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HEAT ACCUMULATION BY PHYSIOLOGICAL AND YIELD TRAITS IN FABA BEAN (*VICIA FABA* L.)

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SUMMARY

In assessing the effect of three planting dates (October 01, mid-October, and November 01) and dual spraying of four levels of potassium sulfate (0, 1000, 2000, and 3000 mg L^{-1}) and proline acid (0, 50, 100, and 150 mg L^{-1}) on the faba bean (*Vicia faba* L.), an experiment commenced in the winter cropping season of 2022–2023 at the University of Basrah, Basrah, Iraq. The experiment, laid out in a randomized complete block design (RCBD), had a factorial arrangement, with two factors and three replications. Results showed mid-October planting is superior for most studied traits, recording the highest average number of accumulated heat units from planting to 50% flowering. Likewise, optimum averages occurred for physiological maturity, leaf area, chlorophyll content, seeds per pod, 100-seed weight, and total seed yield in faba beans. The findings also revealed the combination of potassium (3000 mg L^{-1}) and proline acid (150 mg L^{-1}) excelled for all the studied traits. The combined treatment provided maximum average values for the number of accumulated heat units from planting to 50% flowering and beginning of branches, leaf area, chlorophyll content, seeds per pod, 100-seed weight, and the total seed yield in faba beans.

Keywords: Faba bean (*Vicia faba* L.), planting dates, potassium sulfate, proline acid, physiological indicators, growth and yield traits

Key findings: In faba beans, the mid-October planting showed superiority in most studied traits. Foliar application of potassium and proline acid individually and in interaction revealed significant differences for physiological, growth, and yield-related traits.

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INTRODUCTION

The faba bean (*Vicia faba* L.) belongs to the Fabaceae family, which is an important crop widely grown in the world. It contains about 25%–40% protein-rich multiple amino acids that compensate for animal protein (Alharbi and Adhikari, 2020). An expanding global population requires more food, yet climate change and severe weather make food production harder (Hansen *et al*., 2012). Although, floral development and anthesis were brief, they are vital to crop productivity and especially vulnerable to short periods of high temperature (Luo, 2011).

An ideal planting date optimizes the temperature, humidity, duration of the day, and flowering time. It is best to choose a planting date that avoids overheating, especially during flowering. When shifting the planting date, the plant's ability to adapt to its environment and its vegetative and reproductive growth may take precedence over output (Oplinger *et al*., 2000). Understanding thermal indicators is crucial, since they may help identify critical phases and the ideal planting date. The heat accumulation unit, also known as maturity days in most publications, is one such indication (Lundby *et al*., 2024).

Planting time is one of the critical factors determining plants' productivity due to its importance resulting from the temperature and photoperiod effects on plant growth, flowering, and length of the growing season, especially for faba bean (Abu-Kawochar, 2007 and Alrubaiee et al 2019). Similarly, potassium is one of the crucial and mobile mineral elements needed by crop plants. Potassium presence is also essential for the formation of carbohydrates and protein and the growth of some structural tissues. It also affects vital processes, such as, photosynthesis and respiration (Niewiadomska *et al.,* 2015).

The process of foliar application of amino acids (Alrubaiee *et al.,* 2021), especially proline acid, on the plant contributes to the ease of its absorption through the leaves. Spraying proline acid on the vegetative part leads to stimulating physiological and biochemical processes to take place. The said acid also participates in the synthesis of proteins, the manufacture of carbohydrates, and the activation of photosynthesis by contributing to enhance the photosynthetic synthesis (Kishor *et al.,* 2015 and Attiya *et al.,* 2019). This study aimed to determine the best planting date beneficial from heat accumulation under the combined effect of foliar spraying with potassium sulfate and proline acid. Moreover, it aimed at knowing their interaction on the traits associated with growth and yield in the faba bean.

