PHYSIOLOGICAL AND YIELD PERFORMANCE OF DIFFERENT WHEAT (*Triticum aestivum* L.) VARIETIES UNDER HIGH TEMPERATURE STRESS

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CERTIFICATE

*This is to certify that the thesis entitled "PHYSIOLOGICAL AND YIELD PERFORMANCE OF DIFFERENT WHEAT (Triticum aestivum L.) VARIETIES UNDER HIGH TEMPERATURE STRESS" submitted to the Department of Agricultural Botany, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of MASTERS OF SCIENCE (MS) in Agricultural Botany, embodies the result of a piece of bonafide research work carried out by ASADUR RAHMAN, Registration No.**19-10070** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged

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DEDICATED TO

MY

BELOVED PARENTS

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ABSTRACT

High temperature exerts adverse effect on the growth, physiology, developmental processes and yield of wheat. In Bangladesh the winter is very short. So, timely sowing of wheat seeds can be helpful. The experiment was laid out in a Completely Randomized Design with three replications at the net house of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka during the period from November 2019 to March 2020 to find out the effect of high temperature stress on growth, physiology and yield of wheat. The experiment comprised of two factors; Factor A: Variety (4); V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, V_4: BARI Gom 33 and Factors B: Sowing date (3)-S_1: Sowing at 25 November, S_2: Sowing at 25 December, 2019 and S_3: Sowing at 15 January, 2020. The highest plant height was found from V_4, while the lowest plant height was recorded from V_3. The SPAD value, relative water content (RWC) and membrane stability index (MSI) adversely affected under high temperature mediated by late sowing. The highest filled grains spike^{-1} was observed from V_4S_1, again the lowest filled grains spike^{-1} was recorded from V_1S_3. The highest 1000 grain weight (43.5 g) was found from V_3S_1. The highest grain yield was in V_3 BARI Gom 32 (2.67 t ha^{-1}) and the lowest grain yield (1.1 t ha^{-1}) in V_1 (BARI Gom 29). The highest straw yield (3.4 t ha^{-1}) was recorded from V_4 (BARI Gom 33), and the lowest straw yield (1.14 t ha^{-1}) was recorded from V_1 (BARI Gom 29). When wheat seeds were sown after November 25th, 2019, growth parameters, yield attributes, and yield all decreased gradually. Planting wheat seeds after November 25th is also discouraged because it affects wheat production.

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CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.), the most widely cultivated cereal crop belonging to Poaceae family, is the largest contributor of the world grain production with nearly 30% and 50% grain trade of the world (Akter and Islam 2017). Wheat is the major crop source of carbohydrate and, the most important crop product for human consumption (Curtis and Halford 2014).

Wheat is generally cultivated as a winter irrigated crop in Zambia, Malawi, and Mozambique and a winter rain fed crop in the highlands of Kenya, Ethiopia, Rwanda, Uganda, and Tanzania (Negassa *et al.* 2012). Wheat is the most abundant crop in the world with about a 2.1 million km^2 total harvested area. It is the first rain-fed crop after maize and the second irrigated crop after rice (Portmann *et al.* 2010). Durum wheat is around 6% of total wheat production (37.7 million tones in 2013; International Grain Council October, 2014), occupying approximately 20 million hectares worldwide. Wheat is cultivated on about 218.5 million hectares in a wide range of environments, with annual production of about 712.31 metric tons (FAO, 2014). Bangladesh, wheat is ranked as the second most important crop after rice (Timsina *et al.*, 2016). In the North-Western part of Bangladesh, it is grown in large areas of 130,768 ha in 2015-16 (BBS, 2016). Compared to the international regular wheat production (3.07 t ha^{-1}), average yield of wheat was only 3.03 t h^{-1} in 2015-16 (BBS, 2016) in our country for the same year (Statista, 2016). FAO estimated that the world would require additional 198 million tons of wheat by 2050 to accomplish the future demands, for which wheat production need to be increased by 77% in the developing countries (Sharma *et al.* 2015).

According to the Intergovernmental Panel on Climatic Change (IPCC 2007), the temperature increase in the 20th century was measured as 0.74°C with the progressively increasing rate. IPCC further predicts an increase in temperature between 0.3°C and 0.7°C over the next two decades and depending upon emission scenarios, a rise of 0.3–4.8°C by the end of the 21st century (Collins *et al.* 2013). If present rates of global warming continue, worldwide temperatures are estimated to continue to increase by a further 1.5°C between 2030 and 2052 (IPCC, 2018). Global and regional impact assessments recommended that increasing heat stress already intimidates wheat production and global food safety (Asseng *et al.*, 2015, Liu *et al.*, 2014).

Heat stress is one of the major abiotic stresses prompting yield drop in most wheat growing areas (Tack *et al.*, 2015). Elevated temperature leads to a series of physiological and structural alterations in plant life (Fahad *et al.,* 2016). Wheat is susceptible to high temperature extremely (Wang *et al.,* 2016). Heat stress encourages leaf senescence leads to decreased sugar reserve in plants (Farooq *et al*., 2011; Tovignan *et al.*, 2016). Wheat is often exposed to temperatures above 24°C during reproductive stage in the majority of the regions (Zhao *et al.*, 2016). Optimum sowing time for wheat is very significant due to its requirements for temperature and light for emergence, growth and flowering. For each degree rise in temperature, wheat production is estimated to decrease by 6% (Akter and Islam 2017). Heat stress significantly reduces seed germination, cell turgidity, seedling growth, and plant water-use efficiency. It also decreases grain number and size, assimilate translocation and duration and growth rate of grains. Heat stress is more harmful during the reproductive phase than during the vegetative phase due to the direct effect on grain number and dry weight.

Delayed sowing of wheat exposes its grain filling stage to high temperature (Pandey *et al.,* 2015). Lengthening of the vegetative phase is one of the foremost facts observed in timely sown plants as plants utilize the abundant time for enhancing their height and thus the sugar reservoir (Mondal *et al.,* 2016). Photosynthesis exhibits the maximum sensitivity towards elevated temperature with significant decrease in the net photosynthetic rate and thus reducing plant growth (Mathur *et al.,* 2014). Accumulation of accessory pigment carotenoid, associated with photo-protective mechanism is also troubled due to heat stress (Maria de Leonardis *et al.,* 2015). Temperature stress results in decreased stomatal conductance and transpiration rate (Guptaet *et al.,* 2015).

Grain yield in crops is critically reliant on successful reproductive development and evaluating pollen viability may be considered as an important criterion in selecting the heat tolerant genotype (Mesihovic *et al*., 2016). Predicting the potential effect of climate change on crop yields is a complex task as increasing CO_2 could result in "CO_2 fertilization"; and for wheat, this could offset some of the negative impacts of increased temperatures on yields (Kaur *et al*., 2017; Hatfield and Dold, 2018). The adverse effect of temperature could be minimized by adjusting sowing time to an optimum date and to find out heat tolerant genotypes, which are suitable for late and very early sown conditions. Superior plant performance under hot environments has been linked with root development and plant water uptake (Pinto and Reynolds 2015).

Some advanced wheat genotypes were released as varieties by Wheat Research Center and Bangladesh Agricultural Research Institute, Bangladesh. These varieties were developed for optimum as well as late sown condition i.e., these genotypes have some heat tolerant characteristics (WRC, 2016). Comparatively, the vegetative stage is known to be more tolerant to heat stress than sensitive reproductive stages in most field crops (Prasad *et al.*, 2017). For wheat, the production and/or uptake, transport, storage and remobilization of the critical metabolites required for optimal growth rates and yields are dynamic processes involving feedback and feed forward sink-source interactions that can be disrupted in plants under heat stress (Asseng *et al*., 2017; Kumar *et al*., 2017; Hütsch *et al*., 2018).

Bangladesh Agricultural Research Institute (BARI) has released several wheat varieties some of which are BARI Gom-26, BARI Gom-27, BARI Gom-28, BARI Gom-29, BARI Gom-30, BARI Gom-31, BARI Gom-32, and BARI Gom-33. Among these varieties BARI Gom-26, BARI Gom-27, BARI Gom-28, BARI Gom-29 are older varieties. Among the new varieties BARI Gom-32 has the shortest life span (95 days). Other varieties have comparatively higher life span (100-110 or 110-115 days). Under field condition the wheat plants are often adversely affected by high temperature stress which causes remarkable yield loss. Recently the yield potential of wheat varieties of Bangladesh is under threat due to outbreak of devastating disease blast. Blast disease is capable to destroy the crops of entire field and can cause total yield loss. The latest variety of wheat that is BARI Gom-33 has been recommended for blast disease tolerant. The high temperature tolerance capacity of this variety was not studied well. It is prime important to find out an appropriate high temperature tolerant wheat cultivar. So, the present study has been designed to investigate comparative growth and yield performance of different wheat varieties of Bangladesh under different temperature regimes mediated by delayed sowing.

Objectives:

- To study the growth, physiology and development of different wheat cultivars under high temperature stress
- To observe the yield contributing characters and yield of different wheat cultivars under high temperature stress

CHAPTER II

REVIEW OF LITERATURE

2.1 Growth

Alam *et al.*, (2014) assessed three spring wheat varieties and one advanced line under HT environment to observe the HT stress tolerant varieties and/or genotypes are appropriate for cultivation all over the Bangladesh in increasing temperature. The field trial was conducted at the field of Wheat Research Centre, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur, Bangladesh with two environments; one was normal sowing date on 30 November and another in late sowing date (HT stress) on 30 December). In the late sowing condition, the varieties and advanced lines phased higher temperature compared to normal sowing. The performance was better of the advanced line and varieties in normal growing condition compared to HT stress environment. BARI Gom-27, in stress environment, produced the maximum tillers (706.5, 503.2 & 296.5 m^{-2} at 40, 60 & 80 DAS, respectively) and the second highest were BAW-1151 and BARI Gom-28 at 80 DAS (287.4 m^{-2}). BAW-1151 performed the best in relation to dry matter (631.3 g m^{-2} at 80 DAS), and then BARI Gom-28 (622.9 g m^{-2}at 80 DAS). BAW-1151 produced the highest leaf area (3536.7 cm^3 m^{-2}at 80 DAS) followed by BARI Gom-28 (3199.7 cm^3 m^{-2} at 80 DAS).

2.2 Germination

Nahar *et al.* (2010) examined in case of normal sowing date (at 30 November) the maximum temperature for the period of germination was above 25°C, sometimes close to 30°C and the minimum temperature was between 15 to 20°C. After 13 December, the temperature was slowly decreasing. After 30 December (late sowing condition),the highest and lowest temperature was near 25°C and 12 to 15°C with regular temperature of near 17 to 20°C. Plants with normal sowing date, germinate earlier while temperature was higher as compared to late sowing when temperature was comparatively lower. The germination speed was faster at 29°C. The most appropriate temperature for germination was in the range of 24 to 29°C. Germination rate became lower with the decrease of temperature. In the late sowing, the germination period was lower than the normal sowing date. The days requirement for germination increased by 57.14% in 'Pradip', 48.84% in 'Sufi' 43.5% in 'Sourav', 31.76% in 'Shatabdi' and 28.86% in 'Bijoy'. It was clear that the speed of germination is higher in high temperature.

2.3 Plant height

Plant height of eight wheat varieties at different growing conditions. It was observed that the combined outcome of growing condition and wheat genotypes on plant height was significant. BAW-1146 reached the highest plant height (103.00 cm and 104.67 cm for two years) under normal growing condition. The heat sensitive genotype Pavon-76 attained the lowest plant height (93.53 cm and 95.00 cm for first and second year respectively). Plant height was evidently reduced for all the wheat genotypes under late and very late growing conditions in different magnitudes. Under late sowing and very late sowing, plant height varied due to genotype and the combined effect of growing condition. Shortening of growth and photosynthetic period may be the reason of the decrease in plant height enforced by HT stress in a late sown condition. Varied genetic condition of genotypes might affect the differences in plant height as reported by Bala *et al.* (2018).

Bala *et al.* (2018) experimented eight wheat genotype's plant height at different growing conditions. From the results, it was seen that the combined effect of growing condition and wheat genotypes on plant height was significant. Under normal sowing date, BAW-1146 reached the highest plant height (103.00 cm and 104.67 cm for first and second year). The heat sensitive variety Pavon-76 got the lowest height of the plants (93.53 cm and 95.00 cm for first and second year respectively). Under late and very late growing conditions, plant height was distinctly decreased for all the genotypes in different levels. Under late sowing and very late sowing, plant height varied due to the combined effect of genotype and growing condition. The reduction in plant height may have happened due to shortening of growth and photosynthetic period forced by heat stress in a late sown environment. Wheat varieties exposed a significant effect of varieties on plant height. Varied genetic condition of genotypes might be the cause of the differences in plant height because of various genotypes.

2.4 Number of tillers per plant

Jahan and Adam (2015) conducted an experiment and the results showed that at the age of 42, 49, 84 and 91 days, the highest number of tillers per plant was obtained from 14th November (S1). At the age of 63 days similar number of tillers per plant (5.77) was obtained from both 24th November (S2) and 4th December (S3).

Alam *et al.* (2014), showed that number of tiller/m^2 produced by several genotypes (BARI Gom-26, BAW-1151, BARI Gom-27, BARI Gom-28) in different days was highly significant statistically. Spring wheat genotypes started to produce tiller at just before 20 DAS (Day after sowing). It was the initial stage of tiller production. The maximum tillers were produced by various genotypes at 40 DAS. Then this period, number of tillers was being reduced due to tiller's mortality. At 20 DAS the maximum tillers were produced by BAW-1151 in both seeding conditions, then by BARI Gom-27. At 40 DAS all genotypes produced more tillers in LS condition than in NS (normal sowing date). At this time, the BARI Gom-27 produced the maximum tillers (706.5) followed by BARI Gom-26 (698.3) in LS and also in NS environment the maximum tiller was produced by BAW-1151 (546.6) followed by BARI Gom-26 (512.8). This might be caused due to higher temperature from 20 to 40 DAS in LS condition than NS. All genotypes also had more tillers in LS than in NS at 60 DAS. At 80 DAS, the tiller mortality reached at static condition. In this period, the number of tillers of all varieties was observed higher in NS than LS condition. The BARI Gom-26 produced more tillers (324.3) in NS, but lower tiller number (255.1) in LS. The BARI Gom-28 produced the second highest tillers (287.4) in LS condition among the genotypes where it was lower in (305.5) NS condition. (At 80 DAS) tiller reduction rate was the lowest in BARI Gom-27 (3.5%) in LS and then in BARI Gom-28 (5.9%) compared to NS. It indicated that the BARI Gom-27 had the more tiller producing ability in HT stress than normal growing environment due to genetic makeup, then BARI Gom-28.

2.5 Number of Leaves

The maximum number of leaves per plant was also found from S1 plants from the age of 42 days to harvest and sowing time had major effect in most of the cases. Highest number of leaves was obtained from both S2 and S3 at 35 days. The increase in leaf number is important for photosynthetic activities (Jahan and Adam, 2015).

2.6 Days to emergence

Dwivedi *et al.* (2017) found significant differences in days to germination among the 3 sowing time. Late sowing (LS) took more time to germinate. Early and optimum sowing (OS) took significantly similar time to germinate. On the other hand, no significant among three genotypes to germinate. The maximum temperature was >26 to 28°C in the germination period, sometimes close to 30°C, and the minimum temperature was between 12 and 13°C, in Optimum sowing (15 November). The average maximum and minimum temperatures were near 23 and 10°C at late sown condition (30 December). Sometimes minimum and maximum temperature was between 8-9°C and 20-19°C, respectively.

2. 7 Days to physiological maturity

Dwivedi *et al.* (2017) observed that days to physiological maturity decreased from early sowing to optimum and late sowing. To reach physiological maturity, variety 'Shatabdi' took more time, followed by 'BARI Gom 27' and 'BARI Gom 28' took minimum time.'Shatabdi' required more time to reach physiological maturity in all sowing dates, followed by 'BARI Gom 27' and least time was taken by 'BARI Gom 28' to reach physiological maturity.

2.8 Productive tillers m^{-2}

Productive number tillers m^{-2} varied significantly by various wheat varieties as Dwivedi *et al.* (2017) reported. 'BARI Gom 27' produced significantly higher number of productive tillers m^{-2} followed by 'Shatabdi' while 'BARI Gom 28' had the lowest number of productive tiller m^{-2}. 'BARI Gom 27' and 'Shatabdi' produced the comparable greater numbers of productive tiller in 15th November sowing and were superior over

‘BARI Gom 28’. ‘BARI Gom 27’ and ‘Shatabdi’ were comparable in productive tiller under delayed sowing (30^{th} December), which were significantly higher than ‘BARI Gom 28’. Among the genotypes, ‘BARI Gom 27’ gave more number of productive tiller than ‘Shatabdi’ and ‘BARI Gom 28’ in all sowing dates. ‘BARI Gom 28’ produced the lowest number of productive tiller m^{-2}. Maximum tiller production in 15^{th} November sowings was because of lengthy vegetative phase weather at this period. Wheat sown on 15^{th} November noted significantly higher spike length when compared to early sowing and late sowing. The decrease of ear length under delayed sowing on December 30^{th} could be described in terms of altered phenology resulting in early heading. Significantly more ear length was recorded in ‘Shatabdi’ and ‘BARI Gom 27’ over ‘BARI Gom 28’. The difference of ear length among the genotypes may be caused by genetic variation. The interaction between variety and sowing date had no significant influence on spike length.

2.9 Number of grains per plant

Jahan and Adam (2015) found in their study non-significantly highest number of grains per plant in S2. Increase in number of grains per plant due to S2 was 35.78 % higher over S3. The higher number of grains per plant following S2 was possibly due to increased number of productive tillers per plant. The maximum 1000- seed weight was noted from S1 followed by S2. In S3, BARI Gom-25 produced minimum 1000-seed weight. There was a gradual reduction in 1000-seed weight with delayed sowing.

