Optimizing Planting Date Enhances Growth and Flowering of Broad Bean (Vicia faba L.) under Mediterranean Greenhouse Conditions

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Abstract

This study evaluated the influence of planting date on vegetative growth and flowering performance of broad bean (Vicia faba L.) under semi-controlled greenhouse conditions in Sirte, Libya. A completely randomized design (CRD) was used with three sowing dates (15 February, 15 March, and 15 April 2024). Although the experiment included a limited number of replicates ($n = 3$), strict environmental control and uniform management practices were applied to enhance data reliability.

Average greenhouse temperatures varied across planting periods, ranging from 12–18 °C in February, 15–25 °C in March, and 20–32 °C in April, thereby exposing plants to progressively increasing thermal conditions. These temperature differences provided a practical framework for evaluating plant responses to moderate and elevated temperature regimes.

Results showed that planting date significantly affected plant growth and reproductive performance. Two-way ANOVA revealed significant effects on stem length ($F = 18.4$), leaf number ($F = 12.7$), and number of flowers ($F = 21.5$) ($p < 0.05$). Early planting (February) enhanced vegetative growth, as reflected by increased leaf production and expansion, whereas mid-March planting resulted in the highest flowering performance (13.5 ± 1.2 flowers plant^{-1}). In contrast, April planting, which coincided with higher temperature ranges exceeding 30 °C, led to significant reductions in flowering (6.0 ± 1.5 flowers plant^{-1}), suggesting the onset of heat-induced reproductive limitations rather than optimal growth conditions.

Overall, the findings demonstrate that planting date influences the balance between vegetative and reproductive development in broad bean by altering plant exposure to temperature conditions. Under Mediterranean greenhouse environments, mid-March planting provided the most favorable thermal window for optimizing reproductive performance.

Keywords: Vicia faba, planting date, greenhouse, growth parameters, flowering, temperature stress, Libya

I. Introduction

Broad bean (Vicia faba L.) is an important cool-season legume widely cultivated in Mediterranean and semi-arid regions due to its high nutritional value and its role in sustainable agricultural systems. It serves as a major source of plant-based protein, dietary fiber, and essential micronutrients, while also contributing to soil fertility through biological nitrogen fixation [1,2]. These characteristics make broad bean a key crop for enhancing food security and improving soil sustainability under resource-limited conditions.

Plant growth and productivity are strongly influenced by environmental factors, among which temperature plays a central role in regulating physiological and developmental processes. Temperature directly affects photosynthesis, respiration, and biomass accumulation, thereby determining overall plant performance [3]. When temperature deviates from optimal ranges, plant growth can be significantly constrained. Elevated temperatures, in particular, are known to accelerate metabolic processes beyond optimal levels, leading to reduced leaf expansion, premature senescence, and ultimately decreased photosynthetic efficiency [4].

The impact of temperature becomes even more critical during the reproductive stage, where plants exhibit increased sensitivity to environmental stress. High temperatures during flowering can reduce pollen viability, disrupt fertilization, and increase the rate of flower abortion, resulting in significant reductions in reproductive success and yield [5,6]. In contrast, moderate temperature conditions during this stage promote stable reproductive development and enhance the transition from flowering to pod formation [3]. This differential sensitivity between vegetative and reproductive phases highlights the importance of synchronizing plant development with favorable environmental conditions.

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In this context, planting date represents a critical agronomic strategy for managing crop exposure to temperature variations throughout the growing season. Adjusting sowing time allows farmers to align sensitive growth stages particularly flowering with optimal thermal conditions, thereby minimizing the negative effects of heat stress [7,8]. Previous studies have shown that early planting often enhances vegetative growth due to longer growth duration and favorable temperatures, whereas delayed planting can accelerate phenological development and reduce reproductive performance [9,10].

The effectiveness of planting date depends strongly on local environmental conditions and production systems. While most previous studies have focused on open-field cultivation, limited research has addressed greenhouse environments, where microclimatic conditions differ significantly. In Mediterranean regions, particularly in Libya, there is a lack of recent, region-specific studies examining how planting date affects the balance between vegetative growth and reproductive performance of broad bean under semi-controlled greenhouse conditions.

Addressing this gap is important under increasing climate variability, as temperature fluctuations can directly influence crop performance. A better understanding of how planting date shapes plant responses under controlled environments can support more efficient production practices and improve crop resilience.

