EFFECTS OF GA_3 AND NITROBENZENE ON GROWTH AND YIELD PERFORMANCE OF WHEAT UNDER LATE SOWN CONDITION

A Thesis

By

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Student No. 1701169

MASTER OF SCIENCE

IN

CROP PHYSIOLOGY AND ECOLOGY

DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200, BANGLADESH

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DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

To evaluate the effect of Gibberellic acid (GA_3) and Nitrobenzene on late sown wheat, an experiment was conducted at the research field of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur, during November 2022 to April 2023. The experiment was laid out in a two factorial RCBD design with three replications. The factors used in the experiment were, Factor A: three growing conditions viz. Normal (seeds were sown on November 15, 2022), foliar application of GA_3 under late sown condition (seeds were sown on January 1, 2023), and foliar application of Nitrobenzene under late sown condition (seeds were sown on January 1, 2023). Factor B: three wheat varieties (BARI Gom 28, BARI Gom 30, and BARI Gom 33). Interaction effect of growing conditions and wheat varieties significantly influenced the different physiological traits, yield and yield attributes of wheat. Highest SPAD value was found in BARI Gom 33 under normal condition and the lowest SPAD value was found in BARI Gom 33 under late sowing condition with Nitrobenzene, however they are not statistically different. Canopy temperature was cooler in normal growing condition compared to late sown condition. Foliar application of GA_3 increased plant height, spike length, and biological yield in BARI Gom 28; thousand grain weight in BARI Gom 30 and BARI Gom 33; grains spike^{-1} and grain yield in BARI Gom 30.

Foliar application of Nitrobenzene increased plant height, spike length in BARI Gom 28 and BARI Gom 33; grains spike^{-1}, thousand grain weight, grain yield in BARI Gom 30 and BARI Gom 33; and biological yield in all the varieties.

The results of the present study indicated that the application of GA_3 and Nitrobenzene increased wheat yield at late sown condition, and BARI Gom 33 showed highest yield among the three late sown varieties.

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CHAPTER I
INTRODUCTION

Wheat is one of the oldest cultivated plants in the world and has long been a staple food for many nations. Today, it is the most widely grown crop in the world and is cultivated on an estimated area of 217 million hectares (FAOSTAT 2020). In Bangladesh, it ranks third next to rice and maize both in terms of production and acreage and is grown over an area of 0.329 million hectares with an annual production of about 1.08 million metric tons and an average yield of 3.30 metric tons per hectare (BBS 2022). New Zealand's wheat farms were the most productive in 2022-2023, with a nationwide average of 9.4 tons per hectare, followed by the United Kingdom (8.6), China (5.9), the European Union (5.5), and Japan (4.6) (USDA 2022). So, it is evident that Bangladesh is falling behind in terms of average yield, and likely factors for that are low-fertile soil, lack of quality plant materials, and the use of outdated farming technology; however, the single most important factor is abiotic stress.

In Bangladesh, the optimum sowing time for wheat is between 15 November and 30 November. However, harvesting of transplanted aman rice extends beyond that period and land preparation may contribute to further delay in wheat seeding. Late-sown wheat crops are often exposed to heat stress. Heat stress may be defined as the rise in temperature beyond a threshold level for a duration significant enough to induce irreversible damage to plant growth and development (Wahid *et al.* 2007).

The world bank said in its Climate Afflictions Report that Bangladesh experienced a 0.5°C temperature increase over the past 44 years and by 2050, the temperatures are predicted to rise by 1.4°C. Zhao *et al.* (2017) stated that for every one-degree Celsius rise in global mean temperature, yield of wheat on average would reduce by 6% globally. Akter and Islam (2017) stated that heat stress induces poor germination, impedes seedling growth and reduces plant water-use efficiency; accelerates leaf senescence leading to decline in photosynthesis rate; decreases grain number and size. Wheat is highly sensitive to high temperatures especially during the grain-filling stage. High temperature shortens grain-filling period (Nahar *et al.* 2010) and decreases grain weight (Dias and Lidon 2009). High temperature stress has detrimental effects on plant physiological processes, leading to reduction in growth and yield (Mondal *et al.* 2013). Therefore, heat stress possesses a challenge to successful wheat production.

