering fertilization, and pod setting.

Table (5). Mean Effect of Genotypes, Humic Acid, and Their Interactions on Seed Yield (kg ha^{-1})

Mean Effect of Genotypes	Humic Acid 40 kg/ha	Humic Acid 20 kg/ha	Humic Acid 0 kg/ha	Genotype
3,331.2b	4,787.8b	3,494.3c	1,711.5ef	Syrian Local Large
2,340.0c	3,796.4c	2,129.3de	1,094.4f	Sciabola Verde
3,276.9b	4,871.9b	3,717.6c	1,241.1f	Luz de Otono
3,379.2b	4,689.9b	3,730.7c	1,716.9ef	Aquadulce
4,619.1a	6,410.6a	4,994.9b	2,451.7d	Aqualogy
3,327.9b	4,797.8b	3,592.2c	1,593.8ef	Yildiz
—	4,892.4a	3,609.8b	1,634.9c	Mean Effect of Humic Acid

Biological Yield (kg ha^{-1})

From Table (6) it is possible to notice that there were significance differences between the studied genotypes in biological yield. The highest level of biological yield (10,120.5 kg ha^{-1}) was found in the genotype Aqualogy while Sciabola verde showed the lowest biological yield (5,210.8 kg ha^{-1}). In the case of the genotype About Aqualogy variety the reason for the best performance could be its excellent results concerning all previous parameters. Moreover, due to its genetic and physiological features Aqualogy is characterized by higher resource utilization efficiency. This genotype demonstrates high capacity of nutrient uptake, including nitrogen and humic acid, which improves photosynthesis and respiration. Besides, the genotype Aqualogy has active vegetative development with increased number of leaves and branches, contributing to biomass production. Moreover, this genotype responds to agronomic manipulations, is tolerant to environmental conditions and

ISSN 2072-3857

maintains productivity. A considerable impact of foliar application of humic acid was found on biological yield. It was revealed that the highest yield was observed when applying 40 kg ha^{-1} of humic acid (9,745.7 kg ha^{-1}) while the lowest yield was obtained when using no humic acid (control variant) (5,232.8 kg ha^{-1}). The explanation of the positive impact of humic acid can be in the physiological and metabolic functions of humic acid which promote plant vegetative development through stimulating photosynthesis, enhancing water and nutrients absorption, maintaining water homeostasis, providing stress resistance, and facilitating carbohydrate translocation to other organs increasing dry matter formation (38). The significant interaction between genotype and humic acid concentration was observed during analysis. The combination of Aqualogy genotype with 40 kg ha^{-1} of humic acid provided the highest biological yield (11,690.9 kg ha^{-1}) while Sciabola verde with 0 kg ha^{-1} humic acid showed the lowest level (3,026.3 kg ha^{-1}). It is possible to consider that the positive interaction resulted in the high biological yield in the case of genotype Aqualogy due to both high genetic potential and humic acid's action which includes enhancing photosynthesis efficiency, improving water and nutrients absorption, carbohydrate translocation, plant growth, stress tolerance, and stomata regulation (39).

Table (6). Mean Effect of Genotypes, Humic Acid, and Their Interactions on Biological Yield (kg ha^{-1})

Mean Effect of Genotypes	Humic Acid 40 kg/ha	Humic Acid 20 kg/ha	Humic Acid 0 kg/ha	Genotype
7,898.3b	9,890.1bc	8,610.2cd	5,194.5f	Syrian Local Large
5,210.8c	7,141.6e	5,464.5f	3,026.3g	Sciabola Verde
7,556.8b	9,736.3bc	8,027.9de	4,906.2f	Luz de Otono
7,995.8b	10,133.6b	8,457.0de	5,396.8f	Aquadulce
10,120.5a	11,690.9a	10,877.1ab	7,793.5de	Aqualogy
7,540.2b	9,881.5bc	7,659.7de	5,079.6f	Yildiz
—	9,745.7a	8,182.7b	5,232.8c	Mean Effect of Humic Acid

