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Effect of Temperature stress on Physio-Biochemical traits of Wheat

Alok Kumar Singh*[1], Preeti Singh[2], R. K. Yadav[1], Piyusha Singh[3], Vinod Kumar Singh[3] & Ramesh Pratap Singh[4]

[1]*Department of Crop Physiology, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP) India*
[2]*Department of Resource Management & Consumer Science, College of Community Science, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP) India*
[3]*Department of Genetics and Plant Breeding,Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP) India*
[4]*Department of Agriculture Biochemistry, College of Agriculture, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP) India*

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Corresponding Author: **Alok Kumar Singh** | E-Mail: **(alokksinghcp@nduat.org)**

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ABSTRACT

Wheat (Triticum aestivum L.) is one of the most crucial staple crops globally, providing essential calories and nutrients to a large portion of the world's population. However, the production and quality of wheat are increasingly threatened by climate change, particularly by rising temperatures during the grain-filling period, commonly referred to as "terminal heat." Terminal heat stress, occurring in the final stages of wheat development, can significantly impair grain yield and quality, posing a major challenge to global food security.The present research was conducted at the Student's Instructional Farm (SIF) of Acharya N.D. University of Agriculture and Technology, Kumarganj, Ayodhya. Laboratory analysis was performed in the Crop Physiology Laboratory. The climate of Ayodhya falls under a semi-arid zone, with a mean annual rainfall of 1100 mm, about 80% of which occurs during the monsoon season (November to April), with occasional showers in winter.Three wheat varieties—PBW-343, HD-2967, and Kundan—were selected for the study, with three replications. PBW-343 and HD-2967 are high-yielding varieties commonly used in the North Eastern Plain Zone (NEPZ) for timely sown conditions, but they are susceptible to temperature stress. Kundan, a popular late-sown variety, is known for its tolerance to high-temperature stress. The treatments were based on three sowing dates: D1 (30th November), D2 (15th December), and D3 (30th December).

Keywords: *Catalase, Proline, Biochemical, Chlorophyll, Free Proline, Biological yield, Harvest index,*

Introduction

Wheat (*Triticum aestivum* L.) is a vital crop in India, and Uttar Pradesh (UP) stands as the leading wheat-producing state in the country. With its fertile plains and favorable climatic conditions, UP contributes significantly to India's wheat basket, playing a crucial role in ensuring the nation's food security. The state's diverse agro-climatic zones allow for extensive wheat cultivation, making it a cornerstone of the rural economy and the primary source of income for millions of farming families.

Wheat cultivation in Uttar Pradesh is deeply intertwined with the region's agricultural practices and cultural heritage. The crop is primarily grown during the Rabi season, benefiting from the cool and dry weather conditions that prevail during this period. The widespread adoption of improved wheat varieties, along with the implementation of advanced agronomic practices, has led to substantial increases in productivity over the years. However, the state's wheat farmers face several challenges, including fluctuating weather patterns, soil fertility issues, and the rising costs of inputs.

The impact of terminal heat on wheat is multifaceted, involving complex physiological and biochemical processes. At the physiological level, high temperatures accelerate plant senescence, reduce photosynthetic activity, and disrupt water relations, leading to premature leaf drying and reduced grain filling duration. These changes directly translate to lower grain weight and diminished yields. Biochemically, terminal heat stress induces oxidative stress, alters hormone levels, and disrupts the balance of key metabolic pathways, further exacerbating the negative effects on wheat productivity. In recent years, climate change has emerged as a significant threat to wheat production in Uttar Pradesh, with terminal heat stress during the grain-filling stage becoming a critical concern. This stress not only affects the yield but also the quality of the wheat grains, posing a serious challenge to sustaining the state's agricultural output. Understanding the factors influencing wheat cultivation in UP and addressing the emerging challenges is essential for maintaining and enhancing wheat production in the region.

Materials and Methods

The present research was conducted at the Student's Instructional Farm (SIF) of Acharya N.D. University of Agriculture and Technology, Kumarganj, Ayodhya.

Laboratory analysis was carried out in the Crop Physiology Laboratory. The experimental site is located 42 km from Ayodhya on the Ayodhya-Raebareli road at 26.47°N latitude and 81.12°E longitude, with an elevation of 113 meters in the Gangetic alluvial plains of eastern Uttar Pradesh. The region experiences weather extremes, with a semi-arid climate and an average annual rainfall of 1100 mm, 80% of which occurs during the monsoon season (November to April), with occasional winter showers.Meteorological data, including temperature, rainfall, relative humidity, and sunshine hours, were collected from the meteorological observatory located at Kumarganj, the main campus of the university. The experiment involved 27 plots, each measuring 5 m x 4 m, with plant spacing of 20 cm x 10 cm. Five plants per plot were randomly selected as samples for recording observations.