MATERIALS AND METHODS

A field experiment transpired at the University of Basrah, Basrah, Iraq, during the winter agricultural season of 2022–2023. The experiment, carried out according to a randomized complete block design (RCBD), had three replications. The experiment included two factors. The first factor was planting dates (D1: October 01, D2: mid-October, and D3: November 01). Meanwhile, the second factor included dual spraying of potassium and proline acid at four levels of potassium sulfate (0, 1000, 2000, and 3000 mg L^{-1}) and proline acid (0, 50, 100, and 150 mg L^{-1}) on the faba bean (*Vicia faba* L.), represented as T0, T1, T2, and T3. Two stages of spraying proceeded. The first commenced one month after germination and the second, two months later.

A spacing of 20 cm separated the plants, and 50 cm separated the rows, in which sowing the faba bean seeds occurred. Additionally, the cropping standards followed ensued while applying the mineral fertilizers. The spraying of nitrogen fertilizer had a rate of 120 kg ha^{-1} in equal amounts of urea (N 46%), continued after 15, 30, and 45 days of planting (Kamal *et al*., 2016). When planting, superphosphate (P 43%, a phosphorus fertilizer) application had a rate of 105 kg ha^{-1} (Alshummary *et al*., 2021). Crop management practices proceeded as per the recommended production technology for faba bean. The physical and chemical properties of the experimental field soil are available in Table 1.

Table 1. Physical and chemical properties of the experimental field soil.

Attributes	Value	Unit	
Ph	8.50	1:1	
E.C.$_e$	7.32	Ds m^{-1}	
Ready-elements			
N	53.3	mg kg^{-1}	
P	5.2		
K	12.3		
Organic matter	1.81	g kg^{-1}	
Soil texture			
Sand	385	g kg^{-1}	
Silt	515		
Clay	100		
Concentration of Cations and Anions in the soil			
Cations	Value	Anions	Value
Ca^{+2}	6.93	Cl^-	41.77
Mg^{+2}	9.08	$HCO3^-$	8.19
Na^+	49.81	$SO4^-$	8.33

Data recorded

In faba bean, the number of accumulated thermal units (m), calculated during the different stages of plant growth, are as follows. The number of thermal units accumulated from cultivation to 1) 50% seedlings' appearance (m), 2) branches emergence (m), 3) 50% flowering (m), and 4) physiological maturity (m). The thermal units' measurement comprised calculating the total daily maximum and minimum temperatures from the planting date until the physiological maturity for the three planting dates based on the following equation:

$$GDD = \frac{T_{\max} + T_{\min}}{2} - T_{base}$$

Where:
T_{max}: Maximum daily temperature (°C), T_{min}: Minimum daily temperature (°C), and T_{base}: The smallest plant growth temperature as 1.3 °C for beans (Ajam *et al.,* 2007). Computation also occurred for leaf area (cm^2), leaf chlorophyll content (mg 100 g^{-1} wt), pods per plant, and total seed yield (kg ha^{-1}).

Statistical analysis

All the recorded data for various parameters underwent the analysis of variance (ANOVA), as per the randomized complete block design (Gomez and Gomez, 1984). The least significant difference ($LSD_{0.05}$) test applied compared and separated the mean differences. The statistics software GenStat12 was the version used for the analysis.

RESULTS AND DISCUSSION

Heat units from planting to branching

From planting to branching, significant differences were evident in the accumulated heat units for different planting dates (Table 2). The first date recorded had the highest average of accumulated heat units from planting to the beginning of branching (777.75 °C), compared with the lowest average recorded at the third planting date (610.25 °C). The increase in accumulated thermal units of the first planting date may be due to the appropriate environmental conditions, helping raise the activity of vital processes within the faba bean plants, including photosynthesis, reflecting positively on this trait. These results were greatly analogous to the findings assessing faba bean (*Vicia faba* L.) genotypes to heat stress during floral development and anthesis (Bishop *et al.*, 2016).

Heat units from planting to 50% flowering

The faba bean planting dates significantly affected the average accumulated heat units from planting to 50% flowering (Table 3). It

Table 2. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the thermal units accumulated from planting to the beginning of branches.

