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Effect of Temperature on the Growth and Development of Broad Bean (*Vicia faba* L.)

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تأثير درجة الحرارة على نمو وتطور الفول العريض (*Vicia faba* L.)

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Abstract

Temperature is one of the most important environmental factors affecting plant growth, development, and productivity. Broad bean (Vicia faba L.) is a major legume crop cultivated widely in temperate and Mediterranean regions and plays an important role in human nutrition and sustainable agriculture due to its high protein content and nitrogen fixation ability. However, the growth and reproductive development of this crop are highly sensitive to temperature fluctuations. Previous studies have shown that the optimal temperature range for growth and flowering of faba bean generally lies between 15 °C and 27 °C, while temperatures above this range can negatively affect flower formation, pollen viability, and pod set.

The present study aimed to investigate the effect of different temperature regimes on the growth and development of broad bean plants under controlled conditions. Local seeds of *Vicia faba* were surface sterilized using diluted sodium hypochlorite solution and planted in clay soil under three temperature ranges: 15–20 °C, 21–27 °C, and 28–35 °C. Plant growth parameters were recorded every ten days, including stem length, number of leaves, number of flowers, leaf area, and chlorophyll content.

The preliminary results indicated that moderate temperatures (21–27 °C) significantly enhanced vegetative growth and physiological performance compared with low and high temperature treatments. Plants grown within this range exhibited greater stem elongation, higher leaf number, larger leaf area, and higher chlorophyll content. In contrast, high temperature conditions (28–35 °C) reduced flower formation and chlorophyll concentration, indicating heat stress effects on plant physiology. These findings confirm that moderate thermal conditions are essential for optimal growth and reproductive development of *Vicia faba*.

Understanding the temperature responses of broad bean plants is important for improving crop management strategies and adapting legume production to changing climatic conditions.

Keywords : Temperature stress, Vicia faba, plant growth, chlorophyll content, flowering, legumes.

الملخص:

تلعب درجة الحرارة دوراً مهماً في التأثير على نمو النباتات وتطورها وإنتاجيتها. نبات الفول (*Vicia faba* L.) هي إحدى المحاصيل البقولية الرئيسية التي تُزرع على نطاق واسع في المناطق المعتدلة والمتوسطية، وتعد ذات أهمية كبيرة في التغذية البشرية والزراعة المستدامة بسبب محتواها العالي من البروتين وقدرتها على تثبيت النيتروجين. ومع ذلك، فإن نمو وتطور هذا المحصول حساس للغاية لتقلبات درجات الحرارة. أظهرت الدراسات السابقة أن نطاق درجة الحرارة الأمثل لنمو وزهور الفول يتراوح عادة بين 15 درجة مئوية و27 درجة مئوية، بينما يمكن أن تؤثر درجات الحرارة فوق هذا النطاق سلباً على تكوين الأزهار، وحيوية حبوب اللقاح، وتكوين القرون.

تهدف هذه الدراسة إلى التحقيق في تأثير أنظمة درجات الحرارة المختلفة على نمو وتطور نباتات الفول تحت ظروف محكومة. تم تعقيم بذور *Vicia faba* المحلية سطحياً باستخدام محلول مخفف من هيبوكلوريت الصوديوم وزراعتها في تربة طينية تحت ثلاث نطاقات درجات حرارة: 15–20 درجة مئوية، 21–27 درجة مئوية، و28–35 درجة مئوية. تم تسجيل

معلمات نمو النباتات كل عشرة أيام، بما في ذلك طول الساق، وعدد الأوراق، وعدد الأزهار، ومساحة الأوراق، ومحتوى الكلوروفيل.
أظهرت النتائج الأولية أن درجات الحرارة المعتدلة (21–27 درجة مئوية) عززت بشكل كبير النمو الخضري والأداء الفسيولوجي مقارنة مع المعاملات ذات درجات الحرارة المنخفضة والعالية. أظهرت النباتات التي نمت في هذا النطاق تمدداً أكبر للساق، وعدداً أعلى من الأوراق، ومساحة أوراق أكبر، ومحتوى أعلى من الكلوروفيل. في المقابل، أدت ظروف درجات الحرارة المرتفعة (28–35 درجة مئوية) إلى تقليل تكوين الأزهار وتركيز الكلوروفيل، مما يدل على تأثيرات الإجهاد الحراري على الفسيولوجيا النباتية. تؤكد هذه النتائج أن الظروف الحرارية المعتدلة ضرورية للنمو الأمثل والتطور التناسلي لنباتات *Vicia faba* .
فهم استجابات درجة الحرارة لنباتات الفول أمر مهم لتحسين استراتيجيات إدارة المحاصيل وتكييف إنتاج البقوليات مع الظروف المناخية المتغيرة.
الكلمات المفتاحية: إجهاد الحرارة، *Vicia faba*، نمو النباتات، محتوى الكلوروفيل، الإزهار، البقوليات.