Therefore, this study aimed to evaluate the effects of different planting dates on vegetative growth and flowering of broad bean (Vicia faba L.) under greenhouse conditions. The study specifically quantified key growth and reproductive traits to determine the optimal planting time for maximizing crop performance under Mediterranean conditions.

II. Materials and Methods

The experiment was conducted during the 2024 growing season in a greenhouse located in Sirte City, Libya. The greenhouse (20 m × 8 m) was covered with transparent polyethylene to ensure optimal light transmission and to maintain semi-controlled environmental conditions. Natural ventilation was facilitated through lateral openings to regulate airflow and mitigate excessive heat accumulation.

Temperature conditions inside the greenhouse exhibited clear seasonal variation, ranging from 12–18 °C in February, 15–25 °C in March, and 20–32 °C in April. These temperature ranges are representative of Mediterranean climatic conditions and enabled the assessment of plant responses to contrasting thermal regimes, particularly in relation to growth and reproductive performance [3,4].

A. Soil Characteristics

The experiment was conducted using loamy soil, characterized by a balanced combination of water retention capacity and aeration, which is considered favorable for legume crop growth. Soil pH ranged from 6.8 to 7.3, as determined using a calibrated pH meter prior to planting, indicating near-neutral conditions favorable for broad bean (Vicia faba L.) development [2]. Prior to planting, the soil was thoroughly homogenized and sieved to remove debris and ensure uniform texture, and was then evenly distributed into pots to maintain consistency across all experimental units.

B. Experimental Design

A completely randomized design (CRD) was used to evaluate the effects of planting date on the growth and flowering of broad bean (Vicia faba L.). Three planting dates were tested: 15 February, 15 March, and 15 April 2024.

Each treatment consisted of three replicates, with each replicate represented by a single pot containing one plant. The pot was considered the experimental unit, resulting in a total of nine experimental units (3 treatments × 3 replicates).

Pots were randomly arranged within the greenhouse to minimize spatial variability. In addition, periodic repositioning was performed throughout the experimental period to reduce positional effects and ensure uniform exposure to environmental conditions.

C. Crop Management Practices

Uniform agronomic practices were applied across all treatments to minimize management-related variability. Irrigation, weeding, and greenhouse conditions were maintained consistently throughout the experiment. No pesticides were used due to the absence of pest or disease incidence.

D. Measured Parameters

Plant growth and development were monitored over an eleven-week period, with measurements taken at 10-day intervals to capture temporal variations in both vegetative and reproductive traits.

- Stem length (cm): Measured from the soil surface to the apical meristem using a ruler.
- Number of leaves (leaves plant^{-1}): Determined by counting the number of fully expanded leaves per plant.
- Number of flowers (flowers plant^{-1}): Recorded during the flowering stage as an indicator of reproductive performance.
- Leaf area (cm²): Estimated using a non-destructive method and expressed in square centimeters (cm²), serving as a proxy for photosynthetic capacity [11].
- Chlorophyll content (SPAD units): Measured using a SPAD meter as an indirect indicator of photosynthetic efficiency [12].

E. Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics (Version 25). The application of two-way ANOVA followed by Tukey's HSD test is a standard approach in agronomic research for controlling Type I error in multiple comparisons [13] (Gomez & Gomez, 1984).

Uniform agronomic practices were applied across all treatments to minimize management-related variability. Irrigation, weeding, and greenhouse conditions were maintained consistently throughout the experiment, and all measurements were conducted using standardized protocols at fixed intervals to ensure data reliability. No pesticides were used due to the absence of pest or disease incidence.

III. Results

A. Effect of Planting Date on Vegetative Growth

Planting date significantly influenced vegetative growth parameters of broad bean (Vicia faba L.), including stem length, leaf number, and leaf area ($p < 0.05$; Table 6).

Stem length differed significantly among treatments ($F = 18.4$, $p = 0.002$; Table 1). The highest values were observed in April (49.5 ± 2.5 cm), followed by February (47.0 ± 1.8 cm), while March exhibited significantly lower values (31.5 ± 1.2 cm) (Figure 1). However, the increased stem elongation under late planting may be associated with higher temperature conditions.

Leaf number was significantly higher in February (43.5 ± 2.3 leaves plant^{-1}) compared to March (31.0 ± 1.5) and April (30.5 ± 2.0) ($F = 12.7$, $p = 0.006$; Table 2). No significant difference was detected between March and April.

