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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(4): 2537-2546

www.thepharmajournal.com
Received: 20-02-2023
Accepted: 25-03-2023

**Totewad Prashant Kumar**
Ph.D. Research Scholar, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. Maharashtra, India

**Bhadarge Hiraman**
Pearl Millet Breeder, National Agriculture Research Project, Cha. Sambhajinagar. Maharashtra, India

**Ghuge Shyamrao**
Officer In-Charge, AICRP on Safflower VNMKV, Parbhani, Maharashtra, India

**Jadhav Abhay**
Officer in-Charge Breeder Seed Production, VNMKV, Parbhani, Maharashtra, India

**Thakur Niranjan**
(1) Ph.D. Research Scholar, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. Maharashtra, India
(2) International Crop Research Institute for the Semi-Arid Tropics, Patancheru, Hyderabad, Telangana, India

**Naik Gajanan**
Ph.D. Research Scholar, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. Maharashtra, India

**Corresponding Author:**
**Totewad Prashant kumar**
Ph.D. Research Scholar, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. Maharashtra, India

# Effect of high temperature stress on morpho-physiological and biochemical traits in wheat genotypes for heat tolerance

**Totewad Prashant Kumar, Bhadarge Hiraman, Jadhav Abhay, Ghuge Shyamrao, Thakur Niranjan and Naik Gajanan**

**Abstract**
The field experiment was conducted to study the "Morpho-physiological and biochemical studies for heat tolerance traits in wheat (*Triticum aestivum* L.) genotypes." at the farm of Wheat and Maize Research Unit, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, during *rabi* season of 2020-21 and 2021-22. Total 16 genotypes collected from Wheat and Maize Research Unit, VNMKV, Parbhani was taken to conduct the experiment. The experiment was laid out in simple lattice design. The high temperature stress was induced by manipulation of sowing dates. Different morpho-physiological and biochemical traits *viz.*, plant height, flag leaf area, tillers per meter row length, relative water content, membrane stability index, chlorophyll content, pollen viability and canopy temperature. The genotypes HD-3090, MACS-4058 and MP-1358 were shown to be extremely thermo tolerant based on HSI and grain yield, and they have tremendous economic value. The genotype HD-3090 was shown to be acceptable for both early and late sowing circumstances. These traits may be used in breeding programme for development of thermo tolerant genotypes for late condition under changing climatic scenario.

**Keywords:** Canopy temperature, chlorophyll content, heat stress, heat susceptibility index, pollen viability, simple lattice design

## 1. Introduction
Wheat (*Triticum aestivum* L.), a crop of the gramineae family, is native to South West Asia. It is the most widely grown food crop in the world and is therefore referred to as the "King of all cereal crops" due to its ease of cultivation, economic viability, and high nutritious content. It is abundant in vitamins, minerals, gluten, calcium, lysine, and carbohydrates. It contains 7–12 percent protein. After rice, it is the second-most significant crop in India.
The *Triticeae* family of the Poaceaceae grass family, which includes wheat, is characterized by one to several sessile, alternately positioned, flower-bearing spikelets on the opposite side of the rachis, generating a true spike. According to wheat, which is classified into these three groupings, diploid has 14 (n=7), tetraploid has 28 (n=14), and hexaploid has 42 (n=21) chromosomes. *Triticum dicoccum* L. (2n=14), also referred to as emmer wheat, *Triticum aestivum* L. (2n=42), sometimes referred to as bread wheat, *Triticum durum* L. (2n=28), also referred to as macaroni wheat, and *Triticum dicoccum* L. (2n=14) are the four species. All three of these extinct species were the result of ancestor-to-ancestor hybridization. Since the commencement of the wheat revolution in India in 1967, the amount of land planted with wheat has gradually expanded, as has production and productivity. Wheat output worldwide totals 584.76 MT, with an area of 215.26 Mha and a productivity of 2715 kg/ha. It occupied a 31.35 Mha area in India in 2019–2020, producing 107.86 MT overall and producing at a productivity of 3440 kg/ha. It occupied 1056 Mha in the state of Maharashtra, producing 1793.68 MT overall and 1697 kg/ha on average. (Anonymous, 2020).
A growing global population, coupled with climate change imposing more frequent natural disasters, renders the world's food security with unprecedented pressure and challenges. The world population is expected to reach 9.7 billion by 2050, and about 70% more food needs to be produced in order to meet the food demand (Tripathi *et al*, 2019) [20].
A recent FAO report indicates that in 2020, an additional 83 to 132 million people will be added to the ranks of the undernourished due to the COVID-19 pandemic, which illustrates the fragility of global food production and supply, and a significant delay on the track to achieve Zero Hunger (FAO 2020).

Therefore, it is urgent to design proper crop ideotypes to boost more production and avoid global food insecurity.

Heat stress shortens the grain filling duration and decrease starch and protein accumulation due to reduce activity of grain biosynthesis enzymes and impaired Flag leaf assimilatory efficiency and stem reserve mobilization the development of heat tolerant wheat genotype through screening, selection and breeding using genetic engineering. (Aman Ullah, 2022)

The effects of climate change on crop output constitute a threat to global food security, and it is anticipated that rising temperatures will have a greater influence on maintaining wheat production (Tripathi*et al*. 2016) [22].

The shortest developmental stages caused by high temperatures, lower light perception across the shorter life cycle, and disruption of the carbon absorption mechanisms are the main causes of heat stress-related yield loss in wheat transpiration, photosynthesis and respiration. (Stone., 2001) [23]

## 2. Materials and Methods

### 2.1 Experimental layout

The experiment was carried out at 'Wheat and Maize Research Unit, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, MS, India in two seasons i.e., *Rabi* 2020-21 and *Rabi* 2021-22. Randomization of treatments was made in both the seasons 32 treatments (16 x 2) were laid out in a simple lattice design with two replications. The high temperature stress was induced by manipulation of sowing dates i.e., normal sowing and late sowing. All agronomic packages of practices were carried out as per recommendation for raising for the good quality crop.

### 2.2 Experimental material

Experiment comprises of 32 genotypes collected from Wheat and Maize Research Unit, VNMKV, Parbhani, MS, India. This includes 10 checks and 6 germplasm. Genotypes used in the study are mentioned in Table 1.

**Table 1:** Genotypes used in the experiment for heat tolerance traits

| Sr. No. | Genotype | Sr. No. | Genotype |
|---|---|---|---|
| 1 | MP-3288 | 9 | HI-8823 (d) |
| 2 | MACS-4058 (d) | 10 | MACS-3949 (d) |
| 3 | HI-1636 | 11 | AKDW-2997-16 (d) |
| 4 | UAS-446 (d) | 12 | MP-1358 |
| 5 | HI-8805 (d) | 13 | HD-3090 |
| 6 | DDW-47 (d) | 14 | WH-730 |
| 7 | DBW-150 | 15 | HI-1544 |
| 8 | HI-1605 | 16 | GW-513 |
| (d) indicates *Durum* wheat | | | |

### 2.3 Observation recorded

**2.3.1 Plant height (cm):** Plant height was measured in order to know the extent of plant growth. Records on maximum height of main shoot were started at thirty days after sowing and fortnightly observations were taken both under normal and late sown conditions. The height of the plant was measured in cm from the base of the plant (ground level) to the tip of the plant before earhead emergence and up to the terminal spikelet excluding the awns after earhead emergence until maturity and mean values were calculated.

**2.3.2 Number of tiller:** Total number of tillers including main shoot in one meter row length from each net plot were counted from forty five days after sowing both under normal and late sown conditions. Two rows from each net plot were labeled and counted total tillers from this every time and then mean values were calculated.

**2.3.3 Flag leaf area ($dm^2$) $plant^{-1}$:** Flag leaf area $plant^{-1}$ was measured at 60 DAS from the plants used for measurement total leaf area plant under both normal and late sown condition. Flag leaf area ($dm^2$) plant was measured by using automatic leaf area meter.