The experiment was designed as a split-plot with three replications and three treatments. The three wheat varieties selected were PBW-343, HD-2967, and Kundan. PBW-343 and HD-2967 are popular high-yielding varieties in the North Eastern Plain Zone (NEPZ) for timely sown conditions, but they are sensitive to temperature stress. Kundan, a late-sown variety, is tolerant of high-temperature stress.The three treatments were based on sowing dates: D1 (30th November), D2 (15th December), and D3 (30th December). These sowing dates were selected to allow for the varieties to experience heat stress during later developmental stages. The optimum sowing time for timely sown varieties is mid-November, while for late-sown varieties, it is the first fortnight of December.Plant height and tiller counts were recorded at the maximum tillering stage, and effective tillers were counted at the physiological maturity of each wheat variety. Grain yield and biological yield were measured post-harvest. Chlorophyll content was estimated following the method of Arnon (1949), and free proline content in leaves was measured using a spectrophotometer according to the method of Bates et al. (1973).

Result and Discussion

The plant height recorded at 60, 75, and 90 days after sowing (DAS) under different sowing times and varieties is summarized in Fig. 1. Analysis of the data indicates that shoot elongation increased progressively with crop development. A steady increase in plant height was observed up to 90 DAS, after which the growth rate slowed. The reduced plant height in late-sown crops can be attributed to a shorter growing period. In contrast, early-sown crops benefitted from favorable environmental conditions, particularly optimal temperatures and solar radiation, which led to taller plants.

The variation in plant height among the different varieties can be explained by their inherent genetic diversity. These findings are consistent with previous reports by [33, 2].

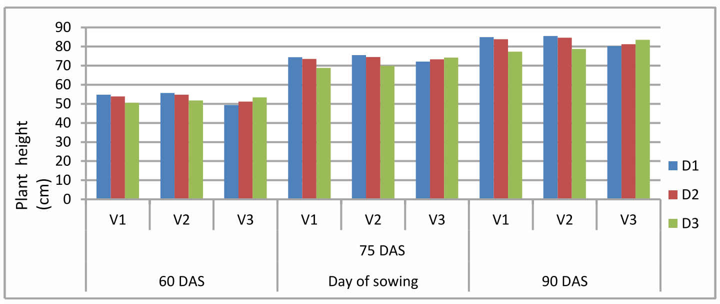

Fig: 1- Effect of date of sowing on plant height at various stages of wheat varieties

The number of tillers per plant, as affected by different sowing times, was recorded at 60, 75, and 90 days after sowing (DAS) and is depicted in Fig. 2. The data clearly indicate that the maximum number of tillers per plant was observed at 75 DAS, regardless of the sowing date.

When analyzing the effect of varieties and planting windows on the number of tillers per plant, it was found that the late-maturing variety V3 (Kundan), when sown early (D1 – 15th November), exhibited a significant decrease in tiller count. Similarly, the early-maturing varieties V1 (PBW-343) and V2 (HD-2967), when sown late, also showed a significant reduction in the number of tillers per plant. This reduction can be attributed to the onset of unfavorable environmental conditions during the crop's critical growth stages.

Early sowing resulted in a higher number of tillers per plant and greater plant height. These findings align with those reported by [14, 26]

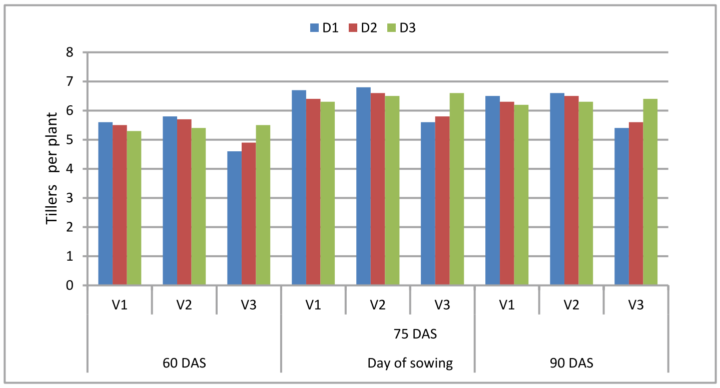

Fig: 2- Effect of date of sowing on tillers per plant at various stages of wheat varieties.

