DOI: https://doi.org/10.4038/sljot.v7i1.16

Sri Lankan Journal of Technology
Research

SEUSL

SLJoT
2026 Issue 01 01-12
ISSN-2773-6970

Combating Moisture Stress in Wheat Through Pre-Sowing Seed Priming

Md. Parvez Anwar[1], Noor-A-Jannat Prome[1], Suriaya Perveen[1], Md. Rashedur Rahman[1], A. K. M. Mominul Islam[1]*, Sabina Yeasmin[1], Priya Saha[1], Afroza Sultana[1]

[1]Department of Agronomy, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

*Corresponding Author: akmmominulislam@bau.edu.bd || ORCID: 0000-0002-9902-0639

Received: 13-02-2026* Accepted: 26-06-2026 * Published Online: 30-06-2026

Abstract – Soil moisture stress causes less germination and poor stand establishment resulting in growth and yield reduction in wheat which can be mitigated by seed priming to some extent. To judge the efficacy of different seed priming agents in enhancing wheat growth and yield under moisture stress an experiment including four irrigation regimes (no irrigation, single irrigation at Crown Root Initiation (CRI) stage, single irrigation at flowering stage and two irrigations at both CRI and flowering stages and six seed priming agents (namely unprimed control, water, $CaCl_2$, KCl, KNO_3 and mannitol) was conducted following a split-plot design with three replications. Seed priming exhibited a positive role in enhancing wheat growth and productivity under both irrigated and moisture stress condition. No irrigation resulted in the lowest grain yield while two irrigations at both the critical stages produced the highest grain yield. The maximum grain yield (3.0 t ha^{-1}) was produced by two irrigations coupled with $CaCl_2$ or KCl priming, while no irrigation coupled with no priming produced the minimum grain yield (1.2 t ha^{-1}). Therefore, seed priming preferably with 20000 ppm KCl or $CaCl_2$ may be practiced to alleviate the moisture stress in wheat to some extent.

Keywords- Drought, Irrigation regime, Seed invigoration, Spring wheat, Yield

Citation

Anwar, M.P., Prome, N.J., Perveen, S., Rahman, M.R., Islam, A.K.M.M., Yeasmin, S., Saha, P. and Sultana, A. (2026). Combating moisture stress in wheat through pre-sowing seed priming. *Sri Lankan Journal of Technology, 07*(01).01-12.

Introduction

Wheat (*Triticum aestivum* L.) is a major cereal crop cultivated globally, with a production of approximately 791 million tons (Food and Agriculture Organization [FAO], 2024). In Bangladesh, wheat occupies 3,16,832 hectares of the country with a total production of 4,071 tons representing an increase of about 7.07% to the previous year (Bangladesh Bureau of Statistics [BBS], 2023). Due to the rising demand, it is necessary to enhance wheat production as expansion of cropping area is not possible (Araus et al., 2003).

Limited water availability is a major constraint affecting agricultural productivity and crop yield worldwide. In Bangladesh, wheat is predominantly grown during the rabi season (November-March) under rainfed conditions, when precipitation is typically low. Consequently, farmers often cultivate wheat without supplemental irrigation, exposing the crop to moisture stress, particularly during the later growth stages. Grain yield in wheat, as in other cereals, is determined by several interrelated components, including the number of grains per spike, the number of spikes per unit area, and average grain weight. The development and expression of these yield components are determined by the interaction of genetic and environmental factors, which influence physiological processes such as tillering, spike formation, and grain filling occurring at different developmental stages (Hussain et al., 2004).

Previous studies have highlighted the detrimental effects of water deficit during critical growth phases. Karim et al. (2000) reported that water stress during the reproductive stage significantly reduced wheat grain development and final yield. Their findings indicated that 94% of tillers in irrigated conditions produced spikes, whereas only 79% did so under water limited conditions, leading to a reduction in grain yield to approximately 65% of that observed in irrigated plants. Further maintaining adequate irrigation at all key growth stages had been shown to maximize wheat productivity (Karim et al., 2000; Wajid et al., 2002). These findings emphasize the necessity of developing effective strategies to enhance moisture stress tolerance and sustain yield under limited water availability.

