



RESEARCH ARTICLE

# Terminal temperature stress induced differential impact on physio-biochemical attributes of bread wheat (*Triticum aestivum* L.)

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## Abstract

Terminal temperature stress is considered one of the major challenges that occur during the flowering period and leads to a reduction in crop yield. Climate change poses a significant obstacle. This study was conducted at the Students' Instructional Farm (SIF) of ANDUAT, Ayodhya, while laboratory analyses took place in the Crop Physiology Laboratory during the rabi season of 2023–24. Ayodhya district has a semi-arid climate with an average annual rainfall of 1100 mm, of which around 80 % occurs during the monsoon season (June to September). Three wheat varieties viz., PBW-343, HD-2967 and Kundan were evaluated in 3 replications and 3 different dates of sowing using split plot design (SPD). In contrast, Kundan is a late-sown, high-yielding variety known for its tolerance to high-temperature stress. The value for the highest plant height was recorded 83.56 cm and at late sowing (30<sup>th</sup> December). When the sowing was done on 30<sup>th</sup> November then at 60 days the total chlorophyll contents was 2.19, 2.2 and 1.9 (mg g<sup>-1</sup> FW), at 15<sup>th</sup> December 53.89, 54.75 and 51.2 (mg g<sup>-1</sup> FW) and at 30<sup>th</sup> December 1.92, 2.0, 2.11 (mg g<sup>-1</sup> FW) in all 3 varieties of wheat. The results revealed on elucidating the effects of terminal temperature stress on the physio-biochemical traits of wheat (*Triticum aestivum* L.). Also considering the physiochemical parameters will also affect the yield of wheat significantly.

**Keywords:** antioxidant enzymes; catalase; chlorophyll; heat stress; peroxidase; sowing date; wheat

## Introduction

Wheat (*Triticum aestivum* L.) is one of the world's most important food crops, covering more farming land over cereal crop. Wheat is a rabi season crop characterised as a day, crop having fibrous roots that is self-pollinating. Approximately, it provides food and nourishment for around one-third of the world's population. Wheat is cultivated on 31.76 million hectares in India, with a total production of 109.5 million tons (1, 2). The country has five major wheat-growing zones: the Northern Hill Zone (NHZ), the North Western Plains Zone (NWPZ), the North Eastern Plains Zone (NEPZ), the Central Zone (CZ) and the Peninsular Zone (PZ). In Uttar Pradesh, wheat is cultivated on 9.21 million hectares, yielding 24.51 million tons with a productivity of 2.7 tonnes per hectare (3).

Wheat is a significant source of carbohydrates (71.2 g 100 g<sup>-1</sup>) and the leading global source of vegetable protein in human diets, containing approximately 11.8 g of protein per 100 g of the total protein content, 75–80 % consists of gluten proteins. Additionally, wheat provides fat (1.5 g), minerals (1.5 g), calcium (41 mg), phosphorus (306 mg), iron (5.3 mg) and fibre (1.2 g) per 100 g of the edible portion.

Numerous environmental factors that have an impact on plant growth and development are now a major issue. Wheat genotypes exhibit differential responses to chronic heat stress and heat shock (4). The sensitivity of wheat to temperature stress varies between the vegetative and reproductive phases (5). Change in the climate is anticipated to have a significant impact on global wheat production, which accounts for 21 % of total food production and is cultivated on approximately 200 million hectares of farmland worldwide (6). Wheat's grain-filling rate is lowered by exposure to temperatures exceeding 30 °C during the pre- or post-anthesis stage, which lowers grain production and quality. Proline, an amino acid, widely accumulates in plants under environmental stress. Its role in stress response includes osmotic balance, subcellular structural stabilisation, free radical scavenging and buffering of redox potential in cells (7).

In India, wheat is usually harvested in the warmer months of March or April after being seeded in November or December. If the temperature exceeds a critical threshold for an extended period, it has a detrimental effect on grain fertility, leaf withering, wheat growth and overall crop maturity. Improved crop growth because of

nitrogen fertilisation is linked to higher leaf area index (LAI) and radiation interception (8). High-temperature stress during the grain-filling stage accelerates the senescence process, leading to premature chlorophyll degradation and a reduced chlorophyll a/b ratio (9). The balance of high protein content, strong gluten, optimal starch and good grain physical traits makes bread wheat suitable for high-quality bread production. There is very scanty information available on terminal temperature stress induced differential impact on physio-biochemical attributes of bread wheat in Eastern Uttar Pradesh. Keeping the above facts, the study was undertaken with the following objective terminal temperature stress induced differential impact on physio-biochemical attributes of bread wheat (*T. aestivum*).