Planting dates	Spray treatments				Means
	T0	T1	T2	T3	
D1	780.03	770.69	780.03	780.26	777.75
D2	703.93	711.54	703.93	696.33	703.93
D3	617.98	610.70	603.43	608.89	610.25
Means	700.65	697.64	695.80	695.16	
$LSD_{0.05}$ Planting dates: 1.387, Spray treatments: N.S., Planting x Spray: N.S.					

Table 3. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the thermal units accumulated from planting to 50% flowering.

Planting dates	Spray treatments				Means
	T0	T1	T2	T3	
D1	1074.92	1096.75	1103.55	1117.15	1098.09
D2	1201.21	1200.02	1206.96	1213.90	1205.52
D3	933.23	958.01	957.92	1118.02	991.80
Means	1069.79	1084.93	1089.48	1149.69	
$LSD_{0.05}$ Planting dates: 4.402, Spray treatments: 5.083, Planting x Spray: 8.803					

was clear the highest average of thermal units for planting to 50% flowering appeared at the second planting, i.e., mid-October (1205.52 °C) compared to the third planting date. The latter recorded the lowest average of thermal units (991.80 °C), with an increase of 21.55%. This may refer to the suitability of the environmental conditions during the second planting, especially the moderate temperatures during the growth period for the said trait, boosting the accumulated heat units compared to other dates (Iannucci *et al.*, 2008).

For faba beans, the heat units from planting to 50% flowering showed the foliar application of potassium sulfate and proline acid also gave a significant effect (Table 3). In comparison to the control treatment, which produced the lowest average for the aforementioned characteristic (1069.79 °C), the foliar spray of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) displayed the greatest average for the collected heat units up to 50% blooming (1149.69 °C). This increase could be because of potassium's beneficial role in facilitating increased nutrient absorption and transfer to areas of need. This, in turn, promoted the plant's vegetative growth, including the number and size of leaves. Furthermore, it facilitated to enhance the plant's exposure to and reception of solar radiation, which increased the plants with accumulated heat units (Barlog and Lukowiak, 2021).

As for proline, its effect could be through contributing to the synthesis of proteins and carbohydrates and activating the process of photosynthesis by participating in an increased synthesis of photosynthetic pigments, such as, chlorophyll and carotenoids. These, then, contributed to raising absorption of the rays falling on the faba bean plants, causing an increase in the accumulated heat units (Kishor *et al.,* 2015). According to interaction between these factors, significant differences appeared for the accumulated heat units from planting to the 50% flowering stage of the faba bean plants (Table 3). The interaction of the faba bean’s second planting date with the foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) revealed the highest average for the said trait (1213.90 °C). When compared with the interaction of the third planting date with the control treatment of potassium sulfate and proline acid, the latter gave the lowest average for the said trait (933.23 °C).

Table 4. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the units accumulated from planting to physiological maturity.

Planting dates	Spray treatments				Means
	T0	T1	T2	T3	
D1	2498.1	2496.6	2528.4	2536.8	2515.0
D2	2587.2	2588.9	2597.4	2609.4	2595.8
D3	2567.2	2566.9	2590.8	2609.4	2588.7
Means (°C)	2550.8	2550.8	2572.2	2592.0	
$LSD_{0.05}$ Planting dates: 6.43, Spray treatments: 7.54, Planting x Spray: 13.07					

Heat units from planting to physiological maturity

On average, the faba bean planting dates substantially influenced the average accumulated heat units from planting to physiological maturity (Table 4). The mid-October planting exhibited the highest average for accumulated heat units (2595.8 °C) versus the first date, showing the lowest average for the accumulated heat units (2515.0 °C). This increase could be due to the suitability of the environmental conditions during the various growth stages, leading up to the physiological maturity, as accompanied by the formation of better root and vegetative system. In turn, it contributed to the transport of products of photosynthesis and increased plant growth, which helped increase the accumulated heat units. Past studies also showed similar findings by studying the effects of the planting date, row spacing, and seed rate on the grain yield and protein content of the faba bean (Rabiee and Jilani, 2014; Manning, 2017).