Various agronomic practices have been proposed to mitigate the adverse effects of moisture stress on wheat production. Among these, seed priming has emerged as a cost-effective and efficient technique for improving crop establishment (Farooq et al., 2006). Seed priming involves controlled hydration followed by re-drying, which initiates early metabolic activities associated with germination while preventing radicle emergence, thereby maintaining the seeds in a pre-germinative state (Paparella et al., 2015). This process allows essential biochemical changes to occur prior to germinate without completing the germination process (Nascimento et al., 2013; Rehman et al., 2011).

Enhanced germination performance in primed seeds is attributed to increased enzymatic activity (such as α-amylase), elevated synthesis of RNA and DNA, improved ATP production, and the activation of functional mitochondria (Afzal et al., 2002). Seed priming is a controlled hydration technique followed by re-drying, including hydro-priming (uncontrolled hydration) and controlled techniques related to germination such as osmopriming and matrix priming (Taylor et al., 1998). These approaches enhance metabolic readiness, promote early growth and reproductive development, accelerate flowering and maturity, and improve the plant's ability to withstand abiotic stresses (Soleimanzadeh et al., 2013; Maasoumeh & Mohammad, 2014; Singh et al., 2015).

Combating moisture stress in wheat has been addressed from different viewpoints including cultivation of drought tolerant varieties, practicing mulching, adjusting sowing time and so on. Global scientific literature confirms the potentiality of seed priming as a sustainable strategy for mitigating moisture stress in a wide range of crops. Nevertheless, the potential of pre sowing seed priming remains largely unexplored as a sustainable tool for improving wheat performances under drought conditions. Therefore, a critical knowledge gap exists regarding the identification of the most suitable priming agent(s) for enhancing wheat tolerance to moisture stress especially under the agro-ecological conditions of Bangladesh.

In this context, the present study was designed to assess the effects of seed priming on wheat growth and yield performance of wheat *cv.* BARI Gom-33 under varying irrigation levels and to determine the most suitable priming technique for improving productivity.

Materials and Methods

Location and Site Description

The field experiment was carried out at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh, during the period from November 2022 to March 2023. The experimental area is situated within a subtropical climatic region characterized by pronounced seasonal variation. The air temperature (ºC), total rainfall (mm) and average relative humidity (%) during the experimental period is given in Figure 1.

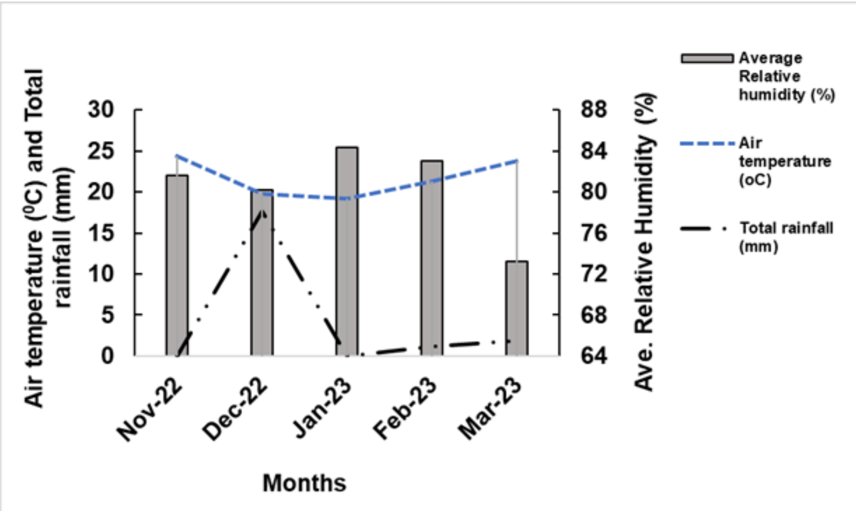

Figure 1. *Weather data from November 2022 to March 2023 at the experimental site during the growing season of wheat (Source: Weather Yard, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh)*

Geographically, the experimental site is located at 24°75′ N latitude and 90°50′ E longitude, with an elevation of approximately 18 m above mean sea level. The area belongs to the Old Brahmaputra Floodplain under Agro-ecological zone 9 (AEZ 9). The soil of the experimental field is classified under the Sonatola series, representing non-calcareous dark-grey floodplain soils of the Old Brahmaputra Alluvial Tract. The land is categorized as medium high with silt loam texture. Pre-experimental soil analysis revealed that the soil had a near-neutral pH (6.7), low organic matter content (0.86%) and total nitrogen content of 0.16%.