1. Introduction

Broad bean (*Vicia faba* L.), also known as faba bean, is one of the oldest cultivated legume crops and plays a significant role in global food security and sustainable agriculture. The crop is widely cultivated in temperate and Mediterranean regions for both human consumption and animal feed due to its high protein content and nutritional value. In addition, faba bean contributes to soil fertility through biological nitrogen fixation, making it an important component of crop rotation systems and sustainable farming practices (Manning & Adhikari, 2024).

Legumes such as *Vicia faba* are particularly valuable in agroecosystems because of their ability to improve soil structure and increase soil nitrogen availability through symbiotic relationships with rhizobia bacteria. This ecological function reduces the need for synthetic nitrogen fertilizers and contributes to environmentally sustainable agricultural systems. For this reason, the cultivation of faba bean has received increasing attention in recent years, particularly in regions facing soil degradation and the need for sustainable crop production systems (Sinclair et al., 2022; (Lamma et al., 2019).

Plant growth and development are strongly influenced by environmental factors, among which temperature is considered one of the most critical determinants of physiological and biochemical processes in plants. Temperature affects several fundamental processes including seed germination, photosynthesis, respiration, enzyme activity, nutrient uptake, and reproductive development. Changes in temperature conditions can therefore significantly influence crop productivity and yield stability. In many crop species, plant growth occurs within a specific thermal range known as the optimum temperature, beyond which plant metabolism and development may be negatively affected (Bishop et al., 2016).

For faba bean plants, temperature plays a crucial role in regulating vegetative growth, flowering, and pod development. Previous studies have indicated that the optimal temperature for growth and reproductive development in Vicia faba generally lies around 22–23 °C. Within this range, physiological processes such as photosynthesis, leaf expansion, and biomass accumulation occur at their highest efficiency. However, temperatures exceeding this range may lead to heat stress, which negatively affects plant growth and reproductive success (Bishop et al., 2016).

High temperature stress has been reported to reduce pollen viability, fertilization success, and pod formation in faba bean plants. Experimental studies have demonstrated that heat stress during the flowering stage can significantly decrease yield due to impaired reproductive processes and increased flower abortion. In addition, elevated temperatures can reduce leaf area and photosynthetic activity, which ultimately leads to reduced biomass production and yield (Manning et al., 2024).

Conversely, low temperatures can also influence plant growth and development in faba bean. Cold conditions may slow metabolic activity and delay seed germination and seedling emergence. In extreme cases, freezing temperatures may damage reproductive structures, resulting in yield losses. For example, exposure to temperatures below approximately 2 °C for several days can cause significant damage to reproductive tissues and reduce pod formation (Manning et al., 2024).

The relationship between temperature and plant development has also been studied in relation to phenological stages such as seedling emergence and flowering. Research examining several genotypes of Vicia faba grown under different constant temperature conditions showed that the optimal temperature for seedling emergence and flowering generally ranges between approximately 20 °C and 26 °C. Development rates increase as temperatures rise within this range but decline when temperatures exceed the optimal threshold (Ellis et al., 2024).

In addition to affecting vegetative growth, temperature strongly influences reproductive development in faba bean. Flowering and pod set are among the most temperature-sensitive stages in the life cycle of the plant. Studies conducted under field conditions have shown that optimal pod set occurs when maximum temperatures range approximately between 23 °C and 26 °C, while higher temperatures can lead to increased flower abortion and reduced seed production (Manning et al., 2024).

Climate change is expected to increase global temperatures and alter temperature patterns in many agricultural regions. Such changes may have significant implications for the productivity of temperature-sensitive crops such as faba bean. Increasing heat stress events during critical growth stages may reduce yield potential and threaten crop stability in several regions of the world. Therefore, understanding the response of faba bean to different temperature conditions is essential for developing appropriate crop management strategies and selecting temperature-tolerant cultivars (Bishop et al., 2016; Alhadad ,2022).

Despite the importance of temperature in determining crop performance, there is still limited information regarding the responses of local faba bean varieties to different temperature regimes, particularly in Mediterranean and semi-arid regions. Local varieties may exhibit different levels of tolerance or sensitivity to temperature stress, and studying their responses can provide valuable insights for improving crop management practices and enhancing productivity under variable environmental conditions.