Significant differences manifested among the accumulated heat units due to foliar application of the potassium sulfate and proline acid (Table 4). In contrast to the control treatment, which displayed the lowest average (2550.8 °C), the foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) exhibited the maximum average of collected heat units (2592.0 °C). The reason for this increase could be the potassium's beneficial effects on proteins and sugars' movement, stored carbohydrates and photosynthesis products inside the plant from the source to the sink, and the regulation of stomata's opening and closing. By raising the accumulated heat units, potassium helps the faba bean plants grow in the best possible way during their vegetative phase (Britto and Kronzucker, 2008). Likewise, the role of proline in stimulating the enzymes help in the plant's photosynthesis process, as reflected positively in enhancing the accumulated heat units.

Leaf chlorophyll content

Notable variations emerged among the planting dates for leaf chlorophyll content (Table 5). The mid-October planting showed the highest average for the leaf chlorophyll content (354.6 mg 100 g^{-1}), with an increase of 7.20%, compared with the first planting (October 01), giving the lowest average for the said trait (336.1 mg 100 g^{-1}). The increase in chlorophyll content may refer to the rise in the number of accumulated heat units during this stage. In turn, it led to an increase in the efficiency of leaf exposure and an upsurge in the solar radiation absorption, thereby, boosting the efficiency of photosynthesis in the leaves, raising the chlorophyll content (Yasmin *et al.,* 2020).

For leaf chlorophyll content, the foliar application of potassium sulfate and proline acid also indicated significant differences (Table 5). The foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) gave the maximum average of leaf chlorophyll content (384.8 mg 100 g^{-1}) compared with the control treatment, which gave the lowest average for the trait (312.0 mg 100g^{-1}). This rise could be because of potassium's beneficial function in the production of auxiliary and chlorophyll pigments during photosynthesis, which ultimately raises the chlorophyll concentration of leaves. Potassium is crucial in lessening the negative effects of abscisic acid,

Table 5. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the leaf chlorophyll content.

Planting dates	Spray treatments				Means (mg 100 g^{-1})
	T0	T1	T2	T3	
D1	308.4	314.2	352.5	369.5	336.1
D2	319.2	332.1	371.0	396.3	354.6
D3	308.4	326.2	349.4	388.6	343.1
Means (mg 100 g^{-1})	312.0	324.2	357.6	384.8	

$LSD_{0.05}$ Planting dates: 8.36, Spray treatments: 9.66, Planting x Spray: N.S.

Table 6. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the leaf area.

Planting dates	Spray treatments				Means (cm^2)
	T0	T1	T2	T3	
D1	2961	3019	3085	3203	3067
D2	3081	3352	3648	3869	3488
D3	2827	3081	3473	3666	3262
Means (cm^2)	2956	3151	3402	3579	

$LSD_{0.05}$ Planting dates: 100.8, Spray treatments: 116.4, Planting x Spray: 201.5

which age leaves and degrade chlorophyll (Cakmak, 2005). Proline, an amino acid, also participates in photosynthesis by activating proteins and enzymes that produce chlorophyll molecules in leaves. Amcoton, proline, and potassium thiosulfate applied topically improved the photosynthetic efficiency of the faba bean varieties, as reported by Emam and Semida (2020) and Al-Hasany *et al*. (2019).

Leaf area

Planting dates revealed remarkable modifications for the leaf area in faba beans (Table 6). The mid-October planting provided the highest average leaf area (3488 cm^2), with a significant increase of 13.72% compared with the first-of-October planting, giving the lowest average for the said trait (3067 cm^2). The increase in leaf area may be due to the suitability of the faba bean planting date with a favorable growth period, resulting in the formation of an ideal root system. It helped to increase the efficiency of transporting nutrients and making their best use to build a better vegetative system and large leaf area. These results agreed with past findings about the effect of sowing date and seed rate on faba bean (*Vicia faba* L.) growth and yield (Wakweya *et al.*, 2016).