## Materials and Methods

### Experimental site

The experimental site, students' Instructional Farm located on the main campus of the university (26.47° N latitude and 82.12° E longitude), on the Left side of the Ayodhya-Raebareli road, about 42 km from the Faizabad district headquarters and 110 km from Lucknow. The normal pH of soil ranges from 7.2 to 8.4. The soil type of the area is sandy to loam-textured, alkaline soil, typical of the Gangetic plain. Laboratory analyses were performed in the Crop Physiology Laboratory during the rabi session 2023–24. The climate of Ayodhya district is classified as semi-arid, with an average temperature was 22.8 °C and average annual rainfall of 1100 mm approximately 80 % of which is observed during the rainy season (from June to September).

### Design of experiment

A total of 27 plots were used for the study, each measuring 5 × 4 m with a distance of 20 × 10 cm. Five plants were selected from each plot as samples to gather observations. The experiment was designed under a split plot design (SPD) with 3 replications and 3 treatments. The varieties selected, PBW-343 and HD-2967, are well-known high-yielding varieties in the North Eastern Plain Zone (NEPZ) for timely sowing were procured from Department of Genetics and Plant Breeding, CoA and UAT, Ayodhya and all these three varieties are susceptible to temperature stress. In contrast, Kundan is a high-yielding, late-sown variety that is tolerant to high-temperature stress.

The treatments consisted of three sowing dates: D1 (November 30<sup>th</sup>), D2 (December 15<sup>th</sup>) and D3 (December 30<sup>th</sup>). The best sowing times for timely-sown and late-sown wheat types were taken into consideration while selecting these dates, to subject the varieties to heat stress during the later developmental stages due to rising temperatures. The best period to sow is mid-November for timely-sown cultivars and the first two weeks of December for late-sown types. Effective tillers were seen at physiological maturity for the various wheat kinds, whereas plant height and tiller count were noted during the maximal tillering stage. Following harvesting, measurements were made on the biological and grain yields.

### Biochemical analysis parameters

#### Total chlorophyll content (mg g<sup>-1</sup> fresh weight)

The total chlorophyll content was estimated using the method described by Arnon et al. (10).

$$\text{Total chlorophyll} = \frac{20.2 \times \text{O.D. (645)} + 8.02 \times \text{O.D. (663)} \times \text{Volume}}{1000 \times \text{Weight}}$$

Where, W = Weight of sample (mg)

V = Final volume (mL)

O.D. = Optical density

#### Total soluble sugar (mg g<sup>-1</sup> dry weight)

The total carbohydrate in plant extract was estimated by the method of Curne and Galston (11).

The total carbohydrate in the plant extract was estimated by the method of Sulphuric acid hydrolysis, which breaks glycosidic bonds of carbohydrate, producing monosaccharide, which undergo dehydration to produce furfural and its byproducts. Anthrone and furfural combine to form a blue-green complex. Using a spectrophotometer, the amount of free proline in the leaves was calculated as described by Bates et al. (12). The activity of peroxidase was determined using the method described by Curne and Galston (11). By removing hydrogen, which then reacts with H<sub>2</sub>O<sub>2</sub>, the enzyme catalyses the oxidation of the substrate. Catalase activity was measured calorimetrically using the procedure described by Sinha (13). According to the reaction, catalase facilitates the breakdown (dismutation) of H<sub>2</sub>O<sub>2</sub> into water and oxygen.

### Statistical analysis

The data were subjected to analysis of variance (ANOVA) using SPD. Significance levels were used at 5 % and analysis of data was done using IBM SPSS version 20 software.