2.10 Stomatal conductance and photosynthetic rate

Singh *et al.* (2017) showed that stomatal conductance followed a decreasing trend generally towards crop maturity. It was higher in HT stress conditions. Photosynthetic rate was highest at 88 days after sowing (DAS) in the ambient condition and then declined towards maturity. But photosynthetic rate was significantly higher in elevated temperature chambers than in ambient grown genotypes till 88 DAS. But in grain filling period, the photosynthesis rates dropped rapidly and were significantly lower than HD 2967 and HD 2985. WR 544had the photosynthesis rates were almost similar in both conditions. HD 2967 had higher photosynthesis rate still 88 DAS in elevated temperature condition, they were significantly higher in WR 544 during grain filling period. After flowering stage the variety WR 544 could continue the photosynthesis rates in raised temperature and thus this variety was least affected by HT stress. In this experiment, the photosynthesis rates were higher in elevated temperature condition till 88 DAS mainly due to the temperature regimes were towards optimum as compared to the ambient. But once the temperatures crossed optimum in elevated temperature condition, photosynthesis rates declined rapidly as compared to the optimum. WR 544 could maintain the photosynthesis rates in elevated temperature condition similar to that of ambient.

2.11 Physiology

Dwivedi *et al.* (2017) studied thirty wheat genotypes to examine their growth, physiology and yield attributes under HT stress mediated by different sowing dates, November (timely), December (late) and January (very late). Destruction of chlorophyll under HT decreased photosynthetic capacity in all spring wheat genotypes. Moreover, impairment in transportation of photosynthate (starch mobilization) from green foliage (source) to anther tissues (sink) was also prominent in all wheat genotypes.

Hossain *et al.* (2017) conducted an investigation during *rabi* season of 2016-17 in the research farm of Wheat Research Centre (WRC), Dinajpur, Bangladesh to evaluate the performance of three wheat varities which are released by BARI (Bangladesh

Agricultural Research Institute). Treatments were three sowing dates *viz.,* early sowing (1st November), optimum sowing (15th November) and late sowing (30th December), and three wheat varieties namely 'Shatabdi', 'BARI Gom 27' and 'BARI Gom 28'. The experiment was laid out in split-plot design with three replications. Three sowing dates were arranged in main plots and three wheat varieties were in sub-plots. Among the three sowing dates, the highest grain yield was obtained from optimum sowing (15th November) sowing and the lowest was from late sowing (December 30th). Among the varieties, 'BARI Gom 28' was found significantly superior to all other varieties with respect to spikelets spike^{-1}, grains spike^{-1}, 1000-grain weight, harvest index, biomass and grain yield. Considering on grain yield, the maximum grain yield was obtained from 'BARI Gom 28' and the lowest was in 'BARI Gom 27'. The combine effect between sowing dates and variety were influenced significantly in respect of yield and yield attributes except spike length. Among three varieties 'BARI Gom 28' produced significantly the highest grain yield in 15th November followed by 'Shatabdi' at the same sowing date and the lowest grain yield was recorded from 'BARI Gom 27'on 30th December sowing. Therefore, it can be concluded that 'BARI Gom 28' is the best variety, followed by 'Shatabdi' and 'BARI Gom 27' for producing higher grain yield and November 15th is the best time for sowing wheat, whereas December 30th is the worst sowing condition that negatively effect on grain yield of wheat.

Aiqing et al., (2018) performed an experiment at HT stress (34/16°C, day/night temperature) and 11 spring wheat genotypes were exposed during flowering to study the effect on time of day of flowering, seed set, grain yield, and quality. The trend was more prominent under HT stress, providing first indication of an alternative mechanism such as heat escape in wheat reducing damage in the time of flowering. On average, significant reduction in net CO_2 assimilation (17%), starch (25%), and protein content in grain (21%), seed set (7–19%), kernel weight (11–15%), and grain yield (22–38%), but with 17% increase in flag leaves proline concentration, was noted under HT stress over control. The negative effect of HT stress on seed set was more among the primary spikes than for the main spike. This differential impact is mainly attributed to inadequate plasticity of early reproductive processes such as gametogenesis to escape HT stress, unlike heat escape phenomena noticed at flowering. KSG1203 and KSG41 showed heat escape strategy, whereas KSG1194 emerged as a true heat-tolerant line.

Bheemanahalli *et al*., (2019) exposed spring wheat to temperatures 30°C in the time of flowering and grain filling stages and it adversely affected seed set and seed weight. For 10 d during flowering and for 30 d during grain filling, the selected set of 28 different spring wheat varieties were exposed to HT stress (34/16°C day/night temperatures) to measure genetic variability in photosynthesis, pollen germination, , and yield parameters in controlled environment. A significant reduction in pollen germination (39.9%, $P < 0.001$) was noted from plants exposed to HT stress. HT stress on main and primary spikes, for 10 d during flowering encouraged significant fall in seed number (15.4 and 23.0%) and seed weight (32.3 and 34.6%), . HT stress during grain filling had a more noticeable influence on seed weight (16 and 22%) than seed number (2.7 and 9.3%) in main and primary spikes, respectively. Varieties KSG025 and KSG1214 with higher seed number, seed weight, and harvest index and significant pollen germination under HT stress were identified.

Joshi *et al*. (2106) directed a study to evaluate the effects of high temperature stress on phenologic, floral, crop production and seed quality attributes of 14 wheat genotypes under four environmental conditions; raised at two dates: November (favorable) and January (Heat stress) during *rabi* seasons. At anthesis and post-anthesis stage, 5-12°C higher temperatures were noted than the usual sowing date. Significant variances among sowing dates was noticed which represents sensitivity to high temperature stress.

Abdelrahman *et al.* (2020) showed that each ℃ rise in global mean temperature is likely to decrease the average global yield of wheat by 4-6%. Source-limitations from the early reproductive stage to anthesis are critical which affect the carbohydrate reserves and biomass accumulation. As a result, the sink capability in terms of grain numbers. Sink-limitations are more significant post-anthesis and during the time of grain filling, which are mostly controlled by the ability of the sink to gather assimilates from the source. By influencing source-sink relations, endogenous change of T6P/trehalose levels in wheat, could have helpful influences on wheat production. High-throughput metabolite profiling combined with other approaches, such as proteomics, transcriptomics, genome-wide association works and quantitative genetics, has been recognized beneficial with respect to improving the yields of many cereal crops under several environmental stresses; and thus, has the potential for use with wheat under HT stress.

In a study De Leonardis *et al.* (2015) showed how HT stress at five days (37°C) after flowering affected the antioxidant capacity, nutritional composition, and metabolic profile of the grain of two durum wheat genotypes: “Primadur”, with high yellow index, and “T1303”, rich in anthocyanin and purple in color. The effects of HT stress were genotype-dependent. Some metabolites (e.g., sucrose, glycerol) increased due to HT stress in both genotypes and clear variations were witnessed. In "Primadur", there was a common increase in most of the studied metabolites and a general decrease in "T1303". Heat shock at seed development produced changes that were observed in immature seeds and also long-term effects that altered the qualitative and quantitative parameters of the mature grain. The nutritional value of grain of durum wheat can be affected by short HT stress in different ways.

Hossain *et al*., (2013) evaluated eight spring wheat varieties under three heat stress condition (early, late and very late). Results show that stress did not adversely affect flag leaf area in 'Prodip' and 'Sufi' and flag leaf dry matter partitioning in 'Prodip', , dry matter partitioning above ground in 'Shatabdi' and 'BARI Gom-26', seedling appearance in 'Sufi' and 'BARI Gom-26', or tiller growth in 'Sufi' and 'BARI Gom-26'.'Sufi' was highly heat stress-tolerant, followed by 'BARI Gom-26' and 'Shatabdi' with respect to lower yield reduction, relative performance and heat susceptibility index (HSI). 'BARI Gom-26' (HSI=0.10, 0.65) and 'Shatabdi' (0.22, 0.62) were highly tolerant to early HT stress and moderately tolerant to extremely late HT stress while 'Sufi' was highly tolerant (0.35) to extremely late HT stress and moderately tolerant (0.51) to early heat stress. Followed by 'Sourav' (1.19, 1.42), 'Prodip' (1.03, 1.23), 'BARI Gom-25' (1.61, 0.89) and 'Bijoy' (1.04, 1.28), 'Gourab' (2.19, 1.46) was the most susceptible. 'BARI Gom-26', 'Shatabdi' and 'Sufi' have the highest potential as high-yielding wheat varieties under warm to hot temperature and.

2.12 Cell membrane stability (CMS) and chlorophyll content

Rehman *et al*. (2016) evaluated cell membrane stability (CMS) and chlorophyll content under high temperature stress at seedling and anthesis stages of 50 various wheat genotypes. A major difference ($P \leq 0.05$) was showed by analysis of variance for all of the characters at seedling and anthesis phases. CMS presented a significant positive correlation with 1000-grain weight (TGW) under high temperature stress. The ratio of chlorophyll *a*/*b* at seedling stage showed a significant negative correlation ($r = –0.39$, $P < 0.05$) with TGW. Under HT at anthesis stage, total chlorophyll content was significantly ($r = 0.42$, $P < 0.05$) correlated with TGW. Genotypes ETAD248 and ETAD7 showed the maximum CMS and TGW values, while chlorophyll *a*/*b* values were low, at both seedling and anthesis stages. Lower chlorophyll *a*/*b*, higher CMS and total chlorophyll content, were effective indicators for identifying genotypes with high TGW under HT stress.

2.13 Heat susceptibility index

Joshi *et al*. (2106) observed the performance of wheat genotypes vary considerably over the two environments viz., non-stress and HT stress environments. The comparison of heat susceptibility index (‘s’ values) between normal versus late sown condition was used to find genotypes which reflected resistant or susceptible genotypes for each trait. For plant height, DL-788-2(0.49), HD-2985(0.53) and HD-3093 (0.54) had least susceptibility to HT stress under HT stress condition. Thus identified as most resistant varieties for this characteristic. Where genotypes HD- 3070 (0.69) and HD-2733 (0.68) presented higher heat susceptibility index, and categorized as susceptible.HD-3093(0.15) and DBW-17 (0.14) showed least susceptibility index for flag leaf area compared to HD-

2985(0.89) and HD-2967(0.70). For days to maturity, HD- 2888 (0.41) had least susceptibility index than the other varieties. So it was recognized as the most resistant genotype for this trait as it was least influenced by HT. The pollen fertility was also affected by HT stress where HD-2985 (0.4) and GW-322 (0.4) displayed least susceptibility. HD-3043(0.14), HD-2888 (0.13) showed higher HSI. For spikelet fertility, GW-366 (0.21) and DBW-17(0.22) showed least susceptibility index whereas HD-3076(0.37) and HD-2733 (0.36) had higher HIS under HT stress condition. For tiller number, HD-3093 (2.14) and HD-3043 (2.15) had least susceptibility index and DL-788-2 (2.58), HD-3076 (2.50) and HD-3086 (2.50) showed highest susceptibility index. And this indicated that they were more affected by HT stress compared to others. For 1000-grain weight; the genotypes showed high heat susceptibility index values ranging from 0.63 to 1.07 for HD-2985 and HD 3093, respectively. For grain yield; GW-366 (1.69) and HD-2888 (1.79) showed least susceptibility index whereas genotypes HD-3070 (2.66), HD-2987 (2.51), HD-3093 (2.39) and HD- 3076 (2.29) showed higher heat susceptibility index, and were categorized as susceptible genotypes. HT stress (+3.0°C seasonal mean and +5.6°C during ripening growth stage) has been described to reduce grain yield and yield contributing attributes to varying extent among the genotypes. Generally yield is decreased by shortening of the grain filling duration by decreasing kernel weight. For the germination percentage; HD-3093 (0.11) and GW-366 (0.12) was least susceptible while the genotypes HD-3086 (0.24) and HD-2985(0.21) had high susceptibility index.

2.14 Days to harvest maturity

Hossain *et al.* (2011) observed that tendency of days to harvest maturity in late sown crop and days to physiological maturity in early sown crop are statistically similar. Because of low temperature, early sowing were matured late. Late sowing needed short time for maturation at grain-filling and maturation time because of HT at grain-filling and maturation stage, and the life span of late sown crop was reduced as consequence. Variety Shatabdi need maximum days to get harvest maturity in all sowing condition, followed by Sourav. Variety Gourab needed minimum time, which was statistically followed by cultivars Sufi, Prodip, BARI Gom-25, Bijoy and BARI Gom-26, respectively. Variety Shatabdi (sown on 08 November) needed significantly maximum days to harvest maturity followed by BARI Gom-26. It was observed that the variety Shatabdi and Sourav needed maximum days to get harvest maturity and variety Gourab needed minimum days to get harvest maturity. It was observed that all varieties sown in early need higher days compared to late sown.

2.15 Crop Growing Cycle

Yang *et al.* (2017) noted that warming would allow for earlier planting of spring wheat and earlier ending of winter wheat dormancy. This would let the crop to mature earlier by avoiding HT stress happened later. They ran simulations on delaying the winter wheat plating dates within 28 days and on bringing forward the spring wheat plating dates of28 days. Winter wheat do not show a statistically significant mitigation outcome. The results for spring wheat showed that about 50-60% of the HT stress induced yield losses can be avoided by this simple adaptation measure. The outcomes at other spring wheat stations did not produce statistically significant mitigation effect.

2.16 Development, yield attributes and yield

Uddin *et al.* (2015) conducted an experiment to examine the effect of variety and sowing date on growth and yield performance of wheat plants. There were four wheat varieties viz., BARI Gom-21, BARI Gom-24, BARI Gom-25 and BARI Gom-26 and three sowing dates viz., 20 November, 01 December and 12 December. Growth and yield contributing characters and yield varied significantly by different varieties and sowing dates. BARI Gom-24 and BARI Gom-25 had early lower lag phase duration of 8 days after anthesis (DAA) and 12 DAA, respectively than BARI Gom-21 (16 DAA) sown at 01 December. The maximum grain growth rate was noticed in BARI Gom-26 sown at 01 December. It reached peak at 20 DAA (1.17 mg /grain/day). The minimum growth rate was maintained by BARI Gom-21 and BARI Gom-24 sown at 12 December (0.15 mg /grain/day). The highest yield (4.6 t ha−1) was obtained from BARI Gom-25 sown at 01 December.. On the other hand, the lowest yield (2.67 t ha^{-1}) was obtained from BARI Gom-21 sown at 20 November.. All the studied wheat cultivars sown at 01 December showed better performance in terms of growth, yield contributing characters and yield, compared to 20 November and 12 December sowing.

Different wheat genotypes (Pavon-76, Prodip, BARI Gom-25, BARI Gom-26, BAW-1143, BAW-1146, BAW-1147 and BAW-118) were tested for their performance in different sowing dates [November 27 (normal), December 17 (late) and January 7 (very late growing condition)]. The study was conducted in two successive years (2011-12 and 2012-13). Morpho-physiological attributes of different wheat genotypes under terminal heat stress were evaluated. Growth attributes such as leaf area ratio (LAR), specific leaf area (SLA) and leaf weight ratio (LWR) decreased throughout the advancement of growth stages. High temperature decreased plant height and grain yields in all wheat genotypes, compared to normal growing condition (Bala *et al.* 2018).

Thirty spring wheat genotypes were evaluated in the field for three consecutive winter seasons with different sowing dates. November (timely), December (late) and January (very late); these were the sowing considered in the study (Dwivedi *et al.* 2017). The average temperature during anthesis stage of late (LS) and very late sowing (VLS) conditions were 2.7°C and 5.2°C higher, compared to timely sowing (TS) date. The average yield reduction of 18% under LS and 34% under VLS conditions were recorded under TS condition. An average reduction of 8.6 days in average grain filling duration was observed under LS and 12.6 days under VLS condition which caused 17 and 39% respective decrease in the test weight. Destruction of of chlorophyll, decreased photosynthetic capacity, impairment in transportation of photosynthate (starch mobilization) from green foliage (source) to anther tissues (sink) resulted in high pollen mortality and thereby decreased grain yield under HT. So, in this study the adverse effect of HT on wheat genotypes at anthesis stage proved a direct association of photosynthesis with starch mobilization, pollen viability and grain yield (Dwivedi *et al.* 2017).

To observe the effect of high temperature stress on the leaf growth and dry matter partitioning of 5 wheat varieties (Sourav, Pradip, Sufi, Shatabdi and Bijoy) a field experiment was conducted with normal sowing (sowing at November 30) and late sowing (sowing at December 30) at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. It was observed that stem dry weight was highest in Shatabdi under both normal (2.267 g) and heat stressed (1.801 g) environment and Pradip (1.202 g) and Sufi (1.166 g) produced the lowest stem dry weight in those conditions. Leaf number of

Pradip (5.37) and Shatabdi (5.01) was the highest in the normal and late sowing condition, respectively and it was lowest in the variety Bijoy (4.87) followed by Sufi (3.62) under the normal and late sowing condition. Both under normal and late sown heat stressed condition the variety Shatabdi showed the highest leaf area, longest leaf sheath and lamina with concomitant increase of dry matter (5.976 g and 4.459 g tiller-1 under normal and heat stress, respectively). However, the spike dry weight was highest in Bijoy and lowest was in Sourav and Sufi regardless the growing condition. In normal sowing the ear weight and husk of main stem was the highest in Shatabdi (2.933 g), whereas seed weight per main stem was highest in Bijoy (2.167 g). In late sown condition, ear weight, seed weight per stem was highest in Bijoy and husk wt. was found the highest in Shatabdi. Grain weight of variety Bijoy (34.94g) and Shatabdi (33.30 g) were higher in late sowing, whereas Sufi had lowest 1000 grain weight (23.81 g) and finally Bijoy produced the highest grain yield both under normal sowing late sown mediated heat stressed condition. Considering all Bijoy can said to be the best performing variety amongst all and Sufi is the worst one considering specially the yield components and yield (Ahamed *et al*. 2010).