In Fig 3 data clearly showed that days to 50% flowering decreased with the different date of sowing. At D1 (15 Nov) and D2 (30 Nov), maximum days to 50% flowering was obtained in V2 i.e., 94.65 and 90.65days respectively. At D3 (15 Dec) a maximum number of days to 50% flowering was obtained in V3 i.e., 85.55 days. It is obvious from the data that early sowing D1 (15 November) reduced the days to 50% flowering of late variety V3 (Kundan) as analyzed to D2 (30 November) and D3 (15 December). The data clearly showed that late sown i.e., D3 (15 December) decreased the days to 50% flowing of varieties V1 (PBW-343) and V2 (HD-2967) as compared to D1 (15 November) sowing at flowering stage. A similar finding was also reported by (1). The varieties showed a greater extent of variation in reduction to days 50% flowering duration under late sowing which perhaps might be due to premature senescence which leads to force maturity of wheat plant under extreme conditions. This is because high temperature accelerates flowering and ultimately resultsin forced maturity (39, 23 and 25). Regardless of varietal differences, the number of days to 50% flowering was significantly reduced with delayed sowing of wheat. Temperature plays a crucial role in determining the duration of a crop's life cycle, and delayed sowing exposes the plants to higher temperatures, accelerating their development.

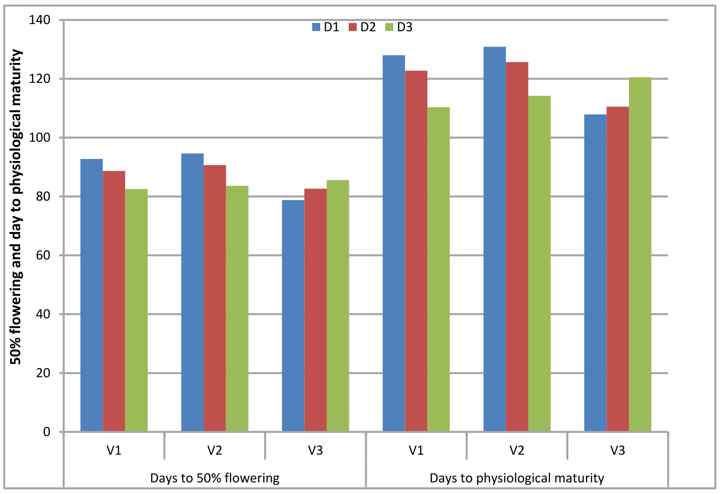

Fig: 3-Effect of date of sowing on day to 50% flowering and day to physiological maturity stage of wheat varieties

The data reveal that days to physiological maturity were influenced with mean maximum and minimum temperatures in both cases.This is because the increase in the temperature and velocity of wind later in April hastens physiological maturity in both early and late sown crop. Physiological maturity of wheat was significantly influenced by sowing dates and the varietal characteristic.

Total chlorophyll content (mg g-1 fresh weight)

The data related to total chlorophyll content at various crop growth stages as influenced by time of sowing are summarized in Fig.4. The chlorophyll content was progressively increased with plant age up to 75 DAS whereas, a decrease in chlorophyll content was observed at 90 DAS in all varieties.

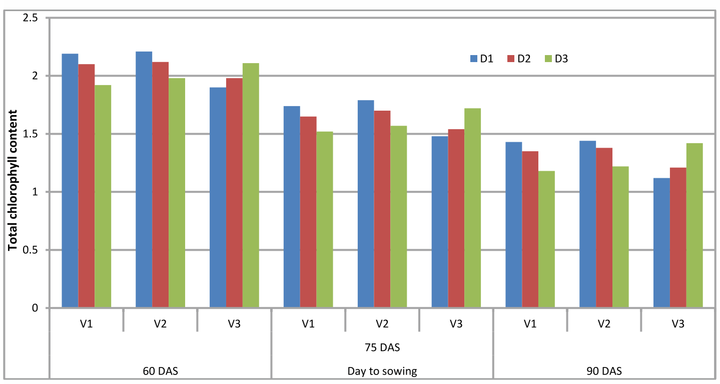

Fig: 4-Effect of date of sowing total chlorophyll at various stage of wheat varieties.