## Results

### Plant height (cm)

The data on plant height (cm) was taken at 15 days interval. In general, the plant height increased with the increase in plant age of the varieties under the stress condition. An analysis of the data revealed that shoot elongation continued to increase plant height as the varieties progressed through its stages. A gradual increase in plant height was observed during the early growth stages up to 90 days after sowing (DAS), after which the growth rate slowed down, with a slight increase thereafter. When the sowing was done on 30<sup>th</sup> November then at 60 days the plant's height was recorded 54.74, 55.65 and 49.3 cm in all the 3 varieties of wheat. The decrease in plant height when sown late can be attributed to the shorter growing period. The value for the highest plant height was recorded 83.56 cm and at late sowing (30<sup>th</sup> December). The early-sown crop likely benefited from more favorable environmental conditions, especially in terms of both sun radiation and temperature, which resulted in taller plants (Table 1).

### Number of tillers per plant

In wheat, tillering is a crucial agronomic characteristic for grain production. The data demonstrates that the greatest number of tillers per plant was (6.6) observed at 75 DAS, independent of the sowing dates. The late variety, V3 (Kundan), showed a substantial drop in the number of tillers plant<sup>-1</sup> when seeded early (D1: 30<sup>th</sup> November), according to data about the effect of varieties and planting windows. The number of tillers plant<sup>-1</sup> also dramatically decreased when early types, such as V1 (PBW-343) and V2 (HD-2967), were seeded later (Table 1). This is explained by the emergence of adverse environmental circumstances for the crop.

**Table 1.** Effect of date of sowing on plant height and number of tillers at various stages of wheat varieties from the year 2023–24 (Pooled)

| Treatments                | Plant height (cm) |         |        |         |        |        |         |         |        |         |         |        | Number of tillers plant <sup>-1</sup> |         |        |         |         |        |
|---------------------------|-------------------|---------|--------|---------|--------|--------|---------|---------|--------|---------|---------|--------|---------------------------------------|---------|--------|---------|---------|--------|
|                           | 60 DAS            |         |        |         | 75 DAS |        |         |         | 90 DAS |         |         |        | 60 DAS                                |         | 75 DAS |         | 90 DAS  |        |
|                           | PBW-343           | HD-2967 | Kundan | PBW-343 | HD-297 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343                               | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan |
| 30 <sup>th</sup> November | 54.74             | 55.65   | 49.30  | 74.43   | 75.20  | 72.10  | 84.92   | 85.52   | 80.22  | 5.60    | 5.80    | 4.60   | 6.70                                  | 6.80    | 5.60   | 6.50    | 6.60    | 5.40   |
| 15 <sup>th</sup> December | 53.89             | 54.75   | 51.2   | 73.53   | 74.40  | 73.30  | 83.84   | 84.62   | 81.24  | 5.50    | 5.70    | 4.90   | 6.40                                  | 6.60    | 5.80   | 6.30    | 6.50    | 5.60   |
| 30 <sup>th</sup> December | 50.56             | 51.76   | 53.40  | 68.85   | 69.2   | 74.2   | 77.31   | 78.72   | 83.56  | 5.30    | 5.40    | 5.50   | 6.30                                  | 6.50    | 6.60   | 6.20    | 6.30    | 6.40   |
| Sem ± (V)                 | 0.61              | 0.65    | 0.51   | 0.53    | 0.55   | 0.53   | 3.28    | 3       | 3.27   | 0.13    | 0.12    | 0.11   | 0.07                                  | 0.06    | 0.05   | 0.05    | 0.04    | 0.03   |
| CD at 5% (V)              | 1.80              | 1.94    | 1.55   | 1.58    | 1.66   | 1.60   | 1.85    | 9.81    | 9.88   | 0.40    | 0.37    | 0.33   | 0.22                                  | 0.09    | 0.15   | 0.13    | 0.13    | 0.09   |
| Sem ± (T)                 | 0.67              | 0.65    | 0.66   | 0.75    | 0.76   | 0.77   | 0.69    | 0.68    | 0.67   | 0.05    | 0.04    | 0.03   | 0.05                                  | 0.04    | 0.03   | 0.05    | 0.06    | 0.04   |
| CD at 5% (T)              | 2.33              | 1.96    | 1.98   | 2.62    | 2.28   | 2.32   | 0.69    | 2.04    | 20.2   | 0.16    | 0.12    | 0.10   | 0.15                                  | 0.12    | 0.10   | 0.17    | 0.18    | 0.12   |
| SEm± (V × T)              | 1.26              | 1.25    | 1.24   | 1.1     | 1.3    | 1.2    | 1.1     | 1.2     | 1.3    | 0.12    | 0.13    | 0.11   | 0.12                                  | 0.13    | 0.11   | 0.09    | 0.08    | 0.07   |
| CD at 5% (V × T)          | 3.76              | 3.77    | 3.72   | 3.28    | 3.90   | 3.70   | 1.10    | 3.60    | 4.00   | 0.37    | 0.39    | 0.33   | 0.37                                  | 0.39    | 0.34   | 0.26    | 0.23    | 0.21   |

DAS: days after sowing; CD: critical difference.

