



RESEARCH ARTICLE

Characterisation of bread wheat genotypes under terminal heat stress based on canopy temperature and relative water content

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Abstract

Terminal heat stress is a major limitation to wheat productivity in India, especially under late-sown conditions where crops are exposed to elevated temperatures during the reproductive stage. The identification of reliable physiological traits for screening heat-tolerant genotypes remains a challenge. In the present study, four bread wheat (*Triticum aestivum* L.) genotypes-DBW222, RAJ4238, HD3118 and HD3171-were evaluated under timely and late-sown conditions during the 2024–25 season at Banasthali Vidyapith. Canopy temperature (CT) and relative water content (RWC) were used as key physiological indicators to assess plant response under heat stress conditions. Significant variation among genotypes was observed, with CT ranging from 31.3 °C (HD3118) to 42.1 °C (HD3171), while RAJ4238 recorded the highest RWC (85.61 %) under stress. The comparatively higher CT in some genotypes indicated reduced cooling ability, whereas higher RWC suggested better water retention capacity. Based on heat susceptibility index (HSI), HD3171 showed higher tolerance, whereas DBW222 was identified as sensitive. A relationship ($R^2 = 0.715$) between CT and RWC suggests that genotypes maintaining better water status were able to regulate CT more effectively. Overall, the findings highlight that CT and RWC can serve as useful physiological traits for screening wheat genotypes under terminal heat stress conditions.

Keywords: canopy temperature; genotype; heat stress; relative water content; wheat

Introduction

Heat stress is one of the major abiotic factors affecting wheat production worldwide. Wheat is cultivated over approximately 218 million hectares globally and in India it contributes significantly to food security, with production reaching about 106.84 million tonnes during 2021–22 (1). However, increasing temperatures in recent years have emerged as a serious concern, particularly during the reproductive stage of the crop. High temperature stress adversely affects grain yield and yields contributing traits in wheat (2).

In India, delayed sowing is a common practice due to late harvesting of preceding crops such as rice and cotton. As a result, a large proportion of wheat is exposed to terminal heat stress during grain filling. This condition accelerates senescence, reduces water status and ultimately affects yield. Among various physiological traits, relative water content (RWC) is considered an important indicator of plant water status under stress conditions (3).

To address this, researchers have used canopy temperature (CT) as an important physiological trait for identifying heat-tolerant wheat (4). Using infrared thermometry, CT can be measured rapidly without damaging the plants (5, 6). Agronomic practices and nutrient management also influence physiological and yield-related traits under stress conditions in wheat (7). It reflects the plant's ability to regulate temperature through transpiration. Since canopy temperature often differs

from ambient air temperature, it provides a better indication of the actual stress experienced by the plant (8–10). This temperature is influenced by plant characteristics, soil moisture and environmental conditions (11). Therefore, CT has been widely used as a useful indicator of plant response under heat stress conditions (12).

Despite this understanding, limited information is available on the performance of recently developed wheat genotypes under terminal heat stress conditions in the Rajasthan region. The present study was conducted to evaluate the physiological response of four bread wheat genotypes. The objective was to assess the usefulness of CT and RWC as screening traits for identifying heat-tolerant genotypes under late-sown conditions.

Materials and Methods

Four bread wheat (*Triticum aestivum* L.) genotypes-DBW222, RAJ4238, HD3118 and HD3171—representing diverse Indian agro-climatic zones were utilised in the study conducted during 2024–25. Seeds of HD3118 and HD3171 were obtained from ICAR–Indian Institute of Wheat and Barley Research (IIWBR), Karnal, Haryana, India, while DBW222 and RAJ4238 were sourced from Krishi Vigyan Kendra, Banasthali Vidyapith, Tonk, Rajasthan, India. The pedigrees of the genotypes are as follows: HD3118 (PBW343 × HD2733), HD3171 (PBW550 × HD2733), DBW222 (PBW343 × HD2967) and RAJ4238 (HD2733 × PBW550).

The trial followed a randomised block design (RBD) with 3 replications. Each plot consisted of four rows (2 m length) with 10 cm plant-to-plant and 22.5 cm row-to-row spacing. Two sowing times were used: mid-November for timely sowing and mid-December for late sowing. Standard agronomic practices, including recommended fertilisation and irrigation, were applied to ensure optimal growth. Weather data for the study period were not recorded; however, all experiments were conducted under field conditions.

Canopy temperature

Measurements were recorded seven days post-anthesis using an infrared thermometer between 12:00 and 15:00 hr on cloudless days (13). The sensor was positioned 50 cm above the canopy at a 30° angle to the horizon to minimise soil interference (14, 15). The selected angle and distance were maintained consistently across all observations to ensure uniformity and minimise measurement bias. This approach allowed accurate assessment of canopy thermal status, which is a reliable indicator of plant response to heat stress.

Relative water content

Leaf hydration was determined using the method described by Barrs and Weatherley. Fresh weight (FW) was recorded immediately after sampling. Turgid weight (TW) was obtained after immersing leaves in distilled water for 18 hr at room temperature and dry weight (DW) was recorded after oven-drying at 80 °C for 48 hr (16).

