Kirkuk University Journal for Agricultural Sciences, Vol.17, No. 3, 2026 Online ISSN: 2958-

Kirkuk University Journal for Agricultural Sciences
ISSN:2958-6585
https://kujas.uokirkuk.edu.iq

RESEARCH ARTICLE
https://doi.org. 10.58928/ku26.17309

Evaluation of Growth and Yield Parameters of Faba Bean (*Vicia faba L.)* Under Foliar Application of Mono- and Di-potassium Phosphate

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Received:04/02/2026 **Revised: 30/07/2026** **Accepted: 31/08/2026** **Published: 06/09/2026**

ABSTRACT

This study aimed to evaluate the growth characteristics and yield of bean plants in response to the foliar application of mono- and dipotassium phosphate fertilizers. A two-year field study was carried out at the research station of Bakrajo Technical Institute in northern Iraq. The experiment followed a randomized complete block design with six replications. The results showed that monopotassium phosphate foliar application significantly increased plant height (6.56%), the number of leaves per plant (22.98%), the number of branches (36.66%), the number of pods per plant (15.19%), pods length (15.32%), pods weight (15.48%), the number of seeds per pods (32.25%), number of days of flowering (2.27%), 100 seed weight (6.36%), seed fresh weight (37.69%), seed dry weight (69.22%), total fresh weight (34.53%) and seed yield (61.89%) compared to the Control treatment. Seed yield has a positive and significant correlation with the number of pods per plant, pod length, number of seeds per pod, seed dry weight, and total fresh weight. Based on the biplot test results from principal components analysis, the first two components explain 100% of the total data variance; in addition, the cluster heatmap and biplot analysis efficiently classified the studied traits and treatments into two distinct groups based on their response to fertilization.

***Keywords*:** Correlation, Fertilizer, Macronutrients, Pods, Yield.

INTRODUCTION

The faba bean (*Vicia faba* L.) belongs to the Fabaceae family and has seeds that are rich in protein, minerals, and vitamins [1]. Phosphorus (P) and potassium (K) are vital macronutrients for plant growth and development. P facilitates energy transfer throughout the plant, aiding in root development and flowering. Potassium is crucial for photosynthesis, numerous metabolic processes essential for growth, and flower and fruit development [2]. P deficiency leads to lackluster foliage, premature leaf drop, frail flower stems, and hindered bud opening [3]. Furthermore, when potassium uptake falls below necessary levels, foliar potassium is moved to the fruit, causing decreases in plant growth, fruit set, and quality [4]. Adequate P and K nutrition has been linked to increased flowering, larger pod size, and improved pod set. [5,6]. Recently, monopotassium phosphate (MKP, KH_2PO_4) has been widely utilized as a source of P and K in crop production [7]. Plants can absorb nutrients through their roots or foliage. Absorbing nutrients through the leaves is a way to address and fix nutrient shortages [8]. Under various nutrient deficiencies, foliar application of nutrients allows for immediate transportation of nutrients to different plant parts from the leaf tissue [9]. Some studies have indicated that foliar application of MKP during critical periods (e.g., reproductive development) led to increased flower diameter, yield, and quality than Controls [5.6]. In contrast, other studies have indicated that foliar fertilization alone is insufficient to meet crops' nutritional needs but can supplement soil fertilization [10]. Adequate soil macronutrients are essential for optimal plant growth and reproductive success. Applying potassium to foliage and soil yields higher yields than potassium to foliage alone [4]. Furthermore, as foliar fertilization can only provide a limited amount of macronutrients to plants, it should be combined with soil-based fertilizers to increase yields [8]. Mineral status affects plant growth, directly and indirectly influencing flowering and fruit sets. MKP fertilization has increased plant productivity [11, 12]. However, the reported concentration of MKP used for fertilization varied significantly between studies. In some cases, the concentration varied more than tenfold [5, 6, 12]. Furthermore, little is known about the effects of MKP concentration on the root growth and flower production of faba beans. Therefore, Therefore, the current study was designed and implemented to evaluate the efficacy of mono- and di-potassium phosphate foliar application in enhancing the growth characteristics, yield components, and overall crop quality of faba beans under regional field conditions.