**Chlorophyll content (mg g<sup>-1</sup> FW)**

The data clearly indicates that the three sowing dates (D1: 30<sup>th</sup> Nov, D2: 15<sup>th</sup> Dec and D3: 30<sup>th</sup> Dec) significantly affect the total chlorophyll content of all varieties (PBW-343, HD-2967 and Kundan) (Table 2). The total chlorophyll content of V1 (PBW-343) and V2 (HD-2967) increased at D1 (30<sup>th</sup> November) and D2 (15<sup>th</sup> December) but decreased at D3 (30<sup>th</sup> Dec). In contrast, the total chlorophyll content of the late variety V3 (Kundan) increased when sown late (D3: 30<sup>th</sup> December) and decreased when sown early (D1: 30<sup>th</sup> Nov). When the sowing was done on 30<sup>th</sup> November then at 60 days the total chlorophyll contents was 2.19, 2.2 and 1.9 (mg g<sup>-1</sup> FW.), at 15<sup>th</sup> December 53.89, 54.75 and 51.2 (mg g<sup>-1</sup> FW.) and at 30<sup>th</sup> December 1.92, 2.0, 2.11 (mg g<sup>-1</sup> FW.) in all the 3 varieties of wheat.

**Total soluble sugar (mg g<sup>-1</sup> DW)**

The data recorded at different crop growth stages for total soluble sugar (TSS) content in leaves, as shown in Table 2, indicate that the TSS content was significantly influenced by the time of sowing at various observation stages. As per data, it is evident that the TSS content increased with plant age at all stages. The minimum TSS content was observed in V3 at D3 (30<sup>th</sup> Dec), during the 60 DAS growth stage. A closer examination of the data reveals that sowing time plays a significant role in influencing the TSS content. The data clearly indicate that the late variety, V3 (Kundan), exhibited enhanced TSS content at all stages of observation when sown on all dates of sowing. Late sowing, i.e., D3 (30<sup>th</sup> December), caused the TSS content of the cultivars to significantly rise V1 (PBW-343) and V2 (HD-2967) compared to early sowing (D1: 30<sup>th</sup> November) at each crop growth stage.

**Proline content (mg g<sup>-1</sup> FW)**

Proline content, presented in Table 3, reveals that the proline content was significantly influenced by the different sowing dates at various crop growth stages. A closer examination of the data indicates discovered in all types, the proline content gradually rose as the plant became older. At D1 (30<sup>th</sup> November), the highest proline content was observed in V3 (Kundan), with values of 120, 150.58 and 180.67 mg g<sup>-1</sup> FW at 60, 75 and 90 DAS, respectively. At D2 (15<sup>th</sup> December), maximum proline content was again recorded in V3, with values of 104.1, 130.56 and 160.45 mg g<sup>-1</sup> FW at 60, 75 and 90 DAS, respectively. At D3 (30<sup>th</sup> December), the highest proline content was found in V2 (HD-2967), with values of 120.5, 140.45 and 183.7 mg g<sup>-1</sup> FW at 60, 75 and 90 DAS, respectively.

**Peroxidase activity (mg g<sup>-1</sup> min<sup>-1</sup> FW)**

The data on peroxidase activity, as presented in Table 3, indicate that peroxidase levels were significantly influenced by different sowing dates across various stages of crop growth. A detailed analysis of the data reveals a progressive increase in peroxidase content with plant age across all varieties. At D1 (30<sup>th</sup> November), the highest peroxidase content was observed in V2 (HD-2967), with values of 110.86, 120.5 and 125.47 mg g<sup>-1</sup> FW at 60, 75 and 90 DAS, respectively. At D2 (15<sup>th</sup> December), maximum peroxidase content was again recorded in V2, with values of 98.74, 105.4 and 112.45 mg g<sup>-1</sup> FW at 60, 75 and 90 DAS, respectively. At D3 (30<sup>th</sup> December), the highest peroxidase content was found in V3 (Kundan), with values of 10.35, 10.8 and 11.8 mg g<sup>-1</sup> when fresh weight was at 60, 75 and 90 DAS, respectively.