There was a maximum decrease in plant height under high temperature stress condition. Phenology was similarly meaningfully affected by high temperature. In November, wheat varieties are sown that took extra time to reach maturity. Late sown material recorded lesser crop growth period. Maximum reduction in tiller number (70%), grain yield (67.3% reduction), 1000-grain weight (47% reduction). The most susceptible traits were these which were susceptible to high temperature stress. A reduction of 39.7% for canopy temperature depression at grain filling stage due to high temperature stress. Flag leaf area, spikelet fertility and pollen fertility reduced by 33.1%, 22.7% and 7.7% respectively and were less affected because of higher temperature. Genotypes GW 366 and HD 2888 showed least heat susceptibility index (HSI) for grain production and HD 3093 presented better tolerance for seed quality (Joshi *et al*., 2106).

2.17 Grains spike^{-1}

Hossain *et al*. (2018) recorded the maximum grains spike^{-1} in irrigated time sowing (ITS) condition, because of favorable weather condition, which helps to increase grains set eventually. The environmental condition of Dinajpur was the best for producing grains spike^{-1} in case of locations. Significant genotypic variation was observed for grains spike^{-1}, due to genetic makeup of the specific variety. The genetic variation, climatic and edaphic factors might be the cause of the genotypic variation difference they also reported that the grains spike^{-1} of wheat varied among cultivars. They also observed that different wheat varieties have significant influence on grain spike^{-1}. Reduced number of grain spike^{-1} in different scale was observed under LS condition as compared to OS temperature. When crop faces a HT stress (>30°C) at the flowering stage, decreases grain set in nearly all field crops. It happens due to lower fertilization caused by pollen sterility and/or ovule abortion that finally reduced the grain number spike^{-1}. The reduction in grain-set was due to both abnormal ovary developments, for example the absence of an embryo sac and reduced nucleus development; dried-up pollen with abnormal cytoplasm, poor pollen dehiscence and pollen tube formation.

2.18 1000-grain weight (TGW)

Hossain *et al.* (2018) observed that under late sown heat stress condition, individual grain weight decreases and so TGW weight decreases because of it. . In OS, higher TGW as a result of higher individual grain weight because of favorable environmental conditions.

Wheat sown ITS condition (20th November) produced the highest TGW and the least TGW was noted from irrigated late sown (ILS) condition (30th December).Maximum TGW was recorded in 'Gen- 48', followed by 'Gen.-40, 33 and 16, and the lowest TGW was in 'Gen.-19' in case of genotypes.

Neware *et al.* (2019) conducted an investigation among the wheat varieties, NIAW 2891 (56.79 g) and NIAW 3523 (48.37 g) genotype gave significantly highest mean test weigh over AKAW 4210-6 (43.61 g). Genotypes AKAW 5023 (44.83 g), PBN 7451-02 (42.12 g) and AKAW 4927 (39.14 g) were found statistically *at par* with AKAW 4210-6. Lowest test weigh was noted in PBN 4905 (39.14 g) in HT stress condition. Significantly higher 1000 grain weight was found in NIAW 2891 and NIAW 3523 (56.79 and 48.37 g, respectively) as compared to rest of the genotypes. Higher ability to use the available resources in vegetative period which might be the cause of the higher yield attributes under stress condition.

Dwivedi *et al.* (2017) got significantly highest 1000-grain weightfrom wheat sown on 15th November followed by 1st November sowing and the least 1000-grain weight was found from 30th December sowing. Early heading and forced maturity because of HT stress and also a reduced amount of time available for grain filling, and grain maturity as a result of reduction in days taken to maturity may be the reason. As the sowing was late, the reduction in the 1000-grain weight also could be attributed to more number of shriveled grains formed due to usual HT at the time of grain filling. 'BARI Gom 28' produced significantly highest 1000-grain weight over 'Shatabdi' and 'BARI Gom 27'. Interaction result between sowing dates and varieties on 1000-grain weight was influenced significantly.

2.19 Yield and yield components

Over three years (2012–2014), Jat *et al.* (2018) carried out a study in which a diverse set of 21 genotypes was evaluated under 10 different sowing dates: D01- D10. Effect of shifted sowing dates was unequally spread across yield stability across management practices. The best varieties and high stable genotypes were 'CSW 18' (G03), 'DPW 621-50' (G05) and 'BAZ' (G01) in early, normal and later sowing dates, respectively. The pattern of expected yield showed that the low performing varieties have a tendency to become high performer during late sowing dates which do not perform better in early sowing dates. Likewise, high predictive yield and high stable genotypes from early planting tend to have variable expected yield with low stability during normal and late sowing. Besides, low predictive yield and low stable genotypes had disease resistant genes.

Alam *et al.,* (2014) showed in an experiment that the highest yield was produced by BARI Gom-28 in HT stress environment (3.59 t ha^{-1}) followed by BARI Gom-27 and BARI Gom-26 (each 3.08 t ha^{-1}), but the worst was BAW-1151 (2.9 t ha^{-1}). According to the results, the prominent variety for HT stress was BARI Gom-28 and then BARI Gom-27 or BARI Gom-26.

Hossain *et al.* (2013) in their study examined that all varieties in optimum sowing condition (OS) (sown on 22 November) gave higher grain yield (GY) than all HT stress conditions which are early heat stress (sown on 8 November) (EHS), late heat stress (LHS) (sown on 13 December) and extremely late heat stress (EXLHS) (sown on 27 December). 'Sourav', 'Gourab', 'Prodip' and 'BARI Gom-26' in OS produced comparatively higher and similar GY. 'BARI Gom-26' produced higher GY in all stress conditions, followed by ‘Shatabdi’ in EHS, ‘Prodip’ in LHS and ‘Sufi’ in EXLHS, which might be due to the stress tolerance of these genotypes. Compared to OS, yield reduction in HT stress (EHS, LHS and EXLHS), ‘BARI Gom-26’ was the lowest (2, 7 and 20%), and then was ‘Sufi’ (9, 12 and 11%) and ‘Shatabdi’ (4, 20 and 19%) and the highest was ‘Gourab’ (40, 27 and 45%).

2. 20 Grain yield (kg ha^{-1}; GY).

Hossain *et al.* (2018) showed that grain yield (GY) of wheat genotypes were influenced significantly by location specific sowing dates and genotypes. Wheat sown on 20th November resulted in significantly highest GY over 30th December. The poor GY of wheat sown on 30th December may be attributed to reduction in number of productive tillers/spikes and grains spike^{-1} and also test weight in December 30th sowing. Among the genotypes, ‘Gen.-30’ gave the GY, followed by ‘Gen.-13’, ‘Gen.-9’ & ‘Gen.-40’, respectively. The higher yields of these selected wheat varieties was for the higher number of productive tillers/spikes and grains spike^{-1}. All genotypes gave the best production in the environmental condition of Dinajpur, followed by Jessore in both the sowing conditions.

Neware *et al.* (2019) recorded top ranking genotype NIAW 2891 has significantly highest GY of 35.65 qt. ha^{-1} followed by NIAW 3523 (33.83 qt. ha^{-1} Genotypes AKAW 5023 (31.41 qt. ha^{-1}) and PBN 4751-02 (28.39 qt. ha^{-1}) found *at par* with superior check AKAW 4210-6. Significantly lowest GY was noted in PBN 4905 and AKAW 4927 (22.48 and 26.66 qt. ha^{-1}, respectively) in HT stress condition. After post anthesis, during *rabi* 2016-17, sudden increase in ambient temperature by (0.51°C)compared with second year *rabi* 2017-18, but in *rabi* 2017-18 minimum temperature was increased by 12.67%

as compared to first year *rabi* 2016-17 which caused reductions in soil moisture content and leaf relative water content because of evapotranspiration. The reduction in general mean GY (ha^{-1}) to the extent of 0.11 % in second year when compared with first year might be due to higher temperature observed after anthesis to grain development stage. The improvement in GY qt. ha^{-1} is to the extent of 20.64 % in high yielding genotype i.e. NIAW 2891. Reduction in GY to extent of 22.91 % in low yielding variety PBN 4905 over a superior check AKAW 4210-6. Reduction in yield under HT stress condition resulted reductions in metabolic processes, in turn affects flowering, grain set, sex ratio and thereby yield.

Singh *et al.* (2017) found high temperature caused a decrease in grain and straw yield in all varieties. More reduction in grain yield found in HD 2967 (25%), followed by HD 2985 (21%) and WR 544 (6%) and ambient grown varieties. Harvest index was decreased more in HD 2967 and least in WR 544. Maximum test weight reduction took place in HD 2967 (8%), followed by HD 2985 (6%) and WR544 (2%). These outcomes showed that WR 544 had more stable HI. Test weight representing its stable source-sink balance even in elevated HT stress condition.

Hossain *et al.* (2011) found that grain yield (GY),in respect of cultivars, was significantly influenced by sowing dates. Crop sown on December 06 was the highest GY, which was statistically similar to December 13, November 29 and 22 sowing. The second highest GY was December 20 sowing and the lowest was noted November 08 sowing followed by November 15 and December 27 sowing. Early sowing (November 08 and 15) and at extremely late sowing (December 27) produced lower yield than other sowings. to the reason might be HT stress in vegetative stage of early two sowing and grain filling stage of extremely late sowing. It was observed that the variety Shatabdi produced the highest GY, closely followed by BARI Gom-26 and Sourav. The second highest GY was noted from Prodip, which was statistically similar to Bijoy, Gourab and Sufi.and the lowest was recorded from BARI Gom-25. Shatabdi produced statistically higher GY across all the sowing dates, which was similar to BARI Gom-26, Sourav. Cultivar BARI Gom-26 produced the lowest GY across all sowing dates. More than 3 t ha^{-1} yield was recorded from cultivar Sourav in all sowing dates. On November 08, 15 and December 27 (extremely late) sown varieties produced lower yield than others, it might be due to unfavorable growing condition.in HT stress, too early (08 November) and very late (27 December) sowing condition, the yield reduction was 20.47 and 19.69% in Sourav, 33.16 and 13.95% in Gourab, 34.62 and 12.50% in Shatabdi, 34.96 and 8.60% in Sufi, 32.08 and 11.05 in Bijoy, 41.18 and 28.92% in Prodip, 27.91 and 11.96% in BARI Gom-25 and 41.15 and 22.73% in BARI Gom-26, respectively as compared to December 06 which had a high GY. In extremely heat stress (November 08 and December 27) condition Prodip was found to be heat sensitive genotype and yield reduction was 41.18 and 28.92%followed by BARI Gom-26 (41.15 and 22.73%). Genotype Sourav and BARI Gom-25 was found to be heat tolerant as compared to yield reduction in both too early and very late sowing condition.

Kamrani *et al.* (2018) observed that the combined analysis of variance showed a significant impact of HT stress on durum wheat grain yield. Under stress, non-stress conditions and stress indices a highly significant ($P < 0.01$) variation was recorded for grain yield among the genotypes. Among the 45 durum wheat varieties, G41, G29 and G10 produced high grain yield under both stress and non-stress conditions. Under non-stress conditions, G5, G16 and G6 had high grain yield but low grain yield under stress conditions.

Dwivedi *et al.* (2017) grain yield (GY) was significantly affected by sowing dates and genotypes. Wheat sown on 15th November resulted in significantly higher production over 1st November and 30th December. Yields (1st November and 30th December sowing) were significantly lower. The poor production of wheat (sown on 1st November and 30th December) may be due to reduction in number of productive tillers and grains ear^{-1} in 1st November sowing. 'BARI Gom 28' gave significantly higher production over 'Shatabdi' and 'BARI Gom 27' and the lowest yield was observed in 'BARI Gom 27'. Interaction of sowing dates and genotypes also significantly influenced GY. Significantly more GY was obtained from w 'BARI Gom 28' (sown on 15th November and 1st November), 'BARI Gom 27' (sown on 15th November) and 'Shatabdi' (sown on 15th November). 'BARI Gom 28' produced highest grain yield in all sowing dates among them followed by 'Shatabdi' and the lowest yield was got from 'BARI Gom 27'. 'BARI Gom 28' was the best performing variety under all sowing conditions according to the experiment, followed by 'Shatabdi'. And the variety 'BARI Gom 27' was the least performing under all sowing conditions.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at Agronomy field of Sher-e-Bangla Agricultural University to find out the effect of high temperature stress and different sowing dates on the growth and yield of wheat. The details of the materials and methods i.e. experimental site, climate, soil, land preparation, planting materials, experimental design, land preparation, fertilizer application, irrigation and drainage, intercultural operation, data collection, data recording and their analysis have been mentioned below:

3.1 Experimental period

The experiment was conducted during the period from November 2019 to March 2020 in rabi season.

3.2 Experimental site

The experiment was conducted in the Net House and Plant Physiology Laboratory of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. The location of the pot experiment at 24º 75′ N latitude and 90º 50′ E longitude at the elevation of above 18m of sea level and it was under the Agro-Ecological Zone-28, namely Madhupur Tract.

3.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by three distinct seasons, namely winter season from the month of November to February and the pre-monsoon period or hot season from the month of March to April and monsoon period from the month of May to October (Edris *et al*., 1979). Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e-Bangla Nagar, Dhaka and details has been presented in Appendix I.

3.4 Soil characteristics of the experimental plot

The soil belongs to "The Modhupur Tract", AEZ-28 (FAO, 1988). Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 6.2 and had organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land.

3.5 Treatment of the experiment

The experiment comprised of two factors.

Factor A: Wheat variety (4)

i) BARI Gom 29 (V_1)

ii) BARI Gom 30 (V_2)

iii) BARI Gom 32 (V_3)

iv) BARI Gom 33 (V_4)

Factors B: Sowing time mediated high temperature stress (3)

i) S_1= Control(Seed sowing on November 25)

ii) S_2= High temperature stress 1 (Sowing on December 25)

iii) S_3= High temperature stress 2 (Sowing on January 15)

Total Number of Pot: 36

There were in total 12 (4×3) treatment combinations such as V_1S_1, V_1S_2, V_1S_3, V_2S_1, V_2S_2, V_2S_3, V_3S_1, V_3S_2, V_3S_3, V_4S_1, V_4S_2, and V_4S_3.

3.6 Experimental design and layout

The experiment was laid out in a Completely Randomized Design with three replications. The experiment area was divided into three equal blocks. Each block contained 12 pots where 12 treatment combinations were allotted at random. There were 36 pots altogether in the experiment. The soil holding capacity of each pot was 12kg. The layout of the experiment is shown below:

R_1	R_2	R_3
T_3	T_7	T_8
T_{12}	T_4	T_7
T_8	T_{12}	T_9
T_{11}	T_1	T_{10}
T_7	T_8	T_2
T_{10}	T_{11}	T_5
T_2	T_6	T_{11}
T_9	T_3	T_1
T_6	T_{10}	T_4
T_4	T_5	T_3
T_1	T_9	T_6
T_5	T_2	T_{12}

Layout of the experiment

Materials used for the experiment

3.7 Collection of seeds

The seeds of different wheat varieties were collected from Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur**.** BARI Gom 29 was released by Bangladesh Agricultural Research Institute (BARI) and BARI Gom 30 was released in 2014, BARI Gom 32 and BARI Gom 33 were released in 2017.

3.8 Plant materials and features

BARI Gom 29: Developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Year of release 2014. Short duration, plant height 95-100 cm. Number of tiller/plant 4-5, 55-60 days require for spike initiation, crop duration 102-108 days, spike broad, grain/spike 45-50, grain white, bright and medium, 1000 grain weight 44-48 g, tiller straight in seedling, plant deep green, very few hair present in upper node of culm. Flag leaf straight, glum of lower portion of spikelet shoulder medium broad and indented, lip tall(>12.1 mm) and spine has present in lip. BARI Gom 29 is tolerant to leaf rust and leaf blight. Yield is 4.0-5.0 t/ha.

BARI Gom 30: Developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Year of release 2014. Short duration, plant height 95-100 cm. Number of tiller/plant 4-5, 55-60 days require for spike initiation, crop duration 102-108 days, spike broad, grain/spike 45-50, grain white, bright and medium, 1000 grain weight 44-48 g, tiller straight in seedling, plant deep green, very few hair present in upper node of culm. Flag leaf straight, glum of lower portion of spikelet shoulder medium broad and indented, lip tall(>12.1 mm) and spine has present in lip. BARI Gom 30 is tolerant to leaf rust and leaf spot disease (blight). Yield is 4.0-5.0 t/ha.

BARI Gom 32: Developed by Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Year of release 2017. The variety is high yielding, early in maturity and tolerant to terminal heat stress. The variety is resistant to leaf rust and tolerant to BpLB disease. The variety also shows tolerance to wheat blast. Grains are white amber in color and large in size (50-58g). Spikes are long with 42-47average grains per spike. Leaves are broad and recurved. Glaucosity is medium in spike, culm and flag leaf sheath. Few hairs present in upper culm node. Lower glume beak (LGB) length is medium in length (7.0 mm). LGB spicules-numerous, LGB shoulder medium in width and elevated. Resistant to leaf rust and Bipolaris leaf blight. The variety also shows tolerance to wheat blast disease. Yield is 4.6-5.0 t/ha.

BARI Gom 33: Developed by Wheat Research Centre (WRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. Year of release 2017. Stem and leaf are dark green color, tillers are semi erect during heading. Flag leaf is wide and droopy. Glaucosity is weak in spike. Zn-enrich variety. Yield is 4-5 t/ha.

3.9 Earthen pot

Earthen pots of having 12 inches diameter, 12 inches height with a hole at the centre of the bottom were used. Silt soil was used in the experiment. Twelve kilogram sun-dried soils were put in each pot. After that, pots were prepared for seed sowing.