ISSN 2072-3857

Estimation of Genetic Parameters

Variances: Phenotypic, Genotypic, and Environmental

Phenotypic variance can be attributed to differences in Morphological characteristics caused by interactions between genotype and environmental factors. Genotypic variance refers to differences in genetic material, which forms the basis of breeding programs, allowing for selecting superior genotypes for varied environmental conditions. On the other hand, environmental variance modifies gene expression depending on factors such as soil composition, climatic conditions, nutrient availability, and other external influences. Foliar application of humic acid provides an excellent example of environmental variance, as it enhances nutrient uptake efficiency, promotes plant growth, and boosts tolerance to stressors. Variance analyses provide insight into the interaction between genetic and environmental factors, helping identify genotypes with higher efficiency and adaptation abilities. In addition, genetic parameters like heritability and additional genetic variance help assess a plant's production capacity (40). Table (7) presents phenotypic, genotypic, and environmental variances for all studied traits within three humic acid foliar application levels (0, 20, and 40 kg ha^{-1}). Under the first environment, growth and yield traits showed a high genotypic variance (biological yield σ^2G = 340,435.02; seed yield σ^2G = 88,331.15), while environmental variance was relatively low, indicating stable environmental conditions. High phenotypic variance compared to environmental variance demonstrates strong genetic influence, making it suitable for selection programs (biological yield σ^2P = 535,735.14; seed yield σ^2P = 141,031.17). In the second environment (20 kg ha^{-1} of humic acid), genotypic variance was markedly higher compared to the first one. Biological yield and seed yield σ^2G = 1,318,325.92 and σ^2G = 223,416.67, respectively, indicated high selection efficiency. High phenotypic variance resulted from the combination of both genotypic and environmental variance (biological yield σ^2P = 1,505,953.55; seed yield σ^2P = 279,092.81). These data show obvious differences between genotypes. Under the third environment (40 kg ha^{-1} of humic acid), most traits showed increased phenotypic variance due to environmental variance (biological yield σ^2P = 494,916.94; seed yield σ^2P = 508,457.87). At the same time, genotypic variance was high only for yield traits (biological yield σ^2G =

ISSN 2072-3857

357,148.71; seed yield σ^2G = 473,685.65), while other traits showed lower variance. Despite high environmental influence, genetic variance was still present in yield-related traits, suggesting its significant role. However, the second environment appears more suitable for selection because of the high level of genotypic variance and heritability, while the first one is more stable. The third environment shows more pronounced environmental variance, although genetic variance remains essential for yield traits.

Broad-Sense Heritability

Heritability of a trait in Vicia faba L. implies transferring of genetic properties from parent organisms to offspring via additive, dominance, or gene-environmental variance components. Additive inheritance occurs when two or more genes independently regulate a specific trait, while dominance inheritance involves interactions between dominant and recessive alleles. The calculation of broad-sense heritability involves assessing the contribution of different genetic variance components, such as allele differences and dominance effects (41). Broad-sense heritability analysis is critical for breeding programs to estimate selection efficiency and determine ways to select genotypes with desirable characteristics like disease resistance, environmental adaptation, and high yields. Additionally, heritability helps explain how environmental factors influence traits, with water availability and nutrient supply affecting growth and yield traits, such as branch number, flowering rate, and seed formation. Heritability calculations allow predicting how plants will respond to genetic improvement under varying environmental conditions (8). According to (8), heritability was estimated by classifying values into different ranges, and those ≥60% were considered high. Table (7) below shows heritability variations for traits and environments. In the first environment (no application), some traits showed high heritability, including seeds per pod (88.27%), biological yield (63.55%), and seed yield (62.63%), which indicates the genetic determination of these traits. In contrast, the pod number had low heritability (13.15%), suggesting a more prominent environmental influence. In the second environment (20 kg ha^{-1}), most traits showed the highest heritability, while pod number demonstrated moderate heritability (49.40%). This information suggests that the second environment provides optimal conditions for maximizing genetic influence, facilitating selection responses. In the third environment (40 kg ha^{-1}), yield traits