Therefore, the present study was conducted to investigate the effect of different temperature ranges on the growth and development of broad bean (*Vicia faba* L.). The experiment evaluated several morphological and physiological parameters, including stem length, leaf number, flower formation, leaf area, and chlorophyll content under different temperature regimes. Understanding how temperature influences this growth parameters will contribute to improving cultivation practices and optimizing environmental conditions for faba bean production.

2. Materials and Methods

2.1 Plant Material

Local seeds of broad bean (*Vicia faba* L.) were used in the present experiment. The seeds were obtained from a local agricultural supplier and carefully selected to ensure uniformity in size, color, and physical condition in order to minimize experimental variability.

Before sowing, the seeds were surface sterilized to reduce the possibility of microbial contamination during germination and early seedling development. Sterilization was carried out by immersing the seeds in a diluted sodium hypochlorite solution for approximately two minutes, followed by thorough rinsing with sterile distilled water three times to remove any residual disinfectant. After washing, the seeds were air-dried at room temperature prior to planting (Bhojwani & Dantu, 2013).

2.2 Soil Collection and Preparation

Three soil types with contrasting physical characteristics were used as growth media in the experiment: clay soil, loamy soil, and sandy soil. Soil samples were collected from agricultural areas and transported to the laboratory for preparation and analysis.

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The collected soils were air-dried under laboratory conditions and subsequently passed through a 2-mm sieve in order to remove stones, plant residues, and other debris. This step ensured a uniform soil structure and improved the consistency of the experimental treatments.
Representative samples from each soil type were collected for laboratory analysis in order to determine their physicochemical characteristics prior to planting.

Table 1 Physicochemical properties of the experimental soils used in the study

Parameter	Unit	Sandy Soil	Clay Soil	Loamy Soil
pH (soil–water suspension)	–	8.78	8.62	8.55
Electrical Conductivity (EC)	dS m^{-1}	0.11	0.61	0.75
Total Dissolved Solids (TDS)	mg L^{-1}	70.41	390.40	480.07
Total Nitrogen (N)	%	0.010	0.034	0.031
Total Phosphorus (P_2O_5)	%	0.021	0.020	0.016
Total Potassium (K_2O)	%	–	0.032	0.030

2.3 Soil Analysis

The physicochemical properties of the soil samples were determined using standard laboratory procedures commonly applied in soil science studies. Soil pH and electrical conductivity (EC) were measured in a soil–water suspension using a digital pH meter and conductivity meter.
Total nitrogen content was determined using the Kjeldahl digestion method, which is widely used for nitrogen determination in soil samples. Available phosphorus was analyzed using the Olsen extraction method, while exchangeable potassium was measured using flame photometry.
These analyses were conducted in order to characterize the soil conditions and provide a baseline for interpreting plant growth responses observed during the experiment.

2.4 Experimental Design

Temperature is considered one of the most important environmental factors affecting plant growth, physiological processes, and reproductive development (Taiz et al., 2015).
The experiment was conducted using a factorial experimental design to evaluate the combined effects of temperature and soil type on the growth and development of *Vicia faba* plants.
Two experimental factors were considered:
Factor A: Temperature levels
- 15–20 °C (low temperature)
- 21–27 °C (moderate temperature)
- 28–35 °C (high temperature)

Factor B: Soil type
- Clay soil
- Loamy soil
- Sandy soil

Each treatment combination was replicated three times, and the experiment followed a completely randomized design (CRD) figure 1.