There are various strategies for improvement of yield under heat stress induced by late sowing, however exogenous application of plant growth regulators (PGRs) is an easy, cost-effective and time-efficient method to improve yield in crops. Gibberellic Acid (GA_3) is a plant growth regulator (PGR) that plays a crucial role in regulating various physiological processes in plants. It regulates various processes in plants such as seed germination, leaf expansion, stem elongation, as well as the development of flower, fruit and seed (Iqbal *et al.* 2014 and Yamaguchi 2008). Although GA_3 is primarily recognized for its growth-promoting properties, research has explored its potential involvement in mitigating the effects of heat stress. Recent studies have shown that exogenous application of GA_3 to plants can enhance the activity of enzymes such as catalase and peroxidase which constitute the antioxidant defence in plants (Uzal and Yasar 2017) can help mitigate the oxidative stress caused by heat stress (Hasanuzzaman *et al.* 2018).

Nitrobenzene is a yield enhancer which stimulates an increase in the roots, leaves and branches count in plants. It improves flower and fruit size in plants. Deb *et al.* (2012) found that Nitrobenzene makes the tomato plants fresher and succulent, increases shoot height, root length and increases overall yield. Nitrobenzene has an advantageous impact on plant growth, in boro rice, it increases grain and straw yield and the impact on morpho-physiological and yield attribute characters are significant (Chowdhury *et al.* 2019). However, the role of Nitrobenzene in late sown wheat is yet to be explored.

To overcome the detrimental effect of late sowing on wheat production, the present study was carried out with the following objectives -

1. To evaluate the effect of GA_3 and Nitrobenzene on growth and yield of wheat in late sown condition.
2. To find out the best variety for late sown condition among the three varieties used in this experiment.

CHAPTER II
REVIEW OF LITERATURE

Late sowing is a significant barrier to successful wheat production in Bangladesh. In the past, a great deal of study was done to mitigate the effects of late sowing on wheat. This chapter aims to review the literature on the effects of late sowing on wheat production and how using GA_3 and Nitrobenzene can help mitigate the negative effects of late sowing.

Abiotic stress negatively impacts plant growth, development and overall productivity. High-temperature stress, especially at the reproductive stage, i.e., terminal heat stress, poses a threat to global crop production (Nagar *et al.* 2021). Heat stress influences plants in different stages of their life-cycle and has an adverse impact on various physiological processes such as photosynthesis, respiration, transpiration.

Wheat (*Triticum aestivum*) is a cereal grain and one of the most widely cultivated and consumed crops globally. As a tropical country the farmers of Bangladesh are cultivating wheat in winter season. But because of their unconsciousness or to adjust other crop in the same field farmers often go for late planting of wheat (Nahar *et al*. 2010). In addition, winter season in Bangladesh is getting shorter due to climate change, therefore in future, timely sown wheat may also be exposed to heat stress.

Late sown plants are often exposed to different temperatures and photoperiods during their life cycle compared to timely sown plants, hence they failed to meet the standard condition to complete their life cycle (Nagar *et al*. 2015). Heat stress is a serious threat to wheat production worldwide. Reynolds *et al.* (2012) stated that heat stress in wheat during anthesis and grain filling stage affects flowering, pollen viability, availability and translocation of photosynthates to the developing kernel, starch synthesis and its deposition within the kernel and as a result reduces grain number, grain weight and grain quality. Mondal *et al.* (2013) observed that heat stress induces an increase in the rate of plant development, reduction in grain growth period and ultimately reduces final yield of wheat. The effects of heat stress on plants are very complex resulting in alteration of growth and development, changes in physiological functions, and reduced grain formation and yield. The high temperature stress, especially at the reproductive stage, i.e., terminal heat stress, poses a threat to global crop production (Nagar *et al*. 2021). Wheat is a major staple cereal along with rice and maize. Zhao *et al*. (2017) estimated that a unit-degree Celsius increase in global mean temperature would, on average, reduce global yields of wheat by 6.0%.