**2.3.4 Chlorophyll content (SPAD):** The observations were recorded during the day time between 11 am. to 14 pm. chlorophyll content values were recorded at the time of 15 days after anthesis and 21 days after anthesis by using the chlorophyll meter, model no. (SPAD-250 plus) was used to measure the greenness or the relative chlorophyll concentration of leaves. Recorded during both the years of experiments, under normal and late sown condition. For recording the observations three leaves were randomly selected from each genotype and replication. Then mean values of chlorophyll content of three leaves were calculated

**2.3.5 Relative water content (%):** Relative water content (RWC) of leaves was estimated by using relative turgidity technique. The standard procedure given by Barrs and Weatherley (1962) [24] was used. RWC were estimated at 60 days after sowing. 2nd leaf from top of the plant and flag leaves were used at 60 DAS respectively. Whole leaves method were used. Three leaves from each genotype and replication for both the years of experiments were used. The relative water content then calculated by formula given below.

$$\text{RWC (\%)} = \frac{\text{Fresh weight (g)} - \text{Dry weight (g)}}{\text{Turgid weight (g)} - \text{Dry weight (g)}} \times 100$$

**2.3.6 Canopy temperature:** Canopy temperature measurements were made by using a hand held infrared thermometer. Two measurements were recorded per plot (genotype and replication wise) at approximately 0.5 m from the edge of the plot and approximately 0.5 m above the crop canopy with an approximately 45° from the horizontal. Measurements were done at 14.00 hours on cloud less, bright days. Two readings in each plot were taken at 2nd week after anthesis and 3rd week after anthesis during both the years under normal and late sown conditions. Rosyara (2008).

**2.3.7 Pollen viability:** Pollen viability was estimated using staining techniques, acetocarmine. 1%acetocarmine (0.2 g acetocarmine and dissolved in 20 ml distilled water) was used in the first step and a drop of the mixture was dropped on a microscope slide and the pollen spread with a slim brush and covered with a cover slip.Pollen viability counts were made five minutes after pollen was placed in an acetocarmine solution. Pollen grains stained dark red or brown color were counted as alive.

**2.3.8 Membrane thermo stability:** Membrane stability index was determined at 60 days after sowing under normal and late sown conditions in both the years of experiments. Membrane stability index was determined by recording the electrical conductivity of flag leaf leachets in double distilled water at 50 and 100 °C (Sairam *et al.*, 1997) [20].

$$\text{Cell membrane thermostability index} = 100 - (c_1/c_2) \times 100$$

Electrical conductivity (EC) meter was used to analyze membrane thermo stability index. SPAD meter is used for measuring chlorophyll content from the leaf. Hand Infrared thermometer was used for measuring canopy temperature and automatic leaf area meter was used for measuring flag leaf area.

**2.4 Statistical analysis**

The analysis of variance was performed as to get the significance of differences between the treatments for all the characters as per the methodology suggested by Jayaraman (1999) [25].The statistical model used for the design was as followes;

$$Y_{ijk} = \mu + \pi_i + \beta_{i(l)} + T_j + E_{ij(l)}.$$

Where,

| | | |
|---|---|---|
| $Y_{ijk}$ | = | Response value of $i^{th}$ treatment in the $i^{th}$ block within $i^{th}$ replication |
| $\mu$ | = | effect of mean |
| $\pi_i$ | = | effect of replicate |
| $\beta_{i(l)}$ | = | effect of incomplete block |
| Ti | = | effect of treatment |
| $E_{ij(l)}$ | = | effect of intra block residual |

The analysis of variance based on this model is given in the Table 2.

**Table 2:** Analysis of variance for experimental design

| Source of variance | Degree of Freedom | Sum of Squares | Mean sum of Squares | Fcal |
|---|---|---|---|---|
| Replications | (r-1) | SSR | MSR | MSR/MSE |
| Treatments (unadjusted) | ($k^2$-1) | SST(adj.) | MST | MST (unadjusted) / MSE |
| Blocks within replication (adjusted) | r(k-1) | SSB | MSB (adj.) | MSB (adjusted) / MSE |
| Intra block error | (k-1) (rk-k-1) | SSE | MSE | - |
| Total | $rk^2$-1 | - | - | - |

## 3. Result and discussion

### 3.1 Plant height cm) at 30, 60, and 90 days after sowing under normal and late sown condition

The genotype in normal sown condition MACS-4058 (45.79 cm) as well as in late sown MACS-4058 (41.29 cm) exhibited tall plant height. However, dwarf plant height was observed in genotype HI-1636 (33.14 cm). The genotype HI-1636 (28.64 cm) dwarf plant height recorded. General mean for plant height of all genotypes tested was 36.48 cm at 30 DAS.

Genotype MACS-4058 (87.55 cm) when sown at normal date exhibited maximum plant height. However, maximum plant height was observed in genotype MACS-4058 (93.05 cm) under late sown condition. While dwarf plant height was observed in the genotype MACS-3949 in normal sown (60.15 cm) and late sown condition (65.65 cm). General mean for plant height of all genotypes tested was 75.05 cm at 60 DAS.

Genotypes *viz.*, MACS-4058 (108.76 cm), WH-730 (101.48 cm), HD-3090 (97.29 cm) showed tall plant type by exhibiting more than 90 cm plant height. However, genotypes *viz.*, MACS-3949 (73.67), HI-1636 (76.96 cm), AKDW-2997-16 (83.84 cm) and HI-8823 (83.40 cm) shown dwarf plant type exhibiting less than 85 cm plant height. The delayed planting high temperature stress at maturity caused a 9.6% decrease in plant height in the present experiment. The suppression of cell elongation over 32 °C may be the cause of the decrease in plant height. Many studies reported finding outcomes that were similar, according to Allan *et al.* (1962) [2], cell elongation is inhibited at temperatures above 32 °C, which shortens wheat coleoptiles. Singh and Pal (2003) [16] found that a one-month delay in planting resulted in a 10% reduction in plant height in a pot experiment. According to a 2009 research by Anonymous, the average plant height of the 36 wheat genotypes examined at 7 sites in India varied from 91 cm under normal sowing conditions to 81 cm in late-sown wheat crops. Also similar findings were previously noticed by Mukherjee (2012) [9] and Nidhi Srivastava *et al.* (2012) [10].

### 3.2 Number of tiller at 45 days after sowing

Among the wheat genotypes, tillers per meter row length varied from 122.13 (HI-1636) to 167.63 (HI-8805) with the general mean for genotypes are 141.00. Significantly highest tillers per meter row length were produced by genotype HI-8805 (167.63) followed by HI-1605 (164.13), MP-1358 (161.63) and MP-3288 (152.13) on the pooled basis. The number of tillers per meter of row length at 45 DAS decreased number of tiller in late sown condition due to high temperature stress. Similar findings were reported by Singh *et al.* (2001$^b$) [26] showed that increased thermal stress caused a reduction in a number of tillers when eight wheat cultivars were grown in timely and hyperthermal field conditions. Venkatramanan and Singh (2009) [19] demonstrated that higher day and night temperatures (+2.40 °C) markedly reduced the production and growth of tillers. Crops with longer stems must compete with tillers for nutrients nitrogen and assimilates in situations with greater temperatures stress due to shorter crop development times, faster respiration growth, and poorer biomass production.