At D1 (15 Nov), total chlorophyll content was obtained maximum in V2 i.e., 2.21, 1.79, and 1.44 mg/g fresh weight at 60, 75 and 90 DAS respectively. At D2 (30 Nov), total chlorophyll content was obtained maximum in V2 i.e., 2.12, 1.70 and 1.38 mg/g fresh weight at 60, 75, and 90DAS respectively. At D3 (15Dec) total chlorophyll content was obtained maximum in V3i.e., 2.11, 1.72 and 1.42 mg/g fresh weight at 60, 75, and 90 DAS respectively.

It is clear from the data that the three dates of sowing D1 (15 Nov), D2 (30 Nov) and D3 (15 December) significantly affect the total chlorophyll content of all the varieties (PBW-343, HD-2967 and Kundan). Total chlorophyll content of V1 (PBW-343) and V2 (HD-2967) increased in D1 (15th November) & D2 (30th November) and decreased in D3 (15th December). Total chlorophyll content in late variety (V3 Kundan) increased when sown late i.e., D3 (15th December) and decreased when sown early i.e., D1. A similar finding was in accordance with (5, 25) they also reported asignificant reduction in chlorophyll content with age and under late sowing at all the stages of plant growth. This may be because high chlorophyll content might contribute to higher photosynthetic rate finally gate more photosynthate (40). High temperature disturbs the chloroplast integrity, leaf senescence, and ultimately photosynthesis in wheat (20).Chlorophyll deficiency reduces the absorbance of light energy and transfer to reaction centers (RCs) of PS-II and PS-I at high temperature in wheat (5).

Total soluble sugar (mg g-1 dry weight)

Data recorded at different crop growth stages on total soluble sugar content in leaves are presented in Fig.5 showed that total soluble sugar content was affected due to time of sowing at different stages of observation. The perusal of data shows that total soluble sugar content was increased with increase in ant age in all the cases. At D1 (15 Nov), the maximum total soluble sugar content was obtained in V2i.e., 48.74, 67.56 and 88.48 mg/g dry weight at 60, 75 and 90 DAS respectively. At D2 (30 Nov), maximum total soluble sugar content was obtained in V2i.e., 44.98, 66.53and 84.10 mg/g dry weight at 60, 75 and V3 at 90 DAS respectively. At D3 (15 Dec) maximum total soluble sugar content was obtained in V3i.e., 45.54, 68.45 and 86.50 mg/g dry weight at 60, 75 and 90 DAS respectively. Minimum total soluble sugar was obtained in V1 at D3, stage of plant growth 60 DAS. A critical examination of data reveals that the difference in sowing times influences total soluble sugar content.The protein content, protein quality, and the glutenin/gliadin ratio are key factors in determining the baking quality of wheat-based bakery products. While high temperatures can increase the total protein content, they negatively affect protein quality, which is largely dependent on grain protein concentration (38). Protein fractions, including albumin, globulin, gliadin, and glutenin, are critical for the end-use quality of wheat grain (41). During the grain filling stage, high temperatures reduce the albumin and globulin content [21], while increasing the gliadin content at the expense of glutenin [11]. Additionally, elevated temperatures lead to higher protein content but lower glutenin production, sedimentation index, and essential amino acids such as lysine, methionine, and tryptophan, all of which are important for determining the viscoelastic properties of wheat dough.

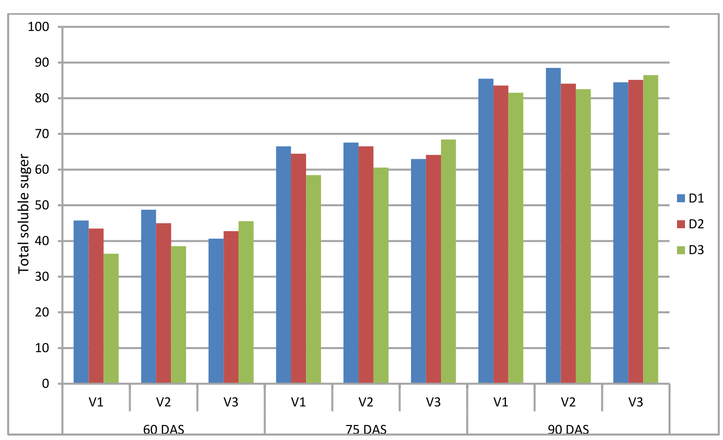

Fig: 5 Effect of date of sowing on total soluble sugar at various stages of wheat varieties.

It is evident from the data that late variety i.e., V3 (Kundan) enhanced the total soluble sugar content in D1 (15 November) and D2 (30 November) and increased in D3 (15 December) at all the stages of observation.

