Evaluation of six elite irrigated spring bread wheat (*Triticum aestivum* L.) varieties tolerant to heat stress during late sowing

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ABSTRACT

To assess the heat stress tolerance of recently released wheat varieties, six of these varieties (Shatabdi, BARI Gom 26, BARI Gom 27, BARI Gom 28, BARI Gom 29 and BARI Gom 30) were evaluated at two sowing conditions (optimum sowing on November 15 and extremely late sowing under heat stress on January 15). All treatments were arranged in a randomized complete block design with a split–plot arrangement and repeated three times. Two sowing dates were arranged in the main plots and six wheat varieties were assigned to sub–plots. The varieties that are suitable to grow under late sowing were recognized based on phenological data such as date of booting, heading, anthesis and physiological maturity, growth data such as plant population, number of tillers m^{-2}, plant height, leaf area index, total biomass at the booting stage and plant height at harvest. Besides phenological and growth data, yield and yield attributes such as spikes m^{-2}, spike length (cm), spikelets $spike^{-1}$, grains $spike^{-1}$, 1000–grain weight (g), grain yield (GY, kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index were also recorded. Stress–related parameters such as yield stability index, stress tolerance index, stress intensity and heat susceptibility index were also estimated for final confirmation of heat tolerance of varieties. In optimum sowing conditions, phenology, growth, yield and yield components were significantly higher than in late sowing under heat stress. Among these wheat varieties, significantly ($p < 0.01$) highest GY was obtained from Shatabdi (5,096 kg ha^{-1}) and lowest from BARI Gom 27 (3,955.33 kg ha^{-1}) when sown under optimum conditions. When sown at late, BARI Gom 30 was found to be heat tolerant and produced maximum GY (1,834.33 kg ha^{-1}), whereas BARI Gom 27 was highly sensitive to heat and produced the lowest GY (1,353 kg ha^{-1}). Under both sowing conditions (optimum and late sowing), significantly maximum GY and biological yield were recorded in variety Shatabdi (3,419 kg ha^{-1}), and the lowest was observed in BARI Gom 27 (2,654 kg ha^{-1}). By evaluating heat tolerance indices, BARI Gom 30, followed by BARI Gom 29, BARI Gom 26 and Shatabdi were found to be tolerant to heat stress, whereas BARI Gom 27 and BARI Gom 28 were susceptible to late–sowing heat stress condition. Therefore, except for BARI Gom 27 and BARI Gom 28, the remaining four varieties (Shatabdi, BARI Gom 26, BARI Gom 29 and BARI Gom 30) are recommended for sown late heat stress condition and could also be used in a future breeding program to develop heat–tolerant varieties.

Keywords: Wheat, heat stress, phenology, growth, yield, stress tolerance indices

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the world's leading cereals. It belongs to the botanical sub–tribe Triticineae, tribe Triticeae (Hordeae) in the family Poaceae (Gramineae) (Briggle and Rietz, 1963). The genus *Triticum* includes two commercially cultivated species, *Triticum aestivum* L. (bread wheat) and *Triticum durum* L. (durum or macaroni wheat). According to the USDA (2014), one cup of whole wheat grain contains 33% protein, 29% carbohydrate and 5% fat. About 65% of the wheat crop is used for human food, 17% for animal feed and 12% for industrial applications. Due to growing populations across the globe, the world's demand for cereals is projected to grow by 56% while demand in the developing world is projected to increase by 60% (1,048 million metric tons; MMT) by 2050 compared to the demand in 2000, and 26% of that demand is expected to be for wheat (FAO, 2015).

In Bangladesh, wheat is the second most important food grain after rice. Even though wheat was introduced to Bangladesh during the period of former East Pakistan in 1967, its reputation increased after 1975. In 2015–2016, 1.35 MMT of wheat was harvested from 0.44 million ha (BBS, 2016) with the national average grain yield being 3.03 t ha^{-1} (BBS, 2016). According to the Bangladesh Wheat and Maize Research Institute (BWMRI) (previously the Wheat Research Center of the Bangladesh Agricultural Research Institute), the attainable average yield of existing elite wheat cultivars is 4.0–4.5 t ha^{-1} (BARI, 2016), with climatic yield potential as high as 6.0 t ha^{-1}. Therefore, it is imperative to minimize the gaps in yield among potential, attainable and actual yields to reduce the import of wheat, thus leading to improved food security (Timsina *et al.,* 2018). The findings of several earlier studies in Bangladesh revealed that the yield gap of wheat between the potential and national average was linked to many factors, the most important being late sowing under terminal high–temperature stress (Hossain *et al.,* 2013).

Farmers in Bangladesh are sowing wheat increasingly late (Badaruddin *et al.,* 1994) due to delays in sowing monsoon rice and subsequent late harvest of *Aman* rice. As a result, wheat is being sown late, causing the crop to face two stresses, initially (germination to seedling stages) low–temperature stress, while in the reproductive stage, particularly during grain development and heat stress. For proper growth and development of wheat, optimal temperatures range between 12°C and 25°C, but temperatures below 10°C or above 30°C alter phenology, growth and development and finally reduce the yield of existing Bangladeshi wheat varieties (Hossain *et al.,* 2013).

BWMRI has already developed a number of new wheat varieties which are playing an important role in human nutrition and also resolving the food security of an increasing population in Bangladesh. Most of these varieties have a good level of abiotic and biotic stress tolerance and high yield potential. However, due to late sowing heat stress, the yield potential of these varieties is often hampered. It is necessary to find varieties that are suitable for growing under late sowing heat stress. Therefore, the present study was undertaken with the following objectives: 1) to evaluate the performance of newly released varieties under the late–sown heat stress condition and 2) to study the phenological changes, growth, yield and yield attributes under high heat stress.

MATERIALS AND METHODS

Description of the Experimental Site

This study was performed at the research field (23°11'14.52" N, 89°11'11.99" E, 10.4 m above sea level) of BWMRI, Nashipur, Dinajpur, Bangladesh. The area falls into the Agro–Ecological Zone (AEZ)–1 (Old Himalayan Piedmont Plain). The experiment was conducted from November 2015 to April 2016. Due to its favorable weather conditions, this AEZ has the largest wheat area and also produces the largest amount of wheat in Bangladesh.

Climatic Condition during the Crop Growth Period

Weather data on weekly average temperature, humidity and rainfall during the experimental period were recorded regularly at the meteorological station of BWMRI. Data are presented in Figure 1.

Soil Characteristics of the Experimental Plot

Soils of the experimental sites were analyzed before sowing wheat. The pre-seeding total soil N was 0.08%, indicating a deficiency in soil N. Soil available K was 0.19 meq 100 g^{-1} soil, and available P, S, Zn and B were 17.5, 6.5, 0.78 and 0.16 μg g^{-1} soil, respectively. Based on the critical level of these plant nutrients, K, S, Zn and B were low, but P was high. Soil pH was 5.4 and organic matter was 1.2%.

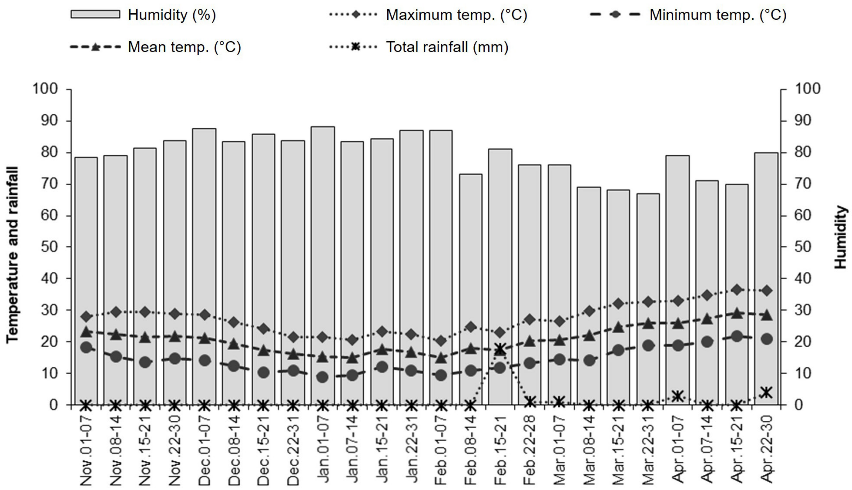

Figure 1 Weekly average temperature, rainfall and humidity during the crop growth period of 2015–2016

Experimental Treatments and Design

The experimental treatments were comprised of two factors. Factor A (main plot) was sowing condition (two levels): optimum sowing sown on November 15 (S_1) and high heat stress sowing sown on January 15 (S_2). Factor B (sub–plot) was six elite wheat varieties: Shatabdi (V_1), BARI Gom 26 (V_2), BARI Gom 27 (V_3), BARI Gom 28 (V_4), BARI Gom 29 (V_5) and BARI Gom 30 (V_6). There were a total of 12 (2 × 6) treatment combinations: S_1V_1, S_1V_2, S_1V_3, S_1V_4, S_1V_5, S_1V_6, S_2V_1, S_2V_2, S_2V_3, S_2V_4, S_2V_5, and S_2V_6.