Materials And Method

2.1 Experimental practice

Faba bean seeds (Luz de Otono Spanish variety) were planted on 30 November 2021 for the first season and 30 November 2022 for the second season on loamy-silty soil. The seeds were planted at the density of 30 seeds per square meter in 2×2 m^2 experimental plots. Each plot contained six rows with row spacing of 35 cm and seed spacing of 10 cm on each row. Three faba bean seeds were planted in each planting spot, and after emergence, they were pruned to one plant per spot. The first and the last rows were considered borders, and no measurements were carried out on these rows. Before planting, tillage operations such as plowing and land leveling were done.

The planting was done by hand. The irrigation was done one day after planting, and during the experiment, the irrigation process was performed regularly according to the norms of the location after consulting with local farmers. No pesticides or any toxic materials were used in the experiment. Weed control was carried out by hand.

2.2 Treatment and measurements

fertilizer; P2, mono-potassium phosphate; and P3, di-potassium phosphate. Mono-potassium phosphate contains 53% P_2O_5 (phosphorus pentoxide) and 34% K_2O (potassium oxide), and di-potassium phosphate (K_2HPO_4) contains 41% P_2O_5 and 53% K_2O. Di-potassium phosphate is a highly water-soluble compound, and it is used as a fertilizer and food additive."

The treatments, foliar application of mono-/di-potassium phosphate, were applied at two different times during the growth stage of faba bean plants: first application, 45 days after planting; second application, at 50% of the flowering stage. No. of days to first flowering, No. of days to 100% of flowering were recorded during the experiment. At the end of the experiment, plant height (cm), No. of tillers per plant, No. of pods/plant, pod length (cm), pod weight (g), No. of seeds/pod were measured. At maturity, the seed's fresh and dry weight per plant and yield of plots were measured and then converted to kg ha^{-1}.

2.3 Statistical analysis

The data were first subjected to a combined analysis of variance (ANOVA), and the mean comparison process was performed based on the LSD (least significant difference) method at $p = 0.05$. The ANOVA, mean comparison, and linear correlation coefficient were evaluated using R 4.2 software with the ‘agricolae’ library. The correlation plot was generated using the ‘ggcorrplot’ library. Furthermore, the ‘NbClust’ and ‘pheatmap’ libraries were used to construct the cluster dendrogram and heatmap plots, respectively. Principal component analysis (PCA) biplots were generated using the ‘factoextra’ library, and colors across all plots were customized using the ‘RColorBrewer’ library.

Results

Table 1 presents combined ANOVA results related to the measured traits. Accordingly, treatment significantly affected all traits except for the number of days to seedling. Only the effect of the year affected the number of days to seeding and the number of days to flowering. The mean comparison-based LSD method at p = 0.05 is presented in Table 2.

The study results indicated that the application of Monopotassium phosphate and Di-potassium phosphate significantly increased plant height by 6.56% and 5.89%, respectively, compared to the Control. Phosphorus (P) and potassium (K) nutrients are crucial in cell division, expansion, and enlargement, contributing to increased faba bean plant height. Consistent with our findings, Abou-Amer et al. [13] "The study results indicated that the application of Monopotassium phosphate and Dipotassium phosphate significantly increased plant height by 6.56% and 5.89%, respectively, compared to the Control. Phosphorus (P) and potassium (K) nutrients are crucial in cell division, expansion, and enlargement, contributing to increased faba bean plant height. Consistent with our findings, several studies have demonstrated that optimal P and K application significantly enhances vegetative growth and plant height in legume crops compared to untreated controls. P promotes root development and nutrient absorption from the soil, which indirectly supports the plant's overall growth and nitrogen assimilation capacity [15]. Additionally, K influences the movement of water, nutrients, and carbohydrates in plant tissue, affecting energy production and regulating the photosynthesis rate [16]."