Prominent diversities were apparent among the treatments of foliar application of potassium sulfate and proline acid used in faba beans (Table 6). The combined foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) revealed the premier average of the leaf area (3579 cm^2), with a significant increase of 21.08% from the control treatment, providing the least average for the said trait (2956 cm^2). This increase in leaf area is referable to the role of potassium in enhancing the cell division and elongation of leaf cells, regulating osmotic pressure, and maintaining the turgor pressure of the cells, thereby, enhancing faba bean plants' leaf area (Mahdy and Abd-El-Raheem, 2015).

Similar results came from the proline acid's action, which promotes and increases the production of proteins involved in photosynthesis, increasing the amount of chlorophyll. By enhancing the vegetative system of the plants, proline acid helps crop plants grow more leaves. These findings are consistent with earlier research by El-Awadi *et al*. (2016), who documented the effects of proline and cysteine on the yield, growth, and biochemical characteristics of faba beans. In comparison to the third planting date (November 01) with the control treatment of potassium sulfate and proline acid, it gave the minimum average for the said trait (2961 cm^2). The interaction of mid-October planting with the foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) significantly outperformed the other interactions, recording the maximum average leaf area of the faba bean plants (3869 cm^2), with an increase of 30.67%.

Seeds per pod

According to the data, the second planting, which took place in mid-October, had the greatest average of 4.84 seeds pod^{-1}, while the third planting date, which fell on November 01, had the least average of 3.98 seeds pod^{-1} (Table 7). A good planting date may have contributed to the rise in collected heat units. This, in turn, formed the best vegetative system and allowed for the greatest possible use of nutrients from the manufacturing sites during the production of seeds in the pods (El-Awadi *et al.,* 2016).

Foliar application of potassium sulfate and proline acid also showed pronounced distinctions for seeds per pod in faba beans (Table 7). Putting potassium sulfate and proline acid (3000 + 150 mg L^{-1}) on the leaves of the plant led to most seeds per pod (5.22 seeds pod^{-1}), which is 37.01% more than the control treatment's lowest figure (3.81 seeds pod^{-1}). This increase might be because potassium helps plants grow and produce more food through photosynthesis. During the early stages of plant growth, the number of seeds in the pod increases at the same time as the plant gets longer. In the later stages of the plant's life, the seeds' weight depends on how dry matter gets transferred to the pod (Britto and Kronzucker, 2008; Al-Falahi and Abdul-Kafoor, 2021). As for the effect of spraying with proline acid, it may refer to the fact that it improves the absorption of nutrients and increases their accumulation inside the crop plants, hence, increasing the number of seeds per pod (Al-Hasany *et al.*, 2018).

On the interaction among the planting dates, potassium sulfate, and proline acid, the interaction influenced considerable variations for seeds per pod (Table 7). The mid-October planting with foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) exhibited the highest average for seeds per pod (5.69 seeds pod^{-1}). However, it did not differ significantly from the interaction of first-of-October planting with the same dose of potassium sulfate and proline acid (5.58 seeds pod^{-1}). In contrast, the interaction of the first-of-October planting with no application of potassium sulfate and proline exhibited the lowest average for the said trait (3.81 seeds pod^{-1}).

100-seed weight

For the 100-seed weight, the faba bean planting times indicated notable disparities (Table 8). The mid-October planting gave the utmost average for 100-seed weight (124.74 g), which also did not differ significantly from the first-of-November planting (124.58 g), compared with the first-of-October planting, providing the lowest average for the said trait (118.55 g). The reason could be referring to the fact that the appropriate planting date coincided with a moderate temperature, led to the formation of a good source, such as, the plant's number and area of leaves and their chlorophyll content. This contributed to the increased transfer of photosynthesis products, and consequently, an increase in the seed size and weight. Al-Tahir *et al.* (2014) also reported similar findings by studying the response of the faba bean (*Vicia faba* L.) genotypes to planting times.