Experimental Treatments and Design

The experiment consisted of two factors; irrigation regimes and seed priming treatments. Four irrigation levels were considered: no irrigation (I_0), single irrigation at Crown Root Initiation (CRI) stage (I_1), a single irrigation at flowering stage (I_2), and two irrigations applied at both critical stages (I_3). In addition, six seed priming treatments were evaluated: no priming (P_0), hydro priming (P_1), priming with 20000 ppm $CaCl_2$ (P_2), priming with 20000 ppm KCl (P_3), priming with 15000 ppm KNO3 (P_4), and priming with 40000 ppm Mannitol (P_5). Priming agents and their concentrations were selected based on the performances of previous studies (Asadujjaman et al., 2023; Saha et al., 2025). The experiment was laid out in a split-plot design with three replications. Irrigation treatments were assigned to the main plots, while seed priming treatments were allocated to the subplots. Each experimental unit measured 2.5 m × 2.0 m. A spacing of 1 m was maintained between blocks and 0.5 m between adjacent plots to minimize interference among treatments.

Conduction of the Experiment

Seeds of wheat *cv.* BARI Gom-33, used as plant material was collected from Bangladesh Wheat and Maize Research Institute (BWMRI), Dinajpur. For seed priming, the collected seeds were immersed in various priming agent solutions (prepared with distilled water) according to the treatment specifications at room temperature (25 ±2 °C) for 6 hours. All chemicals used for seed priming were of analytical (laboratory) grade (Table 1). For hydro-priming, distilled water was employed. Seeds were soaked in their respective priming solutions using a seed-to-solution ratio of 1:5 (g mL^{-1}). After soaking, the seeds were thoroughly rinsed three times with distilled water to remove any residual chemicals. Subsequently, the seeds were dried back to their original moisture content (14%) under forced air conditions. The dried seeds were stored in polyethene bags at 5 ± 1 °C until sowing. Control seeds were kept untreated and did not undergo any priming procedure.

Table 1

Details of the priming agents

Sl. No.	Priming agent	Chemical formula	Manufacturer
1	Calcium chloride	$CaCl_2$	MERCK, India
2	Potassium chloride	KCl	MERCK, India
3	Potassium nitrate	KNO_3	MERCK, India
4	Mannitol	$C_6H_{14}O_6$	MERCK, India

Land preparation was carried out in late November 2022 through repeated dry ploughing using a power tiller at a depth of 5-6 inches. After removing weeds and crop residues, the field was leveled and plots were arranged according to the experimental layout. Fertilizers were applied during final land preparation, consisting of one-third of the total urea (240 kg ha^{-1}), along with full recommended doses of triple super phosphate (150 kg ha^{-1}), muriate of potash (110 kg ha^{-1}), gypsum (120 kg ha^{-1}) and boric acid (8 kg ha^{-1}). The remaining urea was applied as top-dressing in two equal splits at 20 and 55 Days After Sowing (DAS).

Seeds were sown on 01 December at a rate of 120 kg seeds ha^{-1} in rows spaced 20 cm apart. Standard intercultural practices were followed to ensure proper crop growth. Irrigation was applied according to the assigned treatment regimes. Manual weeding was performed twice during the growing period at 20 and 55 DAS. The crop was harvested at full maturity on 27 March on a plot-by-plot basis. After harvesting, the crop from each plot was bundled, tagged, sun-dried, threshed, and the grains were cleaned.