Asseng *et al*. (2014) studied 30 wheat crop models, with the help of artificial heating, he maintained a temperature range from 15 to 32°C during the growing period. The study revealed that the simulated median temperature has impact on wheat yield and the yield varied widely; for an increase in temperature of 2°C, the average yield reduced by 1 to 28% during the period between 1981 and 2010 across 30 sites of the world; and this value rose to between 6 and 55% for a temperature of 4°C increase. In addition, they estimated that global wheat production falls by 6% for each one-degree Celsius of further temperature increase.

High temperature stress disrupts cellular processes impacting their normal functioning. Balla *et al*. (2012) stated that, in imbibing wheat embryos, high temperature stress causes mitochondria to degenerate, alters the protein expression profiles, reduces ATP accumulation, leading to the increased occurrence of loss of seed quality in terms of seed mass, vigor, and germination. High-temperature stress increases the availability of free electrons in chloroplast and mitochondria, leading to the generation of Reactive oxygen species (ROS) (O_2, H_2O_2, OH^-) (Caverzan *et al*. 2016 and Foyer *et al.* 1997). These ROS damage the biomolecules in plant body such as lipids, nucleic acid, and protein, leading to disruption in various physiological processes of plants (Mathur and Jajoo 2014).

Terminal heat stress during anthesis and grain filling stage causes premature flower shedding, loss of pollen viability, availability and translocation of photosynthates to the developing kernel, thus resulting in loss of grain quality in terms of grain number and grain weight (Farooq *et al*. 2011 and Reynolds *et al*. 2012). Nahar *et al*. (2010) found that an increase in temperature of 1–2°C reduces seed weight by accelerating seed growth rate and by shortening the grain-filling periods in wheat. High temperature affects crops in different ways including poor germination and plant establishment, reduced photosynthesis, leaf senescence, decreased pollen viability, and consequently production of less grains with smaller grain size (Asseng *et al*. 2011 and Ugarte *et al*. 2007). The primary effect of heat stress is the impediment of seed germination and poor stand establishment in many crops including wheat (Johkan *et al*. 2011).

Jannat *et al.* found that drought condition adversely affected physiological traits of wheat. Heat stress causes oxidative damage to chloroplasts, lowers photosynthetic capacity of plants through metabolic limitations which leads to reduction in dry matter accumulation and grain yield (Farooq *et al*. 2011). Heat stress affects wheat at different phenological stages but its impact at the reproductive phase is more damaging than the vegetative phase due to the direct effect on grain number and dry weight (Wollenweber *et al*. 2003). Nawaz *et al*. (2013) also found similar result and said heat stress at reproductive phase of plant life is more harmful in wheat production. Even just one-degree rise in average temperature during reproductive phase can cause severe yield loss in wheat (Bennett *et al.* 2012 and Yu *et al.* 2014). Heat stress causes damage in reproductive tissue in plants and leads to a significant cause of yield loss in agricultural production globally (Suzuki *et al.* 2012). Increase in temperature reduces photosynthetic efficiency leading to reduction in crop yield (Mathur *et al*. 2011).

Day and night temperature around 30 and 25°C, respectively, may have severe effects on leaf development and productive tiller formation in wheat (Rahman *et al*. 2009).

The use of plant growth regulators (PGRs) has been evaluated to mitigate the negative effects of heat stress since these substances are actively involved in plant responses or mechanisms to develop physiological protection against this kind of stress (Peleg and Blumwald 2011 and Yin *et al.* 2011). Plant growth regulators (PGRs) are naturally biosynthesized by plants which modify growth (increase in branching and rebranching, shoot and root growth, alter or trigger fruit maturing, reproduction etc.) of crop plants and play a significant role in mitigating abiotic stresses (Takahashi *et al*. 2019 and Verma *et al*. 2016). PGRs also have an important role during stress conditions such as being thermoprotectants, reactive oxygen scavengers, improving photosynthesis, accumulation of stress proteins, and many other regulatory functions related to metabolisms (Akram *et al*. 2017 and Sharma *et al*. 2020). Foliar application of plant growth regulators, both natural and synthetic, has proven worthwhile for improving crop growth against a variety of abiotic stresses (Ramesh *et al*. 2019). Pantoja-Benavides *et al*. (2021) studied the effect of various PGRs against heat stress and concluded that all growth regulators used in his study (auxins, gibberellins, cytokinins, or brassinosteroids) exhibited a certain level of mitigation heat stress.