As for the effect of spraying the faba bean plants with potassium sulfate and proline, it significantly impacted the 100-seed weight (Table 8). A spray of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) on the leaves had the highest average weight for 100 seeds (124.39 g), while the control treatment had the lowest average weight for the same trait (120.82 g), with an increase of 2.95%. Possibly, this rise is because potassium helps respiration and the movement of made materials from the source to the sink. This has a good effect on the faba bean pods' seed size and weight. On the same note, the amino acid proline helps make proteins to support photosynthesis and speeds up the movement of made materials to pods to boost the weight

Table 7. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the seeds' number.

Planting dates	Spray treatments				Means (seeds pod^{-1})
	T0	T1	T2	T3	
D1	3.81	4.15	4.49	5.58	4.50
D2	3.98	4.40	5.28	5.69	4.84
D3	3.65	4.04	3.84	4.38	3.98
Means (seeds pod^{-1})	3.81	4.20	4.54	5.22	
$LSD_{0.05}$ Planting dates: 0.220, Spray treatments: 0.254, Planting x Spray: 0.440					

Table 8. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the 100-seed weight.

Planting dates	Spray treatments				Means (g)
	T0	T1	T2	T3	
D1	116.69	116.78	119.77	120.96	118.55
D2	122.60	124.34	125.39	126.63	124.74
D3	123.17	124.48	125.09	125.58	124.58
Means (g)	120.82	121.86	123.42	124.39	
$LSD_{0.05}$ Planting dates: 0.80, Spray treatments: 0.922, Planting x Spray: N.S.					

Table 9. Effect of planting dates and foliar application of potassium sulfate and proline acid and their interaction on the seed yield.

Planting dates	Spray treatments				Means (kg ha^{-1})
	T0	T1	T2	T3	
D1	1856	2201	3027	3512	2649
D2	2054	2371	2950	3922	2824
D3	1586	1881	2042	2497	2002
Means (kg ha^{-1})	1832	2151	2673	3310	
$LSD_{0.05}$ Planting dates: 231.3, Spray treatments: 267.1, Planting x Spray: N.S.					

of the seeds (Hayssam *et al*., 2013; Kishor *et al*., 2015).

Total seed yield

For total seed yield in faba beans, the planting times revealed significant differences (Table 9). The mid-October planting appeared with the maximum average seed yield (2824 kg ha^{-1}), which also did not differ significantly from the first-of-October planting (2649 kg ha^{-1}). The reason for the said increase in seed yield may be due to the suitability of the planting date, especially the moderation of temperatures and the enhancement in the accumulated heat units. These contributed to increasing efficiency of the transfer of the manufactured materials from the manufacturing sites to the yield components, which enhanced the total seed yield (Gomaa *et al.*, 2023; Hussein *et al*., 2024; Merhij *et al*., 2024).

Foliar application of potassium sulfate and proline notably raised the total yield of the faba bean plants (Table 9). The foliar application of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) enunciated the ultimate average seed yield (3310 kg ha^{-1}), with an increase of 80.68%, compared with the control treatment, with the lowest average seed yield (1832 kg ha^{-1}). The reason for the increase could be because of the positive effects of potassium and proline on the yield components. These indirectly affected the total seed yield in building proteins, amino acids, chlorophyll, carbohydrate metabolism, and boosting the process of transferring manufactured materials to other plant parts. This leads to an increase in vegetative growth indicators, which, in turn, enhances the percentage of flowering and fruit set, and consequently, boosts the total yield in faba beans (Britto and Kronzucker, 2008; Al-Jubouri and Shaker, 2019). The results showed nonsignificant effects of the interaction between planting dates and spraying with potassium sulfate and proline acid on the total seed yield (Table 9).

CONCLUSIONS

Sowing in mid-October with foliar applications of potassium sulfate and proline acid (3000 + 150 mg L^{-1}) improved the plant's ability to grow leaves and stems. It made the photosynthesis process more efficient by giving the plant wider surface area to catch falling sunlight, making the most of heat buildup and intake of more dry matter, as shown in the bean's growth and yield.

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