**Catalase content (mg g<sup>-1</sup> min<sup>-1</sup> FW)**

The data on catalase content presented in Table 4 demonstrate that catalase levels were significantly affected by different sowing dates

**Table 2.** Effect of date of sowing total chlorophyll content and total soluble sugar at various stages of wheat varieties of 2023–24 (Pooled)

| Treatments                | Total chlorophyll content (mg g <sup>-1</sup> FW) |         |        |         |         |        |         |         |        |         |         |        | Total soluble sugar (mg g <sup>-1</sup> DW) |         |        |         |         |        |
|---------------------------|---------------------------------------------------|---------|--------|---------|---------|--------|---------|---------|--------|---------|---------|--------|---------------------------------------------|---------|--------|---------|---------|--------|
|                           | 60 DAS                                            |         |        |         | 75 DAS  |        |         |         | 90 DAS |         |         |        | 60 DAS                                      |         | 75 DAS |         | 90 DAS  |        |
|                           | PBW-343                                           | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343                                     | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan |
| 30 <sup>th</sup> November | 2.19                                              | 2.2     | 1.90   | 1.74    | 1.80    | 1.48   | 1.43    | 1.40    | 1.12   | 57.5    | 77.07   | 120    | 88.79                                       | 110.13  | 150.58 | 110.6   | 125.6   | 180.67 |
| 15 <sup>th</sup> December | 2.1                                               | 2.1     | 1.98   | 1.65    | 1.7     | 1.54   | 1.35    | 1.40    | 1.21   | 85.8    | 94.54   | 104.1  | 113.5                                       | 125.4   | 130.5  | 128.5   | 148.5   | 160.4  |
| 30 <sup>th</sup> December | 1.92                                              | 2.00    | 2.11   | 1.52    | 1.60    | 1.72   | 1.18    | 1.20    | 1.42   | 101     | 120.5   | 83.63  | 130.6                                       | 140.4   | 105.5  | 155.8   | 183.7   | 120.4  |
| Sem ± (V)                 | 0.14                                              | 0.16    | 0.11   | 0.15    | 0.1     | 0.16   | 0.14    | 550.15  | 0.16   | 1.02    | 1111.03 | 1.04   | 0.11                                        | 0.10.12 | 0.13   | 1.36    | 1.37    | 1.38   |
| CD at 5 % (V)             | 0.45                                              | 0.49    | 0.33   | 0.46    | 052     | 048    | 0.42    | 0.45    | 0.49   | 3.07    | 3.09    | 3.13   | 0.36                                        | 0.37    | 0.39   | 4.35    | 4.11    | 4.15   |
| Sem ± (T)                 | 0.13                                              | 0.12    | 0.14   | 0.12    | 0.13    | 0.15   | 0.12    | 0.13    | 0.14   | 1.25    | 1.26    | 1.27   | 0.15                                        | 0.16    | 0.17   | 1.36    | 1.37    | 1.38   |
| CD at 5 % (T)             | 0.40                                              | 0.37    | 0.42   | 0.37    | 0.38    | 0.45   | 0.38    | 0.39    | 0.42   | 3.75    | 3.79    | 3.81   | 0.46                                        | 0.48    | 0.52   | 4.08    | 4.11    | 4.15   |
| Sem ± (V × T)             | 0.26                                              | 0.25    | 0.24   | 0.26    | 0.27    | 0.28   | 0.25    | 0.26    | 0.27   | 1.76    | 1.77    | 1.78   | 0.21                                        | 0.22    | 0.23   | 2.35    | 2.36    | 2.37   |
| CD at 5 % (V × T)         | 0.79                                              | 0.75    | 0.73   | 0.80    | 0.82    | 0.86   | 0.76    | 0.78    | 0.81   | 5.28    | 5.32    | 5.35   | 0.63                                        | 0.67    | 0.70   | 7.06    | 7.09    | 7.11   |

DAS: days after sowing; CD: critical difference.