The experiment was conducted in a randomized complete block design (RCBD) with a split–plot arrangement and three replications. Two sowing dates were arranged in the main plots and six wheat varieties were assigned to sub-plots. The experimental area was divided into three equal blocks. Each block contained 12 plots where 12 treatment combinations were allotted at random. Altogether, there were 36 unit plots in the experiment. Each unit plot size (3 × 2 m) consisted of 10 rows, each 3 m long, and a row-to-row distance of 20 cm. The main plot to main plot distance was 1 m, the sub-plot to sub-plot distance was 0.5 m, and the block-to-block distance was 1.5 m.

Experimental Procedures

Collection of wheat seeds and their characteristics

The seeds of all wheat varieties were collected from BWMRI. A brief list of the characteristics of each variety is presented in Table 1.

Land preparation

The land of the experimental field was first opened on November 8, 2015, with a power tiller. It was exposed to sunshine for 7 days prior to the next ploughing. Thereafter, the land was deep ploughed and cross-ploughed to obtain good tilth, which allows for better crop yield. Laddering was done to break the soil clods into small pieces following each ploughing. All weeds and stubble were removed from the experimental field. The soil was treated with Furadan 5G (marketed by FMC International S.A. Bangladesh Ltd.), which contains Carbofuran, at 8 kg ha^{-1} to protect the young plants from insect attack.

Table 1 The brief description of the six cultivars used in the experiment

Variety	Pedigree	Life span (days)	Yield (t ha^{-1})	Tolerance to major diseases and pests	Year of release	Field appearance
Shatabdi (BARI Gom 21)	MRNG/BVC//BLO/PVN/3/PJB–81CM98472–1JO–0JO–0JO–1JO–0JO–0R2DI	105–110	3.6–5.0	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust	2000	
BARI Gom 26	ICTAL 123/3/RAWAL 87//VEE/HD2285BD (JO)9585–0JO–3JE–0JE–0JE–HRDI–RC5DI	104–110	3.5–5.0	Tolerant of *Bipolaris* leaf blight and resistant to leaf rust diseases (stem rust) race, Ug 99	2010	
BARI Gom 27	WAXWING*2/VIVISTICGSS01BOOO56T–099Y–099M–099M–099Y–099M–14Y–0B	105–110	3.5–5.4	Resistant to leaf rust and tolerant to *Bipolaris* leaf blight and possesses a good level of APR to the Ug99 race of stem rust and its variants	2012	
BARI Gom 28	CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/2*VEE#10CMSS95Y00624S–0100Y–0200M–17Y–010M–5Y–0M	100–105	4.0–5.5	Resistant to leaf rust and tolerant to *Bipolaris* leaf blight	2012	
BARI Gom 29	SOURAV/7/KLAT/SOREN//PSN/3/BOW/4/VEE#5. 10/5/CNO 67/MFD// MON/3/ SERI/6/NL297BD(DI)112S–0DI–030DI–030DI–030DI–9DI	105–110	4.0–5.0	Resistant to leaf rust, stem rust (race Ug99) and tolerant to *Bipolaris* leaf blight	2014	
BARI Gom 30	BAW 677 (PASTOR/3/VEE#5//DOVE/BUC) / BijoyBD(JA)1365S–0DI–15DI–3DI–HR12R3DI	100–105	4.5–5.5	Resistant to leaf rust, stem rust (race Ug99) and tolerant to *Bipolaris* leaf blight	2014	

Source: BARI (2016)

Seed treatment

Before sowing, seeds were treated with Provax–200 WP (marketed by Hossain Enterprise CC Bangladesh Ltd., an agrochemical company, in association with Chemtura Corp., USA), which is a seed-treated fungicide containing carboxin and thiram. Provax–200 WP is a perfect fungicide to control fungi in the soil at the seedling stage (Hossain *et al.,* 2013).

Seed sowing

Seeds were sown at 120 kg ha^{-1} at a depth of 4–5 cm by making specific narrow furrows with an iron rod. After sowing, seeds were covered with soil and slightly pressed by hand. Seeds were sown according to treatment dates continuously and a 20 cm row-to-row distance was opened by a specially made iron hand tine. Special care was taken to protect seeds from birds.

Intercultural operations

The following intercultural operations were performed to ensure normal crop growth. Seedling emergence was complete within 4–9 days after sowing (DAS). Overcrowded seedlings were thinned out twice. The first thinning was performed 15 DAS to remove unhealthy seedlings while the second thinning was performed 10 days after the first thinning. Weeding was performed to maintain the plots free from weeds and ultimately ensure better growth and development of wheat seedlings. Newly emerged weeds were carefully uprooted. Mechanical hand weeding was used starting from 20 DAS, for a total of three times, and at an interval of 15 days.

The first irrigation was performed at 21 DAS at the crown root initiation stage. The second irrigation was performed at 55 DAS at the panicle initiation stage, and the last irrigation was performed at 75 DAS at the grain-filling stage. A proper drainage system was developed to drain off excess water. During the first, second and third irrigation, 0.0251 m or 2.51 cm of water was applied in 6 m^2 size plots.

The crop was attacked by different kinds of insects, mainly cereal aphid and grasshoppers, during the growing period. The experimental plots were sprayed at 35 days with appropriate insecticides to control these insects. Insecticide was applied to the plots after irrigation in the afternoon (3–4 p.m.). Two guards were appointed to protect the wheat grains and seedlings from birds. No disease infestation was found, so no control measures were taken. The plots in the experiment were frequently observed to notice any changes in plant growth, while other parameters were noted immediately to take necessary measures.

Harvesting and post-harvest operation

The crop was harvested when it reached maturity on 15 March 2016 and 1 April 2016 for optimum and late sowing crops. At maturity, when leaves, stems and pods became yellowish, then the plants were harvested. One square meter area from the central position of each plot was harvested for yield data and then converted to t ha^{-1}. The harvested plants were tied into bundles, transferred to a threshing floor, and sun-dried by spreading out evenly on the threshing floor. Seeds were separated from the chaff by a pedal thresher and then cleaned, dried and weighed. Dry straw weight was also assessed from the same area and converted to t ha^{-1}.

Data Collection

Phenological traits

During the crop cycle of both sowing periods, the dates of booting, heading, anthesis and physiological maturity were recorded using the Zadoks scale. Days to booting, heading and anthesis were recorded by counting the days from the date of sowing to the date when about 80% of the plants had completed these stages. Days to physiological maturity was recorded by counting the days taken from the date of sowing to the date when grain growth stopped and was visually determined when the peduncle turned green to brown or yellow. However, the complete loss of green colour of the glumes served as an indication of physiological maturity.

Crop growth parameters

Growth data on plant population, number of tillers m^{-2}, plant height, leaf area index (LAI), total biomass at the booting stage, and plant height at harvest were recorded to know the variation in growth parameters caused by late sown heat stress. Plant population was counted at 12 DAS by randomly selecting five 1 m rows (total = 10 rows, row-to-row distance = 20 cm). The number of tillers m^{-2} was recorded at 45 DAS and then averaged. Data were recorded by randomly selecting five 1 m rows (total = 5 rows, row-to-row distance = 20 cm).

Leaf area of wheat leaves was calculated based on the following equation described by Montgomery (1911).

$$\text{Leaf area} = L \times W \times A \quad \text{----- (1)}$$

where, L, W, and A are leaf length, leaf maximum width and a constant value, respectively. The area was multiplied by 0.75 as a constant value to obtain the actual area of the leaves, as suggested by Yoshida (1981). After calculating the total leaf area of all plants per unit area, the LAI was estimated as the ratio of total leaf area to the total land area available to plants.

Total biomass at the booting stage was calculated by summing uprooted biomass m^{-2}, leaf biomass m^{-2} and stem biomass m^{-2}. Samples were oven-dried at 70°C for 72 hr then transferred to a desiccator and allowed to cool to room temperature. Thereafter, dry weight was measured and expressed in g. Plant height at harvest was assessed from 10 randomly selected plants on each plot prior to harvest from the ground level to the tip of the uppermost spikelets on the spike.

Yield–contributing characteristics

Data on spikes m^{-2}, spike length (cm), spikelets $spike^{-1}$, grains $spike^{-1}$, 1000–grain weight (g), grain yield (GY, kg ha^{-1}), straw yield (SY, kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index was also collected. Spikes m^{-2} was recorded at physiological maturity. Spike length was measured with a meter scale from the base to the tip of the spike of 10 randomly selected spikes and the average value was recorded as spike length in cm. The total number of spikelets from 10 randomly selected spikes from each plot was calculated and then averaged to obtain the number of spikelets $spike^{-1}$. Ten spikes were selected and the total grains from all spikes were recorded and averaged to obtain the number of grains $spike^{-1}$.

One thousand grains were counted from randomly selected samples of each plot and the weight (g) of grains was recorded on an electrical balance after drying in the sun. Then, 1000–grain weight was converted to 12% moisture content (equation 2).

$$Y(M_2) = \frac{100 - M_1}{100 - M_2} \times Y(M_1) \quad \text{----- (2)}$$

where $Y(M_2)$ is grain weight with 12% moisture, $Y(M_1)$ is grain weight with actual moisture (%), M_1 is actual moisture (%) and M_2 is expected moisture (%).