**Table 3:** Mean performances of plant height (cm) wheat genotypes under normal and late sown condition at 30 and 60 DAS

| Sr. No | Genotypes | Plant height at 30 DAS | | | | | | Pooled | | | Plant height at 60 DAS | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | Late | mean | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean |
| 1 | GW-513 | 33.71 | 30.21 | 31.96 | 37.21 | 31.71 | 34.46 | 35.46 | 30.96 | 33.21 | 62.53 | 70.03 | 66.28 | 67.03 | 70.53 | 68.78 | 64.78 | 70.28 | 67.53 |
| 2 | MP-1358 | 38.76 | 35.26 | 37.01 | 42.26 | 36.76 | 39.51 | 40.51 | 36.01 | 38.26 | 72.48 | 79.98 | 76.23 | 76.98 | 80.48 | 78.73 | 74.73 | 80.23 | 77.48 |
| 3 | HI-8823 | 33.95 | 30.45 | 32.20 | 37.45 | 31.95 | 34.70 | 35.70 | 31.20 | 33.45 | 65.33 | 72.83 | 69.08 | 69.83 | 73.33 | 71.58 | 67.58 | 73.08 | 70.33 |
| 4 | WH-730 | 40.55 | 37.05 | 38.80 | 44.05 | 38.55 | 41.30 | 42.30 | 37.80 | 40.05 | 78.87 | 86.37 | 82.62 | 83.37 | 86.87 | 85.12 | 81.12 | 86.62 | 83.87 |
| 5 | AKDW-2997-16 | 32.45 | 28.95 | 30.70 | 35.95 | 30.45 | 33.20 | 34.20 | 29.70 | 31.95 | 60.61 | 68.11 | 64.36 | 65.11 | 68.61 | 66.86 | 62.86 | 68.36 | 65.61 |
| 6 | DDW-47 | 33.20 | 29.70 | 31.45 | 36.70 | 31.20 | 33.95 | 34.95 | 30.45 | 32.70 | 62.13 | 69.63 | 65.88 | 66.63 | 70.13 | 68.38 | 64.38 | 69.88 | 67.13 |
| 7 | HD-3090 | 42.35 | 38.85 | 40.60 | 45.85 | 40.35 | 43.10 | 44.10 | 39.60 | 41.85 | 85.45 | 92.95 | 89.20 | 89.95 | 93.45 | 91.70 | 87.70 | 93.20 | 90.45 |
| 8 | HI-1544 | 38.15 | 34.65 | 36.40 | 41.65 | 36.15 | 38.90 | 39.90 | 35.40 | 37.65 | 69.60 | 77.10 | 73.35 | 74.10 | 77.60 | 75.85 | 71.85 | 77.35 | 74.60 |
| 9 | HI-1605 | 39.92 | 36.42 | 38.17 | 43.42 | 37.92 | 40.67 | 41.67 | 37.17 | 39.42 | 72.32 | 79.82 | 76.07 | 76.82 | 80.31 | 78.56 | 74.57 | 80.06 | 77.31 |
| 10 | HI-8805 | 41.63 | 38.13 | 39.88 | 45.13 | 39.63 | 42.38 | 43.38 | 38.88 | 41.13 | 77.83 | 85.33 | 81.58 | 82.33 | 85.83 | 84.08 | 80.08 | 85.58 | 82.83 |
| 11 | MACS-3949 | 32.25 | 28.75 | 30.50 | 35.75 | 30.25 | 33.00 | 34.00 | 29.50 | 31.75 | 57.90 | 65.40 | 61.65 | 62.40 | 65.90 | 64.15 | 60.15 | 65.65 | 62.90 |
| 12 | MACS-4058 | 44.04 | 40.54 | 42.29 | 47.54 | 42.04 | 44.79 | 45.79 | 41.29 | 43.54 | 85.30 | 92.80 | 89.05 | 89.80 | 93.30 | 91.55 | 87.55 | 93.05 | 90.30 |
| 13 | MP-3288 | 38.55 | 35.05 | 36.80 | 42.05 | 36.55 | 39.30 | 40.30 | 35.80 | 38.05 | 75.15 | 82.65 | 78.90 | 79.65 | 83.15 | 81.40 | 77.40 | 82.90 | 80.15 |
| 14 | UAS-446 | 35.90 | 32.40 | 34.15 | 39.40 | 33.90 | 36.65 | 37.65 | 33.15 | 35.40 | 69.03 | 76.53 | 72.78 | 73.53 | 77.03 | 75.28 | 71.28 | 76.78 | 74.03 |
| 15 | HI-1636 | 31.39 | 27.89 | 29.64 | 34.89 | 29.39 | 32.14 | 33.14 | 28.64 | 30.89 | 62.68 | 70.17 | 66.42 | 67.17 | 74.96 | 71.07 | 64.92 | 72.57 | 68.74 |
| 16 | DBW-150 | 34.93 | 31.43 | 33.18 | 38.43 | 32.93 | 35.68 | 36.68 | 32.18 | 34.43 | 62.53 | 70.03 | 66.28 | 67.03 | 70.53 | 68.78 | 64.78 | 70.28 | 67.53 |
| Mean (S.D) | | 36.98 | 33.48 | 35.23 | 40.48 | 34.98 | 37.73 | 38.73 | 34.23 | 36.48 | 69.98 | 77.48 | 73.73 | 74.48 | 78.25 | 76.37 | 72.23 | 77.87 | 75.05 |
| Ms Error SE + | | | | 2.463 | | | 2.755 | | | 2.609 | | | 5.024 | | | 5.197 | | | 5.018 |
| LSD 5% | | | | 5.572 | | | 6.231 | | | 5.901 | | | 11.37 | | | 11.76 | | | 11.35 |

**Table 4:** Mean performances of plant height (cm) wheat genotypes under normal and late sown condition at 90 DAS

| Sr. No | Genotypes | Plant height (cm) at 90DAS | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | Late | Mean |
| 1 | GW-513 | 85.76 | 80.26 | 83.01 | 89.26 | 82.26 | 85.76 | 87.51 | 81.26 | 84.38 |
| 2 | MP-1358 | 90.96 | 85.46 | 88.21 | 94.46 | 87.46 | 90.96 | 92.71 | 86.46 | 89.58 |
| 3 | HI-8823 | 84.78 | 79.28 | 82.03 | 88.28 | 81.28 | 84.78 | 86.53 | 80.28 | 83.40 |
| 4 | WH-730 | 102.85 | 97.35 | 100.10 | 106.35 | 99.35 | 102.85 | 104.60 | 98.35 | 101.48 |
| 5 | AKDW-2997-16 | 85.22 | 79.72 | 82.47 | 88.72 | 81.72 | 85.22 | 86.97 | 80.72 | 83.84 |
| 6 | DDW-47 | 81.54 | 76.04 | 78.79 | 85.04 | 78.04 | 81.54 | 83.29 | 77.04 | 80.16 |
| 7 | HD-3090 | 98.66 | 93.16 | 95.91 | 102.16 | 95.16 | 98.66 | 100.41 | 94.16 | 97.29 |
| 8 | HI-1544 | 89.43 | 83.93 | 86.68 | 92.93 | 85.93 | 89.43 | 91.18 | 84.93 | 88.05 |
| 9 | HI-1605 | 92.38 | 86.88 | 89.63 | 95.88 | 88.88 | 92.38 | 94.13 | 87.88 | 91.00 |
| 10 | HI-8805 | 96.06 | 90.56 | 93.31 | 99.56 | 92.56 | 96.06 | 97.81 | 91.56 | 94.69 |
| 11 | MACS-3949 | 75.05 | 69.55 | 72.30 | 78.55 | 71.55 | 75.05 | 76.80 | 70.55 | 73.67 |
| 12 | MACS-4058 | 110.14 | 104.64 | 107.39 | 113.64 | 106.64 | 110.14 | 111.89 | 105.64 | 108.76 |
| 13 | MP-3288 | 93.14 | 87.64 | 90.39 | 96.64 | 89.64 | 93.14 | 94.89 | 88.64 | 91.77 |
| 14 | UAS-446 | 88.93 | 83.43 | 86.18 | 92.43 | 85.43 | 88.93 | 90.68 | 84.43 | 87.56 |
| 15 | HI-1636 | 78.34 | 72.84 | 75.59 | 81.84 | 74.84 | 78.34 | 80.09 | 73.84 | 76.96 |
| 16 | DBW-150 | 90.93 | 85.43 | 88.18 | 94.43 | 87.43 | 90.93 | 92.68 | 86.43 | 89.56 |
| Mean (S.D) | | 90.26 | 84.76 | 87.51 | 93.76 | 86.76 | 90.26 | 92.01 | 85.76 | 88.88 |
| Ms Error SE + | | | | 4.9 | | | 4.0 | | | 4.4 |
| LSD 5% (CD) | | | | 11.2 | | | 9.1 | | | 10.0 |

