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# IMPROVING YIELD AND THERMO TOLERANCE IN TOMATO THROUGH MANAGEMENT PRACTICES

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**Abstract**

Heat stress can be mitigated through improved management practices such as sowing dates/planting time and balanced nutrient supply such as potassium and boron. Here, we investigated the yield and thermotolerance in tomato through sowing dates and nutrient application. The experiment was laid out in RCBD split plot arrangement with two factors i-e. sowing dates (20th Feb, 6th March and 21st March) which was placed in main plot and various concentrations of nutrients (potassium at the rate of 150 and 300 mg $L^{-1}$ and boron 20 and 40 mg $L^{-1}$) and combination were 150 K + 20 B mg $L^{-1}$ and 300 K + 40 B mg $L^{-1}$ were arranged in sub plot. Result revealed that heat stress was controlled by sowing dates and different concentrations of nutrients significantly affected growth and yield of tomato. Regarding sowing dates maximum value for plant height (63.61 cm), number of leaves per plant (73.5), pollen viability (80.66 %), yield (12.90 t $ha^{-1}$), leaf potassium content (2.57 mg $g^{-1}$), leaf boron content (2.61 mg $g^{-1}$), starch content in pollen grains (1.36 mg $g^{-1}$), sugar content in pollen grains (2.77 mg $g^{-1}$), DPPH radical scavenging activity (46.78 %) and polyphenol oxidase (41.78 %) were demonstrated on early sowing date (20 Feb). Concerning nutrients foliar application, maximum values for plant height (71.66 cm), number of leaves per plant (83.3), pollen viability (83.04 %), yield (14.67 t $ha^{-1}$), leaf potassium content (3.15 mg $g^{-1}$), leaf boron content (3.06 mg $g^{-1}$), starch content in pollen grains (1.71 mg $g^{-1}$), sugar content in pollen grains (3.18 mg $g^{-1}$), DPPH radical scavenging activity (48.33 %) and polyphenol oxidase (43.33 %) were noted in plants treated with 300 mg $L^{-1}$ K + 40 mg $L^{-1}$ B application. It was concluded the tomato crop could be treated with combine application of potassium and boron in early as well as late sowing days to obtain high quality fruit production under the agro-climatic conditions of Balochistan-Pakistan.

**Key words:** *Solanum lycopersicum*; Thermotolerance; Abiotic stress mitigation; Reproductive development

## Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable plants in the world which belongs to the family Solanaceae. It originated in western South America and domestication is thought to have occurred in Central America. Because of its importance as food, tomato has been bred to improve productivity, fruit quality and resistance to biotic and abiotic stresses. Heat stress is a major abiotic constraint in tomato production, occurring when temperatures exceed the optimum range (≈26–28°C), leading to reduced growth and productivity (Alsamir *et al*., 2021). High temperatures particularly affect reproductive development by reducing pollen viability, impairing fertilization, and causing flower drop, which ultimately lowers fruit set and yield (Raja *et al*., 2019). Heat stress disrupts physiological processes such as photosynthesis and chlorophyll stability while increasing respiration rates, resulting in reduced biomass accumulation (Larkindale *et al*., 2005). Adjustment of sowing dates and proper nutrient management are effective strategies for mitigating heat stress in tomato production. Optimum sowing time helps the crop escape exposure to high temperatures during critical stages such as flowering and fruit set, thereby improving yield stability (Sato *et al*., 2000; Wahid *et al*., 2007). Early or timely planting allows better crop establishment under favorable conditions, reducing the adverse effects of terminal heat stress. In addition, balanced nutrient management especially adequate supply of potassium and micronutrients as boron enhances plant tolerance by improving osmotic regulation, membrane stability, and antioxidant defense systems (Khan *et al*., 2015; Zandalinas *et al*., 2021). The tomato plant has many interesting features such as fleshy fruit, a sympodial shoot and compound leaves, which other model plants do not have (Kimura and Sinha, 2008). The timing of sowing directly affects seed germination, vegetative growth, flowering, and fruit set by exposing the plant to varying degrees of thermal and photoperiodic stress (Kumar *et al*., 2018). Tomatoes are highly sensitive to temperature fluctuations; optimal growth, while temperatures above 35°C significantly reduce pollen viability, fertilization success, and fruit set (Peet & Wolfe, 2000). Potassium is a vital macronutrient in tomato that regulates osmotic balance, enzyme activation, stomatal conductance and photosynthetic efficiency, thereby playing a central role in plant growth and yield formation. Adequate potassium supply enhances stress resilience by improving water-use efficiency, maintaining membrane stability and activating antioxidant defense systems, which are critical under abiotic stresses (Hasanuzzaman *et al*., 2018). Consequently, sowing too early or too late can expose the crop to heat stress during the reproductive stage, leading to flower drop, reduced fruit number, and lower marketable