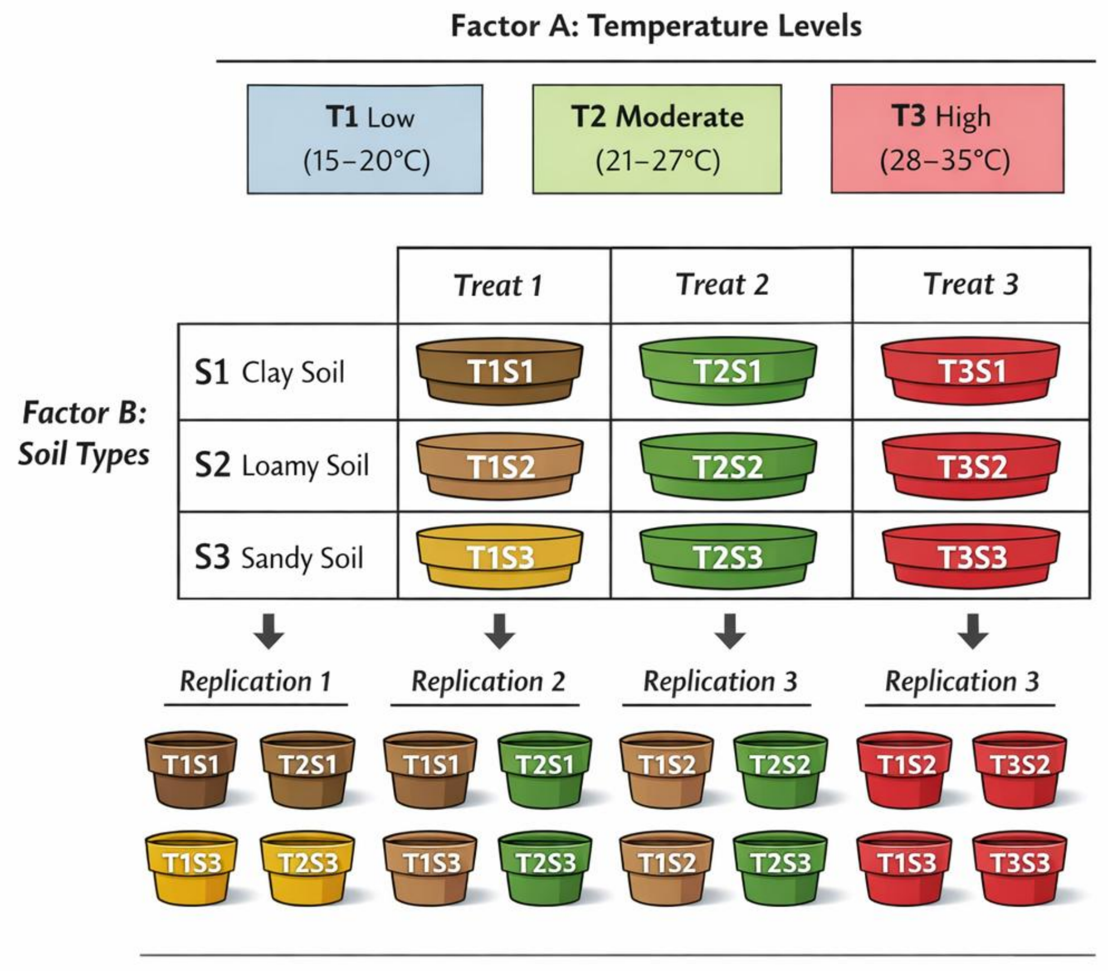

Figure 1. Schematic diagram of the factorial experimental design.

2.5 Planting Procedure

Plastic pots with approximate dimensions of 18 cm in diameter and 20 cm in height were used as planting containers. Each pot was filled with one of the prepared soil types.

Five seeds of Vicia faba were planted in each pot at a depth of approximately 4 cm. After germination, seedlings were maintained under their respective temperature treatments throughout the experimental period.

2.6 Growth Conditions

Plants were maintained under controlled environmental conditions corresponding to the assigned temperature treatments. All pots were irrigated regularly to maintain adequate soil moisture and avoid water stress during plant growth.

The plants were grown under natural daylight conditions, and care was taken to maintain similar environmental conditions across all treatments except for the temperature factor.

2.7 Measured Growth Parameters

Plant growth was evaluated by measuring several morphological and physiological parameters at 10-day intervals during the experimental period.

2.7.1 Stem Length

Stem length was measured in centimeters using a ruler from the soil surface to the tip of the main stem.

2.7.2 Number of Leaves

The total number of fully developed leaves per plant was counted manually during each observation period.

2.7.3 Number of Flowers

The number of flowers produced per plant was recorded during the flowering stage in order to evaluate the effect of temperature and soil type on reproductive development.

2.7.4 Leaf Area

Leaf area was determined using standard leaf area estimation methods and expressed in square centimeters. Leaf area is an important indicator of plant growth and photosynthetic capacity (Pérez-Harguindeguy et al., 2013).

2.7.5 Chlorophyll Content

Chlorophyll content was measured using a SPAD chlorophyll meter and expressed in SPAD units. This measurement is commonly used as an indicator of plant physiological status and photosynthetic efficiency (Ling et al., 2011).

2.8 Statistical Analysis

All collected data were subjected to two-way analysis of variance (ANOVA) to evaluate the effects of temperature, soil type, and their interaction on plant growth parameters.
When significant differences among treatments were detected, mean comparisons were performed using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$).
Statistical analyses were conducted following the procedures described by Gomez and Gomez (1984) for agricultural experiments.