The results indicated that while the highest number of leaves per plant was observed in the Monopotassium phosphate treatment, the Monopotassium phosphate and Di-potassium phosphate increased the number of leaves by 22.98% and 19.90%, respectively, compared to the Control. In this study, the number of lateral branches showed a positive reaction to fertilizer treatment, so using Monopotassium phosphate and Di-potassium phosphate increased the number of lateral branches by 36.66 and 32.56%, respectively. Phosphorus promotes root development, is essential for nutrient absorption from the soil, and aids legumes in fixing nitrogen through their roots [15]. Potassium influences the movement of water, nutrients, and carbohydrates in plant tissue, affecting ATP production and regulating the photosynthesis rate [16]. A well-rounded diet promotes healthy growth, efficient photosynthesis, and increased plant branching [13]. Walled et al. [17] demonstrated that the simultaneous application of N, P, and K fertilizers resulted in the highest number of branches in the faba bean plant compared to the Control.

In this experiment, plots treated with Monopotassium phosphate showed a superiority of 3.50% and 15.18% compared to Di-potassium phosphate and Control in terms of No. of pods. In this research, the pod length increased by 15.32 and 7.15% compared to the Control in Monopotassium phosphate and Di-potassium phosphate treatments. The results showed that the plants that received Monopotassium phosphate and Di-potassium phosphate increased the pod weight by 15.48 and 14.99% compared to the Control. In Ali et al.'s study [18], the highest number of pods was observed in response to the combined application of N, P, and K. In another study, Bezabih et al. [14] found that applying 60 kg ha^{-1} of P_2O_5 along with rhizobium inoculation led to a 72% increase in the number of pods compared to the Control.

The results showed that treatment with Monopotassium phosphate increased the number of seeds compared to Di-potassium phosphate and Control by 23.09 and 32.25%, respectively. The difference between Di-potassium phosphate treatments and Control was insignificant regarding seed number. Abou-Amer et al. [13] found that treating N, P, and K fertilizers at 60:60:80 kg ha^{-1} resulted in the highest number of seeds per pod (4.63 seeds).

The results indicated that treatment with Monopotassium phosphate extended the days until flowering by 3 (equivalent to 2.47%) and 3.33 (equivalent to 2.75%) days compared to Di-potassium phosphate treatment and Control, respectively. The difference between Di-potassium phosphate and Control regarding the number of days to flowering was insignificant. In this study, treatment with Monopotassium phosphate and Di-potassium phosphate significantly increased 100 seed weight by 8.1 g (equivalent to 6.36%) and 6.57 g (equivalent to 5.16%), respectively. The difference between Monopotassium phosphate and Di-potassium phosphate was insignificant regarding the 100 seed weight. The increase in seed weight may be linked to the synergistic roles of nutrients in plant growth [19]. For example, K fertilizer is essential for promoting root growth [20], which creates an ideal condition for the absorption of applied N and P nutrients. Additionally, P plays a crucial role in providing energy for the nitrogen fixation process [21] and enhances seed weight [22]. Abou-Amer et al. [13] discovered that utilizing a combination of mineral fertilizers, especially N and P, resulted in a 68% increase in the weight of 100 seeds compared to the Control plant.

The study's findings showed that using Monopotassium phosphate and Di-potassium phosphate resulted in a 37.34% and 29.03% increase in fresh seed weight compared to the Control treatment. There was no significant difference in seed fresh weight between the Monopotassium phosphate and Di-potassium phosphate treatments. In this study, Monopotassium phosphate and Di-potassium phosphate increased the seed dry weight by 69.14% and 33.72%, respectively, compared to the Control.

The results of the present study indicated that the plants treated with Monopotassium phosphate and Di-potassium phosphate increased the total fresh weight by 286.67 (equivalent to 34.53%) and 153.33 (equivalent to 18.47%) g/m^2, respectively, compared to the Control treatment.