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yield. Therefore, strategy of different planting time is arranged to influence the growth of tomato by thermo tolerance. Potassium (K), an essential macro element for plant growth, is an activator of many enzymes that involve in carbon and nitrogen metabolism in plants (Oosterhuis *et al*., 2014). K is an element of high mobility in plant cells, and play key roles in regulations of carbon fixation, cell turgor, stomatal closure and abiotic stress (Oosterhuis *et al*., 2014). In relation to thermotolerance, heat stress severely impairs tomato productivity by inducing oxidative damage, reducing photosynthetic efficiency, and disturbing reproductive processes; however, tolerance mechanisms are associated with enhanced antioxidant activity, maintenance of photosystem stability, and activation of heat-responsive genes (Graci & Barone, 2024; Xu *et al*., 2024). Although direct studies on boron-mediated thermotolerance in tomato are still limited, its established role in maintaining membrane stability, regulating reactive oxygen species (ROS), and modulating stress-related gene expression suggests that optimal boron nutrition can indirectly enhance heat stress tolerance by sustaining cellular integrity and metabolic function under elevated temperatures. Besides, K has the function of maintaining membrane electrochemical gradient, phloem pressure and serving as a mobile energy source that are necessary for the loading and transportation of assimilates in phloem (Babst *et al*., 2022; Dreyer *et al*., 2017; Oosterhuis *et al*., 2014). Potassium plays a vital role in enhancing tomato (*Solanum lycopersicum* L.) growth, yield, fruit quality, and resilience against environmental stresses, including high temperature. As potassium (K) improves several physiological and biochemical functions essential for optimum tomato productivity. Potassium is the second most required macronutrient after nitrogen and is particularly important for tomato due to its involvement in osmotic regulation, enzyme activation, photosynthetic translocation, and synthesis of organic acids and sugars (Hasanuzzaman *et al*., 2018).

The aim of this experiment was to investigate the effect of nutrients and sowing dates on growth, yield and reproductive heat tolerance of tomato. The key objectives of the experiment were to:

- To compare and analyze the tomato sowing dates for yield and yield related traits.
- To check the effectiveness of nutrients for improving tomato productivity and thermo tolerance.
- To find out the interaction of nutrients and sowing dates for the growth, yield and thermotolerance of tomato crop.

## Material and Methods

The experiment was carried out at Research Farm, Balochistan Agriculture College Quetta, during 2024-25 to see the effect of nutrients and sowing dates on growth, yield and heat tolerance of tomato. Seeds were sown on different sowing dates (20$^{th}$ Feb, 6$^{th}$ March and 21$^{st}$ March) in plastic tunnels for the year 2024 and 2025 for nursery rising. The experiment was laid out in a RCBD split plot arrangement with two factors having three replications. With a 1.98 $m^2$ plot size.

Treatments as sowing dates (20$^{th}$ Feb, 6$^{th}$ March and 21$^{st}$ March) were allotted to main plot while nutrients spray treatments were placed in sub plot. Various concentrations of nutrients (potassium at the rate of 150 and 300 mg $L^{-1}$ and boron 20 and 40 mg $L^{-1}$) and combinations (150 K + 20 B mg $L^{-1}$ and 300 K + 40 B mg $L^{-1}$) were arranged in sub plot. Boric acid contains 17.48% boron, as required amount was 20 and 40 mg $L^{-1}$. 114 mg boric acid in 1 L water gives 20 mg B/L and dissolve 229 mg boric acid in 1 L water gives 40 mg B/L. Potassium sulfate contains 50% potassium. Required amount of potassium was calculated as dissolve 300 mg potassium sulfate in 1 L water gives 150 mg K/L and dissolve 600 mg potassium sulfate in 1 L water gives 300 mg K/L. Before transplantation of seedling, random soil samples at the depth of 25 cm were taken using a gauge auger from different segments of the field trial area and was observed in the laboratory of soil science at Balochistan Agriculture College Quetta, for the analysis of physical and chemical properties of soil (Table 1).