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retained high heritability (seed yield 93.16%), but other traits, such as dry weight and pod number, decreased, which is linked to more pronounced environmental influence during fertilization. However, genetic influence remains noticeable in yield traits, which have higher heritability compared to environmentally sensitive traits. The second environment is optimal for exploring heritability in breeding programs. Expected genetic gain in Vicia faba L. is a priority objective to increase plant productivity and enhance disease resistance and pests as well as nutritional value. Plant breeding programs aim to cultivate superior genotypes with higher yield and resistance to extreme conditions, such as drought and salinity, due to their economic and nutritional importance (8). Genetic improvement is possible by using selective hybridization, genetic modifications, and heritability exploitation of desirable traits. Selective hybridization remains the primary approach to genetic improvement, implying selection and cross-pollination of genetically superior individuals (42). Selective hybridization depends on investigating genotypic variance among various genotypes and finding individuals with valuable genetic variations that positively affect productivity and quality traits. The expected genetic gain increases plant adaptability to environmental conditions and improves yield-related parameters, such as flower number, pollination efficiency, and seed size and quality. Genetic improvement requires examining environmental impacts, especially heat and water stress, thus promoting the development of highly resilient genotypes (2). Expected genetic gain is calculated as a percentage based on methods developed by (26), with cut-off points established by Robinson et al. (1951) and Agarwal & Ahmed (1982). The genetic gain is considered low for values <10%, moderate for 10–30%, and high for >30%. Table (7) shows expected genetic gain for the studied traits under three humic acid applications (0, 20, and 40 kg ha^{-1}). The results reveal significant differences among traits and environments, with the second environment having the highest expected genetic gain for most growth and yield traits (biological yield 18.38%; seed yield 16.40%), which indicates high selection efficiency. Under the first environment, some traits showed moderate gain, such as seeds per pod (27.14%), seed yield (20.14%), and biological yield (12.44%). Other traits were less responsive to genetic improvement. Finally, under the third environment, moderate gain occurred for yield traits (expected seed yield gain at 19.01%), while other traits improved to a lesser

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extent (43). Overall, traits with high heritability, including leaf number, leaf area, biological yield, and seed yield, should be selected for the expected genetic gain. The second environment appears more appropriate for maximizing the selection response. Moreover, the results emphasize the necessity of using innovative breeding technologies, such as molecular genetics and induced mutations, to obtain genotypes with high adaptability to climate changes and efficient nutrient utilization (humic acid and phosphorus).

Conclusions and Recommendations

This study showed differences among the genotypes for all the studied traits. The Aqualogy genotype was the best genotype compared to other genotypes in most growth and yield traits, showing its efficiency. Humic acid foliar application at the rate of 40 kg ha^{-1} was very effective in most traits. The highest mean values were obtained when the interaction between the Aqualogy genotype and the rate of 40 kg ha^{-1} humic acid was considered, which shows the supremacy and effectiveness of the interaction. Large phenotypic and genotypic variances combined with small environmental variances, together with high broad sense heritability, show the reliability of the traits in making direct selections in breeding programs. Consequently, Aqualogy can be recommended for use in breeding programs due to the great potential it has in improving faba beans locally. It is recommended that humic acid be applied at the rate of 40 kg ha^{-1} in order to promote growth, increase nutrients uptake, and enhance stress tolerance. Future studies should focus on the stability of Aqualogy under varying environments in agriculture.

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Table 8. Estimation of genetic parameters of the studied traits under the first environment (no foliar application of humic acid)						
y6 (Harvest index)	**y5 (Biological yield)**	**y4 (Seed yield)**	**y3 (Weight of 100 seeds)**	**y2 (No. of seeds/pod)**	**y1 (No. of pods/plant)**	**Parameter**
98253.33	340435.02	88331.15	6.74	0.57	0.32	σ^2G
179519.89	1240975.71	122557.81	33.94	0.51	2.83	S.E(G)
144800.00	195300.11	52700.02	9.97	0.08	2.12	σ^2e
177343.06	239192.81	64544.08	12.22	0.09	2.60	S.E(e)
243053.33	535735.14	141031.17	16.72	0.64	2.44	σ^2P
88750.53	195622.81	51497.30	6.10	0.23	0.89	S.E(P)
2.11	11.15	18.18	1.95	20.63	4.12	G.C.V (%)
2.56	8.45	14.04	2.37	7.52	10.60	E.C.V (%)
3.32	13.99	22.97	3.07	21.96	11.38	P.C.V (%)
40.42	63.55	62.63	40.34	88.27	13.15	$h^2b.s$ (%)
279.01	651.16	329.29	2.31	0.99	0.29	G.A
1.88	12.44	20.14	1.74	27.14	2.09	G.A (%)