Gibberellic acid (GA_3), is a plant hormone involved in numerous processes such as plant height, leaf expansion, dry matter accumulation, tissue differentiation, cell division, net absorption rate, blooming, photosynthesis and transpiration rate (Fahad *et al*. 2015 and Saleem *et al*. 2015). Gibberellic acid applications have also exhibited a positive response to heat stress. Studies have shown that GA biosynthesis mediates different metabolic pathways and enhances tolerance under high temperature conditions (Alonso-Ramírez *et al*. 2009 and Khan *et al*. 2020). Exogenous applications of Gibberellic acid (GA_3) have been shown in the literature to have a significant impact in wheat growth and development under heat stress condition (Nagar *et al*. 2021). Gibberellins control different stages of plant development, including seed germination, seedling growth, stem elongation, root extension, leaf size and shape, flower and fruit development, pollination (Yamaguchi 2008). The role of phytohormones like abscisic acid, cytokinins, auxins, and salicylic acid is well-established under abiotic stress (Wahid *et al*. 2007). Gibberellic acid (GA_3) is a plant hormone that plays a vital role at every stage of a plant's life cycle. It regulates process such as seed germination, leaf expansion, stem elongation, flower and trichome initiation, source–sink relationship and flower, fruit and seed development (Iqbal *et al*. 2014 and Yamaguchi 2008). Exogenous application of GA_3 improves stomatal conductance, net photosynthesis rate, ion uptake, and hormonal balance (Iqbal and Ashraf 2013).

Nagar *et al*. (2021) observed that, in late sown (LS) wheat plants, average GA_3 content decreased by 33% compared to timely sown (TS) wheat plants. Exogenous application of GA_3 significantly ($P < 0.05$) increased GA_3 content by 13.7 and 36% in all cultivars under (TS) and (LS) conditions, respectively. In addition, foliar application of GA_3 enhanced grain weight per ear, grain number per ear, test weight, and grain yield per plant by 13.4, 3.8, 3.6, and 13.6% in the tolerant cultivars, and by 22.2, 8.2, 10, and 16.5% in susceptible cultivars under stress, respectively. Application of GA_3 had positive impact on photosynthesis rate of wheat plants. A 5.1% increase in photosynthesis rate in (TS) tolerant cultivars and a 6.6% increase in photosynthesis rate in (LS) cultivars was observed.

Various studies have shown that GA_3 may mitigate the adverse impact of heat stress on plant growth and development, and have the potential to improve yield under such condition (Saleem *et al.* 2015 and Ullah *et al.* 2017). GA_3 has also been found to increase the accumulation of osmoprotectants such as proline and soluble sugars, which can help plants cope with heat stress-induced water deficit (Rady *et al.* 2021).

Nitrobenzene is a flowering stimulant which usages is still very limited in agricultural field. It is used as spray or in granular form, which increases flower forming substances by altering auxin, cytokinin, gibberellic acid and ethylene ratio favorably tilting to a higher level of flower forming substances, thereby increasing flowers by more than 40 to 45% and improves overall yield of crops. The yield increase was found to be 30 to 40% in tomato, 25 to 28% in brinjal, 30 to 40% in mango, 20 to 25% in rice, and 30 to 35% in chilies. Application of Nitrobenzene improved plant growth in the mentioned crops and in rice, uniform panicle emergence was observed (Rathinasamy 2015).

Exogenous applications of Nitrobenzene have been shown in the literature to have a significant impact in plant growth and development. Aziz and Miah (2009) studied the effect of Nitrobenzene on wetland rice and concluded that Nitrobenzene increased plant height, tiller and panicle production and 1000-grain weight and decreased the sterility percentage of grain. In addition, grain and straw yield was also shown to have an increase. Hossain *et al*. (2020) concluded that application of Nitrobenzene increases plant height, number of effective tillers hill^{-1}, number of total tillers hill^{-1}, number of grains panicle^{-1}, length of panicle, thousand grain weight, and grain yield in rice.

CHAPTER III

MATERIALS AND METHODS

The experiment was carried out to study the effect of GA_3 and Nitrobenzene on late sown wheat. Details of the methods of the study followed during the research period are presented in this chapter.