Percentage of pollen viability was tested a day before anthesis. Five flower buds were randomly collected from each treatment and replication. Pollens were removed from the anthers by using a needle. The pollen grains were inoculated on glass slide for determining the number of viable pollen grains through triphenyl tetrazolium chloride (TTC) test as per methodology of Eti (1991). Spectrophotometer according to the procedure of Williams (1978) was used to find out the concentration of K and B leaves of tomato plant. Freshly opened flowers of tomato were collected during morning hours at anthesis, and pollen grains were obtained by gently tapping the anthers on clean glass slides. Starch content in pollen grains was determined using the iodine and potassium iodide ($I_2$–KI) staining method, where a drop of $I_2$–KI solution was added to the pollen sample, covered with a coverslip, and observed under a compound light microscope. Pollen grains showing blue-black coloration were considered starch-positive. The method of Johansen (1940) and Baker and Baker (1979) were used. For estimation of total soluble sugars, pollen grains were collected and homogenized in 80% ethanol, followed by centrifugation to obtain the supernatant. The ethanol extract was evaporated and the residue was dissolved in distilled water. Total sugar content was estimated using the anthrone method, in which the extract was reacted with anthrone reagent and heated in a boiling water bath for 10 minutes. After cooling, absorbance was recorded at 620 nm using a spectrophotometer, and sugar concentration was calculated from a glucose standard curve as described by Yemm & Willis (1954) and Stanley & Linskens (1974). The DPPH radical scavenging activity (%) was determined in accordance with the procedure followed by Huang *et al*., (2005). The sample tomato fruits from each treatment were taken. About 5g of fruit pulp were used for determining polyphenol oxidase activity. Polyphenol oxidase activity was determined according to Mayer *et al*., (1965).

**Studied parameters:** Five healthy plants were randomly selected from each plot to record various parameters data on tomato growth yield and thermo tolerance. Plant height (cm), number of leaves per plant, pollen viability (%), yield (t $ha^{-1}$), leaf potassium and boron content (mg $g^{-1}$), starch and sugar content (mg $g^{-1}$), DPPH radical scavenging activity (%) and polyphenol oxidase (%) data were recorded.

**Statistical analysis**

The recorded data were subjected to ANOVA using Statistix ver. 8.1. The means of all treatments were compared using LSD test with significance level of 1% (Steel & Torrie, 1997).

**Table 1. Initial soil Physiological characteristics of experimental site.**

| Properties | Units | Concentrations |
|---|---|---|
| Sand | % | 11-27 |
| Silt | % | 25-50 |
| Clay | % | 21-52 |
| Textural | ---- | Silty loam |
| Organic matter content | % | 0.72 |
| Electrical conductivity (EC) | dS/m | 0.57 |
| Ph | ---- | 7.8 |
| Mineral Nitrogen | % | 0.08-0.14 |
| AB-DTPA extractible phosphorous | mg $Kg^{-1}$ | 0.24-13.5 |
| AB-DTPA extractible potassium | ---- | 57-490 |
| Boron concentration | mg $g^{-1}$ | 0.19 mg $g^{-1}$ |

## Results

### Studied parameters of tomato

**Plant height (cm):** Data concerning plant height is shown in Table 2. Sowing dates were significantly different from one another regarding plant height of tomato. Potassium and Boron application either alone or in combination and years of plantation also significantly affected plant height of tomato. Regarding different sowing dates, early sowing date 20 Feb resulted in maximum plant height (63.61 cm), followed by (56.85 cm) 6 March, while small plant (52.50 cm) was noted when seeds were sown on 21 March. Similarly, regarding various combined concentration of K and B levels, the plant height increased from 44.38 cm in control plot to 71.66cm with 300 mg $L^{-1}$ K + 40 mg $L^{-1}$ B application, followed by (66.55 cm) at 150 mg $L^{-1}$ K + 20 mg $L^{-1}$ B application. Data regarding years of plantation revealed that plant height was maximum (61.17 cm) during the year 2025 as compared to (54.14 cm) during the year 2024.