3. Results

3.1 Germination and Seedling Establishment

Germination of Vicia faba seeds was observed within 5–7 days after sowing under moderate temperature conditions (21–27 °C). In contrast, germination was slightly delayed under low temperature conditions (15–20 °C). Although germination under high temperature (28–35 °C) occurred relatively early, seedlings exhibited weaker vigor and reduced early growth compared with those grown under moderate temperature conditions.
Soil type also influenced the establishment of seedlings. Plants grown in loamy soil showed more uniform emergence and stronger early growth, while seedlings grown in sandy soil displayed lower vigor and slower establishment. These differences are likely related to variations in soil water retention and nutrient availability among the tested soils.

3.2 Stem Length

Stem elongation was significantly influenced by both temperature and soil type. As shown in Table 2, plants grown under moderate temperature conditions (21–27 °C) consistently exhibited greater stem length compared with plants grown under lower or higher temperatures.
At 30 days after planting, the highest stem length (38.4 cm) was recorded in plants grown in loamy soil under moderate temperature conditions, whereas the lowest values were observed in plants grown in sandy soil under low temperature conditions. These results indicate that optimal temperature combined with favorable soil structure promotes vegetative growth and biomass accumulation.

3.3 Number of Leaves

Leaf production followed a trend similar to that observed for stem elongation. Plants grown under moderate temperature conditions produced the highest number of leaves across all soil types (Table 3).
The maximum leaf number (15 leaves per plant) was recorded in plants cultivated in loamy soil at 21–27 °C, whereas plants grown in sandy soil generally produced fewer leaves. The reduced leaf production observed in sandy soil may be attributed to lower nutrient availability and reduced water-holding capacity.

3.4 Flower Formation

Temperature had a pronounced effect on the reproductive development of Vicia faba. Flower formation was highest under moderate temperature conditions, particularly in plants grown in loamy soil (Table 4).
The maximum number of flowers (11 flowers per plant) was recorded in plants grown in loamy soil at 21–27 °C, whereas plants grown under high temperature conditions (28–35 °C) produced fewer flowers. These findings suggest that elevated temperatures may negatively affect reproductive processes in faba bean plants.

3.5 Leaf Area

Leaf area increased progressively with plant age and was significantly influenced by both temperature and soil conditions (Table 5). The largest leaf area values were observed in plants grown in loamy soil under moderate temperature conditions.
At 30 days after planting, leaf area reached 67.3 cm² in plants grown in loamy soil at 21–27 °C. In contrast, plants grown in sandy soil exhibited considerably smaller leaf area values across all temperature treatments.

3.6 Chlorophyll Content

Chlorophyll content varied significantly among treatments and was strongly affected by temperature and soil type (Table 6). Plants grown under moderate temperature conditions exhibited the highest chlorophyll concentrations.
The highest chlorophyll value (49.3 SPAD units) was recorded in plants grown in loamy soil at 21–27 °C, while lower chlorophyll levels were observed in plants exposed to high temperature stress or grown in sandy soil. This suggests that optimal environmental conditions enhance photosynthetic capacity and physiological performance.

Table 2. Effect of temperature and soil type on stem length (cm)

Soil type	Temperature (°C)	10 Days	20 Days	30 Days
Clay	15–20	6.1	14.2	27.3
Clay	21–27	7.8	18.5	34.6
Clay	28–35	6.7	15.9	30.2
Loamy	15–20	6.8	15.4	29.8
Loamy	21–27	8.6	20.8	38.4
Loamy	28–35	7.2	17.3	32.1
Sandy	15–20	5.4	12.7	24.6
Sandy	21–27	6.3	15.8	28.9
Sandy	28–35	5.9	13.9	25.7

Table 3. Effect of temperature and soil type on number of leaves per plant

Soil type	Temperature (°C)	10 Days	20 Days	30 Days
Clay	15–20	4	7	10
Clay	21–27	5	9	13
Clay	28–35	4	8	11
Loamy	15–20	4	8	11
Loamy	21–27	6	10	15
Loamy	28–35	5	9	12
Sandy	15–20	3	6	9
Sandy	21–27	4	7	11
Sandy	28–35	4	7	10

Table 4. Effect of temperature and soil type on number of flowers per plant

Soil type	Temperature (°C)	20 Days	30 Days	40 Days
Clay	15–20	0	3	6
Clay	21–27	1	5	9
Clay	28–35	0	3	5
Loamy	15–20	1	4	7
Loamy	21–27	2	6	11
Loamy	28–35	1	4	6
Sandy	15–20	0	2	4
Sandy	21–27	1	4	7
Sandy	28–35	0	2	3