**Table 5:** Mean performance tillers per meter row length at 45 days after sowing wheat genotypes under normal and late sown condition

| Sr. No | Genotypes | Number of tiller at 45 DAS | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | Late | Mean |
| 1 | GW-513 | 150.00 | 145.00 | 147.50 | 156.00 | 141.50 | 148.75 | 153.00 | 143.25 | 148.13 |
| 2 | MP-1358 | 163.50 | 158.50 | 161.00 | 169.50 | 155.00 | 162.25 | 166.50 | 156.75 | 161.63 |
| 3 | HI-8823 | 125.50 | 120.50 | 123.00 | 131.50 | 117.00 | 124.25 | 128.50 | 118.75 | 123.63 |
| 4 | WH-730 | 146.50 | 141.50 | 144.00 | 152.50 | 138.00 | 145.25 | 149.50 | 139.75 | 144.63 |
| 5 | AKDW-2997-16 | 134.00 | 129.00 | 131.50 | 140.00 | 125.50 | 132.75 | 137.00 | 127.25 | 132.13 |
| 6 | DDW-47 | 129.00 | 124.00 | 126.50 | 135.00 | 120.50 | 127.75 | 132.00 | 122.25 | 127.13 |
| 7 | HD-3090 | 150.50 | 145.50 | 148.00 | 156.50 | 142.00 | 149.25 | 153.50 | 143.75 | 148.63 |
| 8 | HI-1544 | 128.00 | 123.00 | 125.50 | 134.00 | 119.50 | 126.75 | 131.00 | 121.25 | 126.13 |
| 9 | HI-1605 | 166.00 | 161.00 | 163.50 | 172.00 | 157.50 | 164.75 | 169.00 | 159.25 | 164.13 |
| 10 | HI-8805 | 169.50 | 164.50 | 167.00 | 175.50 | 161.00 | 168.25 | 172.50 | 162.75 | 167.63 |
| 11 | MACS-3949 | 128.00 | 123.00 | 125.50 | 134.00 | 119.50 | 126.75 | 131.00 | 121.25 | 126.13 |
| 12 | MACS-4058 | 140.00 | 135.00 | 137.50 | 146.00 | 131.50 | 138.75 | 143.00 | 133.25 | 138.13 |
| 13 | MP-3288 | 154.00 | 149.00 | 151.50 | 160.00 | 145.50 | 152.75 | 157.00 | 147.25 | 152.13 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | UAS-446 | 140.50 | 135.50 | 138.00 | 146.50 | 132.00 | 139.25 | 143.50 | 133.75 | 138.63 |
| 15 | HI-1636 | 124.00 | 119.00 | 121.50 | 130.00 | 115.50 | 122.75 | 127.00 | 117.25 | 122.13 |
| 16 | DBW-150 | 137.00 | 132.00 | 134.50 | 143.00 | 128.50 | 135.75 | 140.00 | 130.25 | 135.13 |
| Mean (S.D) | | 142.88 | 137.88 | 140.38 | 148.88 | 134.38 | 141.63 | 145.88 | 136.13 | 141.00 |
| Ms Error SE ± | | | | 11.342 | | | 8.749 | | | 10.05 |
| LSD 5% (CD) | | | | 25.657 | | | 19.79 | | | 22.72 |

### 3.3 Flag leaf area ($dm^2$) $plant^{-1}$ at 60 DAS

Data pertaining to flag leaf area $plant^{-1}$ at 60 days after sowing (Table 6) revealed that, flag leaf area $plant^{-1}$ significantly increased under normal sown condition (0.51 $dm^2$) as compared to late sown condition (0.43 $dm^2$). Decrease in leaf area was caused due to delayed sowing high temperature stress.

Genotypes shown significant variation in flag leaf area $plant^{-1}$ and ranged in between 0.35 $dm^2$ (UAS-446) to 0.73 $dm^2$ (MACS-4058). Significantly maximum leaf area $plant^{-1}$ was observed in MACS-4058 (0.73 $dm^2$), followed by HI-1605 (0.66 $dm^2$) MP-3288 (0.60 $dm^2$), WH-730 (0.56 $dm^2$), HI-8823 (0.55 $dm^2$) than the general mean (0.47 $dm^2$) on the pooled basis.

Significantly highest flag leaf area $plant^{-1}$ was observed in genotype MACS-4058 (0.77 $dm^2$) which was followed by HI-1605 (0.70 $dm^2$), WH-730 (0.60 $dm^2$) and HI-8823 (0.59 $dm^2$) under normal sown condition while late sown condition significantly highest leaf area $plant^{-1}$ was noted in genotype MACS-4058 (0.69 $dm^2$) which was followed by HI-1605 (0.62 $dm^2$), WH-730 (0.51 $dm^2$). Whereas the genotypes normal sown condition lowest leaf area such as UAS-446 (0.39 $dm^2$) while late sown condition UAS-446 (0.31 $dm^2$). Wheat genotypes showed considerable differences in photosynthesis and respiration in flag leaf area after anthesis (Voldeng and simpson, 1967). Stoy (1973) [27] reported that photosynthesis activity of flag leaf is the most important and that any restriction of this activity would result in drastic yield reduction, because the flag leaf insures a minimum amount of shading as it situated on top and at shortest translocation path. Ramadas and Rajandrudu (1977) [12], Simpson (1968) [15] and Smocek (1969) [17], Aldesuqhy (2000) [1] observed more rapid translocation of assimilates by flag leaves to growing seeds.

**Table 6:** Flag leaf area $plant^{-1}$ ($dm^2$) in wheat genotypes under normal and late sown condition at 60 DAS

| Sr. No | Genotypes | Flag leaf area($dm^{-2}$) at 60 DAS | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean |
| 1 | GW-513 | 0.51 | 0.41 | 0.46 | 0.46 | 0.42 | 0.44 | 0.48 | 0.41 | 0.45 |
| 2 | MP-1358 | 0.49 | 0.37 | 0.43 | 0.44 | 0.39 | 0.41 | 0.46 | 0.38 | 0.42 |
| 3 | HI-8823 | 0.62 | 0.50 | 0.56 | 0.57 | 0.52 | 0.54 | 0.59 | 0.51 | 0.55 |
| 4 | WH-730 | 0.62 | 0.51 | 0.56 | 0.58 | 0.52 | 0.55 | 0.60 | 0.51 | 0.56 |
| 5 | AKDW-2997-16 | 0.43 | 0.31 | 0.37 | 0.38 | 0.33 | 0.35 | 0.40 | 0.32 | 0.36 |
| 6 | DDW-47 | 0.47 | 0.35 | 0.41 | 0.42 | 0.37 | 0.39 | 0.44 | 0.36 | 0.40 |
| 7 | HD-3090 | 0.56 | 0.45 | 0.50 | 0.52 | 0.46 | 0.49 | 0.54 | 0.45 | 0.50 |
| 8 | HI-1544 | 0.45 | 0.34 | 0.39 | 0.41 | 0.35 | 0.38 | 0.43 | 0.34 | 0.39 |
| 9 | HI-1605 | 0.73 | 0.61 | 0.67 | 0.68 | 0.63 | 0.65 | 0.70 | 0.62 | 0.66 |
| 10 | HI-8805 | 0.39 | 0.28 | 0.33 | 0.35 | 0.29 | 0.32 | 0.37 | 0.28 | 0.33 |
| 11 | MACS-3949 | 0.57 | 0.46 | 0.51 | 0.53 | 0.47 | 0.50 | 0.55 | 0.46 | 0.51 |
| 12 | MACS-4058 | 0.80 | 0.68 | 0.74 | 0.75 | 0.70 | 0.72 | 0.77 | 0.69 | 0.73 |
| 13 | MP-3288 | 0.67 | 0.55 | 0.61 | 0.62 | 0.57 | 0.59 | 0.64 | 0.56 | 0.60 |
| 14 | UAS-446 | 0.42 | 0.30 | 0.36 | 0.37 | 0.32 | 0.34 | 0.39 | 0.31 | 0.35 |
| 15 | HI-1636 | 0.44 | 0.33 | 0.38 | 0.40 | 0.34 | 0.37 | 0.42 | 0.33 | 0.38 |
| 16 | DBW-150 | 0.43 | 0.31 | 0.37 | 0.38 | 0.33 | 0.35 | 0.40 | 0.32 | 0.36 |
| Mean (S.D) | | 0.53 | 0.42 | 0.48 | 0.49 | 0.44 | 0.46 | 0.51 | 0.43 | 0.47 |
| Ms Error SE ± | | | | 0.035 | | | 0.028 | | | 0.032 |
| LSD 5% (CD) | | | | 0.08 | | | 0.062 | | | 0.072 |

### 3.4.1 Chlorophyll content index (SPAD) at 15 days after anthesis

The data on chlorophyll content index presented in Table 7.It was evident that chlorophyll content was significantly increased under normal condition (46.29) in comparison to late sown condition (41.99).

