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RESEARCH ARTICLE

Combating Heat Stress in Late Sown Wheat through Pre-Sowing Seed Priming

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ABSTRACT

The goal of the current study was to evaluate the effectiveness of various seed priming methods in enhancing wheat growth and yield when sown late. Therefore, a field experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, following a Split-plot design with three replications. The experiment comprised two factors, Factor A: wheat sowing date viz., (i) 30 November; (ii) 15 December; (iii) 30 December; Factor B: seed priming agent namely, (i) control (no priming); (ii) hydro priming; (iii) priming with 20000 ppm $CaCl_2$; (iv) priming with 20000 ppm KCl; (v) priming with 15000 ppm KNO_3; and (vi) priming with 40000 ppm Mannitol. The study found that BARI Gom-33's grain yield was highest (3.06 t ha^{-1}) when sown on 30 November, which was reduced by 39.87% and 64.37%, respectively, by late and very late sowing. Grain yield was significantly increased by seed priming, especially with $CaCl_2$, by 0.66 t ha^{-1} when compared to the control. Moreover, when $CaCl_2$ priming was used on November 30, the highest grain yield was obtained (3.37 t ha^{-1}). In contrast, when no priming was used on December 30, the lowest yield (1.11 t ha^{-1}) was obtained. Consequently, to mitigate the effects of high temperatures, wheat should be sown by November 30th, ideally with 20,000 ppm of $CaCl_2$.

Keywords: *Seed priming, High temperature stress, Late sown wheat, Grain yield*

INTRODUCTION

Wheat, a cereal grain, has been a cornerstone of human civilization for thousands of years. Its importance goes beyond basic survival because it is intricately linked to history, culture, and international economies. The domestication of wheat 10,000 years ago represents a major turning point in human civilization and is therefore a historically significant staple crop (Singh *et al.,* 2023). A notable source of vegetable protein in human diets, wheat contributes roughly 13% of its protein content. It is primarily composed of gluten, which makes up 75–80% of the protein in wheat. Wheat also contributes significantly to carbohydrates (71%). Whole grains, such as wheat, are a rich source of dietary fiber and other essential nutrients (Srivastava *et al.,* 2023). Bangladesh's agricultural policies now place a strong emphasis on wheat because of the realization that crop diversification is essential for ensuring food security. Currently,

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Bangladesh cultivates 1.23 million tons of wheat on 0.34 million hectares of land, producing an average of 3.63 tons per hectare (BBS, 2022). Bangladesh's modest size and limited climatic diversity make it a less diverse tropical nation than other countries with more varied climates or temperate climates. As a result, Bangladesh produces less wheat on average compared to other countries with diversified climatic conditions or temperate climates (Islam *et al.,* 2023). Stresses from the environment, such as low soil moisture, high temperatures, and inadequate light, can negatively impact wheat growth and yield. Of these, high temperature is the most important (Modarresi *et al.,* 2010; Trnka *et al.,* 2004). Heat stress affects over 50 countries that annually import more than 20 million tons of wheat. This stress is characterized by a mean daily temperature exceeding 17.5 °C during the coolest month of the season and persists throughout the entire wheat growth cycle (Modarresi *et al.,* 2010). When considering the various factors that affect the country's low wheat yield, the date of sowing holds the most tremendous significance.

The precise environmental conditions that every crop variety requires to reach its maximum potential can be helped by choosing the appropriate sowing date. The optimal time to plant wheat in Bangladesh is from mid-November to the first week of December. There are several reasons why the sowing date of wheat is delayed, including inadequate irrigation water, excessive moisture or waterlogging conditions from flooding, and the late harvesting of Kharif crops, particularly transplanting Aman rice. Crucial stages for increasing wheat yield are root development, germination, and grain development. Nevertheless, early sowing severely hinders root development because plants suffer from drought stress at that time, and late sowing hinders germination and grain development due to foggy conditions and dew drops, which affect the development of germination and grain development in wheat (Tahir *et al.,* 2009). Maximizing grain and straw output hinges on prioritizing the tillering phase. This critical stage directly influences tiller count, spike formation, the number of grains per spike, and individual grain weight. Furthermore, timely planting remains a non-negotiable factor in achieving optimal results (Qasim *et al.,* 2008). Wheat production in Bangladesh faces challenges primarily due to environmental limitations, including delayed planting and a brief winter season (Ahmed *et al.,* 2019).