**Number of leaves plant$^{-1}$:** Table 2, demonstrates that sowing dates had a significant effect on the number of leaves per plant in tomato. The application of potassium and boron, as well as the year of cultivation, also significantly influenced leaf production. Among the sowing dates, plants sown on 20 February produced the highest number of leaves per plant (73.5). This was followed by the 6 March sowing, which resulted in (64.6) leaves per plant. In contrast, the lowest leaf count (59.8) per plant was recorded in plants sown on 21 March. With respect to nutrient treatments, a steady increase in leaves per plant was observed from the control treatment (48.3) leaves per plant to the combined application of 300 mg $L^{-1}$ potassium and 40 mg $L^{-1}$ boron, which produced the maximum number of leaves per plant (83.3). The second highest leaf number (77.5) was obtained with the combined application of 150 mg $L^{-1}$ potassium and 20 mg $L^{-1}$ boron. The year of plantation had a significant influence on leaf development. A greater number of leaves per plant (69.9) was observed during the 2025 growing season, as compared to leaves per plant (62.1) in 2024.

**Pollen viability (%):** Data concerning pollen viability are shown in Table 2. Sowing dates were significantly different from one another regarding pollen viability of tomato. Potassium and Boron application either alone or in combination and years of plantation also significantly affected pollen viability of tomato plant, while. Regarding different sowing dates, early sowing date (20 Feb) resulted in high pollen viability (80.6 %), followed by (74.9 %) 6 March, while less pollen viability (70.2 %) was resulted in plants sown at 21$^{st}$ March. Similarly, regarding various concentrations of K and B levels, the more pollen viability (83.0 %) was reported in 300 mg $L^{-1}$ K + 40 mg $L^{-1}$ B application, followed by (79.8 %) at 150 mg $L^{-1}$ K + 20 mg $L^{-1}$ B application, while less viability of pollen was recorded in control (69.5 %). Data regarding years of plantation revealed that maximum pollen viability (76.0 %) was during the year 2025 as compared to (74.5 %) during the year 2024.

**Yield (t ha$^{-1}$):** Data concerning yield (t ha$^{-1}$) is shown in Table 2. Sowing dates were significantly different from one another regarding yield (t h$^{-1}$) of tomato. Potassium and Boron application either alone or in combination and years of plantation also significantly affected yield (t ha$^{-1}$) of tomato plant. Regarding different sowing dates, early sowing date (20 Feb) resulted in high yield 12.90 t ha$^{-1}$, followed by 10.89 t ha$^{-1}$ (6 March), while less yield 9.55 t ha$^{-1}$ was resulted at 21 March. Similarly, regarding various concentrations of K and B levels, the more yield 14.67 t ha$^{-1}$ was reported in 300 mg $L^{-1}$ K + 40 mg $L^{-1}$ B application, followed by 13.16 t ha$^{-1}$ at 150 mg $L^{-1}$ K + 20 mg $L^{-1}$ B application, while less yield was recorded in control 7.92 t ha$^{-1}$. Yield (t ha$^{-1}$) was also significantly affected by K and B application alone, with more yield of tomato 10.01 t h$^{-1}$ was recorded in 300 mg $L^{-1}$ K and 12.0 t haa$^{-1}$ was observed in 40 mg $L^{-1}$ B respectively as compared to control. Data regarding years of plantation revealed that maximum yield 11.52 t ha$^{-1}$ was during the year 2025 as compared to 10.71 t ha$^{-1}$ during the year 2024.

**Leaf potassium content (mg g$^{-1}$):** Data concerning leaf potassium content (mg g$^{-1}$) are shown in Table 3. Sowing dates were significantly different from one another regarding leaf potassium content of tomato. Potassium and Boron application either alone or in combination and years of plantation also significantly affected leaf potassium content of tomato plant. Regarding different sowing dates, early sowing date (20 Feb) resulted in high potassium content in leaf (2.57 mg g$^{-1}$), followed by (2.49 mg g$^{-1}$) 6 March, while less (2.25 mg g$^{-1}$) was resulted at 21 March. Similarly, regarding various concentrations of K and B levels, maximum potassium content in leaf (3.15 mg g$^{-1}$) was reported in 300 mg $L^{-1}$ K + 40 mg $L^{-1}$ B application, followed by (2.80 mg g$^{-1}$) by 150 mg $L^{-1}$ K + 20 mg $L^{-1}$ B application, while minimum (1.21 mg g$^{-1}$) was recorded in control plot. Data regarding years of plantation revealed that maximum potassium content in leaf (2.46 mg $g^{-1}$) was during the year 2025 as compared to (2.41 mg $g^{-1}$) during the year 2024.

