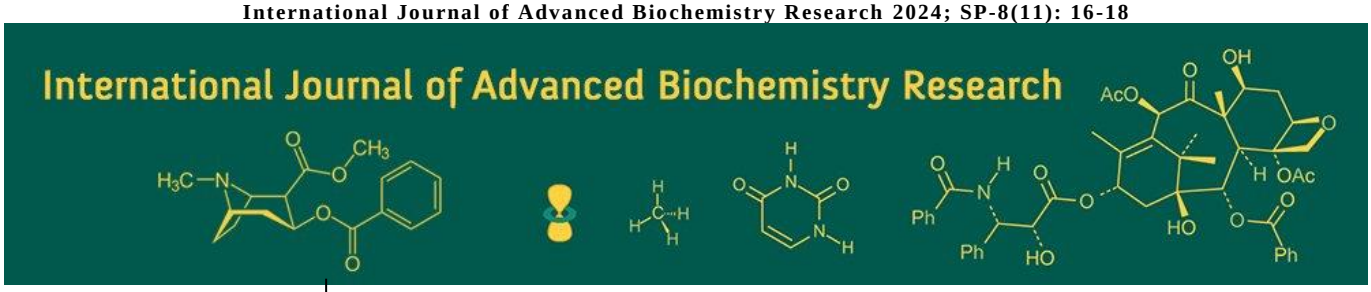


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# Correlation for various traits in wheat under heat stress

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**Abstract**
The study was carried out to evaluate set of 20 genotypes along with four checks for heat stress conditions. The experiment was carried out in randomized block design with two replications under timely (17th Nov) and late sown (19th Dec) conditions at Wheat Research Unit, Dr. PDKV Akola during rabi 2023-24. The data was recorded for the characters *viz.*, days to heading, days to maturity, plant height at harvest (cm), leaf area ($dm^2$), canopy temperature (°C), chlorophyll content (SPAD), protein %, 1000 grain weight (g), grain yield per plot (kg) and biological yield (kg). These characters are recorded and correlated with yield. Results revealed that heat stress conditions induced by late sowing affected various traits, causing reduction in days to heading (4.94 days), days to maturity (5.21 days), plant height at harvest (2.27%), leaf area at 75 Days after sowing(DAS) (23.9%), chlorophyll content at 75 DAS (8.7%), 1000 grain weight (6.4%), grain yield per plot (7.18%), biological yield (10.7%) and there was an increase in protein content (3.4%) and canopy temperature (7.20%). Correlation studies showed significant positive correlation for leaf area, protein content, chlorophyll content, 1000 grain weight, biological yield and significantly negative correlation for canopy temperature and days to maturity with grain yield.

**Keywords:** Wheat, heat stress, chlorophyll content (CC), canopy temperature (CT), leaf area (LA), correlation

## Introduction
Wheat, a major cereal crop, is vital for food security and trade, with around 20% of global production traded internationally. Originating in Central Asia, wheat is cultivated globally and across diverse climates, including tropical, subtropical, and temperate regions. Worldwide, wheat is grown on approximately 215.91 million hectares, making it the crop with the largest cultivation area and yielding an annual production of roughly 765.77 million tonnes. In India, wheat ranks as the second most widely grown crop after rice, covering 31.2 million hectares with an estimated production of 112.3 million tonnes and a productivity rate of 3.6 tonnes per hectare for the 2023-24 season. [Source: Ministry of Agriculture, New Delhi (Economic Times), Final Advance Estimate, Govt. of Maharashtra.]
"The mean global temperature of the Earth is expected to increase by 1.5 °C within the next two decades". "Recent analysis from scientific communities, including the Goddard Institute for Space Studies (GISS), indicated an increase in average global temperature of 1.04 °C from 1880 to 2019". "This elevated temperature is causing heat stress (HS) that triggers significant changes in the biological and developmental process of wheat, leading to a reduction in grain production and grain quality". Limited studies have assessed the long-term impact of climate variability on wheat yield and developed adaptation strategies. Simulation models and field experiments show that terminal heat stress reduces wheat yield by 18.1%, 16.1%, and 11.1% in 2020 and 2050 scenarios (Dubey *et al.* 2020) [3]. Despite advancements from the Green Revolution and ongoing research into high-yield and stress-tolerant varieties, wheat production faces challenges, particularly in the context of climate change. Rising global temperatures and increasing heat stress pose significant threats to wheat yields and quality, especially during sensitive phases like grain filling, where temperature fluctuations can disrupt reproductive development and reduce grain quality. It underscore the urgency of developing resilient wheat varieties and climate-adaptive agricultural practices to sustain

production in changing environmental conditions. This study aims to investigate these impacts and identifying key parameters of wheat genotypes for selection against heat stress which is critical for developing resilient wheat varieties that can thrive under heat stress.