Among the genotypes chlorophyll content ranged from 40.32 to 48.09. The significantly highest chlorophyll content was found in HD-3090 (48.09) over all genotypes and it was followed by MP-1358 (47.16) and UAS-446 (47.12). Significantly lowest chlorophyll content was observed in HI-1544 (37.07) on the basis of pooled data.

The genotype HD-3090 (45.94), MP-1358 (45.01) and UAS-446 (44.97) were the first three top ranking higher chlorophyll content genotypes under late sown condition. While, lowest chlorophyll content was found in HI-1544 (34.92) under late sown condition. While the genotype HD-3090 (50.24), MP-1358 (49.31), DDW-47 and HI-1605 (48.27) higher chlorophyll content genotypes under normal sown condition. Whereas, lowest chlorophyll content which was found in HI-1544 (39.22) under normal sown condition.

### 3.4.2 Chlorophyll content index (SPAD) at 21 days after anthesis

The data regarding chlorophyll content of flag leaves at21 days after anthesis presented in Table 7 which revealed that the CCI was found significantly increased under normal sown condition (41.10) as compared to late sown wheat crop (38.08).

Genotypic variations were found for chlorophyll content ranging from 32.90 to 43.94. Genotypes MACS-4058 (43.94), HD-3090 (42.43) and HI-1605 (41.89) significantly higher chlorophyll content than the general mean (39.59). However lowest value of chlorophyll content was recorded in late genotype HI-1544 (32.90) on basis pooled data.

The genotype MACS-4058 (42.43), HD-3090 (40.92) and HI-1605 (40.38) were the top ranking higher chlorophyll content genotypes under late sown condition. However lowest chlorophyll content was found in HI-1544 (31.39) under late sown condition. However, the genotype MACS-4058 (45.45), HD-3090 (43.94), HI-1605 (43.40) and UAS-446 (43.37) higher chlorophyll content genotypes under normal sown condition. Whereas, lowest chlorophyll content which was found in HI-1544 (34.41) under normal sown condition.

The high temperature hastened the leaf senescence and crop maturity with squeezed reproductive phase in late sown crop. Leaf senescence is the key development state in the life of plant, and is characterized by cell death through highly regulated, genetically controlled process Chandlee (2001) [28], chlorophyll loss, oxidative stress (Upadhyaya *et al*., 2008) [18].

**Table 7:** Mean performances for chlorophyll content (SPAD) at 15 and 21 days after anthesis in wheat genotypes under normal and late sown condition

| Sr. No | Genotypes | Chlorophyll content (SPAD) at 15 days after anthesis | | | | | | Pooled | | | Chlorophyll content (SPAD) at 21 days after anthesis | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean |
| 1 | GW-513 | 45.67 | 41.04 | 43.35 | 45.07 | 41.09 | 43.08 | 45.37 | 41.06 | 43.21 | 42.12 | 39.30 | 40.71 | 41.42 | 38.21 | 39.81 | 41.77 | 38.75 | 40.26 |
| 2 | MP-1358 | 49.61 | 44.99 | 47.30 | 49.01 | 45.03 | 47.02 | 49.31 | 45.01 | 47.16 | 43.38 | 40.56 | 41.97 | 42.68 | 39.47 | 41.07 | 43.03 | 40.01 | 41.52 |
| 3 | HI-8823 | 45.93 | 41.30 | 43.62 | 45.33 | 41.35 | 43.34 | 45.63 | 41.33 | 43.48 | 40.98 | 38.15 | 39.56 | 40.28 | 37.06 | 38.67 | 40.63 | 37.61 | 39.12 |
| 4 | WH-730 | 46.68 | 42.05 | 44.36 | 46.08 | 42.10 | 44.09 | 46.38 | 42.07 | 44.22 | 41.71 | 38.88 | 40.29 | 41.01 | 37.79 | 39.40 | 41.36 | 38.34 | 39.85 |
| 5 | AKDW-2997-16 | 42.77 | 38.15 | 40.46 | 42.17 | 38.19 | 40.18 | 42.47 | 38.17 | 40.32 | 37.70 | 34.88 | 36.29 | 37.00 | 33.79 | 35.39 | 37.35 | 34.33 | 35.84 |
| 6 | DDW-47 | 48.57 | 43.94 | 46.25 | 47.97 | 43.99 | 45.98 | 48.27 | 43.96 | 46.11 | 42.27 | 39.45 | 40.86 | 41.57 | 38.36 | 39.96 | 41.92 | 38.90 | 40.41 |
| 7 | HD-3090 | 50.54 | 45.92 | 48.23 | 49.94 | 45.96 | 47.95 | 50.24 | 45.94 | 48.09 | 44.29 | 41.47 | 42.88 | 43.59 | 40.38 | 41.98 | 43.94 | 40.92 | 42.43 |
| 8 | HI-1544 | 39.52 | 34.90 | 37.21 | 38.92 | 34.94 | 36.93 | 39.22 | 34.92 | 37.07 | 34.76 | 31.94 | 33.35 | 34.06 | 30.85 | 32.45 | 34.41 | 31.39 | 32.90 |
| 9 | HI-1605 | 48.57 | 43.94 | 46.26 | 47.97 | 43.99 | 45.98 | 48.27 | 43.96 | 46.12 | 43.75 | 40.93 | 42.34 | 43.05 | 39.84 | 41.44 | 43.40 | 40.38 | 41.89 |
| 10 | HI-8805 | 46.01 | 41.38 | 43.69 | 45.41 | 41.43 | 43.42 | 45.71 | 41.40 | 43.55 | 41.67 | 38.85 | 40.26 | 40.97 | 37.76 | 39.36 | 41.32 | 38.30 | 39.81 |
| 11 | MACS-3949 | 47.84 | 43.22 | 45.53 | 47.24 | 43.26 | 45.25 | 47.54 | 43.24 | 45.39 | 42.66 | 39.83 | 41.24 | 41.96 | 38.74 | 40.35 | 42.31 | 39.29 | 40.80 |
| 12 | MACS-4058 | 49.57 | 44.94 | 47.25 | 48.97 | 44.99 | 46.98 | 49.27 | 44.96 | 47.11 | 45.80 | 42.98 | 44.39 | 45.10 | 41.89 | 43.49 | 45.45 | 42.43 | 43.94 |
| 13 | MP-3288 | 44.35 | 39.73 | 42.04 | 43.75 | 39.77 | 41.76 | 44.05 | 39.75 | 41.90 | 37.64 | 34.82 | 36.23 | 36.94 | 33.73 | 35.33 | 37.29 | 34.27 | 35.78 |
| 14 | UAS-446 | 49.57 | 44.95 | 47.26 | 48.97 | 44.99 | 46.98 | 49.27 | 44.97 | 47.12 | 43.72 | 40.90 | 42.31 | 43.02 | 39.81 | 41.41 | 43.37 | 40.35 | 41.86 |
| 15 | HI-1636 | 45.98 | 41.35 | 43.66 | 45.38 | 41.40 | 43.39 | 45.68 | 41.37 | 43.52 | 41.65 | 38.82 | 40.23 | 40.95 | 37.73 | 39.34 | 41.30 | 38.28 | 39.79 |
| 16 | DBW-150 | 44.37 | 39.74 | 42.05 | 43.77 | 39.79 | 41.78 | 44.07 | 39.76 | 41.91 | 39.08 | 36.25 | 37.66 | 38.38 | 35.16 | 36.77 | 38.73 | 35.71 | 37.22 |
| Mean (S.D) | | 46.59 | 41.97 | 44.28 | 45.99 | 42.01 | 44.00 | 46.29 | 41.99 | 44.14 | 41.45 | 38.62 | 40.03 | 40.75 | 37.53 | 39.14 | 41.10 | 38.08 | 39.59 |
| Ms Error SE ± | | | | 2.11 | | | 2.00 | | | 1.98 | | | 2.18 | | | 1.69 | | | 1.93 |
| LSD 5% (CD) | | | | 4.76 | | | 4.53 | | | 4.47 | | | 4.92 | | | 3.83 | | | 4.37 |

### 3.5 Relative water content (%) of flag leaf at 60 DAS

The data on relative water content of flag leaf at 60 DAS presented in Table 8 which revealed that RWC (%) was significantly higher under normal sown condition (93.41%) in comparison to late sown condition (90.60%).