An area of 1 m^2 was harvested to measure yield. The crop of each plot was bundled separately, tagged properly, and brought to the threshing floor. Bundles were threshed and dried in open sunshine and then grains were cleaned. The grain and straw weights for each plot were recorded after proper drying in the sun. The GY was converted to 12% moisture content. According to GY and SY together were regarded as the biological yield of wheat, the biological yield was calculated with the following formula.

$$\text{Biological yield} = GY + SY \quad \text{----- (3)}$$

The harvest index denotes the ratio of GY to biological yield and was calculated with the following formula (Gardner *et al.,* 1985).

$$\text{Harvest index (\%)} = \frac{GY}{\text{Biological yield}} \times 100 \quad \text{----- (4)}$$

Stress–related parameters

The yield stability index (YSI) of cultivars was calculated by the following formula (Lewis, 1994).

$$YSI = \frac{\text{Yield of wheat in heat stressed plot}}{\text{Yield of wheat in control plot}} \times 100 \quad \text{----- (5)}$$

The stress tolerance index (STI) of each cultivar was evaluated by the following formula (Fernandez, 1992).

$$STI = \frac{Y_P \times Y_S}{Y_{P^2}} \quad \text{----- (6)}$$

where Y_P is the yield of the cultivar in a normal condition, Y_S is the yield of the cultivar in a stressed condition and Y_{p2} is the total mean yield of all cultivars under the normal condition.

The stress intensity (SI, %) of cultivars was calculated by the following formula (Papathanasiou *et al.,* 2015).

$$SI (\%) = [1 - (Y_S/Y_P)] \times 100 \qquad (7)$$

where Y_S is the total grain yield means in a stressed condition and Y_P is the total grain yield mean in a normal condition.

The heat susceptibility index (HSI) was calculated for each cultivar according to the formula of Fischer and Maurer (1978) as shown in equation 8.

$$HSI = [1 - (Y_S/Y_P)] / [1 - (X_S/X_P)] \qquad (8)$$

where Y_S is the yield of a cultivar in a stressed condition, Y_P is the yield of a cultivar in a normal condition, X_S is the mean Y_S of all cultivars and X_P is the mean Y_P of all cultivars.

Data Analysis

The data obtained for different parameters were statistically analyzed to observe significant differences among the sowing times and wheat varieties and their interaction. The mean values of all characters were calculated. Analysis of variance was performed. Significant differences among treatment means were estimated by using the MSTAT–C statistical package of Michigan State University, USA. The least significance difference (LSD) test at a 5% (or 1%) probability level was used to test for differences among mean values whenever necessary.

RESULTS AND DISCUSSION

Temperature Differences in Relation to Wheat Phenology

Temperature is a modifying factor in all stages of wheat development, including germination, tillering, booting, ear emergence, anthesis and maturity, since it can influence the rate of water supply and other substrates necessary for growth, but varies with variety and the phenological stage. At high temperatures, wheat completes its life cycle much faster than under normal temperatures (Hossain *et al.,* 2013). Delayed planting in a sub-tropical region such as Pakistan, India, or Bangladesh reduced plant height, days to heading, days to maturity and the duration of grain filling and ultimately reduced yield and yield components. In the present study, the crop was sown on November 15 when the average maximum temperature in the vegetative stage was close to 24°C while the minimum temperature was close to 14°C, whereas at the grain–filling stage, an average maximum temperature was also close to 26°C and minimum temperature was close to 12–18°C, which is suitable for good yield in a wheat crop (Figure 1). On the other hand, in late sowing (January 15), during germination, the minimum temperature was very low (≤10°C), at the vegetative stage, the temperature was maximum ≥26°C and minimum ≤10°C, whereas at the grain–filling stage, the maximum was ≥31°C and the minimum was ≤18 to 22°C (February–March), which was also not suitable for proper growth and good yield (Figure 1).

Phenological Variation due to Sowing Date and Variety

Days to booting

Significant differences were observed in days to booting due to different sowing dates. The maximum days to booting (58) was required in optimum sowing, while the fewest days to booting (48) was required in late sowing (Figure 2A). The interaction of sowing date and wheat varieties had a significant effect on days to booting. In optimum sowing, BARI Gom 27 took the maximum days to booting (63), followed by Shatabdi, BARI Gom 26 and BARI Gom 29, whereas BARI Gom 28 and BARI Gom 30 took the minimum days to booting (54). On the other hand, when sown late, BARI Gom 27 also took the maximum days to booting (52), which was statistically similar to BARI Gom 26, whereas the fewest days to booting (42) was recorded in Shatabdi. Similarly, Tarchoun *et al.* (2012) reported in hot pepper that reproductive phases such as booting, fertilization and gametogenesis (8–9 days before anthesis) are most sensitive to high temperature.

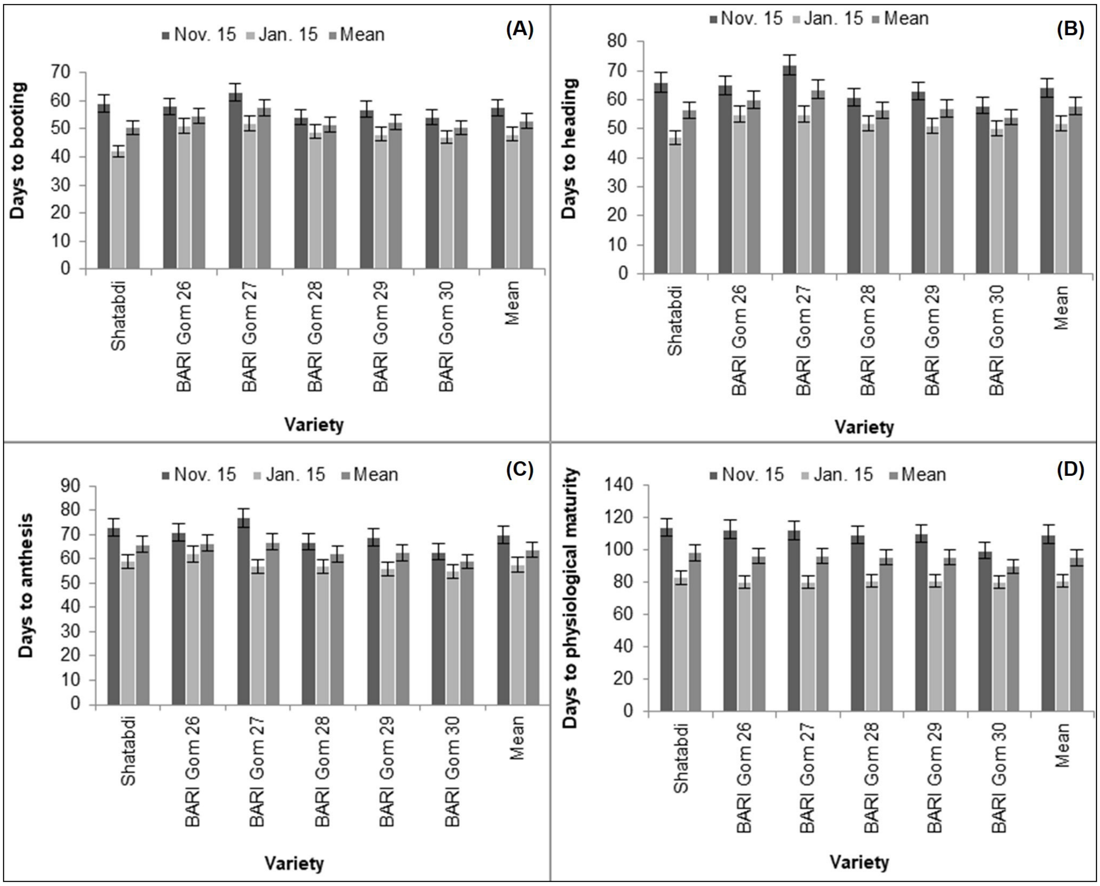

Figure 2 Days to booting (A), heading (B), anthesis (C) and physiological maturity (D) of six wheat varieties when sown under optimum (November 15) and late (January 15) conditions. Mean (± SD) was calculated from three replicates for each treatment. Error bars represent a significant difference at $p \leq 0.05$ (LSD test)

Days to heading

The developmental stage in which the spike or ear partially or fully appears to emerge from its enclosing sheath is also called ear emergence or heading. The time taken for a spike or ear to emerge from its enclosing sheath is entirely dependent on growth conditions as well as the genetic makeup of a genotype. In our study, statistically significant differences were observed in days to heading due to different sowing dates. The highest number of days to heading (64) was observed from optimum sowing, while the fewest days to heading (52) was found in late sowing. The interaction of sowing date and variety had a significant effect on days to heading. Under optimum sowing, BARI Gom 27 showed the most days to heading (72) followed by Shatabdi, whereas BARI Gom 30 showed the fewest days to heading (58). On the other hand, under late sowing, BARI Gom 27 took the most days to heading (55), which was statistically similar to BARI Gom 26, whereas Shatabdi showed the fewest days to heading (47) (Figure 2B). Delayed sowing of wheat shortened the duration of each developmental phase due to a rise in temperature by altering plants' physiological and biochemical mechanisms.