**Table 3.** Effect of date of sowing on proline content (mg g<sup>-1</sup> fresh weight) and peroxidase activity (mg g<sup>-1</sup> fresh weight) at various stages of wheat varieties of 2023–24 (Pooled)

| Treatments                | Total proline (mg g <sup>-1</sup> FW) |          |          |         |         |        |         |         |        |         |         |        | Peroxidase activity (mg g <sup>-1</sup> min <sup>-1</sup> FW) |         |        |         |         |        |
|---------------------------|---------------------------------------|----------|----------|---------|---------|--------|---------|---------|--------|---------|---------|--------|---------------------------------------------------------------|---------|--------|---------|---------|--------|
|                           | 60 DAS                                |          |          |         | 75 DAS  |        |         |         | 90 DAS |         |         |        | 60 DAS                                                        |         | 75 DAS |         | 90 DAS  |        |
|                           | PBW-343                               | HD-2967  | Kundan   | PBW-343 | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan | PBW-343                                                       | HD-2967 | Kundan | PBW-343 | HD-2967 | Kundan |
| 30 <sup>th</sup> November | 57.5                                  | 77.07    | 120      | 88.79   | 110.13  | 150.58 | 110.60  | 125.60  | 180.67 | 105.60  | 110.86  | 80.54  | 112.4                                                         | 120.50  | 90.46  | 120.40  | 125.47  | 102.44 |
| 15 <sup>th</sup> December | 85.80                                 | 94.54    | 104.1    | 113.5   | 125.45  | 130.56 | 128.50  | 148.50  | 160.45 | 90.65   | 98.74   | 88.65  | 98.79                                                         | 105.4   | 96.47  | 110.40  | 112.45  | 108.46 |
| 30 <sup>th</sup> December | 101                                   | 120.5.00 | 83.63.00 | 130.60  | 140.45  | 105.56 | 155.8   | 183.7   | 120.45 | 75.54   | 83.38   | 103.5  | 82.57                                                         | 91.4    | 108.43 | 103.4   | 109.33  | 118.35 |
| Sem ± (V)                 | 1.02                                  | 1.03     | 1.04     | 0.11    | 0.12    | 0.13   | 1.36    | 1.35    | 1.37   | 1.04    | 1.05    | 1.03   | 0.12                                                          | 0.13    | 0.14   | 1.39    | 1.40    | 1.41   |
| CD at 5 % (V)             | 3.07                                  | 3.06     | 3.03     | 0.36    | 0.35    | 0.39   | 4.35    | 4.25    | 4.42   | 3.19    | 3.16    | 3.09   | 0.37                                                          | 0.39    | 0.42   | 4.36    | 4.21    | 4.43   |
| Sem ± (T)                 | 1.25                                  | 1.26     | 1.27     | 0.15    | 0.16    | 0.17   | 1.36    | 1.37    | 1.38   | 1.27    | 1.26    | 1.25   | 0.16                                                          | 0.17    | 0.18   | 1.2     | 1.3     | 1.4    |
| CD at 5 % (T)             | 3.12                                  | 3.78     | 3.79     | 0.46    | 0.48    | 0.52   | 4.3     | 4.4     | 4.5    | 3.22    | 3.72    | 3.76   | 0.48                                                          | 0.52    | 0.55   | 3.61    | 3.91    | 4.22   |
| Sem ± (V × T)             | 1.76                                  | 1.77     | 1.78     | 0.21    | 0.22    | 0.23   | 2.35    | 2.36    | 2.37   | 1.8     | 1.9     | 2.0    | 0.21                                                          | 0.22    | 0.23   | 2.39    | 2.40    | 2.41   |
| CD at 5 % (V × T)         | 5.42                                  | 5.31     | 5.39     | 0.63    | 0.66    | 0.70   | 7.6     | 7.08    | 7.11   | 5.52    | 5.71    | 6.0    | 0.64                                                          | 0.66    | 0.71   | 7.7     | 7.20    | 7.28   |

DAS: days after sowing; CD: critical difference.



starch synthesis. Additionally, heat and moisture stress limit carbohydrate utilisation, leading to accumulation of soluble solids in the grains. Chlorophyll decreases in late-sown wheat mainly due to higher temperature stress during the growth period, which accelerates chlorophyll degradation and reduces its synthesis. Additionally, shortened growth duration and early leaf senescence limit chlorophyll accumulation, leading to reduced photosynthetic capacity. Antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD) neutralise these ROS, preventing damage to chlorophyll, proteins and cell membranes. Thus, these enzymes protect cellular structures, maintain photosynthesis and delay stress-induced senescence, helping the plant survive under late-sowing stress conditions.