Phosphorus is an essential component of ATP, playing a critical role in the entire growth process from the seedling stage to seed formation and maturity. Thus, phosphorus fertilizer plays a crucial role in enhancing the biomass yield of the faba bean. Additionally, potassium is essential for cell growth and contributes to higher-quality biomass yield [23]. The increased biomass production in response to P and K fertilizers can be attributed to these nutrients' essential roles in plant growth. This indicates that the balanced application of these fertilizers meets the growth needs of the faba bean through synergistic effects [18]. Ali et al. [10] showed that biomass positively reacted to chemical fertilizer treatments, especially P_2O_5 (92 kg ha^{-1}) and K_2O (60 kg ha^{-1}) in faba bean. Fatima et al. [24] found that applying 20:60:40 kg ha^{-1} of N, P, and K fertilizers increased soybean biomass yield by 201% compared to the Control treatment. Bezabih et al. [14] demonstrated a 73% increase in faba bean biomass yield with 30 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} in rhizobium-inoculated faba bean.

This research showed that the maximum and minimum seed yield was related to Monopotassium phosphate and Control treatments, respectively. In this experiment, the plants treated with Monopotassium phosphate and Di-potassium phosphate showed superiority of 1219.73 (equivalent to 61.91%) and 509 (equivalent to 25.73%) kg ha^{-1} compared to untreated plants. The increased crop yield from using mineral fertilizers can be credited to the balanced nutrition provided to the crop. Therefore, the combined physiological roles of nitrogen, phosphorus, and potassium may have enhanced the plant's growth and photosynthate distribution to seeds [13]. In this connection, the applied K fertilizer may have contributed to increased root growth, thereby improving water and nutrient uptake, as Marek et al. [20] suggested. Therefore, the combined physiological roles of phosphorus and potassium may have enhanced the plant's growth and photosynthate distribution to seeds [13]. In this connection, the applied K fertilizer may have contributed to increased root growth, thereby improving water and nutrient uptake, as Marek et al. [20] suggested. This creates an ideal condition for optimizing nutrient uptake from the soil. Moreover, P is essential in plant energy metabolism, particularly in energy supply processes [21]. It has been claimed that the supply of P increases the plant's efficiency by facilitating root development, which maximizes the crop's vegetative growth [25]. Applying P and potassium K enhances the accumulation of dry matter in plants, maximizing vegetative growth and enhancing photosynthetic efficiency [18]. This leads to vigorous crop growth and increased carbohydrate production [26].

3.1 Correlation

The results showed a positive and significant correlation between the plant height and the number of leaves (r = 0.66**). The number of branches positively and significantly correlated with plant height (r = 0.84**) and number of leaves (r = 0.87**). The correlation of pod length with the number of leaves (r = 0.75*) and the number of branches (r = 0.80 **) was positive and significant. Pod weight also positively and significantly correlated with the number of leaves (r = 0.85**) and lateral branches (r = 0.76*). The number of days to seeding correlated positively and significantly with plant height (r = 0.86**) and the number of branches (*r = 0.69). The correlation of the 100-weight seeds with plant height (r = 0.83**), the number of branches (r = 0.70*), and the number of seeds per pod (r = 0.97**) was significant. The results showed that the seed fresh weight had a positive and significant correlation with the plant height (r = 0.63*), the number of leaves (r = 0.98**), the number of branches (r = 0.86**), pod length (r = 0.80 **) and pod weight (r = 0.76). Correlation of seed dry weight with the number of leaves (r = 0.65*), pod number (r = 0.88**), pod length (r = 0.77**), number of seeds per pod (r = 0.66*), and seed fresh weight (r = 0.77*), was positive and significant. In this study, the total fresh weight with the number of pods (r = 0.96**), pod length (*r = 0.66), number of seeds per pod (r = 0.97**), and seed dry weight (**r = 0.94), had a positive and significant correlation. Finally, seed yield has a positive and significant correlation with the number of pods per plant (r = 0.82**), pod length (r = 0.80**), number of seeds per pod (r = 0.88**), Seed dry weight (r = 0.85**), and total fresh weight (r = 0.89**) (Fig 1) . It has been proven that there is a positive and significant correlation between seed yield and the number of days to flowering, the number of days to full maturity, the number of pods per plant, and the number of seeds per pod in beans [28]. Another study observed that the correlation coefficient between the number of pods per plant, the length of pods, and the number of seeds per pod with seed yield was positive and significant [29]. Ouji et al. [30] demonstrated a positive and significant relationship between seed yield and plant height, number of pods per plant, seed yield per plot, and number of seeds per plant. It has been reported that grain yield was positively associated with plant height, thickness, number of branches, number of nodules per root, aboveground biomass, number of pods per plant, number of seeds per pod, hundred seed weight, and harvest index [27].