3.10 Preparation of the main field

The selected experiment plot was opened in 15 November, 2019 with a power tiller and was exposed to the sun for a week. Then the land was harrowed, ploughed and cross-ploughed several times followed by laddering on 22 November, 2019. Finally a desired tilth was obtained by removing weeds and stubbles for transplanting of seedlings.

For pot experimentation, required amount of clods and weed free, properly tilted soil were used to fill each pot.

3.11 Application of manure and fertilizers

Recommended doses of fertilizers such as Urea, TSP, MoP, and Gypsum were used as sources for N, P, K, and S respectively, were applied to the each plot and each pot. On 22 November, 2019, the full doses of all fertilizers and one third of urea were applied as basal dose to the individual plot during final land preparation through broadcasting method and to individual pot during pot preparation. Urea was applied in two split dose at 30 and 50 days after transplanting (DAT).

The doses of fertilizers with their sources are given below:

Nutrient	**Source**	**Dose (kg ha−1)**
N (Nitrogen)	Urea (46% N)	163
P (phosphorus)	TSP (20% P_2O_5)	143
K (potassium)	MoP (50% K_2O)	105
S (Sulphur)	Gypsum (18% S)	118

Source: BWMRI Research Program 2019-20

Soil surface area was calculated to use fertilizers following the dose mentioned in above table. As such the pots were fertilized with cow dung 0.5kg/pot, urea 1.65 g/pot, TSP 1.35 g/pot, MP 0.375g/pot corresponding to 10 ton/ha cow-dung, 220 kg urea/ha, 180 kg TSP/ha and 50kg MP/ha. Total amount of TSP, MoP and one- third of the Urea were applied as basal dose. The other two third of the Urea were applied in two equal splits in each pot at 30 and 50 days after transplanting (DAT).

3.12 Seed sowing

Seeds were sown according to treatment dates. The seed rate was 120 kg ha^{-1}. After sowing, the seeds were covered with soil and slightly pressed by hands.

3.13 Cultural operations

The details of different cultural operations performed during the experimentation are given below:

3.14 Irrigation and drainage

The first irrigation was done at 21 DAS, crown root initiation stage. Second irrigation was provided at 55 DAS which was the panicle initiation stage of wheat and the last irrigation was done at 75 DAS, grain filling stage. Proper drainage system was also made for draining out excess water. For instant release of excess water and to top-dress urea, there was a hole at the bottom of each pot through which the irrigated water leached down due to gravitational force.

3.15 Thinning

Emergence of seedling was completed within 10 days after sowing. Overcrowded seedlings were thinned out. First thinning was done after 15 days of sowing which was done to remove unhealthy seedlings. The second thinning was done 10 days after first thinning keeping five healthy seedlings in each pot.

3.16 Weeding

Three weeding done on 10, 30, 45 days after transplanting to keep the crops free from weeds.

3.17 Harvest and post-harvest operation

The crop was harvested at the stage of maturity. At maturity, when leaves, stems and pods became yellowish in colors, then the plants were harvested. The harvested crop of each pot was bundled separately, tagged properly and it was converted to t ha^{-1}. The harvested plants were then carried to the threshing floor. The crops were sun dried by spreading on the threshing floor. The seeds were separated from the plants by pedal thresher and thereafter were cleaned, dried and weighed.

3.18 Data collection

Data were recorded on the following parameters from the sample plants during the course of experiment. Three plants were randomly selected from each unit plot for collection of data.

Collection of data

Crop growth characters

- Germination
- Plant height (cm)
- No. of leaves $plants^{-1}$
- Total tillers $plant^{-1}$
- Chlorophyll content (SPAD value)

Yield contributing characters

- Filled grains $plants^{-1}$ (no.)
- Unfilled grains $plants^{-1}$ (no.)

- Grains plants^{-1} (no.)
- Weight of 1000-grains (g)
- Days of flowering
- Days to maturity

Harvest yields

- Grain yield plant^{-1}
- Straw yield plant^{-1}
- Grain yield ha^{-1}
- Straw yield ha^{-1}

3.19 Germination

Days to germination of first sowing date plants was recorded 5 days after sowing. The second third germinations were recorded after 5 days of sowing as well. The germination percentage of BARI Gom-29 was 57.33%, BARI Gom-30 was 63%, BARI Gom-32 was 60.6%, BARI Gom-33 was 64% at 5 days after first sowing date. The germination percentage of BARI Gom-29 was 45%, BARI Gom-30 was 36.6%, BARI Gom-32 was 38.33%, BARI Gom-33 was 26.6% at 6 days after second sowing date. The germination percentage of BARI Gom-29 was 20%, BARI Gom-30 was 53.3%, BARI Gom-32 was 53%, BARI Gom-33 was 46.6% at 5 days after third sowing date.

3.20 Plant height

The height of plants was recorded at 15 days of interval after planting. The height was taken by a measuring tape from ground level to highest tip portion of the plant. Three plants were randomly selected to measure the height and the mean value was taken and expressed in centimeter.

3.21 No. of leaves plants^{-1}

Leaf numbers were counted from selected plants and from each pot at 15, 30, 45 and 60 DAT. At harvest, leaves of local varieties were completely dried out, so it was not possible to count leaf numbers at harvesting.

3.22 Total tillers plant^{-1}

The number of tillers plant^{-1} was noted at the time of 30, 45, and 60 DAS. Data were recorded by counting tillers from each plant and as the average of 3 plants selected at random from each pot.

3.23 Days of flowering

The day of flowering for the first sowing date was recorded 50 days after sowing. For the second sowing date, it was recorded 45 days after sowing. The day of flowering for the third sowing date was recorded 20 days after sowing.

3.24 Days to maturity

Days to maturity was considered when the 80% grains of the plants within a pot became golden yellow in color. The number of days to maturity was recorded from the date of sowing.

3.25 Flowering

The first flowering was recorded after 45 days after sowing. The second flowering was also recorded after 45 days after sowing. The second flowering was also recorded after 35 days after sowing.

3.26 Filled grains plant^{-1}

The total number of filled grains plants^{-1} was counted as the number of filled grains from 3 randomly selected spikes from each pot and average value was recorded.

3.27 Unfilled grains plant^{-1}

The total number of unfilled grains plants^{-1} was counted as the number of unfilled grains from 3 randomly selected spikes from each pot and average value was recorded.

3.28 Weight of 1000-grains (g)

One thousand seeds were counted randomly from the total cleaned harvested seeds of each individual pot and then weighed in grams and recorded.

3.29 Grain yield plant^{-1}

The samples were collected from each pot by cutting the plant at ground level. Then ears were counted and collected in a cloth bag. The samples were dried in sun, threshed and cleaned manually and fresh weight of grain was taken.

3.30 Straw yield plant^{-1}

The samples were collected from each pot by cutting the plant at ground level. Then grains were separated from the straw. The samples were dried in sun and cleaned manually and fresh weight of straw was taken.

3.31 Grain yield ha^{-1}

The crop was harvested each pot. Then the harvested wheat was threshed, cleaned and then sun dried up to a constant moisture level. The dried grains were then weighed and averaged. The grain yield was converted into t ha^{-1} basis.

3.32 Straw yield ha^{-1}

Straw obtained from each pot were sun-dried and weighed carefully. Then the dry weight of straws was converted into t ha^{-1}.

3.33 SPAD value

SPAD value was taken by a SPAD meter at 30 and 60 days after sowing. 3 leaves were selected randomly and 3 different data were taken from base, middle and top portion of the leaves and then the mean value was taken.

3.34 Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among the wheat variety and sowing dates and their interaction. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatment means was estimated by the Least Significant Difference (LSD) at 5% levels of probability.

CHAPTER IV

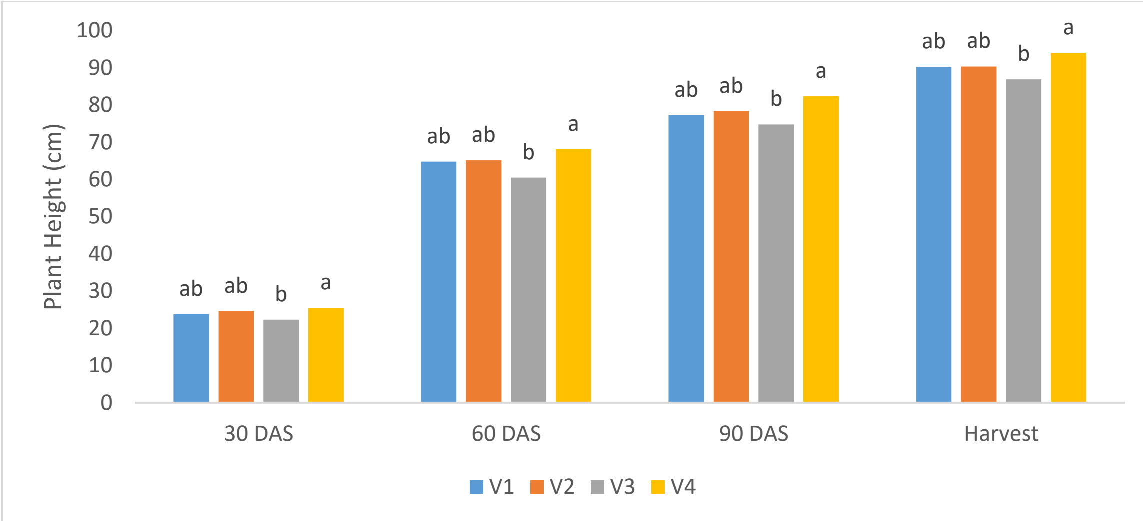
RESULTS AND DISCUSSION

The goal of the experiment was to see how wheat growth and yield performance were affected by variety and sowing dates. Data was collected on several yield contributing features as well as yield. Appendix IV-IX contains the results of the analyses of variance (ANOVA) on the data for various parameters. The findings were presented using tables and graphs, with possible interpretations are given under the headings:

4.1 Plant height

Different wheat varieties showed statistically significant difference on plant height at 30, 60, and 90 DAS and harvest. At 30, 60, 90 DAS and harvest, the longest plant (28.07, 72, 87.37 and 101.03 cm, respectively) was found from V_4S_1 (BARI Gom 33) which was statistically similar (27, 70.1, 85.4 and 99 cm, respectively) to V_2S_1 (BARI Gom 30) and followed (26.2, 68.4, 84.2 and 97.8 cm, respectively) by V_1S_1 (BARI Gom 29), while the shortest plant (19.1, 55.5, 67.5, and 78.9 cm respectively) was recorded from V_3S_3 (BARI Gom 32). Different genotypes produced different plant height on the basis of their varietal characters. Interaction effect of wheat varieties and sowing dates showed significant differences on plant height at 30, 60, 90 DAS and harvest (Table 1).

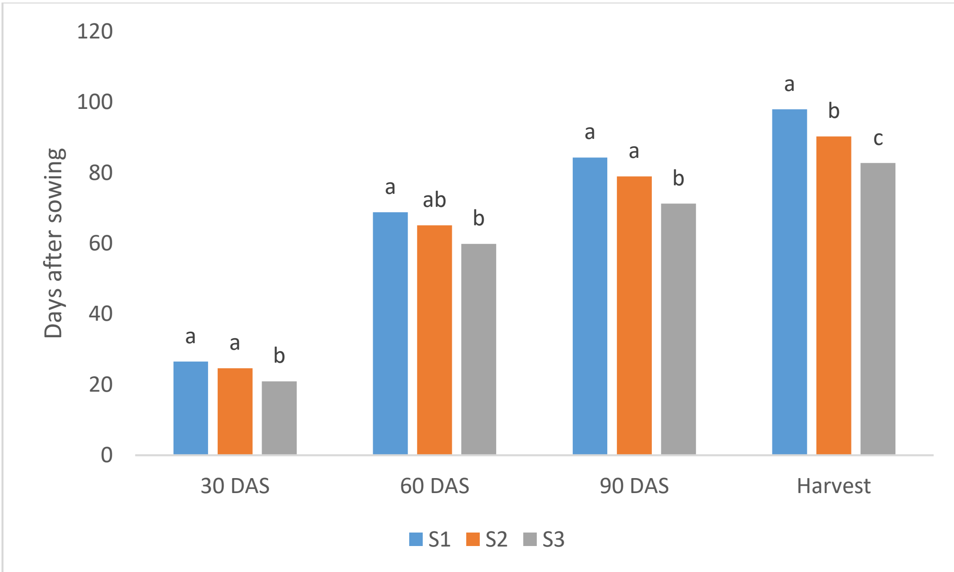
For variety, the highest plant height was found in V_4 (25.5, 68.11, 82.36, and 94.02 cm respectively) which was statistically significant with V_2 (24.62, 65.17, 78.37, and 90.37 respectively). Followed by V_1 (23.73, 64.79, 77.26 and 90.26 cm respectively). And the lowest plant height was V_3 (22.30, 60.46, 74.81, and 86.92 cm respectively).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 1. Effect of different varieties on plant height (cm) of wheat at different days after sowing (LSD (0.05) = 2.00, 6.27, 7.05, and 5.39 at 30, 60, 90 DAS and at harvest, respectively and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Due to different sowing dates, different wheat varieties showed statistically significant difference on plant height at 30, 60, and 90 DAS and harvest (Figure1). The tallest plant height was found in S_1 (26.52, 68.83, 84.35 and 98.02 cm respectively) at 30, 60, 90 and harvest. Which was statistically similar with S_2 (24.64, 65.17, 78.97 and 90.38 cm respectively) followed by S_3 (20.95, 59.90, 71.28 and 82.78 cm respectively).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 2. Effect of different sowing dates on plant height (cm) of wheat at different days after sowing (LSD (0.05) = 2.00, 6.27, 7.05, and 5.39 at 30, 60, 90 DAS and at harvest, respectively and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

According to Qasim *et al*. (2008) plant height differed between wheat cultivars. Sial *et al.* (2005) discovered that delaying planting had a substantial impact on plant organ growth and nutrient transport from source to sink. As a result, the overall height of the plant was lowered. According to Zia-Ul-Hassan *et al.* (2014) sowing dates have a significant impact on plant height in contemporary wheat types.

Bala *et al.* (2018) found that the combined effect of growing condition and wheat genotypes on plant height was significant. The heat sensitive variety Pavon-76 got the lowest height of the plants (93.53 cm and 95.00 cm for first and second year respectively). Under late and very late growing conditions, plant height was distinctly decreased for all the genotypes in different levels. Under late sowing and very late sowing, plant height varied due to the combined effect of genotype and growing condition. The reduction in plant height may have happened due to shortening of growth and photosynthetic period forced by heat stress in a late sown environment. Wheat varieties exposed a significant effect of varieties on plant height. Varied genetic condition of genotypes might be the cause of the differences in plant height because of various genotypes.

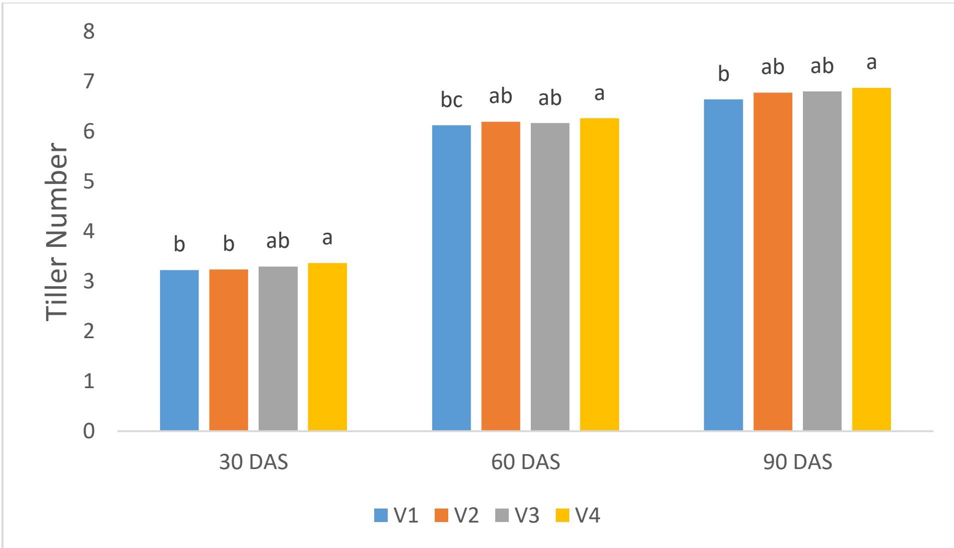
Table 1. Interaction effect of variety and sowing date on plant height of wheat

Treatments	**Plant height (cm) at different days after sowing (DAS)**			
	30 DAS	**60 DAS**	**90 DAS**	**Harvest**
V_1S_1	26.20ab	68.37ab	84.17a	97.83ab
V_1S_2	24.43abc	65.70abc	78.40abc	89.40abc
V_1S_3	20.57bc	60.30bc	69.20cd	83.53abc
V_2S_1	27.07ab	70.13ab	85.37a	99.03ab
V_2S_2	25.27abc	65.67abc	78.90abc	90.23abc
V_2S_3	21.53abc	59.70bc	70.83bc	81.83bc
V_3S_1	24.77abc	64.80abc	80.50abc	94.17abc
V_3S_2	23.00abc	60.93bc	76.40abc	87.73abc
V_3S_3	19.13c	55.63c	67.53d	78.87c
V_4S_1	28.07a	72.00a	87.37a	101.03a
V_4S_2	25.87abc	68.37ab	82.17ab	94.17abc
V_4S_3	22.57abc	63.97abc	77.53abc	86.87abc
LSD(0.05)	6.99	10.57	12.65	18.86
CV(%)	9.88%	5.51%	5.45%	7.09%

Here: V1 = BARI Gom 29, V2 = BARI Gom 30, V3 = BARI Gom 32 and V4 = BARI Gom 33;
S1 = Nov. 25 sowing, S2 =Dec. 25 sowing and S3 = Jan. 15 Sowing

4.2 Number of tillers plant^{-1}

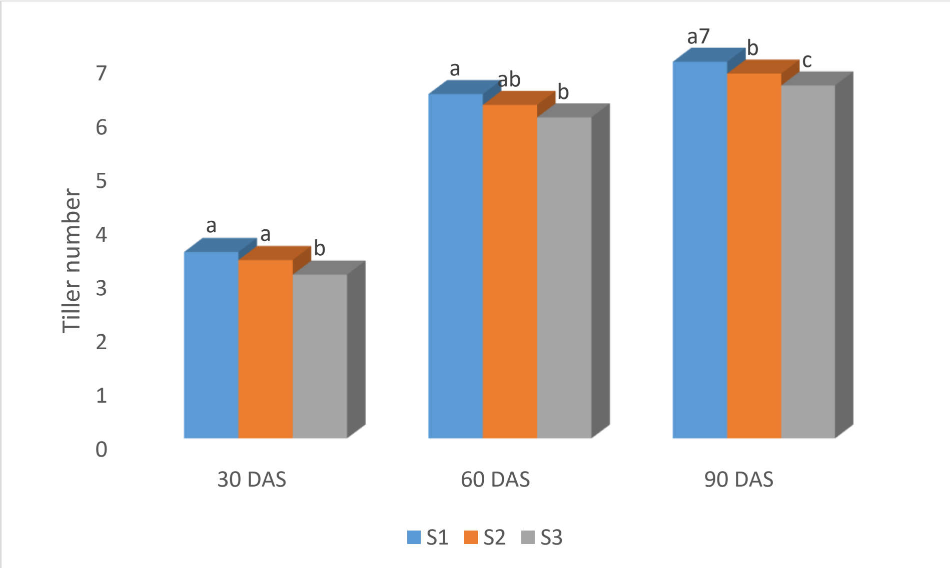
The highest tiller number plant^{-1} was found in V_4 (3.37, 6.27, and 6.88 respectively) which was statistically significant with V_3 (3.30, 6.17, and 6.81 respectively). Followed by V_1 (23.73, 64.79, and 77.26 cm respectively). And the lowest plant height was V_2 (3.24, 6.20, and 6.78 respectively) at 30, 60 and 90 DAS.