**Table 2. Plant height (cm), number of leaves plant$^{-1}$, pollen viability (%) and yield t ha$^{-1}$ of tomato in response to different sowing dates and foliar application of nutrients.**

| Treatments | Treatments | Plant height (cm) | Number of leaves plant$^{-1}$ | Pollen viability (%) | Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|
| Year | 2024 | 54.14 B | 62.09 B | 74.52 B | 10.71 B |
| | 2025 | 61.17 A | 69.95 A | 76.07 A | 11.52 A |
| LSD($p\leq0.01$) | | 4.42 | 1.90 | NS | 0.54 |
| Potassium (K) mg L$^{-1}$ | Control (0) | 44.38 G | 48.33 G | 69.51 G | 7.92 G |
| | 150 K | 48.77 F | 54.22 F | 71.08 F | 8.97 F |
| | 300 K | 52.94 E | 60.16 E | 72.98 E | 10.01 E |
| Boron (B) mg L$^{-1}$ | 20 B | 57.50 D | 66.38 D | 74.38 D | 11.07 D |
| | 40 B | 61.77 C | 72.16 C | 76.22 C | 12.00 C |
| K + B | 150 K + 20 B | 66.55 B | 77.50 B | 79.85 B | 13.16 B |
| | 300 K + 40 B | 71.66 A | 83.38 A | 83.04 A | 14.67 A |
| LSD ($p\leq0.01$) | | 1.03 | 0.84 | 0.68 | 0.23 |
| Sowing dates (SD) | 20 Feb | 63.61 A | 73.52 A | 80.66 A | 12.90 A |
| | 6 March | 56.85 B | 64.66 B | 74.99 B | 10.89 B |
| | 21 March | 52.50 B | 59.88 C | 70.24 C | 9.55 C |
| LSD ($p\leq0.01$) | | 5.42 | 2.33 | 1.53 | 0.66 |

**Table 3. Leaf potassium content (mg g$^{-1}$) and leaf boron content (mg g$^{-1}$) in response to different sowing dates and foliar application of nutrients.**

| Treatments | Treatments | Leaf potassium content (mg g$^{-1}$) | Leaf boron content (mg g$^{-1}$) |
|---|---|---|---|
| Year | 2024 | 2.42 A | 2.22 B |
| | 2025 | 2.46 A | 2.41 A |
| LSD ($p\leq0.01$) | | NS | 0.10 |
| Potassium (k) mg L$^{-1}$ | Control (0) | 1.21 F | 1.47 G |
| | 150 K | 2.39 D | 1.71 F |
| | 300 K | 2.93 B | 1.98 E |
| Boron (B) mg L$^{-1}$ | 20 B | 2.36 D | 2.49 D |
| | 40 B | 2.23 E | 2.86 B |
| K + B | 150 K + 20 B | 2.80 C | 2.62 C |
| | 300 K + 40 B | 3.15 A | 3.06 A |
| LSD ($p\leq0.01$) | | 0.09 | 0.11 |
| Sowing dates (SD) | 20 Feb | 2.57 A | 2.61 A |
| | 6 March | 2.49 B | 2.28 B |
| | 21 March | 2.25 C | 2.04 C |
| LSD ($p\leq0.01$) | | 0.06 | 0.12 |