RWC was calculated using the following formula (16).

$$\text{RWC} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Statistical analysis

The experimental data obtained from 3 replications were subjected to analysis of variance (ANOVA) using Microsoft Excel 2021 (Microsoft Corporation, USA) to determine the significance of differences among genotypes under timely and late-sown conditions. Mean values were compared at a 5 % level of significance ($p \leq 0.05$). Variability among genotypes was assessed using standard error (SE) and coefficient of variation (CV) to evaluate the consistency and reliability of measurements.

Heat susceptibility index (HSI) was calculated to assess genotypic response under stress conditions. Correlation and regression analysis were performed between CT and RWC and the coefficient of determination (R^2) was used to determine the strength of association between these traits.

The following formula was used to calculate the HSI (17, 18).

$$\text{HSI of } X = (1 - X_{\text{heat stress}}/X_{\text{control}})/D$$

The phenotypic value of timely seeded genotypes is denoted by X control, while the phenotypic value of late-sown genotypes is denoted by X heat stress, where X stands for characteristics.

$$D (\text{stress}) = \frac{1 - Y_{\text{heat stress}}}{Y_{\text{control}}}$$

Y heat stress is the X heat stress mean of all genotypes and Y control is the X control mean of all genotypes.

The HSI was used to classify genotypes into different tolerance groups. Genotypes with HSI < 0.5 were considered tolerant, those with HSI between 0.5 and 0.99 were moderately tolerant, while genotypes with HSI ≥ 1 were classified as sensitive (17, 18).

Results and Discussion

Relative water content

Relative water content differed significantly among wheat genotypes under both control and heat stress conditions (Fig. 1). Under control conditions, RWC ranged from 77.27 % in HD3171 to 97.33 % in DBW222, whereas under heat stress it decreased in all genotypes and ranged from 63.89 % in DBW222 to 85.61 % in RAJ4238. The reduction in RWC under stress conditions indicated the adverse effect of elevated temperature on plant water balance and cellular hydration. Similar reductions in RWC under heat stress in wheat have also been reported earlier, where high temperature was found to disrupt water retention capacity and reduce cellular turgidity in wheat plants (14, 16).

Among the studied genotypes, DBW222 showed the highest reduction in RWC with a HSI value of 2.14, indicating greater sensitivity to terminal heat stress. In contrast, HD3171 maintained comparatively stable water status with a lower HSI value (0.05), suggesting better tolerance under stress conditions. RAJ4238 also maintained relatively higher RWC under stress and showed moderate tolerance (HSI = 0.66). The ability of tolerant genotypes to maintain higher RWC under stress conditions may be associated with improved water conservation and better physiological adjustment under elevated temperature conditions (19). The HSI values for RWC under control and heat stress conditions are presented in Table 1.

Canopy temperature response

Canopy temperature differed significantly among wheat genotypes under both control and heat stress conditions (Fig. 2). Under control conditions, CT ranged from 32.7 °C in HD3118 to 43.7 °C in HD3171, while under heat stress it ranged from 31.3 °C in HD3118 to 42.1 °C in HD3171. Significant genotypic variation ($p \leq 0.05$) indicated differential responses of genotypes to stress conditions. Similar variation in CT under stress has also been reported previously (14, 20).

DBW222 showed relatively higher CT under stress with a higher HSI value (1.10), indicating susceptibility. In contrast, HD3118 (HSI = 1.09) and RAJ4238 (HSI = 0.95) maintained comparatively lower CT, suggesting better cooling ability under stress conditions. HD3171 exhibited comparatively higher CT but showed moderate tolerance (HSI = 0.94). Similar findings associating lower CT with improved stress tolerance and yield stability in wheat have also been reported (21).

The variation in CT among genotypes may be related to differences in transpiration efficiency and plant water status under stress conditions (19). Low standard error values indicated consistency among replicates. The HSI values for CT under control and heat stress conditions are presented in Table 2.

Table 1. Heat susceptibility index (HSI) value of relative water content of wheat genotypes

Genotypes	HSI
DBW222	2.14
RAJ4238	0.66
HD3118	1.01
HD3171	0.05

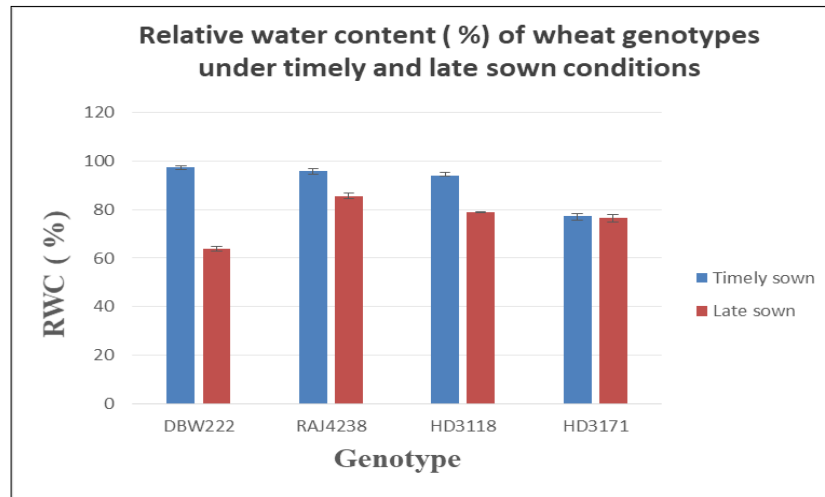


Fig. 1. Relative water content (%) of wheat genotypes under timely and late sown conditions. Error bars represent mean $\pm$ SE (n = 3).