RWC (%) of flag, leaf different wheat genotypes was ranged from 89.04 to 94.09. Genotype UAS-446 (94.09%) recorded significantly highest RWC among all the genotypes. However, it was found at par with genotypes HI-1605 (93.07%), HI-8823, (93.03%), MASCS-3949 (93.01%), HI-1544 (92.09%) and WH-730 (92.08%). Significantly lowest RWC was recorded in DBW-150 (89.04%) on the basis of pooled data.

The genotype recorded HI-1544 (95.2%), UAS-446 (96.3%), HI-8823 (94.7%) and MACS-3949 (94.5%) higher RWC genotypes under normal sown condition. whereas, lowest RWC (%) which was found in DBW-150 (90.8%) under normal sown condition. The genotype UAS-446 (93.5%), HI-1605 (92.3%) and HI-8823 (91.8%) were the top ranking higher RWC (%) genotypes under late sown condition. However lowest RWC (%) was found in DBW-150 (88.0%) under late sown condition.

Almeselmani *et al*. (2009) [3] who stated that water potential was significantly reduced at anthesis, and at 7 and 15 days after anthesis in wheat genotypes (Susceptible to temperature and tolerant) in heat stress treatment (25/35°C temperature stress) and greater reduction was recorded in susceptible genotype PBW-343. Saxena *et al.* (2011) [13] reported that, relative water content was found to be high in high yielding cultivars under early and late growing condition in wheat, maintaining higher water potential.

### 3.6.1 Canopy temperature °C at 15 days after anthesis

The data on canopy temperature at 15 days after anthesis (Table 9) revealed that, CT was more by 3.25 °C under late sown condition (29.10) compared to normal sown condition (26.46°C).

Among the genotypes, canopy temperature was significantly higher in genotype HD-3090 (28.29 °C) than the general mean (27.78°C) and remained at par with HI-8823 (28.64 °C) and HD-3090 (28.54°C) representing hot canopy at 15 days after anthesis on the basis of pooled data.

Genotype HD-3090 (29.85 °C) have significantly highest canopy temperature and remained at par with GW-513 (29.7 °C) and AKDW-2997-16 (28.75 °C) under late sown condition. However, lowest canopy observed in genotype MACS-4058 (27.04 °C). While under normal sown condition genotype HD-3090 (27.23 °C) recorded highest canopy temperature and lowest in AKDW-2997-16 (26.13 °C)

**Table 8:** Mean performances for relative water content (%) at 60 DAS flag leaf in wheat genotypes under normal and late sown condition

| Sr. No | Genotypes | Relative water content (%) 60 DAS | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean |
| 1 | GW-513 | 94.5 | 90.3 | 92.4 | 93.0 | 91.5 | 92.3 | 93.7 | 90.9 | 92.3 |
| 2 | MP-1358 | 91.8 | 87.7 | 89.8 | 90.4 | 88.9 | 89.6 | 91.1 | 88.3 | 89.7 |
| 3 | HI-8823 | 95.4 | 91.3 | 93.3 | 93.9 | 92.4 | 93.2 | 94.7 | 91.8 | 93.3 |
| 4 | WH-730 | 94.9 | 90.8 | 92.9 | 93.5 | 92.0 | 92.7 | 94.2 | 91.4 | 92.8 |
| 5 | AKDW-2997-16 | 94.5 | 90.4 | 92.4 | 93.1 | 91.6 | 92.3 | 93.8 | 91.0 | 92.4 |
| 6 | DDW-47 | 93.5 | 89.4 | 91.4 | 92.1 | 90.6 | 91.3 | 92.8 | 90.0 | 91.4 |
| 7 | HD-3090 | 93.6 | 89.5 | 91.6 | 92.2 | 90.7 | 91.4 | 92.9 | 90.1 | 91.5 |
| 8 | HI-1544 | 95.0 | 90.9 | 92.9 | 93.6 | 92.1 | 92.8 | 94.3 | 91.5 | 92.9 |
| 9 | HI-1605 | 95.9 | 91.8 | 93.8 | 94.4 | 92.9 | 93.7 | 95.2 | 92.3 | 93.7 |
| 10 | HI-8805 | 92.4 | 88.3 | 90.3 | 91.0 | 89.5 | 90.2 | 91.7 | 88.9 | 90.3 |
| 11 | MACS-3949 | 95.3 | 91.1 | 93.2 | 93.8 | 92.3 | 93.1 | 94.5 | 91.7 | 93.1 |
| 12 | MACS-4058 | 93.2 | 89.1 | 91.2 | 91.8 | 90.3 | 91.0 | 92.5 | 89.7 | 91.1 |
| 13 | MP-3288 | 93.5 | 89.4 | 91.5 | 92.1 | 90.6 | 91.3 | 92.8 | 90.0 | 91.4 |
| 14 | UAS-446 | 97.0 | 92.9 | 95.0 | 95.6 | 94.1 | 94.8 | 96.3 | 93.5 | 94.9 |
| 15 | HI-1636 | 94.0 | 89.9 | 91.9 | 92.5 | 91.0 | 91.8 | 93.3 | 90.4 | 91.9 |
| 16 | DBW-150 | 91.5 | 87.4 | 89.5 | 90.1 | 88.6 | 89.3 | 90.8 | 88.0 | 89.4 |
| Mean (S.D) | | 94.13 | 90.01 | 92.07 | 92.68 | 91.18 | 91.93 | 93.41 | 90.60 | 92.00 |
| Ms Error SE ± | | | | 1.005 | | | 0.888 | | | 2.84 |
| LSD 5% (CD) | | | | 2.274 | | | 2.009 | | | 6.424 |

### 3.6.2 Canopy temperature °C at 21 days after anthesis

The data on canopy temperature at 21 days after anthesis (Table 9) revealed that, significant increase in CT by 4.5 °C under late sown condition (30.07 °C) in comparison to normal sown condition (27.10 °C). The CT increased under late sown condition.

Among the genotypes, significantly higher values of canopy temperature have been observed in HD-3090 (29.41 °C), MP-3288 (29.41 °C), AKDW-2997-16 (29.63 °C), HI-8823 (29.50 °C) and WH-730 (29.29°C). Whereas, minimum canopy temperature was found in MP-1358 (26.86°C) and UAS-446 (27.27 °C) which maintained cool canopy relative to other genotypes. Under normal sown condition maximum CT was found in HD-3090 (27.88 °C) followed by HI-8823(27.86 °C) on the basis of pooled data.

Genotype AKDW-2997-16 (31.60 °C) have significantly highest canopy temperature and remained at par with MP-3288 (31.29 °C) and WH-730 (30.99 °C) under late sown condition. However, lowest canopy observed in genotype HI-1605 (28.34 °C). While, under normal sown condition genotype HD-3090 (27.88 °C) recorded highest canopy temperature and lowest in UAS-446 (26.11 °C)

Canopy temperature is strongly influenced by plant water status (Singh and Kanematsu, 1983). Plant water status has a direct bearing on vital physiological processes and morphological characteristics of a plant, which are the primary determinants of seed yield. Munjal and Rana (2003) reported that cool canopy during grain filling period in wheat is an important physiological principle for high temperature stress tolerance.

Higher canopy temperature increase transpiration by changing vapour pressure deficit at leaf surface and secondly may lead to enhanced ageing of foliage and shortening of growing season *i.e.* grain filling duration (Geija and Goudrian, 1996).

Shubhra (2005) [14] also observed increase CT in thermo tolerant high yielding variety WH-730 than the moderately sensitive wheat variety UP- 2565. The lower canopy temperature in AKAW-4636 and AKAW 3997 indicates higher cooling was mainly due to longer stay green character.