**Table 4. Starch content in pollen grains (mg g-1), sugar content in pollen grains (mg g-1), DPPH radical scavenging activity (2, 2-diphenyl-1-picrylhydrazyl) (%) and polyphenol oxidase (%) in response to different sowing dates and foliar application of nutrients.**

| Treatments | Treatments | Starch content in pollen grains (mg g$^{-1}$) | Sugar content in pollen grains (mg g$^{-1}$) | DPPH radical scavenging activity (%) | Polyphenol oxidase (%) |
|---|---|---|---|---|---|
| Year | 2024 | 1.0 A | 2.49 B | 41.33 B | 37.04 B |
| | 2025 | 1.10 A | 2.69 A | 46.33 A | 40.81 A |
| LSD ($p\leq0.01$) | | NS | 0.03 | 1.68 | 1.03 |
| Potassium (K) mg L$^{-1}$ | Control (0) | 0.47 G | 2.31 EF | 39.11 G | 33.72 G |
| | 150 K | 0.70 F | 2.28 F | 41.22 F | 36.05 F |
| | 300 K | 0.95 E | 2.37 E | 42.12 E | 37.61 E |
| Boron (B) mg L$^{-1}$ | 20 B | 1.13 D | 2.49 D | 45.16 C | 39.44 D |
| | 40 B | 1.27 C | 2.64 C | 44.33 D | 40.66 C |
| K + B | 150 K + 20 B | 1.47 B | 2.87 B | 47.44 B | 41.66 B |
| | 300 K + 40 B | 1.71 A | 3.18 A | 48.33 A | 43.33 A |
| LSD ($p\leq0.01$) | | 0.05 | 0.07 | 0.52 | 0.99 |

| | | | | | |
|---|---|---|---|---|---|
| Sowing dates | 20 Feb | 1.36 A | 2.77 A | 46.78 A | 41.78 A |
| | 6 March | 1.05 B | 2.56 B | 44.44 B | 38.71 B |
| | 21 March | 0.89 C | 2.44 C | 40.90 C | 36.28 C |
| LSD (p≤0.01) | | 0.02 | 0.04 | 2.06 | 1.21 |

**Leaf boron content (mg g$^{-1}$):** Data on leaf boron content (mg g$^{-1}$) are presented in Table 3. Leaf boron content in tomato plants was significantly influenced by sowing date, potassium and boron application (either individually or combined), and cultivation year. The earliest sowing date (February 20) resulted in the highest leaf boron concentration (2.61 mg g$^{-1}$), followed by the March 6 sowing (2.28 mg g$^{-1}$). The lowest concentration (2.04 mg g$^{-1}$) was recorded for the latest sowing on March 21. In the nutrient treatments, the combined application of 300 mg L$^{-1}$ K and 40 mg L$^{-1}$ B produced the highest leaf boron level (2.86 mg g$^{-1}$), with the 150 mg L$^{-1}$ K + 20 mg L$^{-1}$ B treatment ranking second (2.62 mg g$^{-1}$). The control plot, which received no K or B application, recorded the minimum concentration (1.47 mg g$^{-1}$). Across years, the 2025 growing season achieved a higher mean leaf boron content (2.42 mg g$^{-1}$) compared to 2024 (2.22 mg g$^{-1}$).

**Starch content in pollen grains (mg g$^{-1}$):** Data on starch content in pollen grains (mg g$^{-1}$) are presented in Table 4. The results showed that sowing dates differed significantly with respect to starch content in tomato pollen grains. Application of potassium and boron, either individually or in combination, as well as year of plantation, also had a significant influence on starch accumulation in pollen grains. Among the different sowing dates, the earliest sowing (20 February) recorded the highest starch content in pollen grains (0.32 mg g$^{-1}$), followed by sowing on 6 March (0.22 mg g$^{-1}$). The lowest starch content (0.15 mg g$^{-1}$) was observed in the late sowing date (21 March). With respect to different K and B concentrations, the maximum starch content in pollen grains (0.22 mg g$^{-1}$) was observed with the application of 300 mg L$^{-1}$ K + 40 mg L$^{-1}$ B, followed by 150 mg L$^{-1}$ K + 20 mg L$^{-1}$ B (0.20 mg g$^{-1}$). In contrast, the minimum starch content (0.15 mg g$^{-1}$) was recorded in the control treatment. Data regarding the years of plantation indicated that the higher starch content in pollen grains (0.23 mg g$^{-1}$) was obtained during 2025, compared to (0.22 mg g$^{-1}$) in 2024.