Wheat typically experiences two distinct types of heat stress: continuous and terminal heat stress. "Continuous heat stress" persists throughout the entire wheat growth season, from sowing to maturity. In contrast, "terminal heat stress" occurs during the reproductive growth stages, specifically from heading to maturity (Reynolds *et al.,* 2001). Elevated temperatures accelerate the development of the spike and decrease the number of grains and spikelets within each spike (Farooq *et al.,* 2011). The worldwide impact of heat stress on wheat is estimated to be 36 million hectares, with 40% of the crop experiencing terminal heat stress (Kumar *et al.,* 2023; Reynolds *et al.,* 2010). In tropical and subtropical regions, however, 25–30 million hectares of wheat are vulnerable to yield loss due to heat stress (including China, Bangladesh, Nepal, India, Pakistan, Ethiopia, Sudan, Egypt, and North Africa). Global warming projections and current trends indicate that this area is expected to experience significant increases. According to reports, the yield drop caused by high temperatures in developing countries is approximately 29%. According to the climate scenario for the future, wheat production is expected to decline significantly due to rising temperatures (Ortiz *et al.,* 2008). Bangladesh's wheat yield would drop by 68% with every 4 °C increase in temperature (Acharjee and Shariot-Ullah, 2021). Moreover, a doubling of temperature and atmospheric CO_2 concentration would result in a 31% decline in wheat yield worldwide. Under terminal heat stress, the lengthening of the grain-filling period results in smaller grains and a lower grain spike^{-1} than in a suitable planting crop (Farhad *et al.,* 2023).

Utilizing a variety of agronomic management strategies can lessen the detrimental effects of high temperatures on wheat yield. Nonetheless, wheat's sensitivity to high temperatures can be reduced by various physiological techniques. One of these low-cost techniques for encouraging crop stand establishment is seed priming (Farooq *et al.,* 2006). The technique known as "seed priming" involves controlling the hydration process inside seeds, re-drying them, and triggering numerous physiological processes related to the initial stages of germination, thereby preparing them for radical protrusion, which suspends the seeds in the lag phase (Paparella *et al.,* 2015). Before distributing seeds, a seed priming treatment is carried out. This means that seeds must be adequately hydrated to permit the occurrence of metabolic processes before germination while inhibiting the formation of radicles (Rehman *et al.,* 2011; Nascimento *et al.,* 2013). Prime seeds may germinate more quickly due to a variety of factors, including increased activity of degrading enzymes such as amylase, RNA and DNA synthesis, the amount of ATP, and the presence of mitochondria (Afzal *et al*., 2002). Due to their many benefits, primed seeds are also more beneficial. Increased metabolic events can trigger the germination of dormant seeds (Soleimanzadeh, 2013), allowing for early flowering and maturity, as well as early reproductive organ growth and improved resistance to abiotic stresses (Maasoumeh and Mohammad, 2014) and soil-borne pathogens such as *Rhizoctonia solani*, *Fusarium* spp., and *Sclerotium rolfsii* (Rafi *et al*., 2015).

Considering that Bangladesh's population is growing rapidly, and that the nation needs wheat daily. Further research endeavors should focus more on enhancing wheat yield under heat stress conditions by developing heat-tolerant cultivars and efficient techniques, such as seed priming. In-depth research on how different seed priming techniques affect wheat development and yield under late-sowing conditions has been limited. Keeping this in mind, this present research work was designed to identify the most suitable priming technique for enhancing the growth and yield of late-sown wheat under high-temperature stress.