## Materials and Methods

The experiment was carried out at the Wheat Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. 24 genotypes of wheat were sown on 17th November (normal sown) and 19th December (late sown) during Rabi 2023-24 in Randomized Block Design with two replications. All the recommended agronomic activities were practiced to raise a healthy crop at the experiment station. Each unit plot size was 6.0 m × 1.80 m (net plot). The observations were recorded for traits *viz.*, days to heading, days to maturity, plant height at harvest (cm), leaf area ($dm^2$), canopy temperature (°C), chlorophyll content (SPAD), protein %, 1000 grain weight (g), grain yield per plot (kg) and biological yield (kg).

To determine the area of photosynthetic leaves, three plants were randomly selected and uprooted from each net plot and their green leaves were separated from the stem and leaf area will be measured by scanning the leaves on automatic leaf area meter CI-202, CID (INK), USA. Leaf area was measured at 30, 45, 60 and 75 days after sowing. Then mean values of leaf area ($dm^2$) plant will be calculated.

The chlorophyll content index of intact leaf is measured by using an instrument 'SPAD 502'. The observations were recorded during the day time between 11 a.m. to 14 p.m. Chlorophyll content values are recorded at 30, 45, 60 and 75 DAS. For recording the observations three leaves were randomly selected from each genotype and replication then mean values of chlorophyll content of three leaves will be calculated.

Canopy temperature was measured by using a handheld infrared thermometer. Two measurements were recorded per plot 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 cloudless and bright days. Two readings in each plot are taken at 45 and 75 DAS.

The available nitrogen was determined by alkaline potassium permanganate method (Subbiah and Asija) 1956 [6] and protein content by using kjeldalh method (Piper) 1966 [8]. The values of nitrogen content were converted into crude protein content by multiplying 'N' percentage with 6.25 conversion factor.

Statistical analysis was done by employing standard statistical methods for randomized block design as suggested by Panse and Sukhatme and correlation analysis was done as per the formula suggested by Karl Pearson's correlation coefficient.

## Results and Discussion

In this study, high-temperature stress induced by late sowing significantly impacted key growth and physiological parameters in wheat. Days to heading were shortened by 4.94 days, while days to maturity were reduced by 5.21 days (5.14%) under heat stress compared to timely sown crops. Plant height at harvest decreased by 2.27%, reflecting the effects of elevated temperatures, with late-sown wheat averaging a shorter height than normally sown wheat.

Leaf area per plant was not significantly different across genotypes at 30 DAS. However, as the crop matured, significant reductions in leaf area per plant were observed due to high-temperature stress from late sowing. At 45 DAS, the leaf area per plant ranged from 0.627 to 0.876 $dm^2$, with a mean of 0.732 $dm^2$, showing a 19.7% reduction in late-sown plants compared to those sown on time. By 60 DAS, the leaf area under heat stress ranged from 0.882 to 1.328 $dm^2$, and the reduction was 16.5% in late-sown plants. At 75 DAS, the range was 0.765 to 1.155 $dm^2$, with a 23.9% decrease due to late sowing.

Leaf chlorophyll content showed a peak at 60 DAS, followed by a significant decline at 75 DAS, especially under late-sown, heat-stress conditions. At 45 DAS, chlorophyll content was significantly impacted by late sowing, with values ranging from 40.13 to 47.53, and a general mean of 44.08. By 60 DAS, pooled data showed chlorophyll values from 42.10 to 50.03, averaging 45.49, with notable reductions due to heat stress in late-sown conditions. At 75 DAS, chlorophyll content further declined, with values ranging from 38.10 to 45.38 and a mean of 41.18. Chlorophyll content showed a decrease over time, with reductions of 4.7%, 3.8%, and 8.7% at 45, 60, and 75 DAS, respectively, under high-temperature stress.

Canopy temperature was elevated in heat-stress conditons, canopy temperature (CT) revealed no significant differences among genotypes at 45 DAS, though CT was 3.24% higher under late-sown (25.83 °C) compared to timely sown conditions (25.02 °C). By 75 DAS, high-temperature stress from late sowing increased CT by 1.98 °C (7.2%), with late-sown plants averaging 29.48 °C, in contrast to 27.50 °C for timely sown plants. The overall mean CT at 75 DAS was 28.49 °C. late-sown crops, with a mean increase of 7.20% at 75 DAS, indicating severe post-anthesis stress.

Protein content in the seed increased by 3.4% under late-sown conditions, likely as a stress response, averaging 12.64% compared to 12.22% in timely sown wheat. The 1000-grain weight also declined by 6.4%, with heat-stressed plants producing lighter grains than those in timely sown plots. Grain yield per plot decreased by 7.2% under heat stress, and biological yield was reduced by 10.7%, indicating a considerable yield loss due to late sowing and associated temperature stress.