**Sugar content in pollen grains (mg g$^{-1}$):** Data on sugar content in tomato pollen grains (mg g$^{-1}$), are given in Table 4, that reveal significant influences from sowing date, potassium and boron application, and the year of cultivation. Sowing dates showed a distinct pattern, where earlier planting resulted in higher sugar concentration. Specifically, the earliest sowing on February 20 recorded the high sugar content in pollen grains as (2.77 mg g$^{-1}$), followed by the March 6 sowing with (2.56 mg g$^{-1}$). The latest sowing date of March 21 produced the lowest observed value of (2.44 mg g$^{-1}$). The application of potassium and boron, both individually and in combination, also significantly affected pollen sugar levels. The most pronounced effect was seen with the combined treatment, where the application of 300 mg L$^{-1}$ potassium and 40 mg L$^{-1}$ boron resulted in the maximum sugar content of (3.18 mg g$^{-1}$). An intermediate combined dose of 150 mg L$^{-1}$ potassium and 20 mg L$^{-1}$ boron recorded sugar content in pollen grains as (2.87 mg g$^{-1}$), while the untreated control plants recorded the minimum value of (2.31 mg/g). Furthermore, a yearly variation was evident, with the 2025 season producing a higher average sugar content (2.69 mg g$^{-1}$) compared to the 2024 season (2.49 mg g$^{-1}$).

**DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity (%):** Data on DPPH radical scavenging activity of tomato plants are presented in Table 4 The results indicated that sowing dates significantly influenced the DPPH radical scavenging activity. Similarly, the application of potassium and boron, whether applied individually or in combination, as well as the year of plantation, significantly affected the antioxidant activity. Among the different sowing dates, the earliest sowing (20 February) exhibited the highest DPPH radical scavenging activity (46.79 %), followed by sowing on 6 March (44.44 %), while the lowest activity (40.90 %) was recorded in the late sowing on 21 March. Regarding nutrient treatments, the maximum DPPH radical scavenging activity (48.33 %) was observed under the application of 150 mg L$^{-1}$ K + 20 mg L$^{-1}$ B, followed by 47.44 % under 300 mg L$^{-1}$ K + 40 mg L$^{-1}$ B, whereas the minimum activity (39.71 %) was recorded in the control plants. Analysis of the year-wise data revealed that the highest DPPH radical scavenging activity (46.76 %) occurred in 2025, compared with 41.33 % in 2024.

**Polyphenol oxidase (%):** Data concerning polyphenol oxidase (%**)** are shown in Table 4. Sowing dates were significantly different from one another regarding polyphenol oxidase of tomato. Potassium and Boron application either alone or in combination and years of plantation also significantly affected polyphenol oxidase of tomato plant. Regarding different sowing dates, early sowing date (20 Feb) resulted in high polyphenol oxidase (41.78 %), followed by 38.71% plants sown at 6 March, while less polyphenol oxidase (36.28 %) was resulted at 21$^{st}$ March. Similarly, regarding various concentrations of K and B levels, the maximum polyphenol oxidase (43.33 %) was reported when plants treated with 300 mg L$^{-1}$ K + 40 mg L$^{-1}$ B application, followed by (41.66 %) at 150 mg L$^{-1}$ K + 20 mg L$^{-1}$ B application and minimum polyphenol oxidase 33.72 was recorded in control. Data regarding years of plantation revealed that maximum polyphenol oxidase (40.81 %) was during the year 2025 as compared to (37.04 %) during the year 2024.