Days to anthesis

Statistically significant differences were observed in days to anthesis due to different sowing dates. The highest days to anthesis (70) was observed in optimum sowing while the fewest (58) was found in late sowing. The interaction of sowing date and wheat varieties had a significant effect on days to anthesis. The BARI Gom 27 showed the highest days to anthesis (77) followed by Shatabdi and BARI Gom 26 whereas BARI Gom 30 took the fewest days to anthesis (63) under optimum sowing. On the other hand, when sown late, BARI Gom 26 took the most days to anthesis (62) followed by Shatabdi whereas the fewest days to anthesis (55) was observed for BARI Gom 30 (Figure 2C). High temperature initially increases the growth rate of wheat in all development phases, but the growth rate declines when the intensity and duration of the stress increase. However, a decrease in the duration of each growth period adversely affects crop performance and yield. This assumption, which was found in this study, was also found in earlier studies on wheat by Ubaidullah *et al*. (2006).

Days to physiological maturity

Statistically significant differences were observed in days to physiological maturity (DPM) due to different sowing dates. The highest DPM (110) was observed in optimum sowing while the lowest DPM (81) was found in late sowing. The interaction of sowing date and wheat variety had a significant effect on DPM. The highest DPM (114) was found in Shatabdi, followed by BARI Gom 26, BARI Gom 27, BARI Gom 28 and BARI Gom 29, whereas the lowest DPM (100) was recorded in BARI Gom 30 under optimum sowing. On the other hand, under late sowing, Shatabdi registered the highest DPM (83) whereas the lowest DPM (80) was recorded for BARI Gom 26, BARI Gom 27 and BARI Gom 28 (Figure 2D). Environmental factors affect the number of days required to reach or achieve different growth stages in wheat, but this varies with genotype due to their different genetic makeups (Araus *et al*., 2007). Hossain *et al*. (2013) also observed that wheat sown late in Bangladesh shortened the duration of each development phase, including physiological maturity, due to high–temperature stress.

Plant Population m^{-2}

Effects of sowing date and variety

In this study, plant populations were significantly influenced by sowing date ($p < 0.01$). The highest number of plants m^{-2} (280) at 12 DAS was obtained during optimum sowing while the fewest plants m^{-2} (251) at 12 DAS was observed in the late sowing treatments. The effect of variety on plants m^{-2} was significant ($p < 0.01$) among the six tested varieties at 12 DAS. Plant number m^{-2} ranged from 216 to 298. The BARI Gom 29 produced the most plants m^{-2} (298) which was superior to all other varieties. On the other hand, BARI Gom 28 produced the fewest plants m^{-2} (216) preceded by BARI Gom 26 at 12 DAS (Figure 3A).

Interaction effect between sowing date and variety

Plants m^{-2} was significantly affected by the interaction of variety and sowing date ($p < 0.01$). The highest number of plants m^{-2} (304.33) was obtained from the S_1V_3 interaction at 12 DAS which was statistically similar to S_1V_6, S_2V_5, S_1V_1 and S_1V_5. On the other hand, the fewest plants m^{-2} (184.33) were obtained from S_2V_4 followed by S_2V_1, S_2V_2 and S_2V_3 (Table 2). Plant population, which is an important growth parameter to obtain maximum yield, is fully dependent on seed rate, genotype, germination percentage and environmental conditions (Hossain *et al.,* 2013). High air temperature along with scorching sunshine may increase soil temperature by 10–15°C above air temperature. Under such conditions, seedlings may die and the number of plants per unit area will be affected. A plant population of less than 100 m^{-2} is considered to be a yield–limiting condition in wheat. Seed germination is one of the most important phases affecting the yield and quality of crop production (Almansouri *et al.,* 2001). Hossain *et al.* (2013) observed that the combined effect of high air temperature (27–33°C) and water stress (–3 to –0.9 MPa) was a critical factor for reducing germination rate and percentage than individual stressor effects.

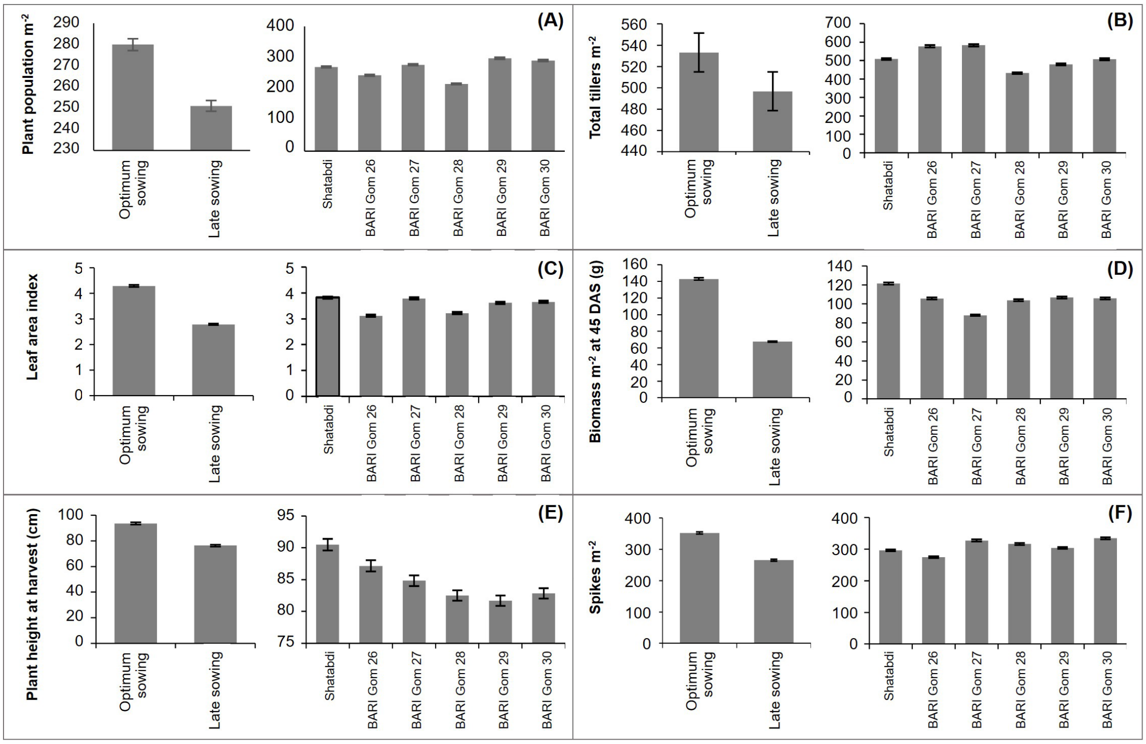

Figure 3 Effects of sowing dates and variety on plant population m^{-2} (A), total tillers m^{-2} (B), leaf area index (C), biomass m^{-2} (D) at 45 days after sowing (DAS), plant height (E) at harvest and spikes m^{-2} (F). Mean (± SD) was calculated from three replicates for each treatment. Error bars represent a significant difference at $p \leq 0.01$ (LSD test).

Total Tillers m^{-2}

Effects of sowing date and variety

Sowing date was not a significant effect on total tillers m^{-2}. The most tillers m^{-2} (533) at 37 DAS were obtained from optimum sowing while the fewest tillers m^{-2} (497) were observed in late sowing. The effect of variety on total tillers m^{-2} was significant ($p < 0.01$) among the six varieties at 37 DAS (Figure 3B). Total tillers m^{-2} ranged from 432 to 583. The BARI Gom 27 produced the most tillers m^{-2} (583), followed by BARI Gom 26, Shatabdi and BARI Gom 30, while BARI Gom 28 produced the fewest tillers m^{-2} (432) at 37 DAS. The results of the present study were also confirmed by the study of Tahir *et al.* (2009), who noticed that the total number of tillers m^{-2} was significantly higher on November 20 (optimum sowing) than on December 20 (late sowing). This is because in November, sowed crops have favorable conditions allowing them to produce more tillers than in late sowing (December 20). Hossain *et al.* (2013) also noted that sowing in mid-November in Bangladesh produced the highest number of total and effective tillers $hill^{-1}$ compared to late sowing because late sown crops face low-temperature stress at initial stages (tillering stage) and heat stress at the reproductive stage.

Interaction effect between sowing date and variety

Tillers m^{-2} was significantly affected by the interaction between variety and sowing date ($p < 0.01$). The maximum tillers m^{-2} (655.67) were obtained in S_2V_2 at 37 DAS which was statistically similar to S_1V_3 and S_1V_6. On the other hand, the fewest tillers m^{-2} (347.67) were obtained in S_2V_4 followed by S_2V_6 (Table 2). Wheat tillers grow from the axis of the main shoot leaves. The potential number of tillers varies among varieties and depends on environmental conditions (Hossain *et al.,* 2013). The tillering ability of the late sowing crop was lower due to low soil moisture (drought), high soil and air temperature, and low relative humidity, which ultimately reduced the number of tillers plant^{-1} (Hossain *et al.,* 2013).