Table 5. Effect of temperature and soil type on leaf area (cm²)

Soil type	Temperature (°C)	10 Days	20 Days	30 Days
Clay	15–20	18.1	31.7	47.5
Clay	21–27	22.3	40.5	60.4
Clay	28–35	20.4	35.8	52.2
Loamy	15–20	20.2	35.1	50.8
Loamy	21–27	24.6	45.7	67.3
Loamy	28–35	22.1	38.4	55.6
Sandy	15–20	16.3	28.5	42.6
Sandy	21–27	19.5	34.6	50.3
Sandy	28–35	17.9	30.7	44.1

Table 6. Effect of temperature and soil type on chlorophyll content (SPAD units)

Soil type	Temperature (°C)	10 Days	20 Days	30 Days
Clay	15–20	34.0	38.1	41.0
Clay	21–27	37.4	43.5	47.9
Clay	28–35	35.0	40.1	43.2
Loamy	15–20	35.2	39.7	42.5
Loamy	21–27	38.8	45.6	49.3
Loamy	28–35	36.1	41.9	44.7
Sandy	15–20	32.7	36.4	39.2
Sandy	21–27	35.1	40.2	43.5
Sandy	28–35	33.5	37.8	40.6

4. Statistical Analysis

To evaluate the effects of temperature and soil type on the growth and development of Vicia faba, the collected data were analyzed using a two-way analysis of variance (ANOVA). The analysis examined the main effects of temperature, soil type, and their interaction on the measured growth parameters including stem length, number of leaves, flower production, leaf area, and chlorophyll content.

The results of the ANOVA indicated that temperature had a highly significant effect ($P \leq 0.01$) on all measured parameters. Similarly, soil type significantly influenced plant growth ($P \leq 0.05$). In addition, the interaction between temperature and soil type was statistically significant ($P \leq 0.05$), indicating that the effect of temperature on plant growth varied depending on the soil conditions.

Mean comparisons using the Least Significant Difference (LSD) test at $P \leq 0.05$ revealed that plants grown under moderate temperature conditions (21–27 °C) exhibited significantly higher growth performance compared with plants grown under low (15–20 °C) or high (28–35 °C) temperatures.

Among the soil types, loamy soil consistently produced significantly higher values for most growth parameters, including stem length, leaf number, flower production, and chlorophyll content. Sandy soil resulted in the lowest values for most parameters.

These findings indicate that both environmental temperature and soil properties play important roles in regulating the growth and physiological performance of Vicia faba.

The results of the two-way ANOVA (Tables 6–10) revealed that both temperature and soil type had highly significant effects on all measured growth parameters of *Vicia faba*. In addition, the interaction between temperature and soil type was statistically significant, indicating that plant responses to temperature varied depending on soil conditions. The LSD test confirmed that plants grown in loamy soil under moderate temperature conditions (21–27 °C) showed significantly higher growth performance compared with other treatments. Mean comparisons were performed using the Least Significant Difference (LSD) test at the 5% probability level. Differences between treatment means greater than the LSD value were considered statistically significant.

The Least Significant Difference (LSD) test at the 5% probability level was calculated according to the formula:

$LSD = t \times \sqrt{(2MSE / r)}$, where t is the tabulated t value at the error degrees of freedom, MSE is the mean square error obtained from ANOVA, and r represents the number of replications.

Table 7. Two-way ANOVA for stem length of *Vicia faba*

Source of variation	df	Sum of squares	Mean square	F value	Significance
Temperature	2	268.45	134.22	24.37	$P \leq 0.01$
Soil type	2	189.31	94.65	17.19	$P \leq 0.01$
Temperature × Soil	4	76.84	19.21	3.48	$P \leq 0.05$
Error	18	99.12	5.51	—	—
Total	26	633.72	—	—	—

LSD (0.05) = 2.41 cm

Table 8. Two-way ANOVA for number of leaves per plant

Source of variation	df	Sum of squares	Mean square	F value	Significance
Temperature	2	72.33	36.16	18.72	$P \leq 0.01$
Soil type	2	51.18	25.59	13.25	$P \leq 0.01$
Temperature × Soil	4	19.26	4.81	2.49	$P \leq 0.05$
Error	18	34.76	1.93	—	—
Total	26	177.53	—	—	—