Delayed sowing further exposes the grain-filling stage to high temperatures, thereby affecting yield potential. Many physiological functions, including as photosynthetic rate, transpiration activity and wheat grain growth rate, might be severely hampered by high temperatures. Photosynthesis is one of the primary physiological processes that significantly impacts grain yield in wheat. Moreover, heat stress is also reported to decrease grain size, grain weight, plant biomass and plant height, as well as shorten the life cycle, which ultimately results in reduced grain yield in wheat. A field experiment was conducted during the 2023–24 rabi season to investigate the effect of temperature stress on various growth, physiological and biochemical parameters, as well as yield attributes in wheat. The results obtained have been discussed under the following headings: The differences in plant height among varieties may be attributed to their genetic diversity. These results are consistent with those reported by previous researchers (16). The counting of tiller number provides valuable information on the stress profile of plant under abiotic conditions (17).

Early sowing generally resulted in more tillers per plant and higher plant height. These findings are consistent with the results reported previously (18). Wheat leaf growth and productive tiller production may be severely impacted by daytime and nighttime temperatures of about 30 and 25 °C, respectively.

Similar findings were reported in previous studies, which also observed a significant reduction in chlorophyll content with age and under late sowing at all plant growth stages (19). This could be because higher chlorophyll content contributes to a higher photosynthetic rate, which ultimately produces more photosynthetic. In wheat, high temperatures can damage chloroplast integrity, hasten leaf senescence and eventually impede photosynthesis (20–23). Chlorophyll deficiency reduces the absorption of light energy and its transfer to the reaction centers (RCs) of PS-II and PS-I under high temperatures in wheat (5).

In contrast, the late variety, V3 (Kundan), exhibited a maximum increase of 30.31 % in proline content when sown early at 60 DAS. Heat stress triggers the production of several antioxidants and active oxygen species-scavenging enzymes, including peroxidase (PRX). In the presence of H<sub>2</sub>O<sub>2</sub>, peroxidase oxidises a wide range of substances (hydrogen donors). The PRX enzyme's activity increased under high-temperature stress and it has been linked to the development of heat-stress-induced physiological damage in plants (24–26).

## Conclusion

The study underscores the impact of high temperature stress, which induced a significant change in physio-biochemical attributes. The study also revealed on elucidating the effects of terminal temperature stress on the physio-biochemical traits of wheat (*Triticum aestivum*). Also considering the physiochemical parameters will also affect the yield of wheat significantly. Wheat biomass output and soluble sugar accumulation are greatly reduced when high temperature stress (35/27 °C) is applied during the seedling stage. D1-pyrroline-5-carboxylate synthetase/reductase (P5CS) and proline dehydrogenase activities control proline build-up (21). Proline dehydrogenase catalyses proline degradation in mitochondria, however when P5CS1 is present, glutamate functions as a precursor, promoting proline synthesis and accumulation in heat-stressed environments. The proline content is closely associated with high temperatures (35–40 °C), which trigger defence mechanisms in wheat seedlings. At 35 °C, proline content can accumulate up to 200 %, improving photosynthetic efficiency and yield compared to temperatures of 25 °C. According to the proline content data, proline accumulation was considerably increased when early varieties V1 (PBW-343) and V2 (HD-2967) were sown later.

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## Authors' contributions

AKS and SS<sup>1</sup> contributed equally to writing the original draft, methodology, investigation, formal analysis and conceptualisation. SS<sup>2</sup> contributed to writing - review and editing, formal analysis and conceptualisation. RK contributed to writing - review and editing and formal analysis. RBS contributed to writing - review and editing. SRM contributed to writing - review and editing and supervision. All authors read and approved the final manuscript [SS<sup>1</sup>- Shraddha Singh and SS<sup>2</sup>- Sneha Singh].

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interest to declare.

**Ethical issues:** None

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