Table 2 Interaction effect of sowing date and variety on plants m^{-2}, total tillers m^{-2}, leaf area index and dry biomass m^{-2}

Treatments	Plants m^{-2} at 12 DAS	Total tillers m^{-2} at 37 DAS	Leaf area index at 45 DAS	Dry biomass m^{-2} at 45 DAS (g)
S_1V_1	295.33	530.00	4.73	170.07
S_1V_2	237.33	500.00	3.30	145.50
S_1V_3	304.33	608.67	4.87	118.17
S_1V_4	247.00	517.00	3.70	131.40
S_1V_5	292.67	473.67	4.50	153.70
S_1V_6	303.67	569.67	4.60	138.80
S_2V_1	244.33	487.00	2.90	72.50
S_2V_2	249.33	655.67	2.93	65.77
S_2V_3	249.67	558.00	2.70	58.00
S_2V_4	184.33	347.67	2.73	76.33
S_2V_5	302.67	485.67	2.73	59.77
S_2V_6	278.33	446.33	2.70	72.93
Mean	265.75	514.94	3.53	105.24
LSD (0.05)	28.97	77.76	0.57	12.28
F–test	**	**	**	**
CV (%)	4.25	5.88	6.23	4.55

Note: ** significance at 1% probability level. S_1 = 15 November sowing, S_2 = 15 January sowing, V_1 = Shatabdi, V_2 = BARI Gom 26, V_3 = BARI Gom 27, V_4 = BARI Gom 28, V_5 = BARI Gom 29, V_6 = BARI Gom 30, DAS = days after sowing, LSD = least significance difference, CV = coefficient of variation

Leaf Area Index

Effects of sowing date and variety

The LAI was significantly influenced by the sowing date ($p < 0.01$). The highest LAI (4.3) was observed in optimum sowing at 45 DAS and the lowest LAI (2.8) was recorded in late sowing. Similar results were also reported by Alam *et al.* (2013), who found that optimum sowing crops got a favorable environment which led to increasing the total crop canopy (leaf area index), finally increased the photosynthesis. In the present study, the effect of variety on LAI was also significant ($p < 0.01$). The LAI ranged from 3.1 to 3.8 at 45 DAS, indicating that the highest LAI (3.8) was obtained from the Shatabdi followed by BARI Gom 27, BARI Gom 30 and BARI Gom 29. The lowest LAI (3.1) was recorded in BARI Gom 27 preceded by BARI Gom 28 (Figure 3C).

Interaction effect between sowing date and variety

Wheat LAI varied significantly due to various treatment combinations of variety and sowing date at 45 DAS ($p < 0.01$). The treatment combination of S_1V_3 produced the highest LAI (4.87) which was statistically similar to S_1V_1, S_1V_5 and S_1V_6. On the other hand, the lowest LAI (2.70) was found in the S_2V_6 treatment combination, which was statistically similar to S_2V_3, S_2V_4, S_2V_5, S_2V_1 and S_2V_2 (Table 2). An increase in high nighttime temperature from 14 to 23°C decreased leaf photosynthetic rate by about 15 μmol m^{-2} s^{-1} in spring wheat (Djanaguiraman *et al.,* 2018). Photosynthesis is a temperature–dependent process, and damages due to high temperature include a wide range of changes in structures or functions of the photosynthetic apparatus, including enzymes (Mathur *et al.,* 2014).

Dry Biomass at 45 DAS

Effects of sowing date and variety

Total dry biomass m^{-2} at 45 DAS was significantly influenced by the sowing date ($p < 0.01$). The heaviest dry biomass m^{-2} (143 g) at 45 DAS was obtained from optimum sowing while the lowest dry biomass m^{-2} (68 g) was observed in late sowing. A similar finding was studied by Ahamed *et al.* (2010). The effect of variety on dry biomass was significant ($p < 0.01$) among the six tested varieties (Figure 3D). The dry biomass m^{-2} ranged from 88 to 121 g. Shatabdi produced the greatest dry biomass m^{-2} (121 g) which was superior to all other varieties. On the other hand, BARI Gom 27 produced the lowest dry biomass m^{-2} (88 g). This difference might be due to the genetic variation, micro–climatic and minor–edaphic factors that can occur under field conditions. The assumption of the present study also confirmed the findings of Malik *et al.* (2013).

Interaction effect between sowing date and variety

Wheat dry biomass recorded at 45 DAS varied significantly ($p < 0.01$) due to various combinations of sowing date and variety treatments (Table 2). The S_1V_1 treatment combination produced the heaviest dry biomass m^{-2} (170.07 g). On the other hand, the lowest dry biomass m^{-2} (58.00 g) was found in the S_2V_3 treatment combination which was statistically similar to S_2V_5 and S_2V_2.

Plant Height at Harvest

Effects of sowing date and variety

Plant height was significantly influenced by the sowing date ($p < 0.01$). The tallest plants (94 cm) at harvest were obtained from optimum sowing whereas the shortest plants (76 cm) were observed in late sowing (Figure 3E). BARI (1984) reported the tallest plants (77 cm) when sowing was done on 20 November and shortest with 30 December sowing. Sial *et al.* (2005) reported that in delayed planting, the development of wheat organs and source–to–sink transfer were affected, and this influence was also reflected by the overall shortening of plant height. Variety affected plant height significantly ($p < 0.01$) among the six tested varieties. Plant height ranged from 82 to 91 cm. Shatabdi produced the tallest plants (91 cm), followed by BARI Gom 26 and BARI Gom 27. On the other hand, BARI Gom 29 produced dwarf plants (82 cm) preceded by BARI Gom 28 and BARI Gom 30 at harvest (Figure 3E).

Interaction effect between variety and sowing date

Plant height was significantly affected by the interaction effect of variety and sowing date (p < 0.01). The tallest plants (101 cm) were obtained in the S_1V_1 interaction at harvest, which was statistically similar to S_1V_2 and S_1V_3, both 96 cm. On the other hand, the shortest plants (72 cm) were obtained in S_2V_4, which was statistically similar to S_2V_3 (74 cm) and S_2V_5 (76 cm). Plant height is an inherent character and varies with genotype and environmental conditions (Hossain *et al.,* 2013). The plant height of all genotypes in late sowing was lower than in optimum sowing (Table 3). High temperature may have reduced plant height in late sowing. On the other hand, Khan *et al.* (2007) found a positive and significant association between plant height and all morphological traits at the genotypic level. They also found that GY plant^{-1} was positively and significantly correlated with plant height, panicle length, flag leaf area and the number of grains panicle^{-1} at the genotype level.

Spikes m^{-2}

Effects of sowing date and variety

Spikes m^{-2} was significantly influenced by the sowing date (p < 0.01). The highest number of spikes m^{-2} (352) was obtained in optimum sowing whereas the lowest number of spikes m^{-2} (265) was observed in late sowing. The effect of variety on spikes m^{-2} was significant (p < 0.01) among the six tested varieties. Spikes m^{-2} ranged from 275 to 334. BARI Gom 30 produced the most spikes m^{-2} (334), followed by BARI Gom 27 and BARI Gom 28. On the other hand, BARI Gom 26 produced the fewest (275) spikes m^{-2} preceded by Shatabdi (Figure 3F). This difference in spikes m^{-2} might be due to the genetic makeup as observed under field conditions (Malik *et al.,* 2013).

Interaction effect between sowing date and variety

Spikes m^{-2} was significantly affected by the interaction effect of variety and sowing date (p < 0.01). Most spikes m^{-2} (401) were obtained from the S_1V_6 interaction which was statistically similar to S_1V_3 and S_1V_4. On the other hand, the fewest spikes m^{-2} (251) was obtained in S_2V_2 which was statistically similar to S_2V_1, S_2V_4, S_2V_6 and S_2V_3 (Table 3).