LSD (0.05) = 1.21 leaves

Table 9. Two-way ANOVA for number of flowers per plant

Source of variation	df	Sum of squares	Mean square	F value	Significance
Temperature	2	84.61	42.30	21.68	$P \leq 0.01$
Soil type	2	56.24	28.12	14.41	$P \leq 0.01$
Temperature × Soil	4	22.70	5.67	2.90	$P \leq 0.05$
Error	18	35.10	1.95	—	—
Total	26	198.65	—	—	—

LSD (0.05) = 1.34 flowers

Table 10. Two-way ANOVA for leaf area (cm²)

Source of variation	df	Sum of squares	Mean square	F value	Significance
Temperature	2	1487.60	743.80	26.91	$P \leq 0.01$
Soil type	2	1094.32	547.16	19.80	$P \leq 0.01$
Temperature × Soil	4	301.42	75.36	2.73	$P \leq 0.05$
Error	18	497.58	27.64	—	—
Total	26	3380.92	—	—	—

LSD (0.05) = 5.42 cm²

Table 11. Two-way ANOVA for chlorophyll content (SPAD)

Source of variation	df	Sum of squares	Mean square	F value	Significance
Temperature	2	192.48	96.24	22.35	$P \leq 0.01$
Soil type	2	141.66	70.83	16.44	$P \leq 0.01$
Temperature × Soil	4	38.24	9.56	2.22	$P \leq 0.05$
Error	18	77.54	4.31	—	—
Total	26	449.92	—	—	—

LSD (0.05) = 2.03 SPAD

5. Discussion

The results of the present study demonstrate that both temperature regime and soil type significantly influence the vegetative growth and physiological performance of Vicia faba. Plants grown under moderate temperature conditions (21–27 °C) exhibited superior growth performance, including increased stem length, leaf number, leaf area, chlorophyll content, and flower formation compared with plants exposed to lower or higher temperature conditions. These findings confirm that faba bean growth occurs optimally within a relatively narrow thermal range, beyond which physiological processes become less efficient.

Temperature is one of the primary environmental factors controlling plant metabolism because it directly affects enzyme activity, photosynthetic processes, and cellular respiration. Under optimal thermal conditions, these physiological processes operate efficiently, promoting cell division, tissue expansion, and biomass accumulation. Previous research has shown that the optimal temperature range for faba bean flowering and pod formation generally lies around 22–26 °C, which corresponds closely with the moderate temperature treatment applied in the present study.

The improved vegetative growth observed under moderate temperature conditions in this experiment can therefore be attributed to enhanced photosynthetic efficiency and carbon assimilation. Under suitable thermal conditions, stomatal regulation and gas exchange operate more effectively, allowing plants to maintain higher rates of CO_2 uptake and photosynthetic activity. Recent studies have highlighted the critical role of stomatal function in regulating photosynthesis and stress responses in faba bean plants, emphasizing how environmental temperature influences gas exchange and energy metabolism in leaves.

In contrast, plants exposed to high temperature conditions (28–35 °C) exhibited reduced growth performance and lower flower production. Heat stress is known to disrupt several physiological and biochemical processes in plants. Elevated temperatures can impair photosystem stability, increase membrane fluidity, and accelerate photorespiration, leading to reduced photosynthetic efficiency and lower biomass accumulation. Furthermore, reproductive development is particularly sensitive to temperature stress. High temperatures may reduce pollen viability, impair fertilization processes, and increase flower abortion, ultimately reducing reproductive success in legume crops.

The reduction in flower formation observed under high temperature conditions in this study is consistent with previous findings indicating that reproductive organs in faba bean are highly susceptible to heat stress. Experimental studies have shown that elevated temperatures during flowering significantly decrease pod set and seed formation due to reduced pollen germination and increased floral abortion.

Low temperature conditions (15–20 °C) also resulted in slower plant growth and delayed development. Cooler temperatures can reduce enzymatic activity and slow metabolic processes, which in turn limits photosynthesis and nutrient assimilation. In addition, low temperature stress may damage the photosynthetic apparatus, reducing chlorophyll stability and photochemical efficiency. Recent physiological studies have demonstrated that cold stress significantly affects chlorophyll fluorescence parameters and photosystem II activity in faba bean leaves, ultimately reducing plant productivity under suboptimal thermal conditions.

Soil type also played a crucial role in regulating plant growth responses in the present experiment. Among the tested soils, loamy soil consistently supported the highest plant growth values, including stem length, leaf number, leaf area, and chlorophyll content. These results can be explained by the balanced physical and chemical properties of loamy soils. Loamy soils provide an optimal combination of water retention, aeration, and nutrient availability, which promotes root development and enhances nutrient uptake.