**Table 9:** Mean performances for canopy temperature at 15 days at 21 days after anthesis in wheat genotypes under normal and late sown condition

| Sr. No | Genotypes | Canopy temperature at 15 days after anthesis | | | | | | Pooled | | | Canopy temperature at 21 days after anthesis | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean |
| 1 | GW-513 | 26.26 | 29.48 | 27.87 | 27.12 | 30.03 | 28.57 | 26.69 | 29.75 | 28.22 | 28.50 | 29.72 | 29.11 | 27.12 | 30.17 | 28.65 | 27.81 | 29.95 | 28.88 |
| 2 | MP-1358 | 25.90 | 28.68 | 27.29 | 26.76 | 29.23 | 27.99 | 26.33 | 28.95 | 27.64 | 25.00 | 27.62 | 26.31 | 26.76 | 28.07 | 27.42 | 25.88 | 27.85 | 26.86 |
| 3 | HI-8823 | 26.55 | 29.33 | 27.94 | 27.41 | 29.88 | 28.64 | 26.98 | 29.60 | 28.29 | 28.30 | 30.92 | 29.61 | 27.41 | 31.37 | 29.39 | 27.86 | 31.14 | 29.50 |
| 4 | WH-730 | 26.15 | 28.93 | 27.54 | 27.01 | 29.48 | 28.24 | 26.58 | 29.20 | 27.89 | 28.15 | 30.77 | 29.46 | 27.01 | 31.22 | 29.12 | 27.58 | 30.99 | 29.29 |
| 5 | AKDW-2997-16 | 25.70 | 28.48 | 27.09 | 26.56 | 29.03 | 27.79 | 26.13 | 28.75 | 27.44 | 28.75 | 31.37 | 30.06 | 26.56 | 31.82 | 29.19 | 27.66 | 31.60 | 29.63 |
| 6 | DDW-47 | 26.00 | 28.78 | 27.39 | 26.86 | 29.33 | 28.09 | 26.43 | 29.05 | 27.74 | 27.20 | 29.82 | 28.51 | 26.86 | 30.27 | 28.57 | 27.03 | 30.04 | 28.54 |
| 7 | HD-3090 | 26.80 | 29.58 | 28.19 | 27.66 | 30.13 | 28.89 | 27.23 | 29.85 | 28.54 | 28.10 | 30.72 | 29.41 | 27.66 | 31.17 | 29.42 | 27.88 | 30.94 | 29.41 |
| 8 | HI-1544 | 26.00 | 28.78 | 27.39 | 26.86 | 29.33 | 28.09 | 26.43 | 29.05 | 27.74 | 26.80 | 29.42 | 28.11 | 26.86 | 29.87 | 28.37 | 26.83 | 29.64 | 28.24 |
| 9 | HI-1605 | 26.50 | 29.28 | 27.89 | 27.36 | 29.83 | 28.59 | 26.93 | 29.55 | 28.24 | 25.50 | 28.12 | 26.81 | 27.36 | 28.57 | 27.97 | 26.43 | 28.34 | 27.39 |
| 10 | HI-8805 | 26.45 | 29.23 | 27.84 | 27.31 | 29.78 | 28.54 | 26.88 | 29.50 | 28.19 | 27.95 | 30.57 | 29.26 | 27.31 | 31.02 | 29.17 | 27.63 | 30.79 | 29.21 |
| 11 | MACS-3949 | 25.90 | 28.68 | 27.29 | 26.76 | 29.23 | 27.99 | 26.33 | 28.95 | 27.64 | 28.05 | 30.67 | 29.36 | 26.76 | 31.12 | 28.94 | 27.41 | 30.90 | 29.15 |
| 12 | MACS-4058 | 25.30 | 28.08 | 26.69 | 26.16 | 28.63 | 27.39 | 25.73 | 28.35 | 27.04 | 26.45 | 29.07 | 27.76 | 26.16 | 29.52 | 27.84 | 26.31 | 29.29 | 27.80 |
| 13 | MP-3288 | 25.75 | 28.53 | 27.14 | 26.61 | 29.08 | 27.84 | 26.18 | 28.80 | 27.49 | 28.45 | 31.07 | 29.76 | 26.61 | 31.52 | 29.07 | 27.53 | 31.29 | 29.41 |
| 14 | UAS-446 | 25.75 | 28.53 | 27.14 | 26.61 | 29.08 | 27.84 | 26.18 | 28.80 | 27.49 | 25.60 | 28.22 | 26.91 | 26.61 | 28.67 | 27.64 | 26.11 | 28.44 | 27.27 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | HI-1636 | 25.70 | 28.48 | 27.09 | 26.56 | 29.03 | 27.79 | 26.13 | 28.75 | 27.44 | 27.05 | 29.67 | 28.36 | 26.56 | 30.12 | 28.34 | 26.81 | 29.90 | 28.35 |
| 16 | DBW-150 | 25.70 | 28.48 | 27.09 | 26.56 | 29.03 | 27.79 | 26.13 | 28.75 | 27.44 | 27.10 | 29.72 | 28.41 | 26.56 | 30.17 | 28.37 | 26.83 | 29.94 | 28.39 |
| Mean (S.D) | | 26.03 | 28.83 | 27.43 | 26.89 | 29.38 | 28.13 | 26.46 | 29.10 | 27.78 | 27.31 | 29.84 | 28.57 | 26.89 | 30.29 | 28.59 | 27.10 | 30.07 | 28.58 |
| Ms Error SE + | | | | 0.191 | | | 0.219 | | | 0.162 | | | 0.992 | | | 0.506 | | | 0.673 |
| LSD 5% (CD) | | | | 0.432 | | | 0.495 | | | 0.366 | | | 2.244 | | | 1.144 | | | 1.524 |

### 3.7 Pollen viability (%)

The data on pollen viability (%) presented in Table 10. which indicated that, significantly maximum pollen viability was found under normal sown condition (96.09%) as compared to late sown condition (94.94%).

The genotypes showed significant variations for pollen viability ranging from 98.05% to 94.14%. The genotypes *viz.,* HD-3090 (98.05%), MACS-4058 (97.49%) and HI-8805 (97.11%) showed significantly higher pollen viability than the general mean (95.52%).

The significantly highest pollen viability was found in HD-3090 (98.63%) followed by MACS-4058 (98.02%) and HI-8805 (97.66%) when sown under normal condition. However, minimum pollen viability was noted in DBW-150 (94.80%) under normal condition. Whereas, the significantly highest pollen viability was found in HD-3090 (97.47%) followed by MACS-4058 (96.97%) and HI-8805 (96.57%) when sown under late condition. However, minimum pollen viability was noted in WH-730 (93.46%) under late sown condition.

Similar result were also noted by Saini *et al.* (1984) [29], Prasad *et al.* (2006) [30], Anjum*et al.* (2008) [31] and Kaur and Behl (2010) [6]. They were concluded that in wheat, two types of abnormal pollen development can be caused by high temperature stress. The first is apparently caused by tapetal degradation during meiosis, when the microspores are not able to complete the first mitosis. They may have an exine but no cytoplasm, and may remain immature. In the second case, all the microspores complete the first mitotic division, but only a few of them are able to divide further to develop into normal tri-cellular pollen grains. The rest of the microspores remain immature and do not accumulate starch, so the anthers contain a mixture of fertile and sterile pollen grains.