## Discussion

**Influence of sowing dates and nutrients spray on studies attributes:** The results of present findings highlight the effectiveness of selected management practices such as sowing dates and nutrients application in enhancing tomato yield and improving plant tolerance to elevated temperatures. The observed responses indicate the potential of these practices to support sustainable tomato production under changing climatic conditions. As our results are related to Hossain *et al*., (2019), who reported that tomato plants sown early attained a maximum height, whereas those sown late can result in smaller compare to early planting, respectively. The improved height from the early sowing was linked to more favorable temperature and photoperiod during vegetative growth. Potassium along with other fertilizers are productive for obtaining higher crop yield in recent decades (Cakmak & Yazici, 2010). In relation to thermotolerance, heat stress severely impairs tomato productivity by inducing oxidative damage, reducing photosynthetic efficiency, and disturbing reproductive processes; however, tolerance mechanisms are associated with enhanced antioxidant activity, maintenance of photosystem stability, and activation of heat-responsive genes (Graci & Barone, 2024). Although direct studies on boron-mediated thermotolerance in tomato are still limited, its established role in maintaining membrane stability, regulating reactive oxygen species (ROS), and modulating stress-related gene expression suggests that optimal boron nutrition can indirectly enhance heat stress tolerance by sustaining cellular integrity and metabolic function under elevated temperatures. Optimized level of nutrients also helps in enhanced photosynthesis regulation along with increased enzymes activities like invertase and sugar synthase that are essential for sucrose transport from source to sink (White & Broadley, 2009). Our findings are in conformity with Choi *et al*., (2015) who investigated boron partitioning in tomato plants and concluded that plant height, leaf length and width was significantly reduced 35-40% with no boron application as compared the plants treated with boron application. Boron deficiency in fresh-market tomato is often not recognized by growers. Boron deficiency, however, is widespread (Gupta *et al*., 1985) and can cause serious yield reductions and uneven ripening of tomato fruit (Adams, 1978). Nutrient management plays a massive role in modulating tomato branching, with macronutrient (potassium) and micronutrients like boron (B) being key regulators of vegetative growth and meristem activity (Adams & Ho, 1995). Under heat stress conditions, potassium contributes to thermotolerance by regulating stomatal function, reducing excessive transpiration, stabilizing photosynthetic machinery and mitigating oxidative damage through enhanced reactive oxygen species (ROS) scavenging (Ahmad *et al*., 2022). Consequently, optimal potassium nutrition supports physiological and biochemical adjustments that help tomato plants sustain growth and productivity under elevated temperatures. Flowering and fruit set are two key processes that are sensitive to high temperature and a basis for identifying heat tolerance in tomato (Berry & Uddin, 1988). Both potassium and boron influence the balance of growth hormones such as auxins (IAA), cytokinin and gibberellins ($GA_3$**)**. Boron maintains auxin stability and transport within the shoot apex, while potassium promotes cytokine synthesis and GA-mediated flowering pathways (Hasanuzzaman *et al*., 2018). In contrast, late sown plants exposed suddenly to high temperature suffer from oxidative damage and poor fruit set. Bahar *et al*., (2011) found that tomato cultivars planted early under mild temperatures had higher yield and fruit quality because plants could complete their reproductive phase before the onset of severe heat stress. Huang and Snapp, (2009) studied the influence of boron and potassium nutrition on enhancement of fruit quality of tomato and noted that boron foliar application enhanced yield as well as fruit quality. Similar findings were reported by Sahin *et al*., (2015) who investigated the interactive effect of boron and calcium on growth and quality of tomato and noted an increased yield as well as quality of tomato fruit. Plants receiving K applications matured earlier and had significantly higher soluble solid concentration, total sugar, ascorbic acid (vitamin C), and beta carotene content than fruits from plants without receiving any K application (Lester *et al*., 2005). The interaction of B and K nutrition will provide a sound basis for nutrient recommendations in fresh market tomatoes (Olson *et al*., 2004). Soil applied B inconsistently influences tomato K concentration in plant tissue (Alpaslan & Gunes, 2001). Tomato are predominantly sugars, which determine flavor and other fruit quality characteristic. When applied together, these nutrients synergistically improve sugar transport and metabolite synthesis, which is expected to increase DPPH radical scavenging activity in fruits, flowers, and potentially pollen grains. The synergism occurs because K ensures sufficient carbon assimilation while B facilitates carbohydrate utilization in secondary metabolite pathways. Similarly, Javaria *et al*., (2012) found that sugar was significantly influenced by the application of K. Fruits soluble solids showed increment when K doses were increased. Thermo tolerance is acquired from prior subjecting the plants to a sublethal high temperature (Hong &d Vierling, 2000). When boron is deficient, sugar accumulates in leaves instead of reaching the buds, delaying flowering (Wimmer & Eichert, 2013).

## Conclusion

From the results of the experiment, it was concluded that in sowing dates of tomato seed, early sowing date (20 Feb) was the robust date for tomato growers with a profitable yield. The foliar application of nutrients (potassium @ 300 mg $L^{-1}$ and boron 40 @ mg $L^{-1}$) when applied to tomato plant showed better result in terms of all the reproductive and qualitative attributes of tomato. In addition, this nutrient combination also contributed in amelioration of the deleterious effects of heat stress in late sown plants.

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