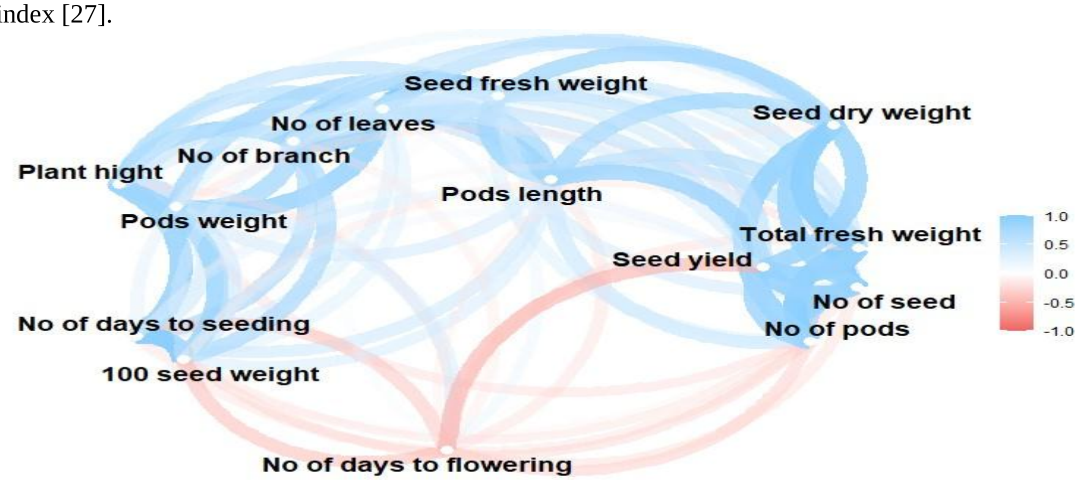

Figure 1. The correlation network plot ،Seed yield showed a positive and significant correlation with the number of pods per plant ($r = 0.85$, $p < 0.01$), pod length ($r = 0.78$), and total fresh weight ($r = 0.92$). Based on the biplot test results from the principal components analysis.

3.2 Biplot analysis

Based on the biplot test results from the principal components analysis, the first two components explain 100% of the total data variance (Fig 2). The results showed that the three treatments were situated in distinct areas of the bi-plot, while the 14 studied traits were located in two separate bi-plot areas. No. of days to flowering, No. of days to seedling, No. of seed, seed yield, plant height, and total fresh weight were located in the 2nd leg of the plot (left side, top) near the Monopotassium phosphate treatment. Characteristics of pod length, number of leaves, seed fresh weight, number of pods, seed dry weight, 100-seed weight, number of branches, and pod weight were recorded in the 3rd area of the plot near the Di-potassium phosphate treatment. In previous studies, biplot analysis has been used to group bean traits and treatments [31].