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 3. Effect of different varieties on tiller number of wheat at different days after sowing (LSD (0.05) = 0.15, 0.23, and 0.15 at 30, 60, and 90 DAS respectively and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Due to different sowing dates, different wheat varieties showed statistically significant difference on plant height at 30, 60, and 90 DAS and harvest. The tiller number plant^{-1} was found in S_1 (3.48, 6.40 and 7.01 respectively) at 30, 60, 90 and harvest. Which was statistically similar with S_2 (3.33, 6.20 and 6.78 respectively) followed by S_3 (3.06, 5.97, and 6.56 respectively).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 4. Effect of different sowing dates on tiller number of wheat at different days after sowing (LSD (0.05) = 0.15, 0.23, and 0.15 at 30, 60, and 90 DAS respectively and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Number of tillers plant^{-1} at 30, 60 and 90 DAS varied significantly due to different wheat varieties under the present trial. Data revealed that at 30, 60 and 90 DAS, the maximum number of tillers plant^{-1} (3.5, 6.4, and 7.1 respectively) was recorded from V_4S_1 (BARI Gom 33) which was statistically similar (3.3, 6.4, and 7 respectively) to V_2S_1 and followed (3.4, 6.4, and 6.9 respectively) by V_1S_1, whereas the minimum number of tillers plant^{-1} (3.1, 6, and 6.6, respectively) was observed from V_3S_3. Different sowing dates showed statistically significant differences in terms of number of tillers plant^{-1} at 30, 60, and 90 DAS. The maximum number of tillers plant^{-1} (3.5, 6.4, and 7.1 respectively) was recorded from S1 followed (3.3, 6.4, and 7 respectively) by S2, while the minimum (3.1, 6, and 6.6, respectively) was recorded from S3. Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on number of tillers plant^{-1} at 30, 60 and 90 DAS (Table 2).

According to Aslam *et al.* (2013), the 5th November sowing produced the most tillers (359 m^{-2}) followed by the 15^{th} November sowing. The 25th October sowing produced the least tillers (232 m^{-2}) due to high temperatures that were not favorable for wheat plant growth.

Table 2. Interaction effect of variety and sowing date on tiller number of wheat

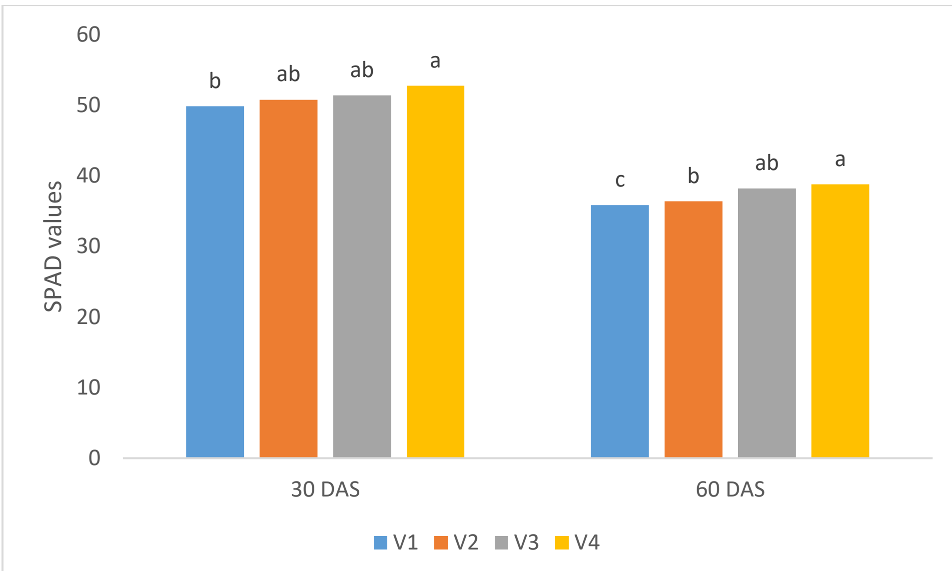
Treatments	**Tiller number at different days after sowing (DAS)**		
	30 DAS	**60 DAS**	**90 DAS**
V_1S_1	3.43ab	6.37a	6.85ab
V_1S_2	3.33ab	6.20ab	6.68ab
V_1S_3	2.93b	5.83c	6.42 b
V_2S_1	3.40ab	6.43a	7.02a
V_2S_2	3.30ab	6.20ab	6.78ab
V_2S_3	3.03ab	5.97bc	6.55ab
V_3S_1	3.53a	6.40a	7.08a
V_3S_2	3.23ab	6.10abc	6.75ab
V_3S_3	3.13ab	6.00bc	6.58ab
V_4S_1	3.53a	6.40a	7.08a
V_4S_2	3.43ab	6.30ab	6.88ab
V_4S_3	3.13ab	6.10abc	6.68ab
LSD(0.05)	0.58	0.35	0.58
CV(%)	6.04%	1.90%	2.92%

Here: V1 = BARI Gom 29, V2 = BARI Gom 30, V3 = BARI Gom 32 and V4 = BARI Gom 33;
S1 = Nov. 25 sowing, S2 =Dec. 25 sowing and S3 = Jan. 15 Sowing

4.3 SPAD value

Chlorophyll content of different wheat varieties at 30 and 60 DAS was significantly influenced by heat stress conditions (Table 3). The highest SAPD value was recorded at 30 and 60 DAS (55.45 and 44.46 respectively) in V_4S_1 followed (54.4 and 43.5 respectively) in V_2S_1 and then was V_1S_1 (48.7 and 42.1 respectively). The minimum SPAD value was found in V_3S_3 (47.82 and 28.63 respectively). Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on SPAD value at 30, and 60 DAS (Table 3).

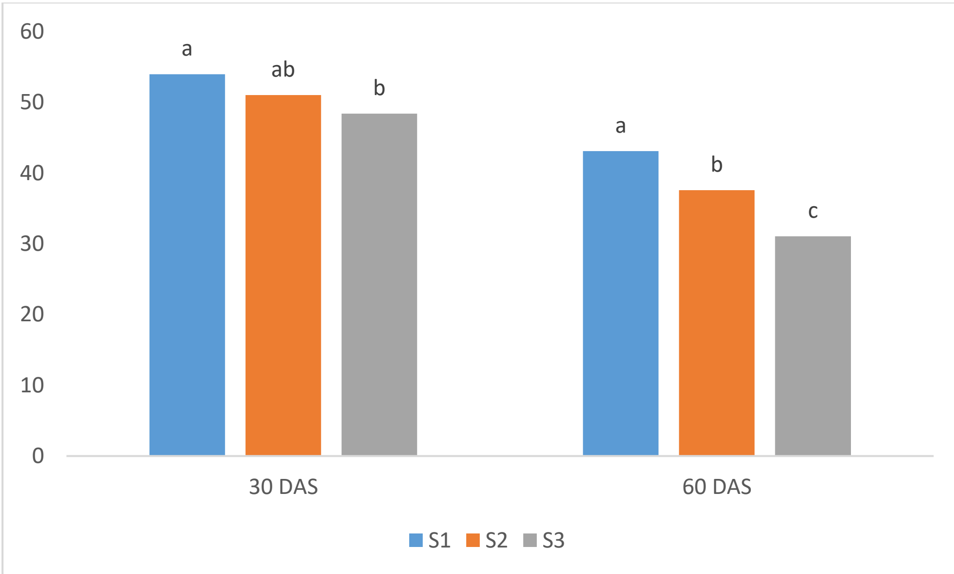
SPAD value was found highest at 30 and 60 DAS in V_4 (52.72, and 38.76 respectively) which was statistically significant with V_3 (51.37 and 38.19 respectively). Followed by V_2 (50.72, and 36.36). Lowest SPAD value was found in V_1 (49.81 and 35.84 respectively) at 30 and 60 DAS.



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 5. Effect of different varieties on SPAD values of wheat at different days after sowing (LSD (0.05) = 3.07, and 2.59 at 30, and 60 DAS respectively and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

SPAD value was found highest at 30 and 60 DAS in S_1 (54.00, and 43.15 respectively) which was statistically significant with S_2 (51.04 and 37.61 respectively). Lowest SPAD value was found in S_3 (48.45 and 31.10 respectively).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 6. Effect of different sowing dates on SPAD values of wheat at different days after sowing (LSD (0.05) = 3.07, and 2.59 at 30, and 60 DAS respectively and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

When plants are stressed during the vegetative and reproductive periods, their photosynthetic rates drop dramatically (Gupta *et al*., 2006). When compared to heat sensitive genotypes, Shukla *et al.* (1997) found that tolerant genotypes mobilize more stem reserves to promote grain filling during crucial stages of dry matter buildup in the grain.

Rehman *et al*. (2016) evaluated cell membrane stability (CMS) and chlorophyll content under high temperature stress at seedling and anthesis stages of 50 various wheat genotypes. A major difference ($P \leq 0.05$) was showed by analysis of variance for all of the characters at seedling and anthesis phases. CMS presented a significant positive correlation with 1000-grain weight (TGW) under high temperature stress. The ratio of chlorophyll *a*/*b* at seedling stage showed a significant negative correlation (r = –0.39, P < 0.05) with TGW. Under HT at anthesis stage, total chlorophyll content was significantly

($r = 0.42$, $P < 0.05$) correlated with TGW. Genotypes ETAD248 and ETAD7 showed the maximum CMS and TGW values, while chlorophyll *a*/*b* values were low, at both seedling and anthesis stages. Lower chlorophyll *a*/*b*, higher CMS and total chlorophyll content, were effective indicators for identifying genotypes with high TGW under HT stress.

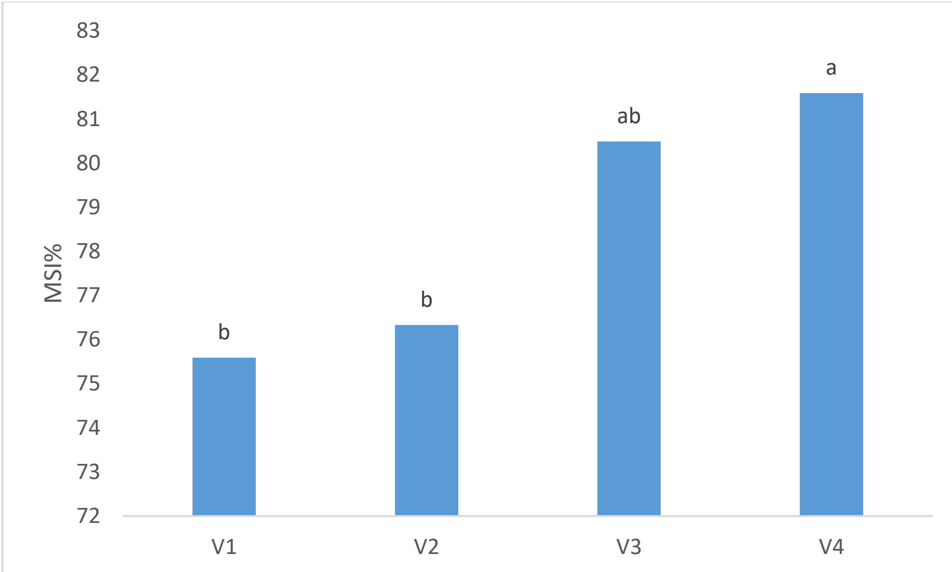
Table 3. Interaction effect of variety and sowing date on SPAD values of wheat

Treatments	SPAD values at different days after sowing (DAS)	
	30 DAS	60 DAS
V_1S_1	52.92ab	42.07ab
V_1S_2	48.68ab	36.83bc
V_1S_3	47.82ab	28.63d
V_2S_1	54.35ab	43.50ab
V_2S_2	51.25ab	36.07bcd
V_2S_3	46.68b	29.50d
V_3S_1	53.28ab	42.43ab
V_3S_2	51.62ab	38.77abc
V_3S_3	49.22ab	33.37cd
V_4S_1	55.45a	44.60a
V_4S_2	52.62ab	38.77abc
V_4S_3	50.08ab	32.90cd
LSD(0.05)	7.91	7.44
CV(%)	5.21%	6.72%

Here: V1 = BARI Gom 29, V2 = BARI Gom 30, V3 = BARI Gom 32 and V4 = BARI Gom 33;
S1 = Nov. 25 sowing, S2 =Dec. 25 sowing and S3 = Jan. 15 Sowing

4.4 Membrane Permeability Index (MSI %) and Relative Water Content (RWC %)

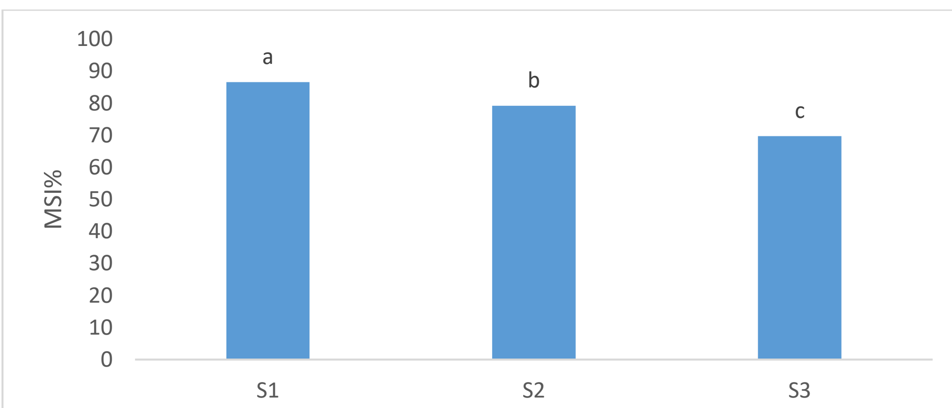
Heat stress has a great effect on membrane permeability leading to destabilization of membrane proteins. Membrane stability index (MSI %) of plants was the highest in V_4 (81.59%) which was significantly different from V_3 (80.49%) followed by V_2 (76.33%) and the lowest MSI% was found from V_1 (75.59%).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 7. Effect of different varieties on MSI% of wheat (LSD (0.05) = 4.40 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

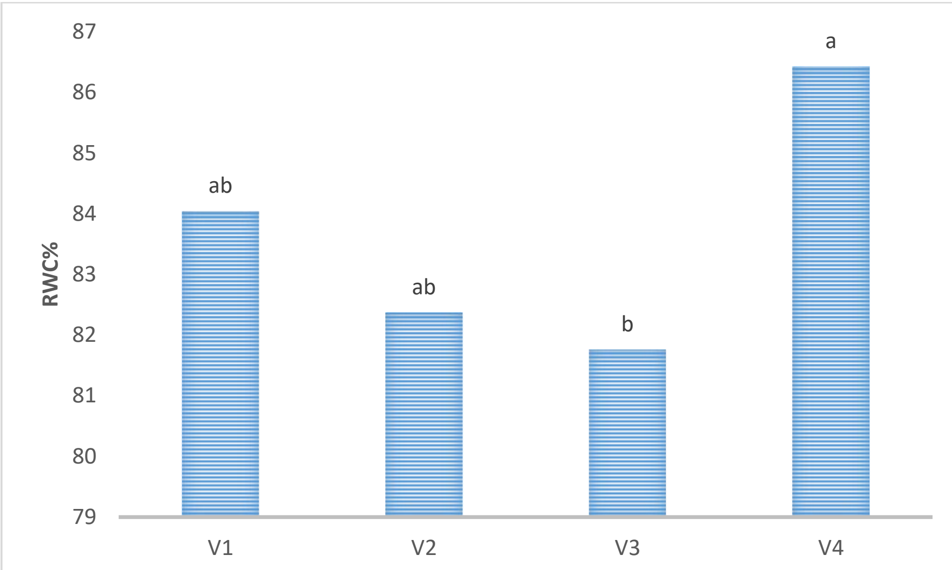
In terms of sowing dates membrane stability index (MSI %) was the highest in S_1 (86.55%) which was significantly different from S_2 (79.19%) and the lowest MSI% was found from S_3 (69.77%).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 8. Effect of different sowing dates on MSI% of wheat (LSD (0.05) = 4.40 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