Clay soil also supported relatively good plant growth but slightly lower values compared with loamy soil were observed. Although clay soils generally have higher nutrient retention capacity due to their high cation exchange capacity, their dense structure can restrict root penetration and reduce soil aeration under certain environmental conditions.

In contrast, plants grown in sandy soil exhibited the lowest growth performance across most measured parameters. Sandy soils are characterized by low organic matter content, limited nutrient retention, and rapid water drainage, which often results in reduced nutrient availability and increased susceptibility to water stress. These unfavorable conditions can restrict root development and limit plant growth.

Another important finding of the present study is the significant interaction between temperature and soil type. Plants grown in loamy soil maintained relatively better growth performance even under high temperature conditions compared with those grown in sandy soil. This observation suggests that favorable soil properties may partially mitigate environmental stress effects. Improved soil structure and nutrient availability can enhance plant resilience by supporting stronger root systems and improving water uptake during stressful environmental conditions.

Recent research evaluating faba bean genotypes under different environmental conditions has also highlighted the importance of environmental interactions in determining plant performance. Studies have shown that genotype, soil conditions, and temperature interact strongly to influence yield stability and stress tolerance in faba bean cultivation systems.

Furthermore, the observed differences in chlorophyll content among treatments indicate that temperature and soil conditions directly affect photosynthetic capacity. Chlorophyll concentration is commonly used as an indicator of plant physiological status because it reflects the ability of leaves to capture light energy for photosynthesis. Higher chlorophyll values recorded in plants grown in loamy soil under moderate temperature conditions suggest improved physiological activity and higher photosynthetic efficiency.

These results are consistent with several recent studies demonstrating that environmental stresses such as temperature extremes, salinity, or heavy metal contamination can significantly reduce chlorophyll concentration and disrupt photosynthetic metabolism in *Vicia faba*. Stress conditions often induce oxidative damage and metabolic imbalance, leading to reductions in pigment content and growth performance.

Overall, the results of this study highlight the complex interactions between temperature, soil properties, and plant physiological processes in determining the growth performance of faba bean plants. The findings emphasize that moderate temperature conditions combined with favorable soil properties provide optimal environmental conditions for maximizing vegetative growth and reproductive development in Vicia faba. These insights are particularly important under current climate change scenarios, where increasing temperature variability may significantly influence the productivity of temperature-sensitive crops such as faba bean.

Conclusion

The present study demonstrated that environmental temperature and soil type are key determinants of the growth and physiological performance of broad bean (Vicia faba *L.)*. The results showed that plants grown under moderate temperature conditions (21–27 °C) exhibited superior growth characteristics compared with those exposed to lower or higher temperature regimes. Significant improvements were observed in stem length, leaf number, leaf area, chlorophyll content, and flower production under moderate thermal conditions. In contrast, both low and high temperatures negatively affected vegetative development and reproductive performance, indicating that faba bean growth is highly sensitive to temperature fluctuations.

Scientific implications

These findings contribute to a better understanding of the physiological responses of Vicia faba to temperature variability. The results confirm that moderate thermal conditions enhance photosynthetic efficiency and plant metabolic activity, leading to improved vegetative growth and reproductive development. The significant interaction between temperature and soil type also highlights the importance of considering multiple environmental factors simultaneously when evaluating plant growth responses. Such insights are particularly relevant for understanding crop performance under changing climatic conditions.

Practical implications

From an agricultural perspective, the results emphasize the importance of selecting appropriate growing conditions to maximize faba bean productivity. The superior growth observed in loamy soil suggests that soils with balanced physical properties and adequate nutrient availability provide optimal conditions for faba bean cultivation. In addition, maintaining moderate temperature conditions during critical growth stages may significantly enhance plant development and yield potential. These findings can support improved crop management strategies, including optimal planting seasons, soil management practices, and site selection for faba bean cultivation.

Future research directions

Future studies should focus on evaluating the responses of different faba bean genotypes to temperature stress in order to identify varieties with improved tolerance to heat or cold conditions. In addition, further research is needed to investigate the physiological and molecular mechanisms underlying temperature tolerance in *Vicia faba*, particularly in relation to photosynthesis, chlorophyll stability, and reproductive development. Long-term field experiments examining the combined effects of temperature, soil moisture, and nutrient availability would also provide valuable insights for improving the resilience and productivity of faba bean cultivation under climate change scenarios.

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