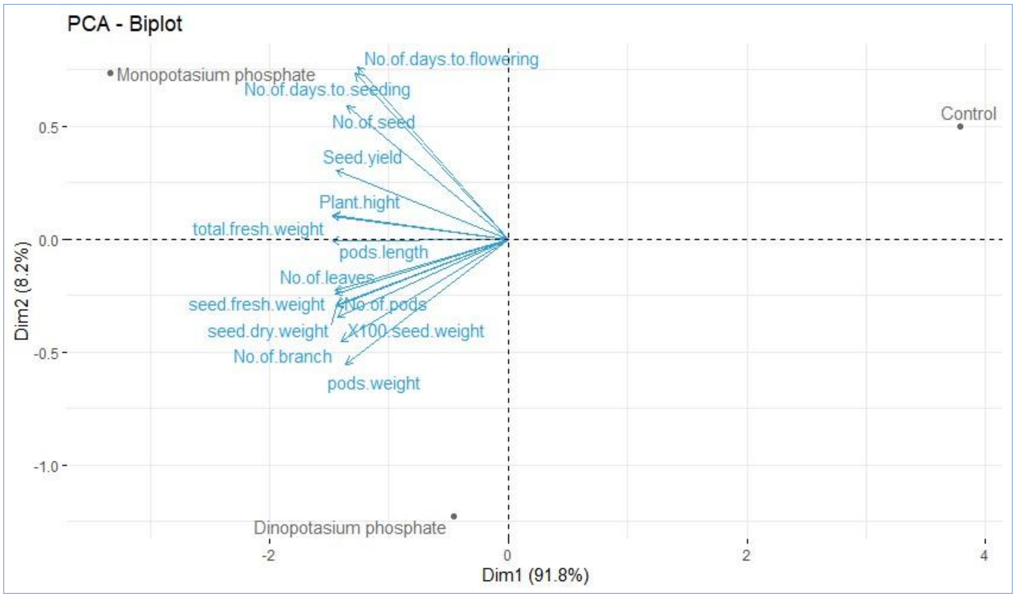

Figure 2. Biplot shape of the treatment and measures traits in faba bean under foliar treatments in two years

3.3 Cluster analysis

The cluster heatmap method categorized the treatment groups and analyzed traits into two distinct groups. Based on this classification, the treatments Monopotassium phosphate and Di-potassium phosphate were placed in the same group. The results indicated that No. of seed, no. of days to seeding, and the number of days to flowering were placed in cluster 1; the mentioned traits showed their maximum values in response to the Monopotassium phosphate treatment, while the lowest values of these traits were recorded in the Control treatment. Plant height, No of leaves, No. of the branch, no. of pods, pods length, pods weight, 100 seed weight, seed fresh weight, total fresh weight, seed dry weight, and seed yield were in cluster 2. These traits also displayed the maximum and minimum values of the mentioned traits in Monopotassium phosphate and Control treatments (Fig 3). Cluster analysis was used to investigate performance stability in a study on different bean cultivars [32].