Sampling and Data Recording

For the assessment of plant characteristics, ten hills per plot were randomly selected and uprooted prior to harvest. Data on plant height, spikes m^{-2}, number of spikelets spike^{-1}, number of grains spikelets^{-1}, number of grains spike^{-1} were recorded, and mean values were calculated. The 1000- grain weight was determined from the bulk harvest of each plot. Grain and straw yields were recorded separately for each plot after sun-drying and adjusting the grain moisture content to 14% (measured by LDS-1G Grain Moisture Meter). The yields were then converted to t ha^{-1}. Biological yield and harvest index were calculated using the following relationships (Equation 1 and 2):

$$\text{Biological yield (t ha}^{-1}\text{)} = \text{Grain yield} + \text{Straw yield} \quad (1)$$

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \quad (2)$$

Statistical Analysis

The recorded data were systematically compiled and tabulated for statistical evaluation. Analysis of variance was performed using the MSTAT at a 5% probability level. When treatment effects were found to be significant, mean comparisons were conducted using Duncan's Multiple Range Test (DMRT) as a post hoc procedure.

The research design, participants, materials, and procedures are detailed in the materials and methods section. This section should be comprehensive enough to allow for replication of the study. It includes information on the sample size, data collection methods, and analysis techniques, providing a clear roadmap of how the research was conducted.

Results

Effect of Irrigation Regimes

Irrigation regimes had a significant influence on all the growth attributes and yield contributing parameters of wheat (Table 2 and Figure 2). The tallest plants (90 cm) were recorded under two irrigations applied at the CRI and flowering stages, which was statistically similar to the height obtained with a single irrigation at the flowering stage (88.4 cm).

In contrast, the shortest plants (80.0 cm) were observed under rainfed conditions without irrigation (Table 2). Similarly, the highest values for spike m^{-2} (141.7), spikelets spike^{-1} (17.0), grain spikelets^{-1} (3.0) and grain spike^{-1} (50.9) were achieved with two irrigations at CRI and flowering stages. The lowest values for these traits, 116.7 spike m^{-2}, 13.7 spikelets spike^{-1}, 2.6 grain spikelets^{-1}, and 35.3 grain spike^{-1} were recorded under no irrigation (Table 2).

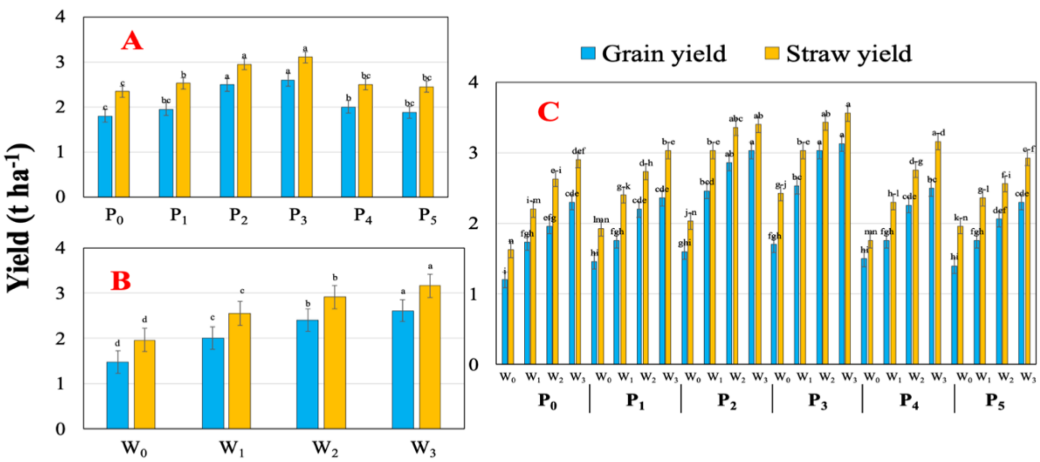

Figure 2. *Effect of Seed priming (A), Irrigation regime (B) and their interaction effect(C) on yield of wheat cv. BARI Gom-33. P_0= no priming, P_1= priming with water, P_2= priming with 20000 ppm $CaCl_2$, P_3= priming with 20000 ppm KCl, P_4= priming with 15000 ppm KNO_3, P_5= priming with 40000 ppm mannitol, I_0 = no irrigation, I_1 = single irrigation at CRI stage, I_2 = single irrigation at flowering stage, I_3 = Two irrigations at CRI and flowering stages*

The maximum1000-grain weight (45.1 g) was also obtained under two irrigations, which was statistically comparable to the single irrigation at flowering stage (44.7 g). Likewise, the highest harvest index (45.0) was recorded under two irrigations, whereas the lowest (43.0) was found in the non-irrigated treatment (Table 2).