Table 3 Interaction effect of sowing date and variety on plant height, spikes m^{-2}, spike length, spikelet spike^{-1} and grains spike^{-1}

Treatments	Plant height at harvest (cm)	Spikes m^{-2}	Spike length (cm)	Spikelets spike^{-1}	Grains spike^{-1}
S_1V_1	101.33	335.33	8.67	15.50	37.67
S_1V_2	96.00	299.33	9.33	15.33	41.67
S_1V_3	96.00	381.33	8.33	15.33	39.00
S_1V_4	92.67	376.67	8.33	15.00	37.33
S_1V_5	87.67	320.00	9.33	15.50	38.33
S_1V_6	87.67	401.33	8.67	16.33	37.00
S_2V_1	79.67	256.67	8.00	14.33	29.67
S_2V_2	78.33	251.00	7.67	14.33	32.33
S_2V_3	73.67	273.33	8.33	13.33	28.00
S_2V_4	72.33	256.67	8.00	12.33	30.33
S_5V_5	75.67	287.67	8.00	13.33	23.33
S_6V_6	78.00	267.33	8.00	14.67	30.33
Mean	84.92	308.89	8.39	14.61	33.75
LSD (0.05)	5.35	25.97	–	1.40	2.65
F–test	**	**	ns	**	**
CV (%)	2.46	3.28	6.47	3.73	3.06

Note: * significance at 5% probability level, ** significance at 1% probability level, ns = non–significant. S_1 = 15 November sowing, S_2 = 15 January sowing, V_1 = Shatabdi, V_2 = BARI Gom 26, V_3 = BARI Gom 27, V_4 = BARI Gom 28, V_5 = BARI Gom 29, V_6 = BARI Gom 30, LSD = least significance difference, CV = coefficient of variation

Spike Length

Effects of sowing date and variety

Spike length was not significantly affected by the sowing date. However, numerically longer spikes (8.8 cm) were found in optimum sowing than in late sowing (8.0 cm) as shown in Figure 4A. Terminal heat stress might be affected by late sowing. High temperature during reproductive stages of the late sowing crop affected spike length. Hossain *et al.* (2013) also observed similar results, noting that under stress (late sowing), all genotypes had shorter spikes (18–40%) which ultimately reduced final yield. Chowdhury (2002) experimented with four sowing dates and reported that spike length decreased when the sowing date was delayed from November 15 and the lowest spike length was recorded on December 15. These results are in agreement with Alam *et al.* (2013). Spike length presented no statistically significant differences across the tested six varieties under the present trial. However, numerically longer spikes (8.67 cm) was found in BARI Gom 29 followed by BARI Gom 26 whereas shorter (8.17) spikes were observed in BARI Gom 28. Although management practices influence wheat spike length, the genotype itself produces different spike lengths.

Interaction effect between sowing time and variety

The interaction between variety and date of sowing had no significant effect on spike length (Table 3). A numerically longer spikes (9.33 cm) was recorded from the interaction of S_1V_2 which was similar to S_1V_5 and a lower spike length (7.67 cm) was recorded from S_2V_2. These results were found to be in accordance with Singh and Pal (2003).

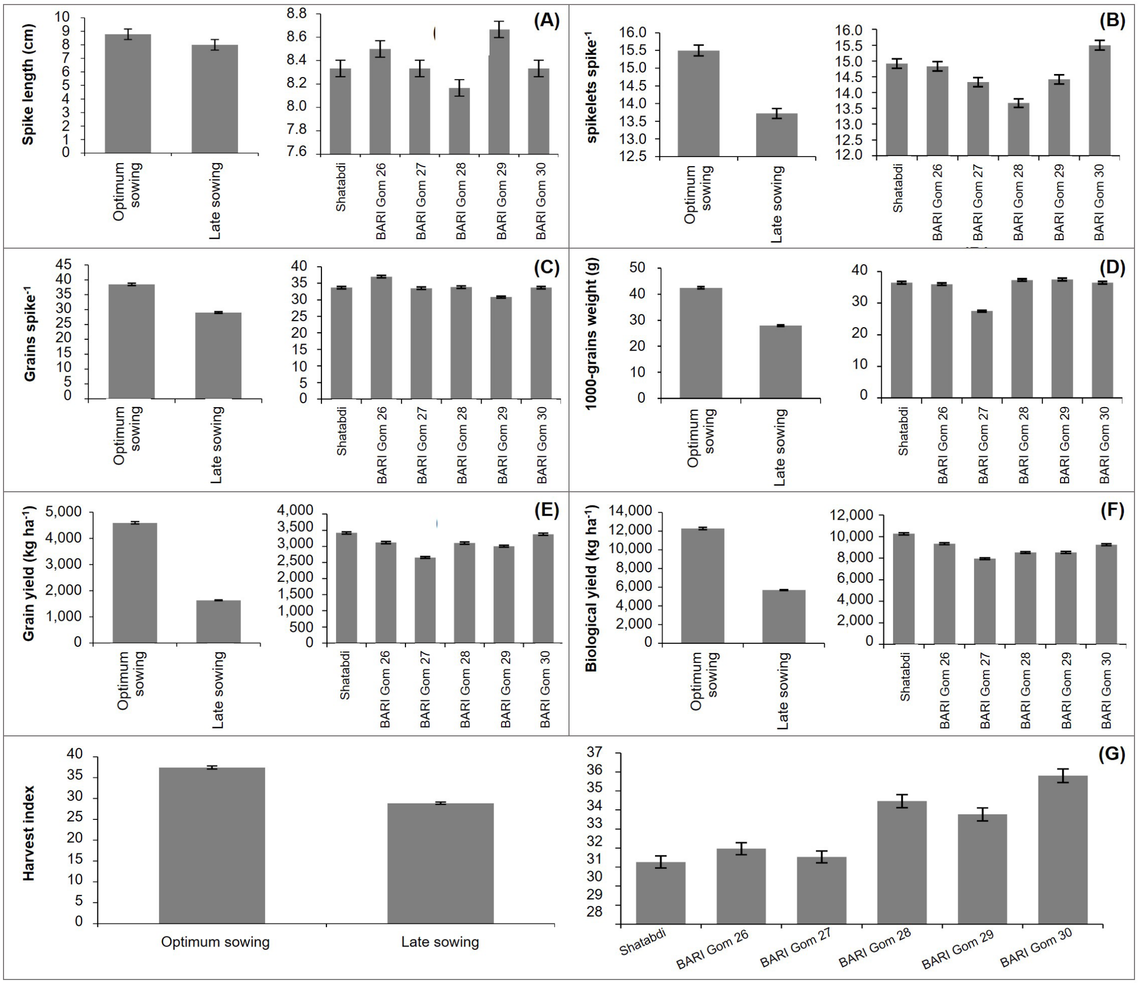

Figure 4 Effects of sowing time and variety on spike length (A), spikelets spike^{-1} (B), grains spike^{-1} (C), 1000–grain weight (D), grain yield (E), biological yield (F) and harvest index (G). Mean (± SD) was calculated from three replicates for each treatment. Error bars represent a significant difference at $p \leq 0.01$ (LSD test)

Spikelets Spike^{-1}

Effects of sowing date and variety

Spikelets spike^{-1} was significantly influenced by the date of sowing ($p < 0.01$) under the present trial. The highest number of spikelets spike^{-1} (15.50) at harvest was obtained from optimum sowing, whereas the lowest number (13.72) of spikelets spike^{-1} was observed in late sowing (Figure 4B). This might be due to the effect of terminal heat stress in late sowing. Suleiman *et al.* (2014) reported that sowing dates have a significant effect on yield components that decreased with the delay in sowing date and the highest values were obtained when cultivars were sown on 1st November and 15th November.

The effect of variety on a number of spikelets spike^{-1} was significant ($p < 0.01$) among the tested six varieties. The total number of spikelets spike^{-1} ranged from 13.7 to 15.5 (Figure 4B). The BARI Gom 30 produced the most spikelets spike^{-1} (15.5) which were superior to all other varieties followed by Shatabdi and BARI Gom 26. On the other hand, BARI Gom 28 produced the fewest spikelets spike^{-1} (13.7) preceded by BARI Gom 27 and BARI Gom 29. This difference in spikelets spike^{-1} might be due to the genetic makeup in the field (Malik *et al.,* 2013).

Interaction effect between sowing date and variety

Spikelets spike^{-1} of wheat varied significantly due to various treatment combinations of variety and sowing date ($p < 0.01$). The S_1V_6 treatment combination produced the most spikelets spike^{-1} (16.33) and was statistically similar to S_1V_1 and S_1V_5. On the other hand, the fewest spikelets spike^{-1} (12.33) were observed in the S_2V_4 treatment combination, which was statistically similar to S_2V_3 and S_2V_5 (Table 3). The reproductive stage is considered to be the most temperature–sensitive period in wheat. The main sensitive trait to temperature (high and low temperature) stress at this stage is spikelets spike^{-1} (Sangtarash, 2010). High temperatures in the reproductive stage force premature death in more distal and basal florets, and as a result, grain number decreases drastically (Hossain *et al.,* 2013). Those studies also reported that all varieties showed more spikelets spike^{-1} in optimum sowing due to a more favorable environment than early and late sowing.

Grains Spike^{-1}

Effects of sowing date and variety

Grains spike^{-1} was significantly influenced by the sowing date ($p < 0.01$) in the present trial. The highest number of grains spike^{-1} (39) at harvest was obtained from optimum sowing, whereas the lowest number of grains spike^{-1} (29) was observed in late sowing (Figure 4C). This result might be due to the effect of terminal heat stress under late sowing. Chowdhury (2002) experimented with four sowing dates and reported that grains spike^{-1} decreased with a concomitant delay in sowing date from November 15 and the lowest grains spike^{-1} was recorded in plants that had been sown on December 15.

The effect of variety on grains spike^{-1} was significant ($p < 0.01$) among the six tested varieties. The total number of grains spike^{-1} ranged from 30.8 to 37.0 (Figure 4C). The BARI Gom 26 produced the most grains spike^{-1} (37.0) which was superior to all other varieties followed by BARI Gom 28, 'Shatabdi', BARI Gom 30 and BARI Gom 27. On the other hand, BARI Gom 29 produced the fewest grains spike^{-1} (30.8). This difference might be due to genetic variation, climatic and edaphic factors as realized in the field. Different wheat genotypes had a significant effect on grains spike^{-1}.