Late sowing i.e., D3 (15 December) caused enhancement in the total soluble sugar of varieties V1 (PBW-343) and V2 (HD-2967) in comparison to when sown early i.e., D1 (15 November) at each stage of crop growth.

Proline content (mg g-1 fresh weight)

The data on proline content is presented in Fig.6 that the proline content influenced by different time of sowing at different crop growth stages, A perusal of data showed that proline content progressively increased with the increase of plant age in all the treatments. At D1 (15 Nov), the highest proline content was obtained in V2i.e., 77.07, 110.13 and 125.56 mg/g fresh weight at 60, 75 and 90 DAS respectively. At D2 (30 Nov), maximum proline content was obtained in V2i.e., 94.54, 125.45 and 148.46 mg/g fresh weight at 60, 75 and 90 DAS respectively. At D3 (15 Dec) maximum proline content was obtained in V3i.e., 83.63, 105.56 and 120.45 mg/g fresh weight at 60, 75 and 90 DAS respectively. Proline accumulation in plants is regulated by the activity of proline dehydrogenase and Δ1-pyrroline-5-carboxylate synthetase/reductase (P5CS) (Sharma et al., 2019). Under high-temperature conditions, P5CS activity increases while proline dehydrogenase activity decreases in heat-tolerant wheat seedlings. Proline dehydrogenase catalyzes the breakdown of proline in the mitochondria, whereas glutamate, in the presence of P5CS1, serves as a precursor for proline synthesis, leading to its accumulation in plants under heat stress [19].

Proline content is directly linked to elevated temperatures of 35–40°C, which enhances the plant's defense mechanisms in wheat seedlings. At a temperature of 35°C compared to 25°C, proline content can increase by up to 200%, improving both photosynthetic efficiency and yield [17]. The effect of different sowing dates on proline content (mg g^{-1} fresh weight) at various stages of wheat varieties is highlighted in Fig. [6].

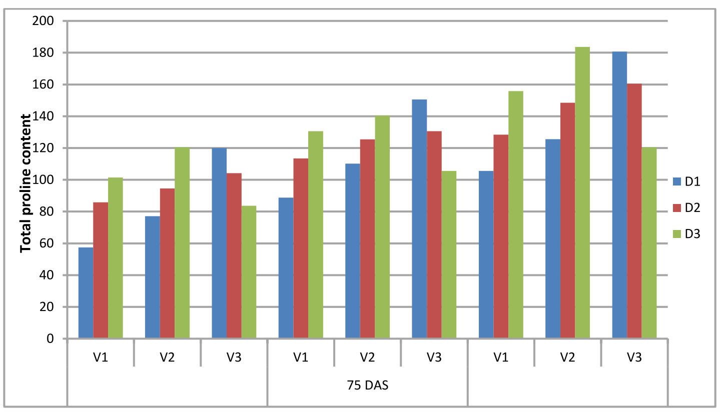

Fig: 6 Effect of date of sowing on proline content (mg g^{-1} fresh weight) at various stages of wheat varieties.

Data pertaining to proline content indicated that delayed sowing of early varieties V1 (PBW-343) and V2 (HD-2967) significantly increase the proline content. A maximum reduction of 30.31% was obtained in late variety i.e., V3 (Kundan) when late sown at 60 DAS. Sami et al. (2015) Data pertaining toproline content indicated that delayed sowing of early varieties V1 (PBW-343) and V2 (HD-2967) significantly increased the proline content.

Number of grains ear-1

Grain number ear-1 varied considerably with time of sowing. Grain number was almost identical but did vary in individual treatment presented depicted in (Fig. 7). D1 (15 Nov) and D2 (30 Nov), maximum number of grains ear-1 was obtained in V2i.e., 43.77 and 42.55 respectively. At D3 (15 Dec) maximum number of grains ear-1 was obtained in V3i.e., 41.54. Minimum number of grains ear-1 was recorded in V1 at D3. It is clear from the data that early sowing in D1 (15 November) and D2 (30 November) scaled down the grain number ear-1 of the late variety i.e., V3 (Kundan) as analyzed to D3 (15 December) sowing after harvesting. The evidenceof the data that delayed sowing i.e., D3 (15 December) reduced the grain number ear-1 of varieties V1 (PBW-343) and V2 (HD-2967) as situated at D1 (15 November) sowing after harvesting. Less number of grains ear-1 in late sowing in V1 and V2 was due to less production of photosynthates due to a shorter growing period. These results are in line with those of [33 and 23]. Differences in number of grains per ear among varieties might be attributed to their genetic variability. The early sowing resulted in better development of the grains due to longer growing periods[33].