Table 2
Effect of seed priming and irrigation regime on yield contributing characters of wheat cv. BARI Gom-33

Treatments	Plant height (cm)	Spikes m^{-2} (no.)	Spikelets $spike^{-1}$ (no.)	Grains $Spikelets^{-1}$ (no.)	Grains $Spike^{-1}$ (no.)	1000-grain weight (g)	Harvest Index (%)
Seed Priming							
P_0	81.6^{c}	127.6^{c}	14.1^{b}	2.6	37.4^{b}	43.0^{b}	43.3
P_1	84.7^{c}	133.4^{abc}	15.4^{ab}	2.9	44.2^{ab}	43.4^{ab}	43.5
P_2	90.6^{ab}	138.8^{ab}	17.4^{a}	2.9	50.5^{a}	43.8^{ab}	45.5
P_3	91.9^{a}	141.8^{a}	15.7^{ab}	3.0	46.7^{ab}	43.9^{a}	45.1
P_4	86.3^{bc}	133.3^{abc}	16.0^{ab}	2.9	46.2^{ab}	43.3^{ab}	44.6
P_5	81.7^{c}	129.6^{bc}	15.1^{ab}	2.7	41.0^{ab}	43.2^{ab}	43.2
$S\bar{x}$	1.71	3.56	0.87	0.12	3.33	0.29	0.86
Level of sig.	**	**	**	NS	**	**	NS
CV (%)	4.87	6.50	13.59	10.38	18.38	1.62	4.75
Irrigation Regime							
I_0	80.0^{c}	116.7^{b}	13.7^{b}	2.6^{b}	35.3^{b}	40.3^{c}	43.0^{b}
I_1	86.2^{b}	138.2^{a}	15.9^{a}	2.8^{ab}	45.2^{a}	43.5^{b}	43.8^{ab}
I_2	88.4^{ab}	139.8^{a}	15.9^{a}	2.9^{a}	45.9^{a}	44.7^{a}	45.0^{a}
I_3	90.0^{a}	141.7^{a}	17.0^{a}	3.0^{a}	50.9^{a}	45.1^{a}	45.0^{a}
$S\bar{x}$	1.40	2.91	0.71	0.10	2.72	0.23	0.70
Level of sig.	**	**	**	**	**	**	**
CV (%)	4.87	6.50	13.59	10.38	18.38	1.62	4.75

Note: ** =significant at 1% level of probability, NS = non-significant, $S\bar{x}$= Standard error of the mean, CV= coefficient of variation. P_0= no priming, P_1= priming with water, P_2= priming with 20000 ppm $CaCl_2$, P_3= priming with 20000 ppm KCl, P_4= priming with 15000 ppm KNO_3, P_5= priming with 40000 ppm mannitol, I_0 = no irrigation, I_1 = single irrigation at CRI stage, I_2 = single irrigation at flowering stage, I_3 = Two irrigations at the CRI and flowering stages

Grain yield (2.6 t ha^{-1}) and straw yield (3.2 t ha^{-1}) were highest under two irrigations, while the lowest grain yield (1.5 t ha^{-1}) and straw yield (2.0 t ha^{-1}) were recorded under no irrigation conditions. Consequently, the maximum biological yield (5.8 t ha^{-1}) was obtained with two irrigations at CRI and flowering stages, whereas the minimum (3.4 t ha^{-1}) occurred without irrigation (Figure 2).

Effect of Seed Priming

Most of the growth and yield parameters were significantly affected by seed priming treatments, except grains $spikelets^{-1}$ and harvest index (Table 2 and Figure 2). The highest plant height (91.9 cm) was observed with KCl priming at 20000 ppm, which was par statistically similar to $CaCl_2$ priming (90.6 cm). The shortest plants (81.6 cm) were recorded in the non-primed control (Table 2).