Similarly, leaf area declined significantly with delayed planting ($F = 16.2$, $p = 0.003$; Table 4). February produced the highest leaf area (285.0 ± 12.5 cm²), followed by March (240.5 ± 10.2 cm²), while April showed the lowest values (198.0 ± 11.3 cm²) (Figure 3). All treatments differed significantly according to Tukey's HSD test.

These findings indicate that early planting enhances vegetative development, particularly leaf production and leaf area.

B. Effect of Planting Date on Chlorophyll Content

Chlorophyll content was significantly affected by planting date ($F = 14.5$, $p = 0.004$; Table 5). The highest values were recorded in February (52.3 ± 2.1) and March (49.8 ± 1.8), with no significant difference between them, while April showed a significantly lower value (41.2 ± 2.5) (Figure 4).

This decline may be associated with higher temperature conditions under late planting.

C. Effect of Planting Date on Flowering

Flower production was highly sensitive to planting date ($F = 21.5$, $p = 0.001$; Table 3). The highest number of flowers was recorded in March (13.5 ± 1.2 flowers plant^{-1}), followed by February (11.0 ± 1.7), while April produced the lowest values (6.0 ± 1.5) (Figure 2).

All treatments were significantly different from each other, indicating a strong effect of planting timing on reproductive performance.

Table I Effect of planting date on stem length

Planting Date	Stem Length (cm, Mean ± SD)
February	47.0 ± 1.8 a
March	31.5 ± 1.2 b
April	49.5 ± 2.5 a

ANOVA: F (2,6) = 18.4, **p = 0.002**

Note: Means followed by different letters are significantly different according to Tukey's HSD test at $p < 0.05$. Means followed by different letters are significantly different according to Tukey's HSD test at $p < 0.05$.

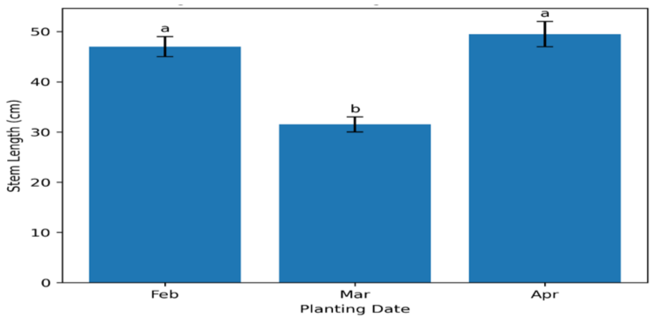

Figure I Effect of planting date on stem length (cm) of broad bean (Vicia faba L.).

Table II Effect of planting date on number of leaves

Planting Date	Leaves per plant (Mean ± SD)
February	43.5 ± 2.3 a
March	31.0 ± 1.5 b
April	30.5 ± 2.0 b

ANOVA: F (2,6) = 12.7, p = 0.006

Table III Effect of planting date on number of flowers

Planting Date	Flowers per plant (Mean ± SD)
February	11.0 ± 1.7 b
March	13.5 ± 1.2 a
April	6.0 ± 1.5 c

ANOVA: F (2,6) = 21.5, p = 0.001

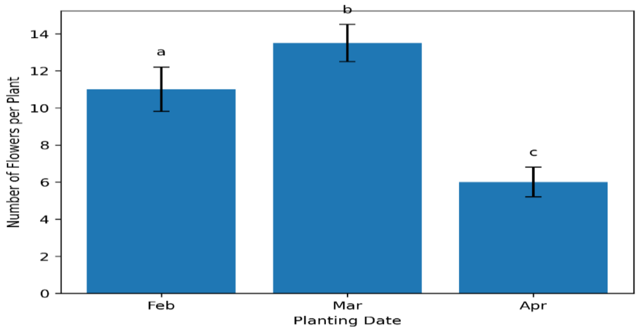

Figure II Effect of planting date on number of flowers per plant.

Table IV Effect of planting date on leaf area

Planting Date	Leaf Area (cm², Mean ± SD)
February	285.0 ± 12.5 a
March	240.5 ± 10.2 b
April	198.0 ± 11.3 c

ANOVA: F (2,6) = 16.2, p = 0.003

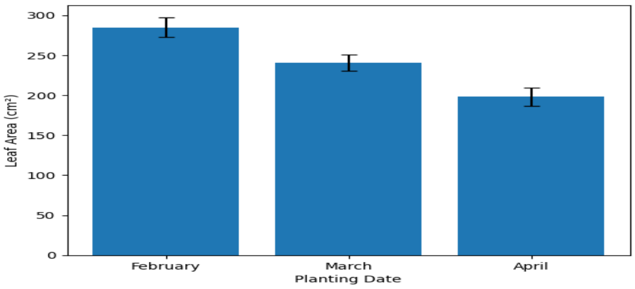

Figure III Effect of planting date on leaf area (cm²) of broad bean (Vicia faba L.) under greenhouse conditions. Values represent mean ± SD. Different letters indicate significant differences at $p < 0.05$ (Tukey's HSD test).