The correlation analysis indicates that certain morphological, physiological, and yield-contributing traits show significant associations with yield. Leaf area at 45 DAS ($r = 0.663^{**}$) and 75 DAS ($r = 0.656^{**}$) exhibit strong positive correlations with yield, while leaf area at 60 DAS ($r = 0.504^{*}$) shows a moderate correlation. Canopy temperature at both 45 and 75 DAS shows significant negative correlations with yield (CT45, $r = -0.493^{*}$; CT75, $r = -0.487^{*}$). Chlorophyll content, particularly at 45 DAS ($r = 0.571^{**}$) and 60 DAS ($r = 0.551^{**}$), displays significant positive correlations, while chlorophyll at 75 DAS ($r = 0.486^{*}$) maintains a moderate association. Protein percentage also shows a moderate positive correlation ($r = 0.508^{*}$) with yield.

**Table 1:** Correlation study of various traits with yield of wheat under heat stress condition

| | Days to 50% heading | Days to maturity | Plant height | LA30 | LA45 | LA60 | LA75 | CT45 | CT75 | CC30 | CC45 | CC60 | CC75 | Protein content | 1000 seed wt. | Biological yield | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days to 50% heading | 1 | 0.788** | 0.609** | 0.028 | -0.033 | -0.024 | -0.059 | 0.108 | 0.120 | -0.150 | -0.339 | -0.310 | 0.070 | -0.090 | -0.304 | -0.162 | -0.312 |
| Days to maturity | | 1 | 0.466* | 0.008 | -0.258 | -0.067 | -0.204 | 0.313 | 0.299 | -0.293 | -0.578** | -0.555** | -0.209 | -0.186 | -0.385 | -0.231 | -0.457* |
| Plant height | | | 1 | 0.458* | 0.289 | 0.045 | 0.279 | 0.154 | -0.018 | -0.261 | -0.232 | -0.263 | 0.100 | 0.301 | -0.114 | 0.297 | -0.175 |
| LA30 | | | | 1 | 0.258 | 0.329 | 0.310 | 0.231 | -0.138 | -0.354 | 0.034 | 0.046 | 0.205 | 0.235 | 0.157 | 0.459* | 0.154 |
| LA45 | | | | | 1 | 0.540** | 0.769** | -0.232 | -0.393 | -0.001 | 0.481* | 0.405* | 0.659* | 0.551 | 0.537** | 0.665** | 0.663** |
| LA60 | | | | | | 1 | 0.664** | -0.084 | -0.273 | -0.128 | 0.378 | 0.274 | 0.369 | 0.362 | 0.530** | 0.525** | 0.504* |
| LA75 | | | | | | | 1 | -0.226 | -0.356 | -0.0.30 | 0.296 | 0.300 | 0.407* | 0.613** | 0.627** | 0.736** | 0.656** |
| CT45 | | | | | | | | 1 | 0.263 | -0.285 | -0.350 | -0.383 | -0.269 | -0.161 | -0.423* | -0.342 | -0.493* |
| CT75 | | | | | | | | | 1 | -0.265 | -0.481* | -0.448* | -0.599 | -0.179 | -0.449* | -0.130 | -0.487* |
| CC30 | | | | | | | | | | 1 | 0.353 | 0.420* | 0.235 | -0.281 | 0.307 | -0.119 | 0.137 |
| CC45 | | | | | | | | | | | 1 | 0.925* | 0.662** | 0.250 | 0.580** | 0.201 | 0.571** |
| CC60 | | | | | | | | | | | | 1 | 0.738** | 0.204 | 0.575** | 0.180 | 0.551** |
| CC75 | | | | | | | | | | | | | 1 | 0.206 | 0.448* | 0.202 | 0.486* |
| Protein content | | | | | | | | | | | | | | 1 | 0.373 | 0.515* | 0.508* |
| 1000 seed wt. | | | | | | | | | | | | | | | 1 | 0.553** | 0.890** |
| Biological yield | | | | | | | | | | | | | | | | 1 | 0.627** |
| yield | | | | | | | | | | | | | | | | | 1 |

Among yield-contributing traits, 1000-grain weight stands out with the highest positive correlation to yield (r = 0.890**), followed by biological yield (r = 0.627**). Days to maturity displays a significant negative correlation with yield (r = -0.457*), while days to heading has a weaker negative correlation (r = -0.312). Plant height shows a non-significant, weak correlation (r = -0.175).

## Conclusion

The findings of this investigation provide insights into the effects of heat stress caused by delayed sowing on various morpho-physiological, biochemical, and thermal indices, as well as their relationship with the yield of wheat genotypes. Plants exhibit different adaptive mechanisms to cope with heat stress conditions, and wheat genotypes can utilize one or more of these mechanisms to escape or tolerate such stress. Different morpho-physiological traits *viz.*, leaf area, canopy temperature, biochemical traits like chlorophyll content, protein content in seeds and yield traits viz., 1000 grain weight and biological yield were found associated with grain yield. These traits should be used in the breeding programme for the development of heat stress tolerant genotypes.

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