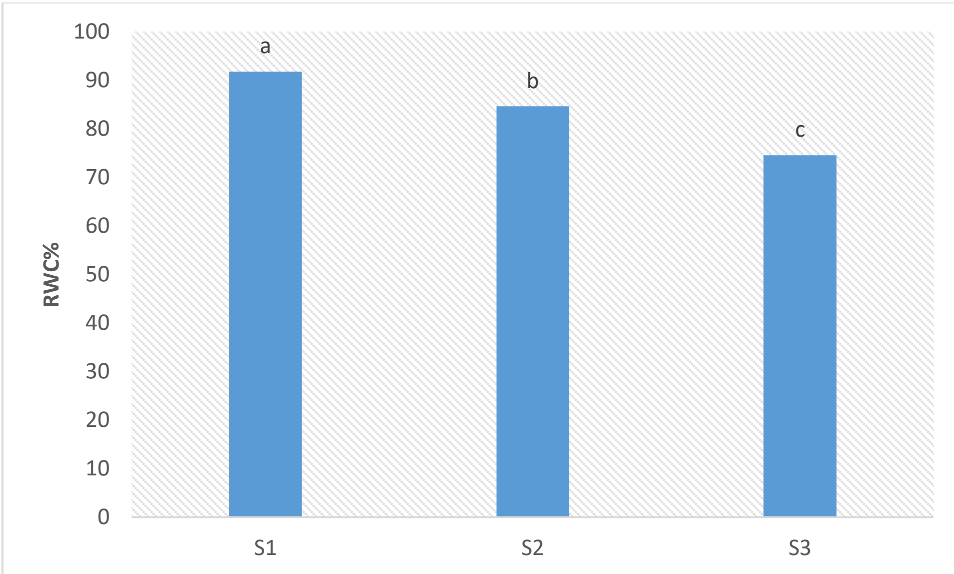
In terms of varieties, relative water content (RWC %) was the highest in V_4 (86.43%) which was significantly different from V_1 (84.04%) followed by V_2 (82.37%) and the lowest MSI% was found from V_3 (81.76%).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 9. Effect of different varieties on RWC% of wheat (LSD (0.05) = 4.00 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

In terms of sowing dates relative water content (RWC %) was the highest in S_1 (91.77%) which was significantly different from S_2 (84.64%) and the lowest RWC% was found from S_3 (74.54%).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 10. Effect of different sowing dates on RWC% of wheat (LSD (0.05) = 4.00 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Table 4. Interaction effect of variety and sowing date on MSI% and RWC% of wheat

Treatments	**MSI (%)**	**RWC (%)**
V_1S_1	84.78a	93.33a
V_1S_2	77.83ab	85.79abc
V_1S_3	64.17b	72.99c
V_2S_1	86.97a	91.76a
V_2S_2	75.89ab	83.79abc
V_2S_3	66.14b	71.56c
V_3S_1	86.23a	89.73a
V_3S_2	81.41a	81.49abc
V_3S_3	73.84ab	74.06bc
V_4S_1	88.21a	92.26a
V_4S_2	81.64a	87.46ab
V_4S_3	74.91ab	79.56abc
LSD(0.05)	14.42	14.44
CV(%)	6.24%	5.86%

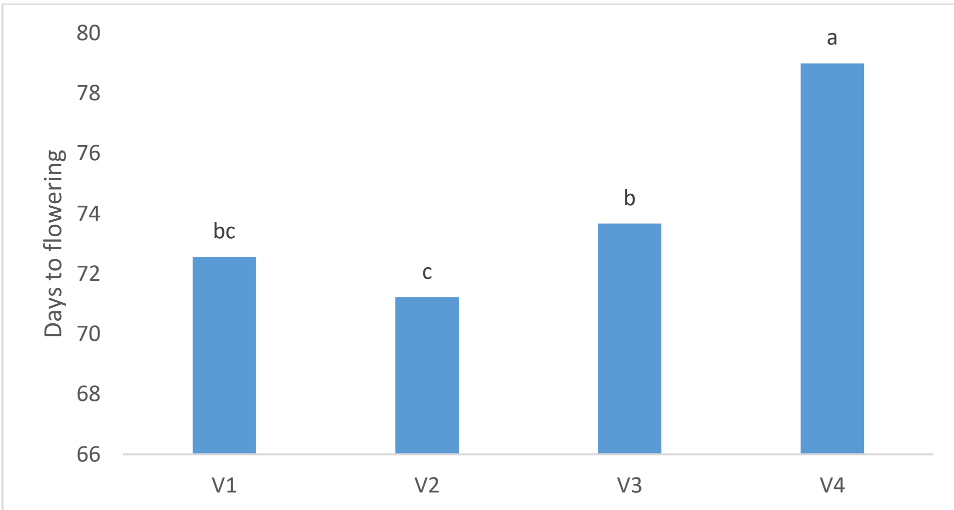
Here: V1 = BARI Gom 29, V2 = BARI Gom 30, V3 = BARI Gom 32 and V4 = BARI Gom 33;
S1 = Nov. 25 sowing, S2 =Dec. 25 sowing and S3 = Jan. 15 Sowing

Under salinity stress, various growth indices such as number of tillers plant-1, leaf area, chlorophyll content (SPAD value), membrane stability index (MSI percent), and leaf relative water content (RWC percent) were significantly reduced, with the exception of days to blooming. This could be because salt reduced root nutrient intake while simultaneously limiting mineral transport from the roots to the shoots due to reduced transpiration rates and impaired membrane permeability (Alam, 1999). Under salt stress, the presence of high ratios of Na+/K+ and Na+/Ca2+ ions creates a toxic and unbalanced ionic environment that inhibits plant growth and eventually leads to plant cell death (Grattan and Grieve, 1999b) (Bhardwaj and Yadav, 2012). Because of its importance in metabolic processes, sulfur may have played an essential part in rice plant growth and development. Sulfur-containing metabolites, amino acids (cysteine and methionine), vitamins (biotin and thiamine), the thioredoxin system, glutathione lipoic acid, and glucosinolates all have the ability to enhance or change physiological and molecular processes in plants when they are exposed to salt. As a result, altering the production of sulfur metabolites could change physiological and molecular mechanisms to give tolerance to salinity (Khan *et al*., 2014).

Sulfur has a critical function in the production of proteins and a variety of metabolites that are required for the growth of plants' fresh and dry weights (Ali *et al*., 1990; Zhao *et al*., 1993). The use of sulfur boosted the fresh and dry weights of shoots and roots, according to Gilbert and Robson (1984).

4.5 Days to flowering

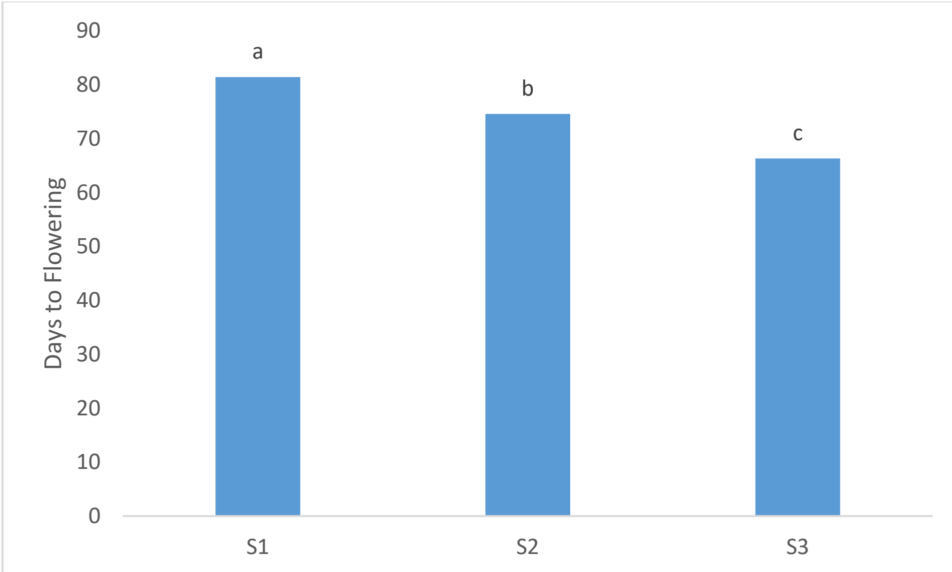
Days to flowering showed statistically significant difference in terms of different wheat varieties (Table 5). The highest days to flowering (79) was recorded from V_4 which was statistically similar to V_3 (73.67) and followed by V_1 (72.56), while the lowest days to flowering was found from V_2 (71.22).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 11. Effect of different varieties on days to flowering of wheat (LSD (0.05) = 5.04 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

In terms of sowing dates, the highest days to flowering (81.42) was recorded from S_1 which was statistically similar to S_2 (74.58) and followed by S_3 (66.33).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 12. Effect of different sowing dates on days to flowering of wheat (LSD (0.05) = 3.73 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

The highest days to flowering (85.33) was recorded from V_4S_1 which was statistically similar to V_1S_1 (81.11) and followed by V_3S_1 (80), while the lowest days to flowering was found from V_1S_3 (62.33).

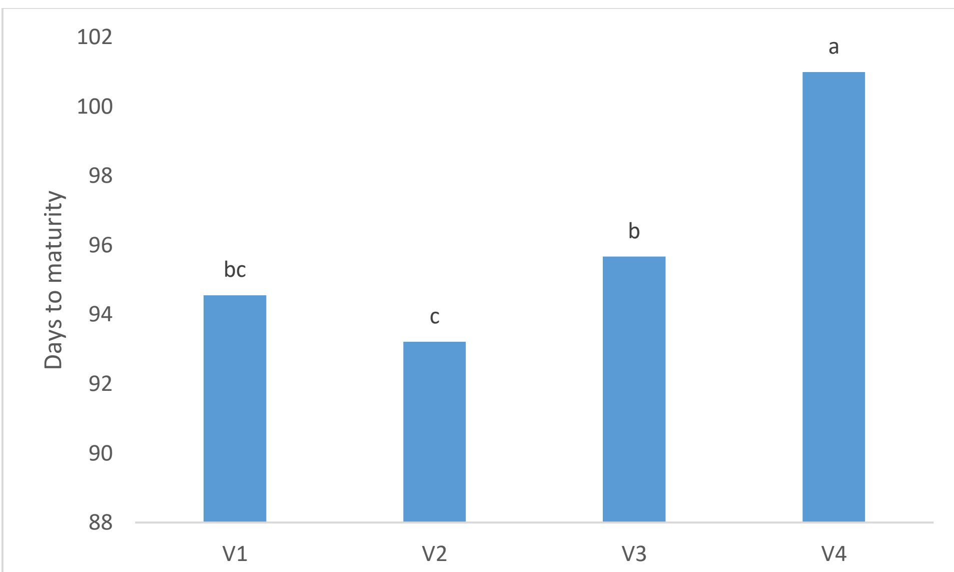
Oliveria *et al.* (2012) found the main effects of genotype and combinations of CO_2 + temperature were highly significant for time to flowering and physiological maturity. Time to flowering was 20–21 days earlier in 38–19 than in Janz under high temperature. Time to flowering was significantly reduced by 11 days when crops were grown under ECO2 + HT6. Physiological maturity of both genotypes was also significantly reduced by 8–12 days under ECO2 + HT6 than under any other combination of CO_2 and temperature. Terminal drought did not affect the time to physiological maturity of either genotype under any climate combination ($P > 0.05$). The vigorous line 38–19 flowered

20–21 days earlier and reached physiological maturity 20–23 days earlier than Janz under all climate and watering combinations

4.6 Days to maturity

The highest days to maturity (107.3) was recorded from V_4S_1 which was statistically similar to V_1S_1 (103.3), while the lowest days to maturity was found from V_1S_3 (84.3). Different wheat varieties and sowing dates revealed statistically significant differences in days to maturity (Table 5).

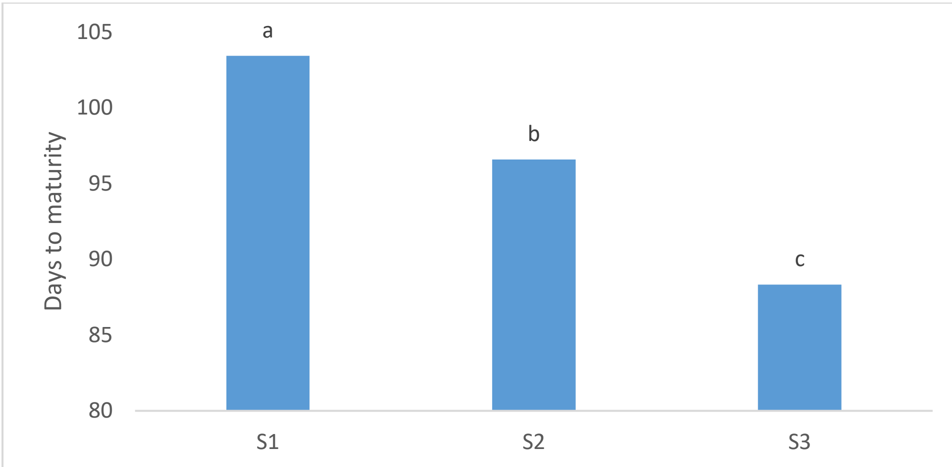
The highest days to maturity was found from V_4 (101) which was statistically similar to V_3 (95.67) followed by V_1 (94.56) whereas the lowest days to maturity was recorded from V_2 (93.22).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 13. Effect of different varieties on days to maturity of wheat (LSD (0.05) = 3.73 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

The highest days to maturity was found from S_1 (103.42) which was statistically similar to S_2 (96.58), whereas the lowest days to maturity was recorded from S_3 (88.33).



S_1: November 25, S_2: December 25, and S_3: January 15

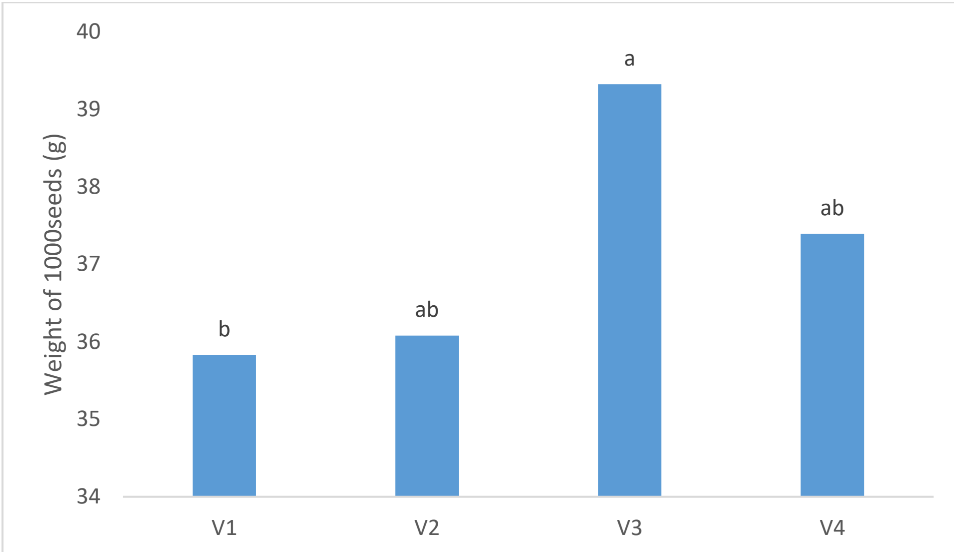
Figure 14. Effect of different sowing dates on days to maturity of wheat (LSD (0.05) = 3.73 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Dwivedi *et al.* (2017) observed that days to physiological maturity decreased from early sowing to optimum and late sowing. To reach physiological maturity, variety 'Shatabdi' took more time, followed by 'BARI Gom 27' and 'BARI Gom 28' took minimum time. 'Shatabdi' required more time to reach physiological maturity in all sowing dates, followed by 'BARI Gom 27' and least time was taken by 'BARI Gom 28' to reach physiological maturity.

4.7 Weight of 1000-grains (g)

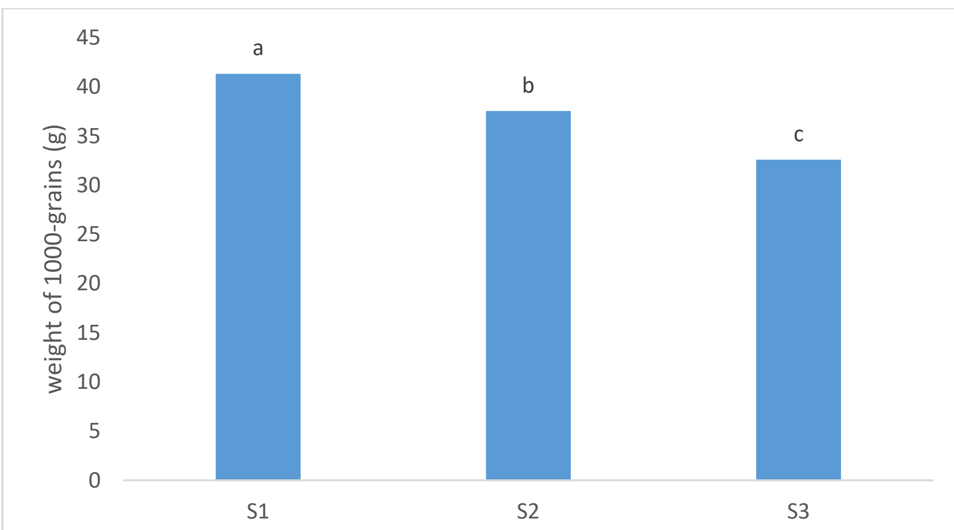
Different wheat varieties showed statistically significant difference on weight of 1000-seeds (Table 5). The highest weight of 1000-seeds (39.32 g) was recorded from V_3 which was statistically similar (37.39 g) to V_4, followed by V_2 (36.08 g) whereas the lowest weight of 1000-seeds (35.83 g) was found from V_1. The highest weight of 1000-seeds

(41.33 g) was recorded from S_1 which was statistically similar (37.54 g) to S_2, and the lowest weight of 1000-seeds (32.6 g) was found from S_3.