MATERIALS AND METHODS

Experimental sites

A field trial was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University (24°43'12"N 90°25'37"E and 18.6 m above sea level) from November 2022 to March 2023. The area belongs to the non-calcareous, dark gray floodplain soil of the Old Brahmaputra Floodplain agroecological zone (AEZ 9). The land had a silty-loam texture, was medium to high in elevation, and was well-drained. At pH 6.65, with 1.21% of organic matter, 0.12% of total nitrogen, 26.07 ppm of available phosphorus, 0.15 me % of exchangeable potassium, and a moderate overall fertility level, the soil in the experimental field was essentially neutral in reaction. The experimental site is located in a humid, sub-tropical monsoon climate. Table 1 provides information on the pattern of rainfall, sunlight hours, temperature fluctuations, and relative humidity over the research period, and also shows the maximum, minimum, and average temperatures during the experimental period.

Treatments and design

Two factors were involved in the experiment, Factor A: sowing date and Factor B: priming agents. Three dates were selected for sowing, *viz.,* D_1: optimum sowing (30 November), D_2: late sowing (15 December), and D_3: very late sowing (30 December). The experiment employed only laboratory-grade priming agents manufactured by MERCK, India. Six conditions were created by using five priming agents such as a) no priming (P_1) (b) hydro priming(P_2) (c) priming with 20000 ppm $CaCl_2$ (P_3) (d) priming with 20000 ppm KCl (P_4) (e) priming with 15000 ppm KNO_3 (P_5) and (f) priming with 40000 ppm Mannitol ($C_6H_{14}O_6$) (P_6). A split-plot design with three replications was used to set up the experiment, resulting in a total of 54 plots (18 × 3). The date of sowing was assigned in the main plots, while seed priming practices were assigned in the sub-plots. Plot dimensions were 2.5 m × 2.0 m.

Table 1. Weather data from November 2022 to March 2023 at the experimental site during the growing season of wheat

Month and year	Air temperature (°C)			Total rainfall (mm)	Average relative humidity (%)	Total sunshine (hrs.)
	Maximum	Minimum	Average			
November 2022	30.4	18.3	24.4	0	81.6	187.8
December 2022	25.4	13.5	19.8	17.7	80.2	201.3
January 2023	24.02	12.15	19.22	0.00	84.35	227.2
February 2023	26.8	15.54	21.28	1.17	83.00	164.8
March 2023	30.65	17.70	23.76	1.90	73.19	208.2

Source: Weather Yard, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh.

The distances between plots and blocks were 0.5 and 1.0 meters, respectively.

Plant material

BARI Gom-33 is a Zn-enriched and wheat blast-resistant variety with weaker glaucosity in the spike, released by the Wheat Research Centre, Bangladesh Agricultural Research Institute (BARI), Dinajpur, in 2017 [this research center is currently renamed as the Bangladesh Wheat and Maize Research Institute (BWMRI)]. The variety has a dark green stem and leaf. It needs roughly 60–65 days for heading and 110–115 days for physiological maturation. Tillers are semi-erect during heading, and the flag leaf is broad and droopy. A well-managed crop can yield 4-5 tons per hectare of grain.

Crop husbandry

After collecting BARI Gom-33 seeds, they were soaked in a priming agent solution at a ratio of 1:5 (seed weight to solution volume) for 6 hours. The seeds were then thoroughly washed to remove chemical particles, and after maintaining the proper moisture content, they were stored in a refrigerator for sowing. Following the implementation of appropriate management practices, the land was prepared for use. Subsequently, fertilizers were applied at the following rates: 240, 150, 110, 120, and 8 kg ha-1 of urea, Triple Super Phosphate (TSP), Muriate of Potash (MoP), Gypsum, and Boric acid, respectively. The treated seeds were planted in the plot at a rate of 120 kg seeds ha^{-1} in rows 20 cm apart by the predetermined sowing dates. Following the proper intercultural practices, such as irrigation and weeding, the crop eventually reached maturity. When the crop reached full maturity, it was first harvested individually, plot-wise, on March 16, 23, and 31, 2023, for the first, second, and third sowing dates, respectively.

Data collection procedure

Before harvesting, ten randomly chosen hills from each plot were removed. Plot-wise data on grain and straw yields were obtained on 14% moisture basis, and the results were expressed in tons per hectare (t ha^{-1}). Plant height, spikes m^{-2}, spikelets $spikes^{-1}$, and grains $spikelet^{-1}$ were measured by selecting 10 plants randomly from each plot and then averaging. The weight of 1000 grains was collected after the entire plot was harvested. Then, grain yield and straw yield were calculated after proper sun drying, and the biological yield was the sum of grain and straw yield. Finally, the harvest index was calculated as follows: (Grain yield/Straw yield) × 100.