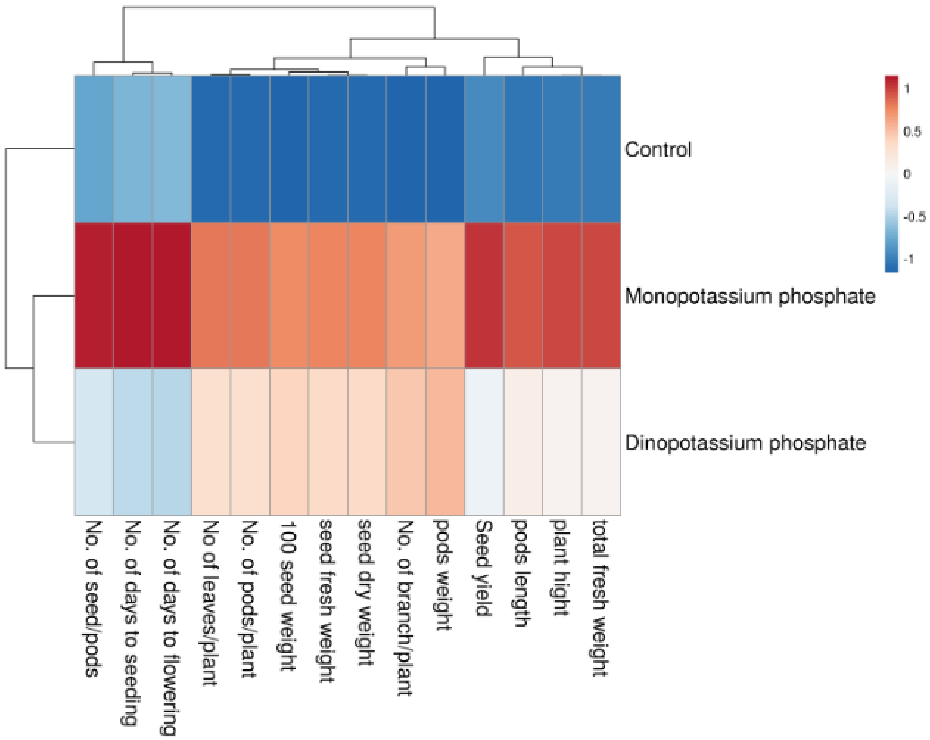

Figure 3. Heatmap plot of the treatment and measures traits in faba bean under foliar treatments in two years

Table 1. Analysis of variance for the measured traits faba bean under foliar treatments in two years

SOV	Df	Mean of Squares						
		Plant height	No of leaves/plant	No. Of branch/plant	No. Of pods/plant	Pods length	Pods weight	No. Of seed/pods
Year (Y)	1	15.12^{ns}	2.41^{ns}	0.12^{ns}	0.30^{ns}	0.06^{ns}	0.11^{ns}	0.05^{ns}
Block/Y	10	4.01	1.69	0.131	0.097	0.051	0.099	0.032
Treatment (T)	2	54.22**	206.89**	3.69**	2.2**	13.52**	19.86**	2.78**
Y*T	10	1.17^{ns}	5.9^{ns}	0.09^{ns}	0.09^{ns}	0.51^{ns}	0.78^{ns}	0.15^{ns}
Error	20	0.86	4.76	0.061	0.042	0.243	0.383	0.088
CV (%)		11.07	13.9	15.16	12.45	12.34	12.72	16.5

ns: not statistically significant; *: statistically significant at α=0.05; **: statistically significant at α=0.01; No: Number.

Continuation of Table 1.

SOV	Df	Mean of Squares						
		No. Of days to seeding	No. Of days to flowering	100 seed weight	Seed Fresh Weight (g/m²)	Seed Dry Weight (g/m²)	Total Fresh Weight (g/m²)	Seed yield
Year (Y)	1	5.10*	20.91*	2.15^{ns}	880.0^{ns}	0.01^{ns}	8020.12^{ns}	5641.21^{ns}
Block/Y	10	1.07	3.82	1.05	240	0.002	2026.67	1698.21
Treatment (T)	2	12.67^{ns}	20.22**	111.08**	26516.67**	0.1657**	123466.67**	261437.55**
Y*T	10	5.53^{ns}	0.31^{ns}	3.11^{ns}	946.76^{ns}	0.01^{ns}	3133.30^{ns}	4946.52^{ns}
Error	20	3.33	0.36	1.92	566.67	0.0032	2333.33	3621.49
CV (%)		11.9	10.49	11.05	15.71	15.44	14.95	13.23

ns: not statistically significant; *: statistically significant at α=0.05; **: statistically significant at α=0.01; No: Number.

Table 2. Mean comparison for the measured traits

Treatment	Plant height	No. of Leaves / Plant	No. of Branches / Plant	No. of Pods / Plant	Pod Weight (g/plant)	Pod Length (cm)	No. of Seeds / Pod
Monopotassium phosphate	88.63±0.17[a]	60.67±0.23[a]	5.33±0.039[a]	8.87±0.045[a]	22.57±0.06[a]	23.87±0.085[a]	5.33±0.056[a]
Dinopotasium phosphate	88.07±0.29[a]	57.67±0.46[b]	5.17±0.052[a]	8.57±0.046[b]	20.97±0.067[b]	23.77±0.075[a]	4.33±0.046[b]
Control	83.17±0.21[b]	49.33±0.23[c]	3.9±0.052[b]	7.7±0.031[c]	19.57±0.082[c]	20.67±0.106[b]	4.03±0.023[b]

In each column, means with the same letter(s) are not significantly different based on Duncan's test (α=0.05) Mean(±standard error of the mean) significant letters

Continuation of Table 1.