Priming with $CaCl_2$ at 20000 ppm produced the highest number of spikelets $spike^{-1}$(17.40) and grains $spike^{-1}$ (50.5), while the lowest values (14.1 and 37.4, respectively) were found in the control treatment. Other priming methods also showed statistically comparable performance for these traits (Table 2). The highest number of spikes m^{-2} (141.8) and 1000-grain weight (43.9 g) were recorded with KCl priming at 20000 ppm. In contrast, the lowest values for these parameters were observed under no priming (Table 2).

Grain yield and straw yield were significantly influenced by priming treatments (Figure 2). The maximum grain yield (2.6 t ha^{-1}) and straw yield (3.1 t ha^{-1}) were achieved with KCl priming (20000 ppm), whereas, the minimum grain yield (1.8 t ha^{-1}) and straw yield (2.3 t ha-

^{1}) were recorded in the no priming. Similarly, the highest biological yield (5.7 t ha^{-1}) was obtained with KCl priming (20000 ppm), while the lowest (4.1 t ha^{-1}) occurred without priming (Figure 2).

Interaction Effect of Irrigation Regimes and Seed Priming

The interaction between irrigation regimes and seed priming significantly affected most growth and yield attributes of wheat, except spikelets spike^{-1}, grain spikelets^{-1} and harvest index, which remained non-significant (Table 3).

Table 3

Interaction effect of seed priming and irrigation regime on yield contributing characters of wheat cv. BARI Gom-33

Seed priming × Irrigation regime	Plant height (cm)	Spikes m^{-2} (no.)	Spikelets spike^{-1} (no.)	Grains Spikelets^{-1} (no.)	Grains Spike^{-1} (no.)	1000-grain weight (g)	Harvest Index (%)
P_0I_0	75.8^{f}	111.7^{g}	12.1	2.4	29.0^{b}	40.1^{e}	42.4
P_0I_1	82.3^{b-f}	131.3^{a-g}	14.0	2.6	36.5^{ab}	43.2^{d}	44.0
P_0I_2	83.0^{b-f}	132.7^{a-g}	15.3	2.8	41.6^{ab}	44.1^{a-d}	42.7
P_0I_3	85.2^{a-f}	134.7^{a-g}	14.9	2.8	42.4^{ab}	44.5^{a-d}	44.2
P_1I_0	78.9^{def}	115.3^{efg}	13.0	2.5	32.2^{ab}	40.3^{e}	43.1
P_1I_1	84.9^{a-f}	136.7^{a-g}	15.1	2.8	42.9^{ab}	43.5^{cd}	42.4
P_1I_2	86.2^{a-f}	139.7^{a-f}	16.4	3.0	49.9^{ab}	44.7^{a-d}	44.6
P_1I_3	88.8^{a-f}	142.0^{a-e}	17.1	3.0	51.7^{ab}	45.0^{a-d}	43.8
P_2I_0	82.9^{b-f}	120.7^{c-g}	14.9	2.7	40.6^{ab}	40.5^{e}	44.1
P_2I_1	91.3^{a-d}	144.3^{abc}	17.9	2.9	52.0^{ab}	43.6^{bcd}	44.8
P_2I_2	93.3^{abc}	143.7^{a-d}	18.2	2.9	52.8^{ab}	45.3^{a-d}	46.0
P_2I_3	94.8^{ab}	146.7^{abc}	18.6	3.0	56.5^{a}	45.7^{ab}	47.1
P_3I_0	84.3^{a-f}	122.3^{b-g}	15.0	2.8	41.4^{ab}	40.6^{e}	41.1
P_3I_1	91.7^{a-d}	146.3^{abc}	17.1	3.0	51.7^{ab}	43.6^{bcd}	45.5
P_3I_2	95.3^{ab}	148.3^{ab}	12.4	3.0	36.5^{ab}	45.5^{abc}	46.9
P_3I_3	96.3^{a}	150.3^{a}	18.4	3.1	57.0^{a}	46.0^{a}	46.8
P_4I_0	80.2^{c-f}	116.7^{d-g}	14.0	2.6	36.9^{ab}	40.3^{e}	45.9
P_4I_1	86.7^{a-f}	137.7^{a-g}	16.1	2.9	47.4^{ab}	43.5^{cd}	43.4
P_4I_2	88.2^{a-f}	138.7^{a-g}	16.9	2.9	49.1^{ab}	44.5^{a-d}	45.0
P_4I_3	90.2^{a-e}	140.3^{a-f}	17.0	3.0	51.5^{ab}	45.0^{a-d}	44.1
P_5I_0	77.5^{ef}	113.3^{fg}	12.8	2.5	32.0^{ab}	40.3^{e}	41.6
P_5I_1	80.2^{c-f}	133.0^{a-g}	15.3	2.6	40.3^{ab}	43.4^{cd}	42.8
P_5I_2	84.3^{a-f}	135.7^{a-g}	16.1	2.8	45.3^{ab}	44.3^{a-d}	44.6
P_5I_3	84.7^{a-f}	136.3^{a-g}	16.0	2.9	46.4^{ab}	44.5^{a-d}	44.0
$S\bar{x}$	3.43	7.12	1.73	0.24	6.65	0.57	1.71
Level of sig.	**	**	NS	NS	**	**	NS
CV (%)	4.87	6.50	13.59	10.38	18.38	1.62	4.75