Table V Effect of planting date on chlorophyll content

Planting Date	**Chlorophyll content (SPAD units, Mean ± SD)**
February	52.3 ± 2.1 a
March	49.8 ± 1.8 a
April	41.2 ± 2.5 b

ANOVA: $F(2,6) = 14.5$, $p = 0.004$

Data are presented as mean ± standard deviation (SD). Chlorophyll content is expressed in SPAD units. Statistical differences among treatments were determined using one-way ANOVA followed by Tukey's HSD test at $p < 0.05$.

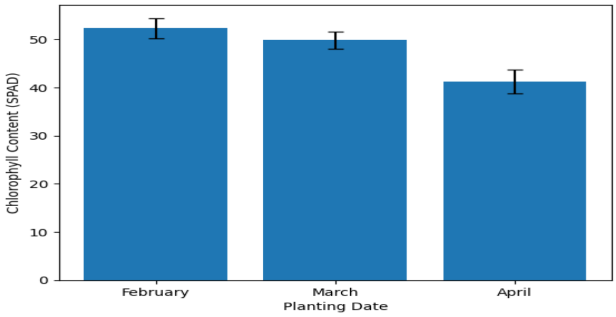

Figure IV Effect of planting date on chlorophyll content (SPAD units) of broad bean (Vicia faba L.) grown under greenhouse conditions. Values are presented as mean ± SD. Different letters indicate significant differences at $p < 0.05$.

Table VI Two-way ANOVA results

Source of Variation	**df**	**Stem Length (F)**	**Leaves (F)**	**Flowers (F)**	**p-value**
Planting Date	2	18.4	12.7	21.5	<0.05
Time	5	45.2	38.6	29.8	<0.05
Planting Date × Time	10	6.9	5.4	7.2	<0.05

All effects are significant at $p < 0.05$.

Two-way ANOVA indicated that planting date, sampling time, and their interaction significantly affected all measured traits ($p < 0.05$; Table 6; Figure 5), with sampling time showing the highest F-values across parameters.

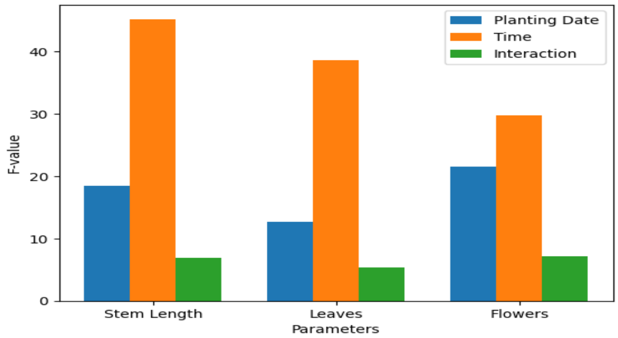

Figure V Two-way ANOVA showing the effects of planting date, sampling time, and their interaction on growth and flowering parameters of broad bean (Vicia faba L.), expressed as F-values. All effects are statistically significant at $p < 0.05$.

IV. Discussion

Planting date had a significant effect on the balance between vegetative growth and reproductive performance of broad bean, as evidenced across Tables 1–6 and Figures 1–5. The observed patterns reflect temperature-driven trade-offs between growth phases under different sowing dates.

Vegetative growth was enhanced under early planting (February), which can be attributed to more favorable thermal conditions that support leaf development and canopy expansion. In contrast, delayed planting exposed plants to higher temperatures, leading to reduced leaf development and photosynthetic capacity. A similar decline was observed in chlorophyll content, suggesting that heat stress negatively affects physiological performance.

These findings are consistent with previous studies reporting that moderate temperatures promote vegetative growth, while elevated temperatures reduce leaf expansion and photosynthetic efficiency [3,4]. The reduction in chlorophyll content under late planting further supports the well-documented sensitivity of photosynthetic processes to heat stress. These reductions indicate a substantial limitation in canopy development and photosynthetic capacity under elevated temperatures. Comparable studies have reported reductions of 20–35% in leaf expansion and photosynthetic performance under heat stress conditions [3,4], placing the present findings within the same quantitative range, but under greenhouse conditions, which enhances their applied relevance.