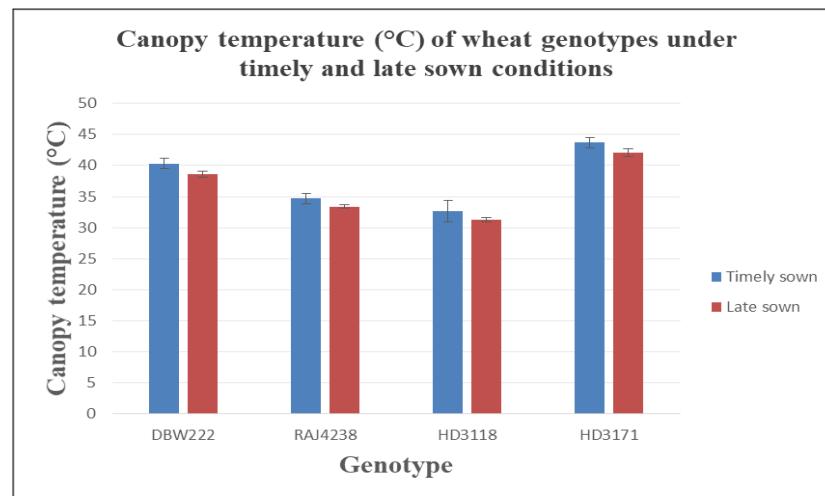


Fig. 2. Canopy temperature (°C) of wheat genotypes under timely and late sown conditions. Error bars represent mean $\pm$ SE (n = 3).

Table 2. Heat susceptibility index (HSI) value of canopy temperature of wheat genotypes

Genotypes	HSI
DBW222	1.10
RAJ4238	0.95
HD3118	1.09
HD3171	0.94

Variability and association between relative water content and canopy temperature

Variability among genotypes was assessed using standard error (SE) and coefficient of variation (CV). For RWC, the CV ranged from 0.90–1.53 % under control conditions and 0.35–1.92 % under heat stress, indicating low experimental variation. Similarly, CT showed CV values ranging from 2.02–5.42 % under control and 0.69–1.45 % under stress conditions, suggesting good consistency of observations across replications.

Low SE and CV values indicated the reliability and uniformity of the recorded data. Similar use of CV and SE for evaluating precision in physiological studies of wheat under stress conditions has also been reported (22).

Regression analysis between CT and RWC showed a significant association ($R^2 = 0.715$), indicating that genotypes maintaining higher plant water status were able to regulate CT more effectively under stress conditions. Similar relationships between CT and plant water status under stress have also been reported previously (14, 19).

Heat susceptibility index interpretation

HSI clearly differentiated genotypes:

- HSI < 0.5 $\rightarrow$ Tolerant (HD3171 for RWC)
- HSI 0.5–0.99 $\rightarrow$ Moderately tolerant (RAJ4238)
- HSI $\geq 1 \rightarrow$ Sensitive (DBW222, HD3118)

The heat susceptibility index effectively differentiated the wheat genotypes into tolerant and sensitive groups. HD3171 showed greater tolerance based on lower HSI values, whereas DBW222 was identified as sensitive to terminal heat stress. RAJ4238 exhibited moderate tolerance and stable physiological performance under stress conditions. The usefulness of HSI for identifying tolerant genotypes under stress conditions has also been reported previously (17). The present findings therefore indicate that relative water content, CT and heat susceptibility index are reliable physiological indicators for screening wheat genotypes against terminal heat stress.

Conclusion

The study demonstrated clear differences among wheat genotypes under terminal heat stress. Relative water content (RWC) proved to be a more reliable indicator of tolerance, as it directly reflects plant water status under stress conditions. Although canopy temperature (CT) provided useful insights into cooling ability, it was not sufficient alone, as observed in HD3118.

Among the genotypes, DBW222 showed higher sensitivity due to a greater reduction in RWC, whereas RAJ4238 and HD3171 maintained better water status and exhibited improved tolerance. Overall, the combined use of RWC and CT can serve as an effective approach for screening heat-tolerant wheat genotypes.

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Authors' contributions

MC performed the experiment, completed data analysis and wrote the manuscript. PH and AK edited the manuscript. GCP reviewed the research, provided guidance and assisted with data analysis and manuscript improvement. All authors have read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used QuillBot tool to paraphrase the content. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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