Note: ** =significant at 1% level of probability, NS = non-significant, $S\bar{x}$= Standard error of the mean, CV= coefficient of variation. P_0= no priming, P_1= priming with water, P_2= priming with 20000 ppm $CaCl_2$, P_3= priming with 20000 ppm KCl, P_4= priming with 15000 ppm KNO_3, P_5= priming with 40000 ppm mannitol, I_0 = no irrigation, I_1 = single irrigation at CRI stage, I_2 = single irrigation at flowering stage, I_3 = Two irrigations at CRI and flowering stages.

The tallest plants (96.3 cm) were observed under KCl priming (20000 ppm) combined with two irrigations at CRI and flowering stages, which was statistically similar to mannitol priming (40000 ppm) with a single irrigation at the flowering stage. The shortest plants (75.8 cm) were recorded under the combination of no irrigation and no priming (Table 3).

The highest number of spikes m^{-2}(150.3), grains spike^{-1} (57.0), and 1000-grain weight (46.0 g) were also obtained from the combination of KCl priming (20000 ppm) and two irrigations. Conversely, the lowest values for these parameters 111.7 spike m^{-2}, 28.7 grains $spike^{-1}$, and 40.1 g for 1000-grain weight were recorded under no priming (Table 3).

Grain yield, straw yield, and biological yield were significantly influenced by the combined effects of irrigation and priming (Figure 2). The highest grain yield (3.1 t ha^{-1}), straw yield (3.6 t ha^{-1}) and biological yield (6.7 t ha^{-1}) were obtained with KCl priming (20000 ppm) along with two irrigations at CRI and flowering stages. In contrast, the lowest grain yield (1.2 t ha^{-1}), straw yield (1.6 t ha^{-1}) and biological yield (2.8 t ha^{-1}) were observed under the combination of no irrigation and no priming (Figure 2).

Discussion

Seed priming initiates-controlled hydration that activates several pre-germinative metabolic processes without allowing radicle protrusion, thereby inducing physiological changes conducive to rapid germination, uniform emergence, and enhanced seedling vigor (Anwar et al., 2012; 2024; Islam et al., 2026; Mim et al., 2021). During priming, repair of cellular membranes, synthesis of proteins and nucleic acids, activation of hydrolytic enzymes, and mobilization of stored reserves are enhanced, resulting in improved seedling establishment and vigor (Zulfiqar, 2021). In addition, primed seeds often exhibit stronger antioxidant defense systems, greater osmotic adjustment, and improved regulation of stress-responsive genes, which reduce oxidative damage under adverse environmental conditions and improve stress tolerance (Zulfiqar, 2021). These physiological and biochemical modifications create a form of stress memory that enables plants to respond more effectively to subsequent biotic and abiotic stresses (Patanè et al., 2009; Wahid et al., 2008). Consequently, primed plants generally demonstrate improved growth, resource-use efficiency, and yield performance under stressful environments (Arun et al., 2022; Zulfiqar, 2021).