Statistical analysis

For statistical analysis, the recorded data were collated and tabulated. The software program MSTAT was used to perform an analysis of variance at the 5% probability level. Duncan's Multiple Range Test (DMRT) was used to determine the mean differences between the treatments.

RESULTS AND DISCUSSION

Effect of sowing date on wheat

Sowing dates had a significant impact on all plant characters, including yield-contributing characters and wheat yield. Planting later than the optimum time resulted in shorter wheat plants because it created unfavorable conditions for wheat plants. When sowing was completed on November 30, the highest plant height (87.51 cm) was discovered. In comparison to the ideal sowing date of November 30, the plant (73.96 cm) was 13.55 cm shorter at the extremely late sowing date of December 30. The number of spikes m^{-2} exhibited a similar pattern, with the highest value (186.79) being attained on November 30, the day of optimal sowing. Unfortunately, only 66.87 spikes m^{-2} were obtained from the very late sowing date of 30 December; that amount is less than half of the optimum sowing date obtained. In terms of spikelets $spike^{-1}$, 30 December sowing yielded the lowest results, 6.20 (Table 2). When seeds were sown on November 30 (14.21) and December 15 (9.28), there was a definite benefit to the sowing date in terms of increasing spikelets $spike^{-1}$, but not after that. When it came to wheat grains $spikelet^{-1}$, the sowing on November 30 displayed the highest number of grains $spikelet^{-1}$ (2.84), while the sowing on December 30 displayed the lowest number of grains $spikelet^{-1}$ (1.72) (Table 2). Moreover, it is evident that until 15 December sowing time, the number of grains $spikelet^{-1}$ (2.20) of wheat was tolerable (Table 2). The weight of 1000-grain drastically falls according to the delay of sowing time. When the sowing date was 30 November, it produced the highest weight of 1000-grain, accounting for 40.50 g. However, when the sowing date became 30 December, the weight of 1000-grain (25.97 g) dropped by almost 15 g compared to the optimum sowing date (30 November) (Table 2). The retarded sowing also resulted in a lower wheat grain yield. The sowing date, which took place on 30 November, resulted in the highest grain yield (3.06 t ha^{-1}). Due to the extremely late sowing (30 December) and late sowing (15 December), wheat grain yield (1.19 t ha^{-1}, 1.84 t ha^{-1}) was reduced by 64.37% and 39.87% respectively. Furthermore, the highest straw yield (3.78 t ha^{-1}) was obtained from early sowing, while the lowest straw yield (1.77 t ha^{-1}) was found from very late sowing. When the wheat was sown on November 30, it had the most excellent harvest index (44.42%). The harvest index steadily decreased as sowing was postponed (Table 2). High temperatures caused late-sown wheat cv BARI Gom-33 to produce fewer spikes per m^{-2}, which could potentially negatively impact grain yield $plant^{-1}$ and 1000-grain weight. According to research by Nawaz *et al.* (2013) and Farooq *et al.* (2011), high temperatures reduced the number of grains $spike^{-1}$ and ear heads as well as hindered pollination and seed set. Better spikes m^{-2} and grain yield $plant^{-1}$ evidence improved wheat performance following seed priming treatments. In the case of late-sown conditions, this lessened the harsh consequences of rising temperatures. Priming functions as a form of immunization against impending illnesses, such as high temperatures (Arun *et al.,* 2021; Patanè *et al.,* 2009; Wahid *et al.,* 2008). Zulfiqar *et al.* (2022) reported that seed priming correlates with seedlings' capacity to tolerate both biotic and abiotic stress. The hypothesis was that pre-sowing seed treatment could improve germination, increase the germination rate, and enhance seedling vigor and growth in Bangladesh, where late wheat planting is becoming increasingly common. In overcoming different abiotic and biotic obstacles, this may help wheat seedlings.