In contrast, stem length exhibited an opposite trend, peaking under April planting (49.5 cm) compared with only 31.5 cm in March (Table 1; Figure 1), representing an increase of approximately 57%. However, this elongation occurred simultaneously with reductions in leaf area, chlorophyll content, and flowering (Figures 3–5), indicating a decoupling between structural growth and functional performance. Similar responses have been reported under heat stress, where stem elongation may increase by 40–60% without corresponding gains in biomass or yield [14], which closely aligns with the current observations.

Reproductive performance was highly sensitive to planting date, with flowering peaking in March (13.5 flowers plant^{-1}) and declining sharply to 6.0 flowers plant^{-1} in April (Table 3; Figure 3), representing a reduction of approximately 55%. This magnitude of decline is consistent with previous studies reporting reductions of 40–70% in reproductive output under high-temperature stress during the flowering stage [4,6]. The present results therefore confirm, with precise quantitative evidence, that reproductive processes are more vulnerable to temperature stress than vegetative traits.

Two-way ANOVA indicated that plant responses are jointly influenced by planting date and developmental stage, with a significant interaction highlighting increased sensitivity at later growth stages, particularly during flowering. This pattern reflects the greater vulnerability of reproductive processes to thermal stress, as reported in previous studies [7,15].

Overall, the findings reveal a clear trade-off between vegetative growth and reproductive performance. Early planting favored vegetative development, whereas mid-season planting enhanced flowering, while delayed planting reduced both physiological efficiency and reproductive output.

From an agronomic perspective, maximum productivity is associated with moderate thermal conditions that facilitate coordination between vegetative growth and reproductive development. In this study, mid-March planting achieved the best balance, indicating its suitability as the optimal planting window under Mediterranean greenhouse conditions.

V. Conclusion

This study highlights that crop performance is governed by the interaction of temperature, planting time, and genotype.

First, temperature acts as the primary driver, with moderate conditions enhancing physiological efficiency, while elevated temperatures reduce chlorophyll content and reproductive success.

Second, planting time determines plant exposure to these thermal regimes, where mid-season sowing optimizes the balance between vegetative growth and flowering.

Third, although not directly tested, genotype is expected to modulate these responses, emphasizing the need for cultivar-specific adaptation under climate variability.

VI. Recommendations

Based on the findings of the present study, several practical and research-oriented recommendations can be proposed to enhance the productivity and sustainability of broad bean (Vicia faba L.) cultivation under greenhouse and semi-arid conditions.

First, it is strongly recommended to optimize planting schedules, with particular emphasis on mid-season planting (March), which demonstrated superior reproductive performance. Aligning planting time with favorable temperature conditions is essential to maximize flowering and potential yield.

Second, late planting (April) should be avoided in regions characterized by rising temperatures, as exposure to heat stress during the reproductive stage significantly reduces flowering and may compromise overall productivity. Adjusting sowing time remains one of the most effective and low-cost strategies for mitigating climate-related stress.

Third, greenhouse management practices should be improved to regulate temperature, especially during critical growth stages. The use of ventilation systems, shading techniques, and temperature control measures can help minimize heat stress and improve plant performance.

Fourth, future research should focus on evaluating different cultivars of broad bean for their tolerance to heat stress, with the aim of identifying genotypes better adapted to changing climatic conditions. This is particularly important in the context of global warming and increasing temperature variability.

Fifth, it is recommended to integrate planting date optimization with other agronomic practices, including irrigation scheduling and soil fertility management, to develop a comprehensive crop management strategy that enhances both vegetative growth and reproductive success.

Finally, further studies should incorporate advanced physiological and molecular approaches to better understand the mechanisms underlying plant responses to temperature stress, particularly during flowering and pod formation stages. Such insights will support the development of more resilient and climate-adaptive agricultural systems.

VII. Limitations and Future Perspectives

Despite the controlled experimental conditions, some limitations should be acknowledged. The relatively small sample size and single-season, single-location design may limit the generalizability of the findings. In addition, the greenhouse setting may not fully capture the variability of open-field conditions. Future research should therefore include multi-season and multi-location studies to strengthen the robustness and applicability of the results.

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