The findings of the present study confirm that seed priming significantly improves growth attributes, yield components, and overall yield performance of wheat under moisture stress conditions. Similar results were reported by Asadujjaman et al. (2023), who found that priming with $CaCl_2$ and KCl enhanced plant height, number of spike m^{-2}, spikelets $spike^{-1}$, grain and straw yields compared to unprimed seeds. Primed seeds generally produce greater biomass and exhibit improved plant height and root development relative to non-primed seeds (Farooq et al., 2011). Likewise, Ali et al. (2013) reported increased plant height and yield attributes in wheat due to seed priming.

Increased yield performances of wheat were the cumulative positive influence of seed priming on wheat growth like plant stature and yield attributes such as number of Spikes m^{-2}, Spikelets $spike^{-1}$, Grains $Spike^{-1}$ and 1000-grain weight. Although not studied in this research, higher competitive ability against weeds (Anwar et al., 2012) and better resilience to different abiotic stresses like heat stress (Asadujjaman et al., 2023) of the wheat plants grown from primed seeds also might contribute to improved yield.

However, yield attributes of a crop are mostly governed by the genetic characters with a very little or no influence by environmental factors. But crop management practices including seed priming can enhance yield attributes up to the maximum potential limit particularly when environmental and/or input stresses limit crop performances. Hamed et al., (2022) also confirmed from their study that seed priming can serve as potential agronomic tool for improving wheat yield traits, yield performances and grain quality under moisture-limited environments.

Under moisture stress, reduced spike density (spikes m^{-2}) adversely affects grain yield and 1000-grain weight. In the present study, seed priming improved these parameters, thereby mitigating the negative effects of water deficit. Moisture stress during germination often leads to poor seedling establishment, reduced vigor, and ultimately lower yield. However, priming treatments enhanced emergence, stand establishment, tiller production, and yield components, contributing to improved productivity under stress conditions.

Consistent with these findings, Farooq et al. (2007) reported that seed priming improved emergence, tillering, grain yield, straw yield, and harvest index in wheat under moisture stress. Similarly, Ali et al. (2013) observed improvements in yield components, including plant height, tiller number, and grain weight, following priming treatments. Toklu et al. (2015) demonstrated that polyethylene glycol (PEG), KCl, and hydro-priming increased wheat grain yield compared to unprimed controls. Ramamurthy et al. (2015) also reported a 17% increase in grain yield due to seed priming. The role of seed priming in alleviating both biotic and abiotic stresses has been widely documented (Anwar et al., 2021; Miah et al., 2022).

In this study, KCl priming was particularly effective in enhancing plant height, spike m^{-2}, 1000-grain weight, and grain and straw yields of wheat *cv.* BARI Gom-33 under moisture stress. Other priming agents also performed better that the control. These findings are supported by Suryakant et al. (2000), who reported that primed or sprouted seeds produced higher grain, straw, and biological yields than dry seeds. Overall, the results highlight the potential of seed priming as an effective strategy to improve wheat performance under moisture-limited conditions, particularly during critical growth stages.

Conclusion

Moisture stress adversely affects wheat establishment, growth, and yield, leading to significant reductions in productivity. In contrast, seed priming enhances stand establishment, and overall crop performance, resulting in increased grain yield under both irrigated and water-limited conditions. Based on the findings of this study, the application of irrigation at both CRI and flowering stages, combined with seed priming, particularly using 20000 ppm KCl or $CaCl_2$ is recommended to maximize wheat productivity under moisture stress. However, further research involving multi-location trails, diverse climatic conditions, and multiple growing seasons is necessary to validate and generalize these findings results across different agro-ecological environments.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Bangladesh Agricultural University Research System (BAURES), Bangladesh Agricultural University, Mymensingh, under the research project entitled "*Induction of Heat and Drought Tolerance in Wheat through Seed Priming*" (Project No. 2021/35/BAU).

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