**Table 10:** Mean performances for pollen viability (%) in wheat genotypes under normal and late sown condition

| Sr. No | Genotypes | Pollen viability (%) | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | late | mean |
| 1 | GW-513 | 95.67 | 94.16 | 94.91 | 94.62 | 93.80 | 94.21 | 95.14 | 93.98 | 94.56 |
| 2 | MP-1358 | 96.46 | 94.95 | 95.70 | 95.41 | 94.59 | 95.00 | 95.93 | 94.77 | 95.35 |
| 3 | HI-8823 | 95.82 | 94.31 | 95.06 | 94.77 | 93.95 | 94.36 | 95.29 | 94.13 | 94.71 |
| 4 | WH-730 | 96.96 | 93.64 | 95.30 | 94.10 | 93.28 | 93.69 | 95.53 | 93.46 | 94.49 |
| 5 | AKDW-2997-16 | 96.95 | 95.44 | 96.19 | 95.90 | 95.08 | 95.49 | 96.42 | 95.26 | 95.84 |
| 6 | DDW-47 | 96.36 | 94.85 | 95.60 | 95.31 | 94.49 | 94.90 | 95.83 | 94.67 | 95.25 |
| 7 | HD-3090 | 99.16 | 97.65 | 98.40 | 98.11 | 97.29 | 97.70 | 98.63 | 97.47 | 98.05 |
| 8 | HI-1544 | 95.44 | 94.09 | 94.76 | 94.39 | 93.57 | 93.98 | 94.92 | 93.83 | 94.37 |
| 9 | HI-1605 | 97.63 | 96.28 | 96.95 | 96.58 | 95.76 | 96.17 | 97.11 | 96.02 | 96.56 |
| 10 | HI-8805 | 98.18 | 96.83 | 97.50 | 97.13 | 96.31 | 96.72 | 97.66 | 96.57 | 97.11 |
| 11 | MACS-3949 | 95.50 | 94.24 | 94.87 | 94.45 | 93.63 | 94.04 | 94.98 | 93.93 | 94.45 |
| 12 | MACS-4058 | 98.54 | 97.28 | 97.91 | 97.49 | 96.67 | 97.08 | 98.02 | 96.97 | 97.49 |
| 13 | MP-3288 | 96.96 | 95.70 | 96.33 | 95.91 | 95.09 | 95.50 | 96.44 | 95.39 | 95.91 |
| 14 | UAS-446 | 96.42 | 95.38 | 95.90 | 95.37 | 94.55 | 94.96 | 95.90 | 94.96 | 95.43 |
| 15 | HI-1636 | 95.48 | 94.62 | 95.05 | 94.43 | 93.61 | 94.02 | 94.96 | 94.11 | 94.53 |
| 16 | DBW-150 | 95.33 | 93.50 | 94.41 | 94.28 | 93.46 | 93.87 | 94.80 | 93.48 | 94.14 |
| Mean (S.D) | | 96.68 | 95.18 | 95.93 | 95.51 | 94.69 | 95.10 | 96.09 | 94.94 | 95.52 |
| Ms Error SE + | | | | 0.201 | | | 0.991 | | | 0.503 |
| LSD 5% (CD) | | | | 0.455 | | | 2.242 | | | 1.139 |

### 3.8 Membrane thermo-stability index (%) at 60 days after sowing

The data on membrane stability index (MSI %) presented in Table 11. which indicated that, significantly maximum membrane stability index was found under normal sown condition (73.26%) as compared to late sown condition (68.47%).

The genotypes showed significant variations for MSI ranging from 64.2% to 76.7%. The genotypes *viz.,* HI-1605 (76.7%), GW-513(75.4%) and HI-8823 (74.3%) showed significantly higher MSI than the general mean (70.87%) on the basis of pooled data.

Significantly highest MSI was observed in genotype HI-1605 (79.6%) which was followed by GW-513 (78.6%), HD-3090 (77.1%) and HI-8823 (76.7%) under normal sown condition. While, late sown condition significantly. Highest MSI was noted in genotype HI-1605 (73.7%) which was followed by MP-1358 (73.02%) and GW-513 (72.3%). Whereas, the genotypes normal sown condition lowest MSI such as UAS-446 (65.5%) while, late sown condition HI-1544 (64.0%).

Almeselmani *et al.* (2006) [4], Dias *et al.* (2009) [5], Pandey and Srivastava (2009) [11], Dias and Lidon (2009) [5], Kour *et al.* (2010) [32], Kumar *et al.* (2011) [7], and Kushwaha *et al.* (2011) [8] all found similar findings that heat stress may also impact the integrity of membranes in *Triticum species*, increasing electrolyte leakage due to the loss of membrane selectivity.

**Table 11:** Mean performances for membrane thermo-stability index at 60 DAS flag leaf in wheat genotypes under normal and late sown condition 60 DAS

| Sr. No | Genotypes | Membrane thermo stability (%) index 60 DAS | | | | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020-21 | | | 2021-22 | | | | | |
| | | Normal | Late | Mean | Normal | Late | Mean | Normal | Late | mean |
| 1 | GW-513 | 80.2 | 73.2 | 76.7 | 77.1 | 71.3 | 74.2 | 78.6 | 72.3 | 75.4 |
| 2 | MP-1358 | 76.1 | 69.1 | 72.6 | 72.9 | 77.2 | 75.1 | 74.5 | 73.2 | 73.9 |
| 3 | HI-8823 | 78.3 | 71.3 | 74.8 | 75.1 | 72.5 | 73.8 | 76.7 | 71.9 | 74.3 |
| 4 | WH-730 | 77.7 | 70.7 | 74.2 | 74.5 | 70.5 | 72.5 | 76.1 | 70.6 | 73.3 |
| 5 | AKDW-2997-16 | 75.1 | 68.1 | 71.6 | 71.9 | 61.3 | 66.6 | 73.5 | 64.7 | 69.1 |
| 6 | DDW-47 | 67.2 | 60.2 | 63.7 | 64.0 | 65.4 | 64.7 | 65.6 | 62.8 | 64.2 |
| 7 | HD-3090 | 78.7 | 71.7 | 75.2 | 75.5 | 66.9 | 71.2 | 77.1 | 69.3 | 73.2 |
| 8 | HI-1544 | 76.2 | 69.2 | 72.7 | 73.0 | 58.8 | 65.9 | 74.6 | 64.0 | 69.3 |
| 9 | HI-1605 | 81.2 | 74.2 | 77.7 | 78.0 | 73.3 | 75.6 | 79.6 | 73.7 | 76.7 |
| 10 | HI-8805 | 74.9 | 67.9 | 71.4 | 71.7 | 73.3 | 72.5 | 73.3 | 70.6 | 71.9 |
| 11 | MACS-3949 | 70.7 | 63.7 | 67.2 | 67.5 | 71.3 | 69.4 | 69.1 | 67.5 | 68.3 |
| 12 | MACS-4058 | 78.2 | 71.2 | 74.7 | 75.0 | 65.5 | 70.3 | 76.6 | 68.4 | 72.5 |
| 13 | MP-3288 | 72.7 | 65.7 | 69.2 | 69.5 | 65.3 | 67.4 | 71.1 | 65.5 | 68.3 |
| 14 | UAS-446 | 67.1 | 60.1 | 63.6 | 63.9 | 73.2 | 68.6 | 65.5 | 66.7 | 66.1 |
| 15 | HI-1636 | 75.2 | 68.2 | 71.7 | 72.0 | 66.1 | 69.1 | 73.6 | 67.2 | 70.4 |
| 16 | DBW-150 | 68.3 | 61.3 | 64.8 | 65.1 | 73.3 | 69.2 | 66.7 | 67.3 | 67.0 |
| Mean (S.D) | | 74.86 | 67.86 | 71.36 | 71.66 | 69.08 | 70.37 | 73.26 | 68.47 | 70.87 |
| Ms Error SE ± | | | | 2.079 | | | 2.79 | | | 1.663 |
| LSD 5% (CD) | | | | 4.703 | | | 6.31 | | | 3.763 |

## 4. Conclusion

1. Sixteen potential wheat genotypes were tested in the field for high temperature stress brought on by late sowing. The genotypes HD-3090, MACS-4058 and MP-1358 were shown to be extremely thermo tolerant based on HSI and grain yield, and they have tremendous economic value. The genotype HD-3090 was shown to be acceptable for both early and late sowing circumstances.
2. The moderately resistant wheat genotypes, such as MP-1358, HI-8823, AKDW-2997-16, MP-3288, and HI-8805, with high mean yield, have economic worth but also have strong academic value and may be exploited for future exploitation in breeding programmes.
3. Heat stress also reduces grain number and size by affecting grain setting, assimilate translocation and duration and growth rate of grains.
4. Effective approaches for managing heat stress in wheat include screening available germplasm under field trials and employing marker-assisted selection, application of exogenous protectants to seeds or plants, mapping quantitative trait locus conferring heat resistance and breeding

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