Effect of priming agents on wheat

All yield parameters, except 1000 grain weight and straw yield, were significantly influenced by seed priming (a technique for hydrating seeds before sowing that promotes germination and consistent seedling emergence). It was demonstrated that priming the seeds elevated the height of the wheat plant when compared to non-primed seeds. While seed priming outperformed the control (76.46 cm) by a significant margin, hydropriming (79.44 cm), $CaCl_2$ priming (82.53 cm), KCl priming (80.94 cm), KNO3 priming (79.81 cm), and mannitol priming (80.21 cm) did not differ significantly from one another. From Table 3, it is evident that seed priming resulted in an average increase of 5 cm in plant height. Ali *et al.* (2013) also found that various seed priming techniques in wheat increased plant height. Farooq *et al.* (2011) reported that primed seeds generally outperform control seeds in terms of dry matter production, plant height, and root weight. For the impact of seed priming, it was observed that more spikes per square meter were obtained from primed seeds than from seeds without priming. The highest number of spikes m^{-2} (126.57) was produced with $CaCl_2$ priming, which was similar(statistically) to KCl (125.92), while other seed priming (hydro, KNO_3, mannitol) produced statistically identical results (Table 3). The lowest number of spikes m^{-2} (119.56) was recorded with no priming. In terms of number of spikelets $spike^{-1}$, seed priming with $CaCl_2$ (11.34) performed significantly better than the control (8.73), however, there was no statistically significant difference between $CaCl_2$ (11.34) and KCl (10.84) priming, while KNO_3 (9.47) and hydro (8.90) priming

Table 2: Effect of sowing date on plant characters, yield parameters, and yield of wheat cv BARI Gom-33

Sowing date	Plant height (cm)	Spikes m^{-2} (no.)	Spikelets $spike^{-1}$ (no.)	Grains $spikelet^{-1}$ (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest Index (%)
30 November	87.51[a]	186.79[a]	14.21[a]	2.84[a]	40.50[a]	3.06[a]	3.78[a]	44.42[a]
15 December	78.22[b]	115.68[b]	9.28[b]	2.20[b]	35.32[b]	1.84[b]	2.56[b]	41.92[b]
30 December	73.96[c]	66.87[c]	6.20[c]	1.72[c]	25.97[c]	1.19[c]	1.77[c]	40.20[c]
Sx	1.77	2.21	0.45	0.14	0.40	0.12	0.13	0.77
Level of sig.	**	**	**	**	**	**	**	**
CV (%)	6.63	5.38	13.56	18.14	3.56	17.91	14.38	5.47

In a column, figures with the same letter do not differ significantly (as per DMRT), **=significant at 1% level of probability, NS=Non-significant.

produced statistically different results from $CaCl_2$ and KCl priming (Table 3). Seed priming increased yield and exceeded the control by a significant margin. According to Asadujjaman *et al.* (2023), primed seed treated with KCl and $CaCl_2$ under high temperature stress resulted in the highest plant height, number of spikes m^{-2}, spikelets $spike^{-1}$, grain yield, and straw yield of wheat compared to the control. When seeds primed with $CaCl_2$ had the highest harvest index (43.65%), and no priming produced the lowest harvest index of 38.15% (Table 3). Seed priming induced an average 5% rise in the harvest index (Table 3). To verify the foundation and maximize plant yield, Arun et al. (2021) stated that priming intended to ensure the germination process while protecting the seed from environmental stress during the seedling stage.

Interaction effect of sowing date and seed priming

All plant characters, yield parameters, and wheat yield were significantly varied when sowing date and seed priming interacted with each other. The plants with the tallest height (90.10 cm) and the highest number of spikes per m^2 (189.8) were observed in the $CaCl_2$ priming and sowing on November 30. On the contrary, the lowest height of plants (71.33 cm) was found in no priming and sowing on extremely late sowing (30 December).

To achieve the highest plant height and number of spikes m^{-2}, wheat should be planted on 30 November with $CaCl_2$ priming. Upon combining $CaCl_2$ priming with 30 November sowing, the most significant number of spikelets $spike^{-1}$ (15.73), grains $spikelet^{-1}$ (3.16), the highest 1000-grain weight (40.76 g), and the highest grain yield (3.37 g) were observed (Table 4, Figure 1). On the contrary, the lowest number of grains $spikelet^{-1}$ (1.23) and the weight of 1000 grains (25.86 g) were found in the combination of no priming and 30 December. The highest straw yield (4.09 t ha^{-1}) was produced by the interaction of mannitol priming and 30 November sowing, while the maximum harvest index (47.22%) was observed in the combination of $CaCl_2$ and 30 November sowing. Before December 15^{th} sowing, priming was advantageous in raising the harvest index, but not after that.