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 15. Effect of different varieties on weight of 1000-grains (g) of wheat (LSD (0.05) = 2.50 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 16. Effect of different sowing dates on weight of 1000-grains (g) of wheat (LSD (0.05) = 2.50 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

The highest weight of 1000-seeds (43.5 g) was recorded from V_3S_1 which was statistically similar (41.1 g) to V_2S_1, followed by V_4S_1 (40.5 g) whereas the lowest weight of 1000-seeds (31 g) was found from V_1S_3.

According to Abdullah *et al.* (2007), 1000-grain weight decreased with delayed sowing, with the highest value in the initial planting date, 25th October, and the lowest value in the last planting date, 10th January.

Hossain *et al.* (2018) observed that under late sown heat stress condition, individual grain weight decreases and so TGW weight decreases because of it. . In OS, higher TGW as a result of higher individual grain weight because of favorable environmental conditions. Wheat sown ITS condition (20th November) produced the highest TGW and the least TGW was noted from irrigated late sown (ILS) condition (30th December).Maximum TGW was recorded in ‘Gen- 48’, followed by ‘Gen.-40, 33 and 16, and the lowest TGW was in ‘Gen.-19’ in case of genotypes.

Table 5. Interaction effect of variety and sowing date on days to flowering, days to maturity, and 1000 seed weight of wheat

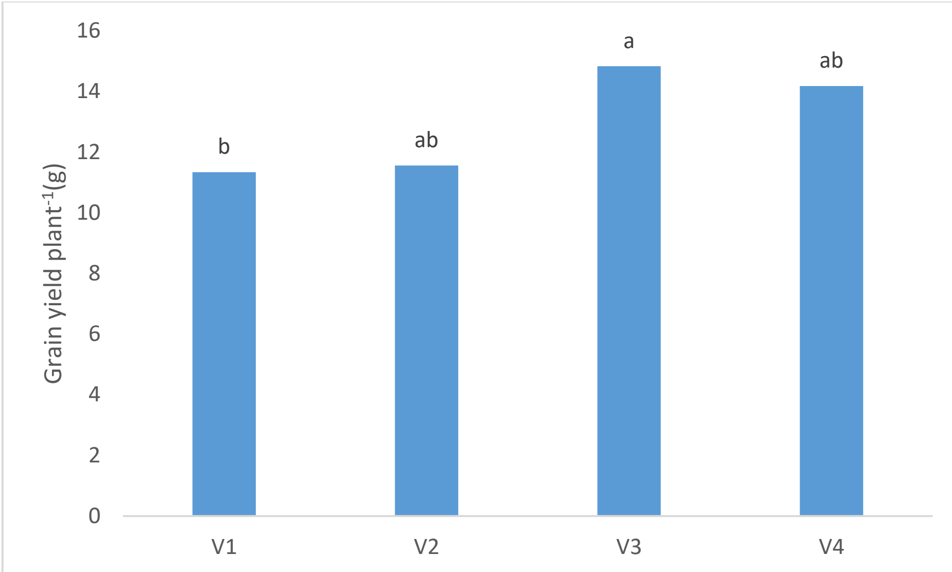
Treatments	Days to flowering	Days to maturity	1000 seed weight
V_1S_1	81.33ab	103.33ab	40.17ab
V_1S_2	74.00abcd	96.00bc	36.37abcd
V_1S_3	62.33d	84.33d	30.97cd
V_2S_1	79.00abcd	101.00ab	41.07ab
V_2S_2	71.67abcd	93.67bcd	37.37abcd
V_2S_3	63.00cd	85.00d	29.80d
V_3S_1	80.00abc	102.00ab	43.53a
V_3S_2	73.67abcd	95.67bc	39.17abc
V_3S_3	67.33bcd	89.33cd	35.27abcd
V_4S_1	85.33a	107.33cd	40.53a
V_4S_2	79.00abcd	101.00a	37.27abc
V_4S_3	72.67abcd	94.67ab	34.37bc
LSD(0.05)	17.58	10.48	8.57
CV(%)	8.06%	3.71%	7.84%

Here: V1 = BARI Gom 29, V2 = BARI Gom 30, V3 = BARI Gom 32 and V4 = BARI Gom 33;
S1 = Nov. 25 sowing, S2 =Dec. 25 sowing and S3 = Jan. 15 Sowing

4.8 Grain yield plant^{-1}

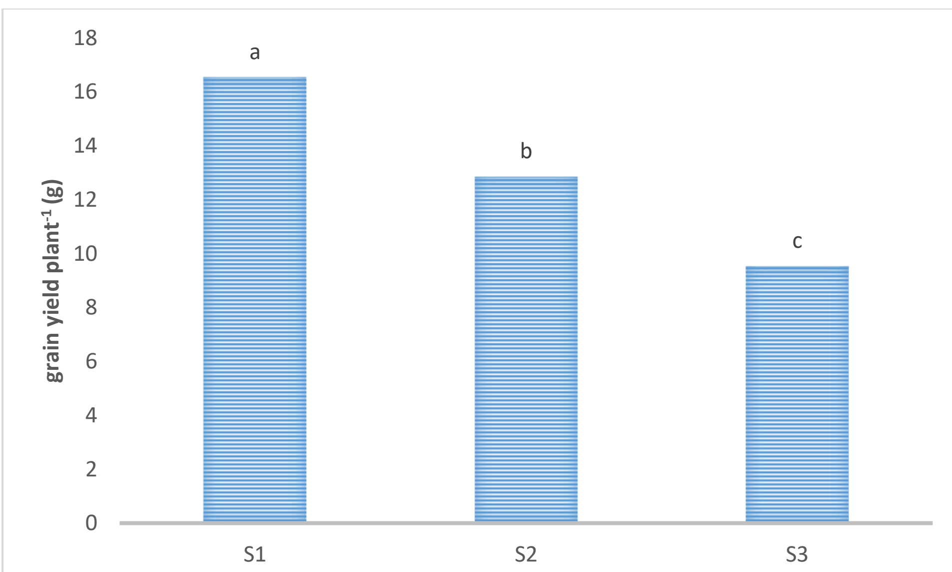
Statistically significant variation was observed for different wheat varieties in terms of grain yield (Table 6). The highest grain yield was found from V_3 (14.83 g) which was statistically similar to V_4 (14.18 g) and followed by V_2 (11.56 g), whereas the lowest grain yield was found from V_1 (11.34 g).

The highest grain yield was found from S_1 (16.54 g) which was statistically similar to S_2 (12.85 g) and the lowest grain yield was found from S_3 (9.5 g).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 17. Effect of different varieties on grain yield plant^{-1} of wheat (LSD (0.05) = 1.84 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 18. Effect of different sowing dates on grain yield plant^{-1} of wheat (LSD (0.05) = 1.84 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

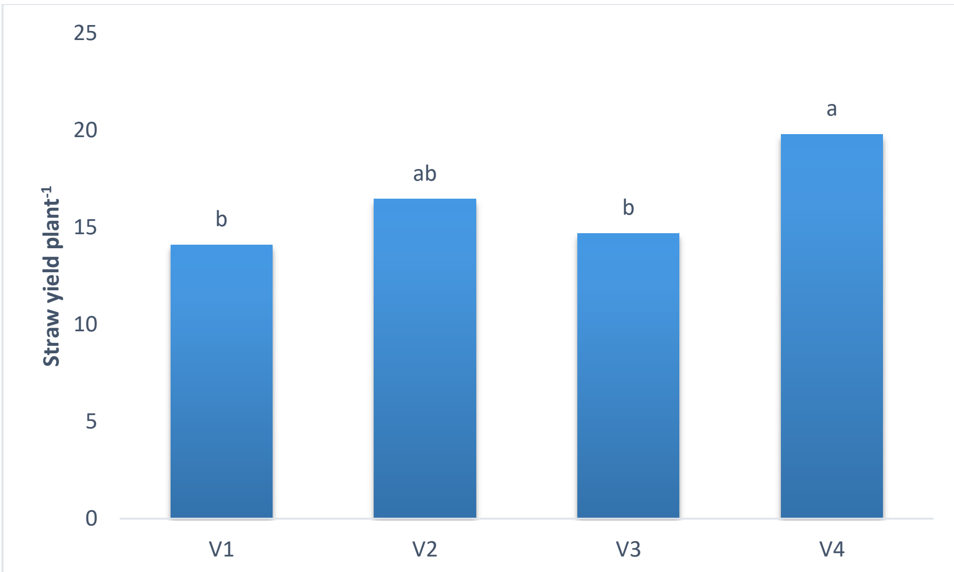
The highest grain yield was found from V_3S_1 (18.9 g) which was statistically similar to V_4S_1 (17.2 g) and followed by V_1S_1 (15.2 g), whereas the lowest grain yield was found from V_1S_3 (7.5 g). Early sowing increased wheat yields, but seeds planted after the optimum period resulted in lower yields, according to numerous publications (Bassu *et al.*, 2009 and Bannayan *et al.*, 2013).

Chowdhury (2002) conducted an experiment with four sowing dates and found that grain spike$_{-1}$ declined as the sowing date was advanced from November 15 to December 15, with the lowest grains spike^{-1} recorded in the December 15 sowed plants. Sowing dates on grains spike^{-1} remained significant, according to Zia-Ul-Hassan *et al.* (2014), with early sowing producing the best results.

Hossain *et al.* (2018) showed that grain yield (GY) of wheat genotypes were influenced significantly by location specific sowing dates and genotypes. Wheat sown on 20th November resulted in significantly highest GY over 30th December. The poor GY of wheat sown on 30th December may be attributed to reduction in number of productive tillers/spikes and grains spike^{-1} and also test weight in December 30th sowing. Among the genotypes, ‘Gen.-30’ gave the GY, followed by ‘Gen.-13’, ‘Gen.-9’ & ‘Gen.-40’, respectively. The higher yields of these selected wheat varieties was for the higher number of productive tillers/spikes and grains spike^{-1}. All genotypes gave the best production in the environmental condition of Dinajpur, followed by Jessore in both the sowing conditions.

4.9 Straw yield plant^{-1}

The highest straw yield (19.80 g) was found from V_4 which was statistically similar (16.47 g) to V_2 and followed (14.69 g) by V_3, again the lowest straw yield (14.1 g) was recorded from V_1.

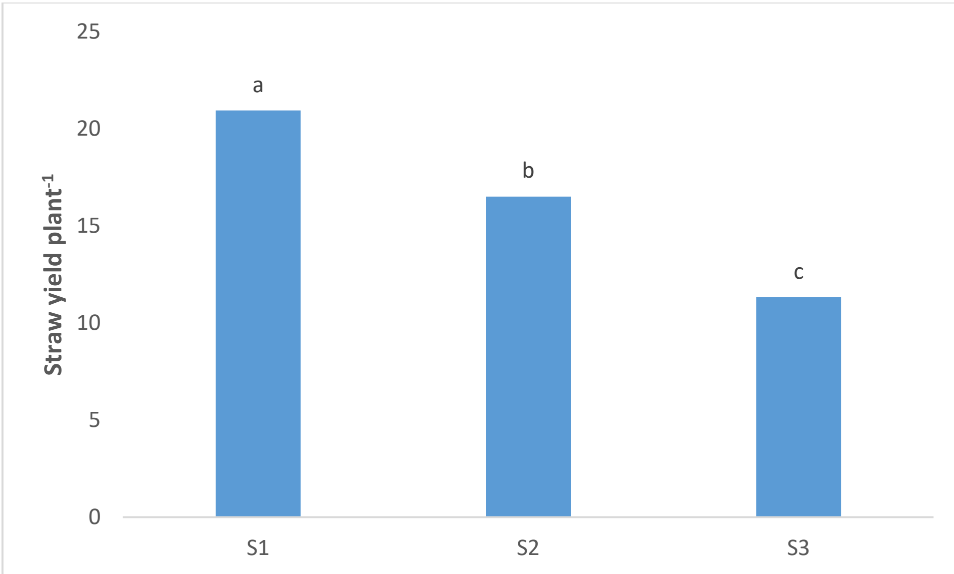


V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 19. Effect of different varieties on straw yield plant^{-1} of wheat (LSD (0.05) = 4.26 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

The highest straw yield (20.95 g) was found from S_1 which was statistically similar (16.52 g) to S_2 and the lowest straw yield (11.33 g) was recorded from S_3.

The highest straw yield (24.3 g) was found from V_4S_1 which was statistically similar (21.6 g) to V_2S_1 and followed (19.6 g) by V_1S_1, again the lowest straw yield (8.1 g) was recorded from V_1S_3. Straw yield showed statistically significant differences due to different sowing dates (Table 6).



S_1: November 25, S_2: December 25, and S_3: January 15

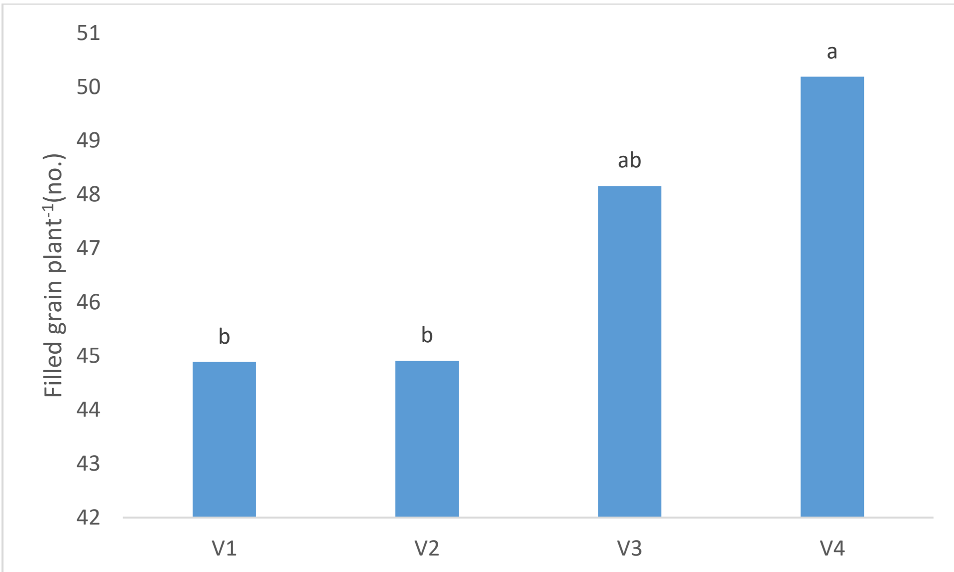
Figure 20. Effect of different sowing dates on straw yield plant^{-1} of wheat (LSD (0.05) = 2.29 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Singh *et al.* (2017) found high temperature caused a decrease in grain and straw yield in all varieties. More reduction in grain yield found in HD 2967 (25%), followed by HD 2985 (21%) and WR 544 (6%) and ambient grown varieties. Harvest index was decreased more in HD 2967 and least in WR 544. Maximum test weight reduction took place in HD 2967 (8%), followed by HD 2985 (6%) and WR544 (2%). These outcomes showed that WR 544 had more stable HI. Test weight representing its stable source-sink balance even in elevated HT stress condition.

4.10 Filled grains plants^{-1} (no.)

The highest filled grains spike^{-1} was observed from V_4S_1 (58.3) which was statistically similar to V_3S_1 (56.4) and followed by V_2S_1 (53.7), again the lowest filled grains spike^{-1} was recorded from V_1S_3 (35.5). Filled grains spike^{-1} varied significantly due to different wheat varieties under the present trial (Table 6).

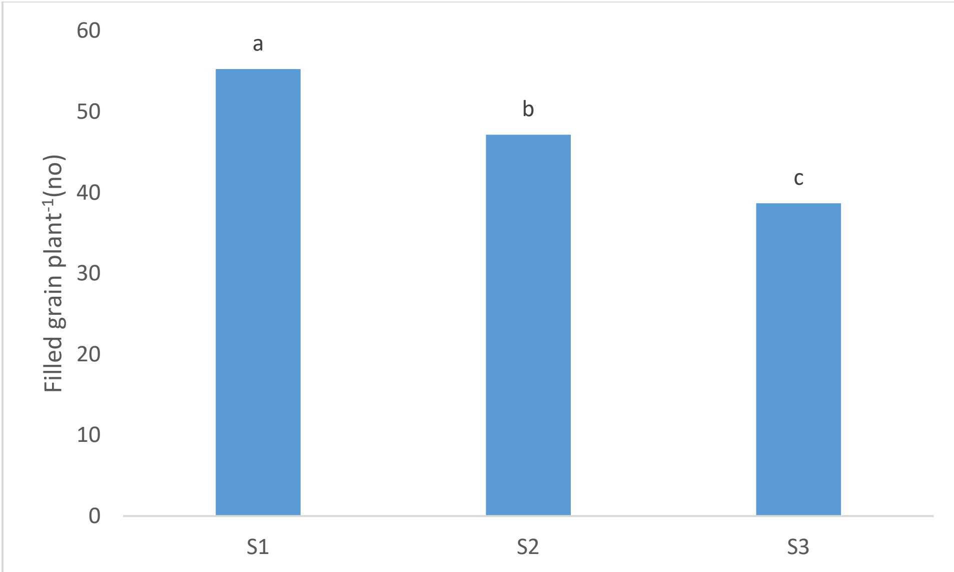
The highest filled grains spike^{-1} was observed from V_4 (50.19) which was statistically similar to V_3 (48.16) and followed by V_2 (44.91), again the lowest filled grains spike^{-1} was recorded from V_1 (44.89).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 21. Effect of different varieties on filled grains plants^{-1} (no.) of wheat (LSD (0.05) = 3.17 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

The highest filled grains spike^{-1} was observed from S_1 (55.27) which was statistically similar to S_2 (47.16) and the lowest filled grains spike^{-1} was recorded from S_3 (38.68).