Interaction effect between sowing date and variety

Grains spike^{-1} of wheat varied significantly ($p < 0.01$) due to the various treatment combinations of variety and sowing date (Table 3). The treatment combination of S_1V_2 produced the most grains spike^{-1} (41.67). On the other hand, the fewest grains spike^{-1} (23.33) was found in the S_2V_5 treatment combination. Wheat sown on November 15 produced a significantly higher number of grains than in late sowing on January 15. The reproductive stage is considered to be the most temperature–sensitive period in wheat. High temperature during the flowering stage decreases grain set in almost all field crops due to lower fertilization caused by pollen sterility and/or ovule abortion. Seed-set in wheat was dramatically decreased when a high temperature of 30°C was applied for three days at the onset of meiosis in the anthers. Similarly, a higher decline in grain number is observed when drought occurs at or immediately after anthesis in wheat (Sangtarash, 2010). The number of grains ear^{-1} in wheat as influenced by sowing date and genotype. Altered phenology results in early heading and forced maturity due to heat stress, and less time available for grain formation results in a reduction of the number of grains. Hossain *et al.* (2013) also observed a reduced number of grains spike^{-1} but at a different magnitude under late sowing or high–temperature conditions compared to optimum sowing temperature.

1000–Grain Weight

Effects of sowing date and variety

The date of sowing had a significant effect on 1000–grain weight ($p < 0.01$) in the present study. The largest 1000–grain weight (43 g) at 12% moisture was obtained from optimum sowing, whereas the least 1000–grain weight (28 g) was observed in late sowing (Figure 4D). This might be due to the effect of terminal heat stress at late sowing. Chowdhury (2002) experimented with four sowing dates and reported that 1000–grain weight decreased with a delay in sowing date from November 15 and the lowest 1000–grain weight was recorded in plants sown on December 15. Abdullah *et al.* (2007) found that 1000–grain weight declined progressively with delayed sowing and the maximum value in the first planting date, i.e., October 25, and the minimum value in the last planting date, i.e., January 10.

The effect of variety on 1000–grain weight was significant ($p < 0.01$) among the tested six varieties (Figure 4D). The range of 1000–grain weight was 28–38 g. The BARI Gom 29 produced the highest 1000–grain weight (38 g) which was superior to all other varieties followed by BARI Gom 28, Shatabdi, BARI Gom 30 and BARI Gom 26. On the other hand, BARI Gom 27 produced the least 1000–grain weight (28 g). Grain size is very stable for all wheat genotypes to the development and synthetic activity of GY (Asana and Williams, 1965). The 1000–grain weight differed among varieties (BARI, 2003).

Interaction effect between sowing date and variety

The 1000–grain weight of wheat varied significantly due to various treatment combinations of variety and sowing date ($p < 0.01$). The S_1V_4 treatment combination produced the heaviest 1000–grain weight (45.00 g) which was statistically similar to S_1V_2, S_1V_6 and S_1V_1. On the other hand, the lowest 1000–grain weight (19.00 g) was found in the S_2V_3 treatment combination (Table 4). The 1000–grain weight is the most important parameter for final yield. High-temperature stress during anthesis to maturity (GS_3) induces leaf senescence that decreases the availability of assimilates to growing grain and also starch synthesis and deposition, which ultimately decreases individual grain weight (grain size). Again, high temperature at this stage also decreases the duration of grain filling, which outweighs the increase in the rate of grain–filling. The decrease in grain weight under high temperatures at the GS_3 stage (tillering stage) is well documented (Khanna–Chopra and Viswanathan, 1999). Yang *et al.* (2002) reported a 50% decline in average grain weight of 30 synthetic hexaploid wheat varieties subjected to a high temperature of 10°C higher than ambient temperature (20/15°C) at 10 days after anthesis.

Early sowing increased 1000–grain weight compared to late sowing, however, under stress conditions, 1000–grain weight decreased due to a decrease in individual grain weight. In optimum sowing, all genotypes produced higher individual grain weight due to favorable environmental conditions at that time (Hossain *et al.,* 2013). High temperature (soil and air) and deficit soil moisture (drought) stress in late sowing reduced individual grain weight, which ultimately affected 1000–grain weight (Hossain *et al.,* 2013). Alam *et al.* (2013) concluded that decreased weight on December 20 might be due to delayed sowing that reduced the growth period and shriveled grain due to high temperatures that prevailed during the grain–filling stage. Asana and Saini (1962) also stated that relatively high temperature during early grain development increased the initial rate of grain filling, enhanced the yellowing and loss of stem sugars, and hence reduced final grain weight. The reduction in 1000–grain weight caused by delayed sowing could also be attributed to more shriveled grains that formed due to prevailing high temperature at the time of grain filling.

Grain Yield

Effects of sowing date and variety

The GY was significantly influenced by the date of sowing ($p < 0.01$) in the present trial. The highest GY ha^{-1} (4,591 kg) was obtained from optimum sowing, whereas the lowest (1,633 kg) GY ha^{-1} was observed in late sowing (Figure 4E). This might be due to the adverse impact of heat stress, particularly in the reproductive stages. Delayed planting reduced the days to heading, days to maturity grain filling and ultimately showed a reduction in yield and yield components. Late-planted wheat plants face a period of high-temperature stress during reproductive stages causing reduced kernel number spike^{-1} as well as a reduction in seed yield. Numerous publications have reported an increase in wheat yield with early sowing and a reduction in yield when sowing was delayed after the optimum time. Hossain *et al.* (2013) observed the highest yield with wheat sown from November 22 to December 20 compared to November 8, November 15 and December 27. This might be due to the adverse impact of terminal heat stress, particularly in the reproductive stages.

The effect of variety on GY was significant ($p < 0.01$) among the six tested varieties. The range of GY ha^{-1} was 2,654–3,419 kg (Figure 4E). Shatabdi produced high GY ha^{-1} (3,419 kg) which was superior to all other varieties followed by BARI Gom 30. On the other hand, BARI Gom 27 produced the lowest GY ha^{-1} (2,654 kg). This difference might be due to the genetic variation, micro–climatic and minor-edaphic factors as realized in the field. Hossain *et al.* (2013) and Kumar *et al.* (2013) also observed a similar trend among different varieties. Qasim *et al.* (2008) also conducted experiments with different varieties and observed the effect of varieties on yield.

Interaction effect between sowing date and variety

The GY of wheat varied significantly due to the various treatment combinations of variety and sowing date ($p < 0.01$). The S_1V_1 treatment combination produced the highest GY ha^{-1} (5,096 kg) which was statistically similar to S_1V_6. On the other hand, the lowest GY ha^{-1} (1,353 kg) was found in the S_2V_3 treatment combination which was statistically similar to S_2V_4 (Table 4). In field conditions, most of the time, high temperatures follow drought, that is, drought and high temperature occur simultaneously causing significant yield loss (Lott *et al.,* 2011). This is because, in late sown conditions, climate and soil moisture are unfavorable (high temperature, low relative humidity in the air and low soil moisture) for crop production, which ultimately affects crop growth and yield (Hossain *et al., 2013*). Kumar *et al.* (2013) also reported a significant variation of GY due to the interaction of variety and sowing date.

Table 4 Interaction effect of sowing date and variety on 1000–grain weight, grain yield, biological yield and harvest index

Treatments	1000–grain weight (g)	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
S_1V_1	43.33	5,096.00	13,587.33	37.53
S_1V_2	44.67	4,528.67	12,626.66	35.87
S_1V_3	36.00	3,955.33	10,805.00	36.60
S_1V_4	45.00	4,673.33	11,884.00	39.33
S_1V_5	41.33	4,374.67	11,624.00	37.63
S_1V_6	44.67	4,918.33	13,132.33	37.43
S_2V_1	29.67	1,742.00	6,952.33	25.00
S_2V_2	27.33	1,705.33	6,076.33	28.07
S_2V_3	19.00	1,353.00	5,113.00	26.47
S_2V_4	29.67	1,529.33	5,176.67	29.60
S_2V_5	33.67	1,631.67	5,459.67	29.90
S_2V_6	28.33	1,834.33	5,388.00	34.17
Mean	35.22	3,111.83	8,985.44	33.13
LSD $_{(0.05)}$	2.00	263.74	352.62	4.47
F–test	**	**	**	**
CV (%)	2.22	3.30	1.53	5.26

Note: ** significance at 1% probability level. S_1 = 15 November sowing, S_2 = 15 January sowing, V_1 = Shatabdi, V_2 = BARI Gom 26, V_3 = BARI Gom 27, V_4 = BARI Gom 28, V_5 = BARI Gom 29, V_6 = BARI Gom 30, LSD = least significance difference, CV = coefficient of variation

Biological Yield

Effects of sowing date and variety

The biological yield was significantly influenced by the sowing date in the present investigation ($p < 0.01$). The largest biological yield ha^{-1} (12,277 kg) was obtained in optimum sowing, but the lowest biological yield ha^{-1} (5,694 kg) was observed in late sowing (Figure 4F). Similar effects of sowing date on straw yield, biological yield and harvest index were found by Qasim *et al.* (2008). Said *et al.* (2012) reported significant differences in biological yield and maximum biological yield (11,953 kg ha^{-1}) among planting dates between November 1 and November 15. Atikulla (2013) observed the highest biological yield (8.94 t ha^{-1}) on November 19, 2012, but the lowest biological yield (8.25 t ha^{-1}) on December 9, 2012 sowing date. This might be caused by the effect of heat stress in late sowing. The effect of variety on biological yield was significant at $p < 0.01$ among the six tested varieties. The biological yield ha^{-1} ranged from 7,959 to 10,270 kg (Figure 4F). Shatabdi produced the largest biological yield ha^{-1} which was superior to all other varieties followed by BARI Gom 26 and BARI Gom 30. On the other hand, BARI Gom 27 produced the least biological yield ha^{-1}. This difference might be due to the genetic variation, micro-climatic and minor-edaphic factors as realized in the field.