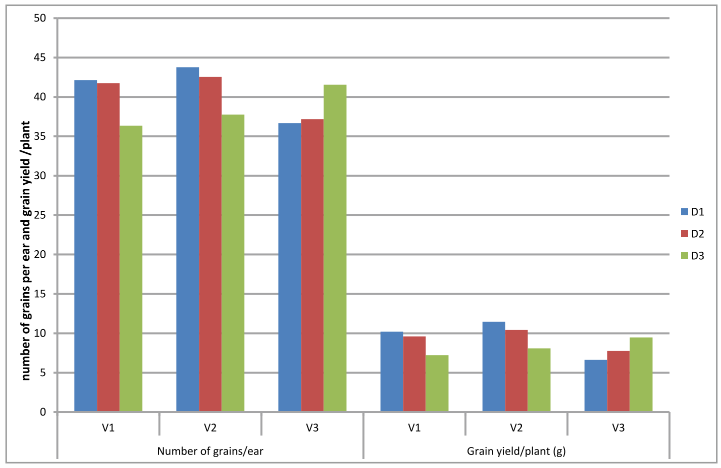

Fig-7 Effect of date of sowing on number of grain per ear and grain yield /plant (g) at various stages of wheat varieties

Grain yield plant-1 (g)

Data pertaining to grain yield plant-1 of wheat as influenced by time of sowing have been presented in Fig.7. Further, data indicate that the grain yield per plant was also differed significantly under different wheat varieties. At D1 (15 Nov) and D2 (30 Nov), the highest grain yield plant-1 was obtained in V2i.e., 11.48 g and 10.41 g respectively. At D3 (15 Dec) highest grain yield plant-1 was obtained in V3i.e., 9.48 g. Minimum grain yield plant-1 was recorded in V3at D1. Effect of time of sowing on data pertaining to grain yield plant-1 of different wheat varieties sown in different dates significantly affect the grain yield of early sown varieties V1 (PBW-343) and V2 (HD-2967). Lower grain yield at early sowing in V3 was mainly due to a smaller number of tillers, and a smaller number of grains per spike weight. It is clear from the data that early sowing in D1 (15 November) and D2 (30 November) scaled down the grain number ear-1 of the late variety i.e., V3 (Kundan) as analyzed to D3 (15 December) sowing after harvesting. The evident of the data is that delayed sowing i.e., D3 (15 December) reduced the grain number ear-1 of varieties V1 (PBW-343) and V2 (HD-2967) as situated at D1 (15 November) sowing after harvesting. Less number of grains ear-1 in late sowing in V1 and V2 was due to less production of photosynthates due to a shorter growing period. These results are in line with those of (Shahzad et al., 2002). Differences in number of grains per ear among varieties might be attributed to their genetic variability. The early sowing resulted in better development of the grains due to longer growing period [33].

Conclusion

Days to 50% flowering and to physiological maturity weremarkedly reduced by delayed sowing of wheat. It was found that with the delayed sowing, days to 50% flowering and to physiological maturity was reduced. Maximum and minimum number of days for 50% flowering and physiological maturity was found in early varieties and D3 respectively. This may be because high temperature accelerates flowering and ultimately resultsin forced maturity. Biochemical parameters like total chlorophyll, total soluble sugar and peroxidae content for V1 (PBW-343), V2 (HD-2967) and V3 (Kundan) was found maximum in D1, D1, and D3 respectively, at 60, 75 and 90 DAS. A significant reduction in chlorophyll content was observed with plant aging and under delayed sowing conditions. The decrease in total soluble sugar content is likely due to the onset of high temperatures, which impaired photosynthetic activity and hastened the crop towards senescence or forced maturity. Maximum proline and catalase activity in V1 (PBW-343), V2 (HD-2967), and V3 (Kundan) was recorded at D3 (30th December) at 60, 75, and 90 days after sowing (DAS), respectively.Yield and yield-contributing parameters such as effective tillers per plant (EBT), number of grains per plant, ear length (cm), grain yield per plant, biological yield per plant, test weight (g), and harvest index were found to be highest for V1 (PBW-343) and V2 (HD-2967) in D1 (15th November), and for V3 (Kundan) in D3. The maximum grain yield was obtained from crops sown on D1 (15th November), which can be attributed to the fact that yield attributes were adversely affected by delayed sowing, leading to forced maturity due to higher temperatures.

Acknowledgments

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Conflict of Interest

The authors declare that they have no conflict of interest.

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