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 22. Effect of different sowing dates on filled grains plants^{-1} (no.) of wheat (LSD (0.05) = 3.17 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

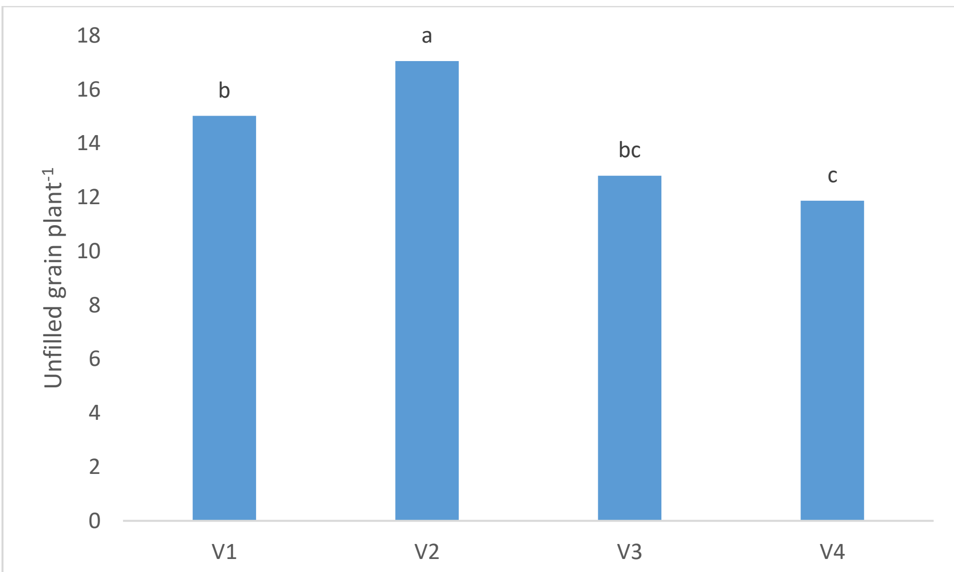
Suleiman *et al.* (2014) found that sowing dates have a substantial impact on yield components, with the highest values achieved when cultivars were sown on November 1st and 15th. Jahan and Adam (2015) found in their study non-significantly highest number of grains per plant in S2. Increase in number of grains per plant due to S2 was 35.78 % higher over S3. The higher number of grains per plant following S2 was possibly due to increased number of productive tillers per plant. The maximum 1000-seed weight was noted from S1 followed by S2. In S3, BARI Gom-25 produced minimum 1000-seed weight. There was a gradual reduction in 1000-seed weight with delayed sowing.

4.11 Unfilled grains plants^{-1}

Different wheat varieties showed statistically significant difference on unfilled grains spike^{-1} (Table 6). The highest unfilled grains spike-1 was found from V_2 (17.06) which was statistically similar to V_1 (15.02), followed by V_3 (12.8) whereas the lowest unfilled grains spike^{-1} was recorded from V_4 (11.88).

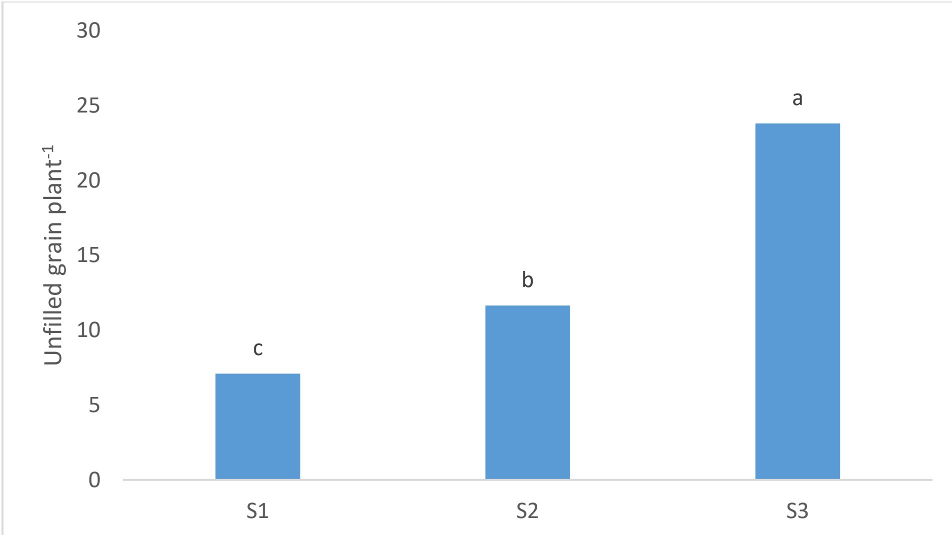
The highest unfilled grains spike-1 was found from S_3 (23.81) which was statistically similar to S_2 (11.65), and the lowest unfilled grains spike^{-1} was recorded from S_1 (7.1).

The highest unfilled grains spike-1 was found from V_2S_3 (29.5) which was statistically similar to V_1S_3 (25), followed by V_3S_3 (21.4) whereas the lowest unfilled grains spike^{-1} was recorded from V_3S_1 (6).



V_1: BARI Gom 29, V_2: BARI Gom 30, V_3: BARI Gom 32, and V_4: BARI Gom 33

Figure 23. Effect of different varieties on unfilled grains plants^{-1} of wheat (LSD (0.05) = 2.31 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)



S_1: November 25, S_2: December 25, and S_3: January 15

Figure 24. Effect of different sowing dates on unfilled grains plants^{-1} of wheat (LSD (0.05) = 2.31 and bars with different letters are significantly different at $p \leq 0.05$ applying LSD)

Table 6. Interaction effect of variety and sowing date on grain yield plant^{-1}(g), straw yield plant^{-1}(g), filled grain spike^{-1}, and unfilled grain spike^{-1} of wheat

Treatments	**Grain yield plant^{-1}(g)**	**Straw yield plant^{-1}(g)**	**Filled grain spike^{-1}**	**Unfilled grain spike^{-1}**
V_1S_1	15.17ab	19.58bcd	52.77abc	7.70fg
V_1S_2	11.33bc	14.67ef	46.40bcde	12.35de
V_1S_3	7.53c	8.06g	35.50f	25.00b
V_2S_1	14.97ab	21.56ab	53.67abc	8.33efg
V_2S_2	11.20bc	16.89cde	44.63cdef	13.33d
V_2S_3	8.50c	10.96fg	36.43ef	29.50a
V_3S_1	18.87a	18.35bcde	56.37ab	5.97g
V_3S_2	14.87ab	14.53ef	47.70bcd	11.07def
V_3S_3	10.77bc	11.21fg	40.40def	21.37bc
V_4S_1	17.17a	24.32a	58.27a	6.40g
V_4S_2	14.00ab	20.01abc	49.90abcd	9.87def
V_4S_3	11.37bc	15.08def	42.40def	19.37c
LSD(0.05)	5.05	4.52	10.12	4.11
CV(%)	13.24%	9.45%	7.32%	9.85%

Here: V1 = BARI Gom 29, V2 = BARI Gom 30, V3 = BARI Gom 32 and V4 = BARI Gom 33;
S1 = Nov. 25 sowing, S2 =Dec. 25 sowing and S3 = Jan. 15 Sowing

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period from November 2019 to March 2020 to find out the effect of high temperature stress on growth and yield of wheat. The experiment was laid out in a CRD design with three replications. The diameter of the individual pot (top) was 30 cm and total numbers of plots were 36. There were 12 treatment combinations. The experiment was carried out with four wheat varieties *i.e.* V1: BARI Gom 29, V2: BARI Gom 30, V3: BARI Gom 32, V4: BARI Gom 33 and three different sowing dates viz. S1: Sowing at 25 November, S2: Sowing at 25 December, 2019 and S3: Sowing at 15 January, 2020 in CRD design. Seeds were collected from Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur**.** The selected experiment plot was opened in 15 November, 2019 with a power tiller and was exposed to the sun for a week. Then the land was harrowed, ploughed and cross-ploughed several times followed by laddering on 22 November, 2019. Finally a desired tilth was obtained by removing weeds and stubbles for transplanting of seedlings. For pot experimentation, required amount of clods and weed free, properly tilted soil were used to fill each pot. Sowing was done as per sowing date treatments. The data on growth parameters viz. plant height (cm) were recorded during the period from 30, 60, 90 DAS and at harvest. At harvest, characters like plant height (cm), number of filled grain spike^{-1}, number of unfilled grain spike^{-1}, grain yield plant^{-1}, number of tillers plant^{-1}, 1000 grain weight, grain yield, and straw yield were recorded.

The highest grain yield was recorded from the wheat variety BARI Gom 32 (V_3S_1) (18.9 g/ plant). BARI Gom 29 (V_1S_3) produced the lowest grain yield (7.5 g/plant). BARI Gom 33 produced the highest tiller number at 30, 60 and 90 DAS (3.5, 6.4 and 7.1 respectively). highest number of grains spike^{-1} (58.3) was from BARI Gom 33 (V_4S_1), the highest 1000-grain weight (43.5 g) in BARI Gom 32 (V_3S_1). Thus it recorded the highest grain yield was in V_3 BARI Gom 32 (2.67 t ha^{-1}) and the lowest grain yield (1.1 t ha^{-1}) in V_1 (BARI Gom 29). The highest straw yield (3.4 t ha^{-1}) was recorded from V_4 (BARI Gom 33), and the lowest straw yield (1.14 t ha^{-1}) was recorded from V_1 (BARI Gom 29).

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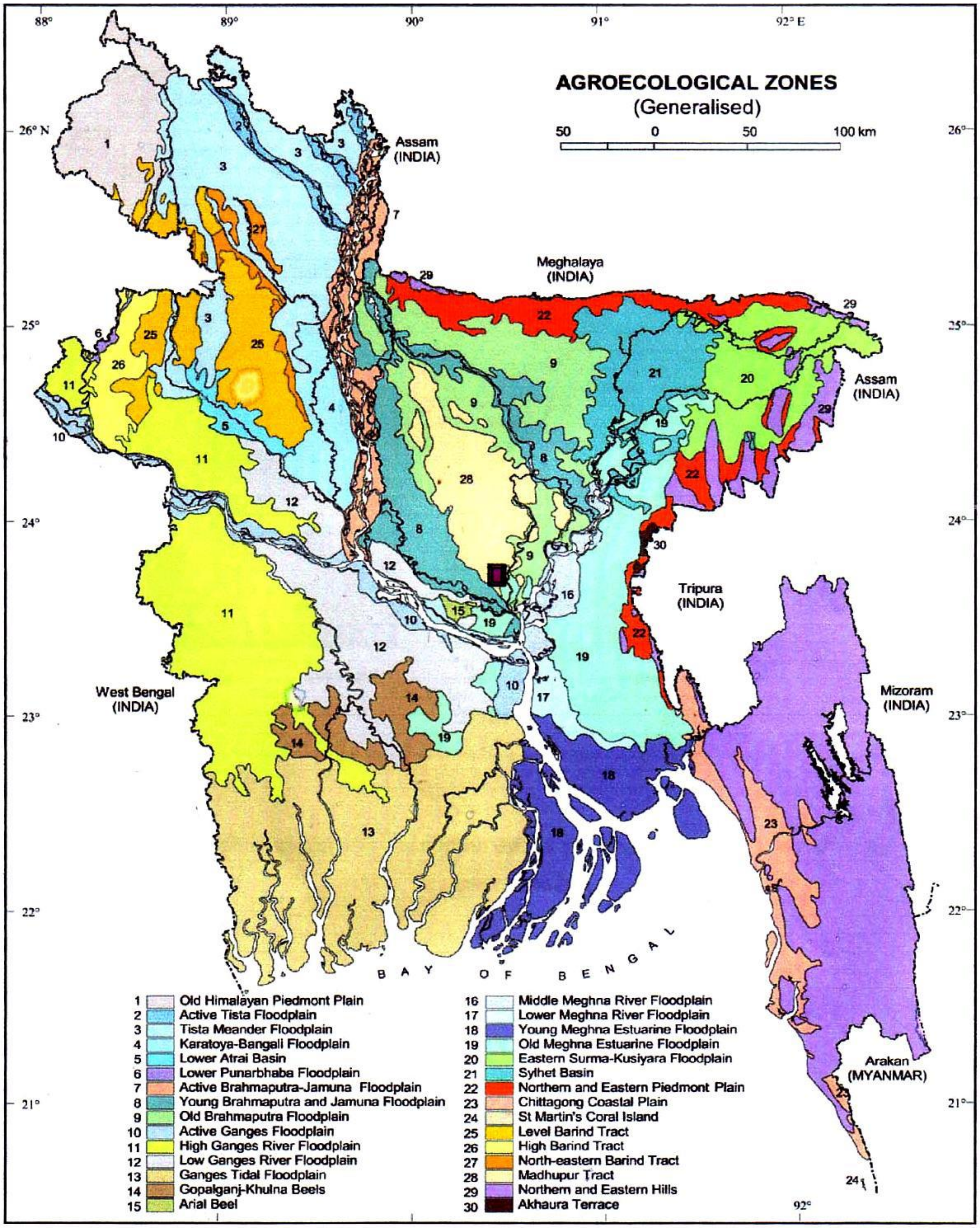
APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. A. Morphological Characteristics of the Experimental Field

Morphology	**Characteristics**
Location	SAU Farm, Dhaka
Agroecological zone	Madhupur Tract (AEZ- 28)
General Soil Type	Deep Red Brown Terrace Soil
Parent material	Madhupur clay
Topography	Fairly level
Drainage	Well drained
Flood level	Above flood level
Soil series	Tejgaon

(SAU Farm, Dhaka)

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% Clay	30
Textural class	Silty-clay
pH	6.2
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: SRDI

Appendix III. Monthly record of air temperature, rainfall, relative humidity and sunshine of the experimental site during the period from November 2019 to March 2020

Month	*Air temperature (℃)		*Relative humidity (%)	*Total rainfall (mm)
	Maximum	Minimum		
November, 2019	29.6	19.2	73	00
December, 2019	26.4	14.1	73	00
January, 2020	25.4	12.7	71	00
February, 2020	28.1	15.5	64	39
March, 2020	32.5	20.4	62	23

Monthly average,
Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka-1212

Appendix IV. Analysis of variance of the data on plant height as influenced by high temperature of wheat varieties

Source of Variation	Degrees of freedom	Mean square			
		30 DAS	60 DAS	90 DAS	Harvest
Replication	3	43.37	525.15	640.77	1.08
Factor A	3	16.77	89.57	89.01	75.71
Error	24	8.85	56.85	85.91	74.82
Factor B	2	96.51	241.55	518.19	696.92
AB	6	0.06	1.13	5.39	2.54
Error	35	5.64	55.38	70.02	41.05

**, indicates significant at 1% level of probability

*, indicates significant at 5% level of probability

^{NS}, indicates Non significant

Appendix V. Analysis of variance of the data on tiller number as influenced by high temperature of wheat varieties

Source of Variation	Degrees of freedom	Mean square		
		30 DAS	60 DAS	90 DAS
Replication	3	0.45	1.10	0.30
Factor A	3	0.03	0.02	0.08
Error	24	0.06	0.11	0.06
Factor B	2	0.53	0.54	0.60
AB	6	0.01	0.01	0.04
Error	35	0.03	0.10	0.03

**, indicates significant at 1% level of probability

*, indicates significant at 5% level of probability

^{NS}, indicates Non significant

Appendix VI. Analysis of variance of the data on SPAD values as influenced by high temperature of wheat varieties

Source of Variation	Degrees of freedom	Mean square	
		30 DAS	60 DAS
Replication	2	119.91	52.67
Factor A	3	13.38	17.75
Error	24	18.69	35.71
Factor B	2	92.54	436.54
AB	6	2.86	4.41
Error	35	16.49	10.14

**, indicates significant at 1% level of probability

*, indicates significant at 5% level of probability

^{NS}, indicates Non significant

Appendix VII. Analysis of variance of the data on Days to flowering, Days to maturity, 1000 seed weight (g), and Grain yield plant^{-1}(g) as influenced by high temperature of wheat varieties

Source of Variation	Degrees of freedom	Mean square			
		Days to flowering	Days to maturity	1000 seed weight(g)	Grain yield plant^{-1}(g)
Replication	2	341.36	65.36	93.87	31.46
Factor A	3	104.59*	104.59	22.97	28.72
Error	32	71.05	53.80	21.54	11.58
Factor B	2	684.52*	684.52*	229.71*	147.14*
AB	6	8.00	8.00	4.40	0.90
Error	24	35.69	12.69	8.48	2.95

**, indicates significant at 1% level of probability

*, indicates significant at 5% level of probability

^{NS}, indicates Non significant

Appendix VIII. Analysis of variance of the data on Days to flowering, Days to maturity, 1000 seed weight (g), and Grain yield plant^{-1}(g) as influenced by high temperature of wheat varieties

Source of Variation	Degrees of freedom	Mean square		
		Straw yield plant^{-1}(g)	Filled grain spike^{-1}	Unfilled grain spike^{-1}
Replication	2	5.79	115.75	8.94
Factor A	3	59.12*	60.95	48.51
Error	32	19.73	60.89	59.43
Factor B	2	278.59*	825.15*	895.26*
AB	6	2.95	2.38	10.74*
Error	24	2.36	11.83	1.95

**, indicates significant at 1% level of probability

*, indicates significant at 5% level of probability

^{NS}, indicates Non significant

PLATES

Plate I: Seedlings of wheat

Plate II: Vegetative Stage

Plate III: Reproductive Stage