This study demonstrates that late-sown wheat can perform better when seed priming techniques are employed. The occurrence of low temperatures during the sowing of wheat cv. BARI Gom-33 leads to poor seed germination, establishment, and vigor of seedlings when sowing is too late. Due to inadequate stand establishment, a lack of spikes per square meter subsequently results in lower grain production, straw yield, and harvest index. Seed priming improved tiller counts, emergence, stand establishment, grain

Table 3. Effect of seed priming on plant characters, yield parameters, and yield of wheat cv BARI Gom-33

Treatments	Plant height (cm)	Spikes m^{-2} (no.)	Spikelets $spike^{-1}$ (no.)	Grains $spikelet^{-1}$ (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest Index (%)
No Priming	76.46^{b}	119.56^{b}	8.73^{c}	1.88^{c}	33.67	1.60^{b}	2.68	38.15^{b}
Hydro Priming	79.44^{ab}	121.08^{ab}	8.90^{bc}	2.02^{bc}	33.70	1.98^{a}	2.51	43.16^{a}
Priming with 20000 ppm $CaCl_2$	82.53^{a}	126.57^{a}	11.34^{a}	2.56^{a}	34.23	2.26^{a}	2.82	43.65^{a}
Priming with 20000 ppm KCl	80.94^{ab}	125.92^{a}	10.84^{a}	2.42^{a}	34.02	2.16^{a}	2.75	43.19^{a}
Priming with 15000 ppm KNO_3	79.81^{ab}	121.56^{ab}	9.47^{bc}	2.31^{ab}	33.95	2.06^{a}	2.64	42.86^{a}
Priming with 40000 ppm Mannitol	80.21^{ab}	124.00^{ab}	10.10^{ab}	2.33^{ab}	34.01	2.11^{a}	2.81	42.06^{a}
Sx	2.50	3.12	0.63	0.19	0.57	0.17	0.18	1.09
Level of significance	**	**	**	**	NS	**	NS	**
CV (%)	6.63	5.38	13.56	18.14	3.56	17.91	14.38	5.47

In a column, figures with the same letter do not differ significantly (as per DMRT), **=significant at 1% level of probability, NS=Non-significant.

Table 4. Interaction effect of seed priming and sowing date on plant characters, yield parameters, and yield of wheat cv BARI Gom-33