Interaction effect between sowing and variety

The biological yield of wheat varied significantly at $p < 0.01$ due to the various treatment combinations of variety and sowing date (Table 4). The S_1V_1 treatment combination produced the largest biological yield ha^{-1} (13,587 kg). On the other hand, the lowest biological yield ha^{-1} (5,113 kg) was found in the S_2V_3 treatment combination which was statistically similar to S_2V_4, S_2V_6 and S_2V_5. These results are similar to the findings of Hossain *et al.* (2013), who also reported higher biomass when crops were sown at optimum sowing than early and late sowing. Nicolas *et al.* (1984) also found a greater decrease in biomass under high temperature and drought stress in the early and late stages of grain development.

Harvest Index

Effects of sowing date and variety

Harvest index was significantly influenced by the sowing date ($p < 0.01$) in the present trial. The highest harvest index (37%) was obtained from optimum sowing, whereas the lowest (29%) was observed in late sowing (Figure 4G). This might be due to the effect of heat stress in late sowing. Similar effects of sowing date on straw yield, biological yield and harvest index were found by Qasim *et al.* (2008). Samuel *et al.* (2000) reported that late sowing (January 6, 1997) reduced harvest index (36.1%) from in normal sowing (41.5%) (November 29, 1996) in wheat. Similar results were also reported by Alam *et al.* (2013) and Kumar *et al.* (2013).

The effect of variety on harvest index was significant at $p < 0.01$. Harvest index ranged from 31 to 36%. The highest harvest index performed in BARI Gom 30 followed by BARI Gom 28 and BARI Gom 29, and the lowest (31%) in Shatabdi preceded by BARI Gom 27 and BARI Gom 26 (Figure 4G). Kumar *et al.* (2013) reported that the harvest index of wheat was affected significantly by wheat variety. Genetic improvement of GY in wheat is closely associated with increases in harvest index, but not with increases in total biomass (Slafer and Andrade, 1991).

Interaction effect between sowing date and variety

The harvest index of wheat varied significantly due to various treatment combinations of variety and sowing date ($p < 0.01$). The S_1V_4 treatment combination produced the highest harvest index (39.33%) which was statistically similar to S_1V_1, S_1V_5, S_1V_6, S_1V_3 and S_1V_2. On the other hand, the lowest harvest index (25.00%) was found in the S_2V_1 treatment combination which was statistically similar to S_2V_3 and S_2V_2 (Table 4). Similarly, Sandhu *et al.* (1999) found that the harvest index was the highest in normal sowing but decreased gradually with a delay in sowing. Dixit and Gupta (2004) reported that a higher harvest index was obtained when the crop was sown on a normal date than late sowing.

Stress-related Parameters

The performance of different cultivars under stress may be observed by calculating YSI (Lewis, 1994), STI (Fernandez, 1992), SI (Papathanasiou *et al*., 2015) and HSI (Fischer and Maurer, 1978). In the present study, under late sown heat stress, SI was higher (67%) in BARI Gom 28 followed by BARI Gom 27 (66%), Shatabdi (66%), BARI Gom 30 (63%), BARI Gom 29 (63%) and BARI Gom 26 (62%) as shown in Figure 5. The SI was lower in BARI Gom 26, BARI Gom 29 and BARI Gom 30 and these genotypes also produced higher GY under late sown heat stress than BARI Gom 28, BARI Gom 27 and Shatabdi, indicating that BARI Gom 26, BARI Gom 29 and BARI Gom 30 were tolerant to late sown heat stress.

From a heat tolerance point of view, STI was higher (0.43) in BARI Gom 30 followed by Shatabdi (0.42), whereas a lower STI (0.25) was recorded in BARI Gom 27 (Figure 5). BARI Gom 30 and Shatabdi recorded higher STI. The STI can identify only cultivars that produce a higher yield in both conditions. Fernandez (1992) reported that selection based on STI would result in genotypes with higher stress tolerance and good yield potential.

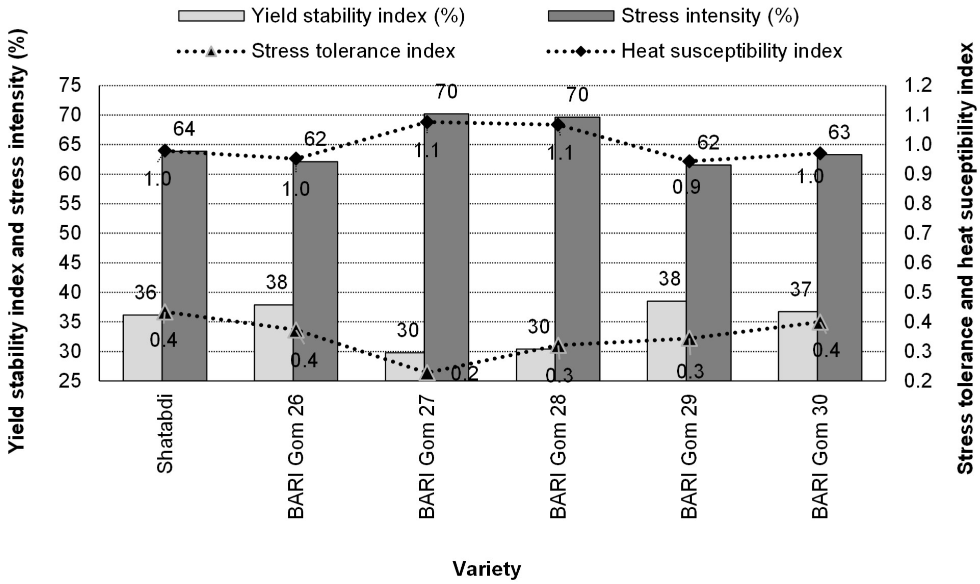

Figure 5 Stress tolerance indices of six wheat varieties under late sown heat stress

In the case of HSI, a larger value shows relatively more sensitive to stress thus smaller values of HSI are favored. Selection based on this index favors genotypes with low yield under non–stress conditions and high yield under stress. From this point of view, the lower HSI (0.97) recorded in BARI Gom 26, BARI Gom 29 and BARI Gom 30. A higher value in BARI Gom 28 (1.04) followed by BARI Gom 27 (1.02) and Shatabdi (1.02) were similar with the genotypes selected by YSI (Figure 5). The YSI was higher in BARI Gom 26 (38%) followed by BARI Gom 29 (37%) and BARI Gom 30 (37%) whereas lower YSI was recorded in BARI Gom 28 (33%) preceded by BARI Gom 27 (34%) and Shatabdi (34%). In the case of higher YSI, genotypes produced more yield under stress compared to normal conditions while at lower YSI, genotypes produced less yield under stress than in the normal condition.

CONCLUSIONS

The present study revealed that wheat sown under optimum sowing conditions took more time to reach physiological maturity, while late sowing treatments took a shorter duration. This is due to heat stress under late sowing in which all wheat varieties completed their life cycles much faster, leading to reduced GY as a consequence of altering the physiological and biochemical activities of the plant. Under optimum sowing, growth, yield and yield components were maximized compared with late-sown heat stress. Among the wheat varieties, significantly maximum GY ($p < 0.01$) was obtained in Shatabdi, but the lowest in BARI Gom 27 when sown under favorable conditions (optimum sowing). Under late sowing, BARI Gom 30 was found to be heat tolerant and produced maximum GY whereas BARI Gom 27 was found to highly heat sensitive and produced the lowest yield. Under both sowing conditions (optimum and late sowing), maximum grain, as well as biological yield, were recorded in Shatabdi and the lowest in BARI Gom 27. After evaluation using four heat tolerance indices, BARI Gom 30, followed by BARI Gom 29, BARI Gom 26 and Shatabdi were found to be heat–tolerant varieties, whereas BARI Gom 27 and BARI Gom 28 were susceptible to late heat stress. Therefore, except for BARI Gom 27 and BARI Gom 28, the other four varieties (Shatabdi, BARI Gom 26, BARI Gom 29 and BARI Gom 30) may be recommended for future breeding programs to develop heat-tolerant varieties, as well as for current cultivation under late sown conditions.

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