Table 8 (continued): Estimation of genetic Parameters of the Studied Traits under the Second Environment (20 kg/ha)						
y6 (Harvest index)	**y5 (Biological yield)**	**y4 (Seed yield)**	**y3 (Weight of 100 seeds)**	**y2 (No. of seeds/pod)**	**y1 (No. of pods/plant)**	**Parameter**
2491039719.3	1318325.92	223416.67	8.04	0.18	7.00	σ^2G
3710420300.0	1627211.64	444259.75	23.93	0.68	6.82	S.E(G)

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781125063.98	187627.63	55676.15	12.74	0.06	7.17	σ²e
956678916.02	229795.98	68189.07	15.60	0.08	8.79	S.E(e)
3272164783.3	1505953.55	279092.81	20.77	0.25	14.18	σ²P
1194825642.4	549896.49	101910.29	7.59	0.09	5.18	S.E(P)
11.64	14.03	13.09	1.97	8.18	13.48	G.C.V (%)
6.52	5.29	6.54	2.48	4.85	13.64	E.C.V (%)
13.34	15.00	14.63	3.16	9.51	19.17	P.C.V (%)
76.13	87.54	80.05	38.69	73.97	49.40	h²b.s (%)
60966.48	1503.99	592.06	2.47	0.52	2.60	G.A
14.22	18.38	16.40	1.71	9.85	13.26	G.A (%)

Table 8 (continued): Estimation of genetic Parameters of the Studied Traits under the Third Environment (40 kg/ha)

y6 (Harvest index)	**y5 (Biological yield)**	**y4 (Seed yield)**	**y3 (Weight of 100 seeds)**	**y2 (No. of seeds/pod)**	**y1 (No. of pods/plant)**	**Parameter**
831366348.8	357148.71	473685.65	10.39	0.51	10.54	σ²G
5373174620.0	1151130.54	381644.31	28.78	0.82	14.76	S.E(G)
2127238401.8	137768.23	34772.22	4.89	0.22	5.66	σ²e
2605324322.9	168730.94	42587.09	5.99	0.27	6.93	S.E(e)
2958604750.7	494916.94	508457.87	15.28	0.73	16.20	σ²P
1080329707.1	180718.12	185662.56	5.58	0.27	5.92	S.E(P)
3.31	6.13	14.07	2.09	10.52	12.12	G.C.V (%)
5.30	3.81	3.81	1.43	6.84	8.88	E.C.V (%)

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6.25	7.22	14.57	2.54	12.55	15.03	P.C.V (%)
28.10	72.16	93.16	68.02	70.31	65.07	h^2b.s (%)
21398.1	710.74	930.02	3.72	0.84	3.67	G.A
2.46	7.29	19.01	2.42	12.35	13.69	G.A (%)

Parameter Definitions:

- σ^2G = Genetic variance
- S.E(G) = Standard error of genetic variance
- σ^2e = Environmental variance
- S.E(e) = Standard error of environmental variance
- σ^2P = Phenotypic variance
- S.E(P) = Standard error of phenotypic variance
- G.C.V = Genotypic coefficient of variation (%)
- E.C.V = Environmental coefficient of variation (%)
- P.C.V = Phenotypic coefficient of variation (%)
- h^2b.s = Broad-sense heritability (%)
- G.A = Expected genetic advance
- G.A% = Expected genetic advance as percentage of mean (%)

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