Sowing date × seed priming	Plant height (cm)	Spikes m^{-2} (no.)	Spikelets $spike^{-1}$ (no.)	Grains $spikelet^{-1}$ (no.)	1000-grain weight g)	Straw yield (t ha^{-1})	Harvest Index (%)
D_1P_1	84.10^{a-d}	183.33^{a}	12.90^{bc}	2.53^{a-e}	40.16^{a}	3.67^{a}	36.92^{f}
D_1P_2	86.20^{abc}	185.07^{a}	13.06^{bc}	2.66^{a-d}	40.23^{a}	3.60^{a}	46.69^{ab}
D_1P_3	90.10^{a}	189.80^{a}	15.73^{a}	3.16^{a}	40.76^{a}	3.77^{a}	47.22^{a}
D_1P_4	89.23^{ab}	189.10^{a}	15.10^{ab}	3.03^{ab}	40.60^{a}	3.82^{a}	45.85^{abc}
D_1P_5	87.20^{abc}	186.17a	13.73^{ab}	2.83^{abc}	40.73^{a}	3.71^{a}	46.36^{abc}
D_1P_6	88.23^{ab}	187.27^{a}	14.73^{ab}	2.83^{abc}	40.50^{a}	4.09^{a}	43.44^{a-e}
D_2P_1	73.96^{ef}	110.17^{b}	7.80^{fgh}	1.90^{e-h}	35.00^{b}	2.73^{b}	37.30^{f}
D_2P_2	76.93^{def}	112.00^{b}	8.16^{fgh}	2.03^{d-g}	35.06^{b}	2.31^{bcd}	41.61^{de}
D_2P_3	81.16^{b-e}	120.17^{b}	11.10^{cd}	2.46^{b-f}	35.56^{b}	2.79^{b}	43.46^{a-e}
D_2P_4	79.23^{c-f}	119.33^{b}	10.63^{de}	2.20^{c-f}	35.36^{b}	2.57^{b}	43.54^{a-d}
D_2P_5	79.00^{c-f}	115.23^{b}	8.63^{efg}	2.26^{c-f}	35.43^{b}	2.43^{bcd}	42.55^{cde}
D_2P_6	79.06^{c-f}	117.20^{b}	9.36^{def}	2.36^{b-f}	35.50^{b}	2.53^{bc}	43.04^{b-e}
D_3P_1	71.33^{f}	65.17^{c}	5.50^{i}	1.23^{h}	25.86^{c}	1.65^{e}	40.23^{def}
D_3P_2	75.20^{ef}	66.17^{c}	5.46^{i}	1.36^{gh}	25.80^{c}	1.61^{e}	41.19^{de}
D_3P_3	76.33^{def}	69.73^{c}	7.20^{f-i}	2.06^{def}	26.36^{c}	1.89^{cde}	40.26^{def}
D_3P_4	74.36^{ef}	69.33^{c}	6.80^{ghi}	2.03^{d-g}	26.10^{c}	1.87^{de}	40.18^{def}
D_3P_5	73.23^{ef}	63.27^{c}	6.06^{hi}	1.83^{fgh}	25.70^{c}	1.79^{de}	39.67^{ef}
D_3P_6	73.33^{ef}	67.53^{c}	6.20^{hi}	1.80^{fgh}	26.03^{c}	1.80^{de}	39.69^{ef}
Sx	4.33	5.40	1.10	0.33	0.99	0.32	1.88
Level of sig.	**	**	**	**	**	**	**
CV (%)	6.63	5.38	13.56	18.14	3.56	14.38	5.47

In a column, figures with same letter do not differ significantly (as per DMRT), **=significant at 1 % level of probability. D_1= 30 November, D_2= 15 December, D_3= 30 December. P_1= No Priming, P_2= Hydro Priming, P_3= Priming with 20000 ppm $CaCl_2$, P_4= Priming with 20000 ppm KCl, P_5= Priming with 15000 ppm KNO_3, P_6= Priming with 40000 ppm mannitol.

and straw yields, and harvest index in late-sown wheat (Farooq *et al.,* 2008). Numerous seed priming techniques improved the yields of viable tillers, plant height, 1000-grain weight, yield, and grain and biological components in wheat (Ali *et al.,* 2013). In a similar vein, Toklu *et al.* (2015) demonstrated that hydro-priming, PEG, and KCl treatments increased wheat grain yield relative to the control. Additionally, seed priming in wheat produced a noticeably higher grain yield (17%) compared to the non-primed control, according to Ramamurthy *et al.* (2015).

The highest plant height, spike m^{-2}, 1000-grain weight, grain yield, and straw yield of wheat cv. BARI Gom-33 under high-temperature stress was obtained in this study using primed seed, particularly $CaCl_2$. Other priming agents, in addition to $CaCl_2$, also outperformed the control. Similarly, Suryakant *et al.* (2000) found that the highest yields of wheat grain, straw, and biological material were obtained from sprouted seeds, followed by priming treatments with KCl, water, and $ZnSO_4$, and the lowest yields from dry seed sowing (control).