Treatment	No. of days to seeding	No. of days to flowering	100 seed weight (g)	Seed fresh weight (g m-2)	Seed dry weight (g m^{2-1})	Total fresh weight (g m^{2-1})	Seed yield (kg ha^{-1})
Monopotassium phosphate	97.67±0.23[a]	124.33±0.23[a]	135.33±0.11[a]	468.33±3.01[a]	98.66±0.75[a]	1116.67±5.37[a]	3190.39± 219.76[a]
Dinopotasium phosphate	95.33±0.15[a]	121.33±0.15[b]	133.8±0.33[a]	440±3.01[a]	78±0.75[b]	983.33±5.24[b]	2477.62±192.40[a]
Control	95±0.38[a]	121±0.23[b]	127.23±0.11[b]	341.67±4.47[b]	58.33±1.11[c]	830±11.39[c]	1970.66±165.56[c]

In each column, means with the same letter(s) are not significantly different based on Duncan's test (α=0.05) Mean(±standard error of the mean) significant letters

Conclusion

In summary, this investigation demonstrates that seed yield in faba beans is strongly linked to key yield-related traits, showing highly favorable associations with pod measurements, seed weights, and biomass production. Ultimately, the foliar application of monopotassium phosphate serves as an effective strategy to optimize essential yield components—particularly pod and seed development—alongside vegetative growth, thereby driving significant improvements in overall bean productivity.

Acknowledgments

The authors are thankful to the Head of food science department, the institute of Bakrajo, Sulaimani polytechnic University , Iraq.

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تقييم مؤشرات النمو والحاصل لنبات الباقلاء *(Vicia faba L.)* تحت تأثير الرش الورقي بفوسفات أحادي وثنائي البوتاسيوم

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الخلاصة

هدفت هذه الدراسة إلى بحث خصائص النمو وإنتاجية باقلاء استجابةً للرش الورقي بأسمدة فوسفات أحادي وثنائي البوتاسيوم. أُجريت تجربة ميدانية استمرت لمدة عامين في محطة البحوث الحقلية التابعة للمعهد التقني في بكرجو بشمال العراق. نُفذت التجربة باستخدام تصميم القطاعات العشوائية الكاملة (***(RCBD*** بستة مكررات. أظهرت النتائج أن الرش الورقي بفوسفات أحادي البوتاسيوم أدى إلى زيادة معنوية في كل من: ارتفاع النبات (6.56%)، عدد الأوراق لكل نبات (22.98%)، عدد الفروع (36.66%)، عدد القرنات لكل نبات (15.19%)، طول القرنة (15.36%)، وزن القرنة (15.47%)، عدد البذور في القرنة (32.25%)، عدد أيام التزهير (2.27%)، وزن 100 بذرة (6.36%)، الوزن الرطب للبذور (37.69%)، الوزن الجاف للبذور (69.22%)، الوزن الرطب الكلي (34.53%)، وحاصل البذور (61.89%) مقارنة بمعاملة المقارنة (السيطرة). كما ارتبط حاصل البذور بارتباط إيجابي ومعنوي مع عدد القرنات في النبات، طول القرنة، عدد البذور في القرنة، الوزن الجاف للبذور، والوزن الرطب الكلي. وبناءً على نتائج تحليل المكونات الرئيسية ***(PCA)***، تبيّن أن المكونين الأولين يفسران 100% من التباين الكلي للبيانات. بالإضافة إلى ذلك، ساهمت طريقة الخريطة الحرارية العنقودية (***(Cluster Heatmap*** ومخطط (***(Biplot*** في تصنيف المعاملات والصفات المدروسة بوضوح إلى مجموعتين متمايزتين بناءً على استجابتها للتسميد .

الكلمات المفتاحية: الارتباط، الأسمدة، المغذيات الكبرى، القرنات، الحاصل.