The current study demonstrates that seed priming, when applied later in the growing season, can effectively boost wheat plant growth and yield even in the face of heat stress. Without a doubt, seed priming with $CaCl_2$ proved to be the most

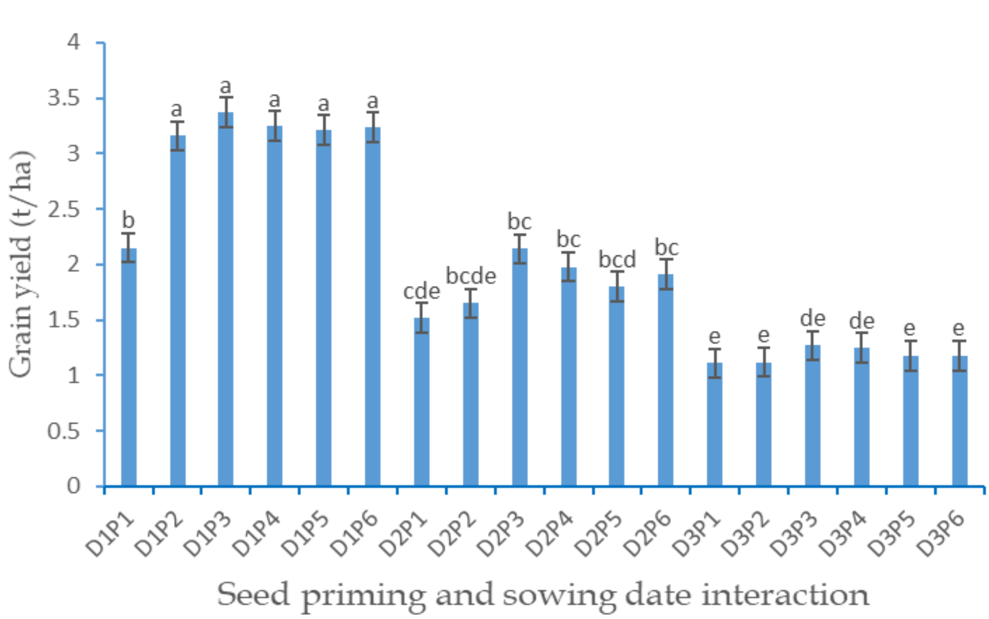

Figure 1. Grain yield of wheat cv BARI Gom-33 as influenced by the interaction between seed priming and sowing date.

The bar represents the standard error of the means. Here, D1=30 November, D2= 15 December, D3= 30 December P1= No Priming, P2= Hydro Priming, P3= Priming with 20000 ppm $Cacl_2$, P4= Priming with 20000 ppm KCl, P5= Priming with 15000 ppm KNO_3, P6= Priming with 40000 ppm mannitol

effective method of priming. However, wheat cv BARI Gom-33's growth and yield were also enhanced by additional priming agents. These results will open up new possibilities for improving seed priming to protect late-sown wheat from heat stress, especially during the reproductive stage.

CONCLUSION

The study found that the sowing date, priming agent, and their interaction significantly impacted the plant height, spikes per m², spikelets per panicle, grains per spike, and grain yield of wheat. Seed priming showed a positive effect on plant characteristics, yield parameters, and yield of wheat cv BARI Gom-33. The grain yield of BARI Gom-33 decreased with a delay in sowing, with the highest yield (3.06 t ha^{-1}) found when sowing on 30 November. Seed priming with $CaCl_2$ resulted in the highest grain yield (2.26 t ha^{-1}), while no priming produced the lowest yield of 1.60 t ha^{-1}. On average, seed priming increased grain yield by 0.66 t ha^{-1} compared to the control. A delay in sowing caused poor crop stand and growth; however, seed priming improved stand establishment and growth, resulting in a substantial increase in grain yield. Therefore, it is recommended to sow wheat by November 30, after seed priming, ideally with 20,000 ppm $CaCl_2$. If sowing is delayed, seed priming is essential to alleviate temperature stress partially. However, this research is conducted in a single year and location; hence, multi-location and especially multi-year trials should be conducted based on these preliminary results before drawing a conclusion.

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Author Contributions:

Study conception and design: Md. Parvez Anwar; data collection: Priya Saha and Noor-A-Jannat Prome; analysis and interpretation of results: Priya Saha, Md. Parvez Anwar and A. K. M. Mominul Islam; draft

manuscript preparation: Priya Saha, Md. Parvez Anwar, A. K M Mominul Islam, Sharah Jabeen Mou, and Afroza Sultana; reviewing and editing: Sharah Jabeen Mou, Afroza Sultana, Nazmun Naher Priya and Sabina Yeasmin. All authors reviewed the results and approved the final version of the manuscript.

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