3.1 Location and duration

The experiment was set up at the research farm of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur during November, 2022 to April, 2023. The experimental site is situated under the Dinajpur Sadar Upazila and located at 25°39' N latitude and 88°41' E longitude with an elevation of 37.58 meter above the sea level.

3.2 Soil and climate

The experimental field was a medium high land belonging to the non-calcareous dark gray floodplain soil under the agro-ecological zone (AEZ-1) of Old Himalayan Piedmont Plain. The soil was sandy loam under the Order Inceptisol. Soil analysis report of the experimental area was collected from SRDI, Noshipur, Dinajpur. The experimental site is situated in the sub-tropical region characterized by heavy rainfall during the months from May to September and little to none infrequent rainfall for the rest of the year. Details of the soil characteristics of the experimental site have been presented in Appendix I.

3.3 Experimental design and layout

The experiment was conducted in a two-factorial RCBD design with three replications. Two factors were used in the experiment, viz. Three growing conditions, and three varieties of wheat. There were twenty-seven plots. The unit plot size was 1.4 m x 1.5 m with plot to plot and block to block distance of 0.5 m and 1.0 m respectively.

3.4 Experimental treatments

The experiment had nine treatment combinations and they were distributed randomly in twenty-seven plots. The experiment was consisted of two factors:

Factor A: Three growing conditions

1. Normal growing condition (the seeds were sown on November 15, 2022)
2. Foliar application of GA_3 under late sown condition (the seeds were sown on January 1, 2023)
3. Foliar application of Nitrobenzene under late sown condition (the seeds were sown on January 1, 2023)

Factor B: Three wheat varieties

1. BARI Gom 28
2. BARI Gom 30
3. BARI Gom 33

3.5 Land preparation

The land was ploughed by a power tiller and was levelled by harrowing and laddering. The weeds and stubbles were removed and main plots, sub-plots and blocks were prepared. The unit plot was spaded one day before the sowing of wheat seeds. Basal doses of fertilizers were applied and mixed thoroughly with the soil before final land preparation.

3.6 Fertilizer application

Recommended doses of fertilizers for wheat were used in this experiment. For all wheat varieties, each plot was fertilized with urea @150kg ha^{-1}, TSP @135kg ha^{-1}, MoP @110kg ha^{-1}, gypsum @125 kg ha^{-1} and boric acid @7.5kg ha^{-1}. The whole quantity of TSP, MoP and gypsum and two-third of urea were incorporated into the soil as basal dose during the final land preparation. It is to be mentioned that during final land preparation, instead of cowdung, poultry litter composts (10 t ha^{-1}) were used for all the treatments as basal dose (Chowdhury *et al.* 2020). The rest of the of the urea was top dressed at 20 days after sowing.

3.7 Sowing of seed

In normal growing condition, seeds were sown on November 15, 2022 and in late sown condition, seeds were sown on January 1, 2023. The seed rate was 120 kg/ha and row to row distance was 18 cm. After sowing, the seeds were covered with thin layer of loose soil and light irrigation was given for uniform germination after sowing.

3.8 Irrigation

All the plots of both normal and late sown condition were irrigated three times (at 18, 50 and 75 days after sowing). There was no variation of irrigation between normal and late sown condition.

3.9 Intercultural operations

At 20 days after sowing, thinning of seedlings was done to maintain a plant-to-plant distance of 10 cm. It ensures that plants get adequate water and nutrients and have a proper air circulation. Hand weeding was done at 25 days after sowing to keep the plots weed free. For crop protection, Tilt 250 EC was sprayed twice at 30 and 40 days after sowing in both normal and late sown conditions.

3.10 Preparation and foliar application of GA_3

The GA_3 solution of 300 ppm concentrations was prepared by dissolving 300 mg of GA_3 in 10 ml methanol prior to dilution with distilled water. Then distilled water was added to make the volume 1 litre to get 300 ppm GA_3 solution. The foliar spraying was done at 40, 60 and 70 days after sowing with the help of a hand sprayer until all leaves were completed wetted.

3.11 Preparation and foliar application of Nitrobenzene

The Nitrobenzene solution was prepared by dissolving 3 ml of Flora (Nitrobenzene 20%

w/w) in 1 litre of water. The foliar spraying was done at 20, 40 and 60 days after sowing with the help of a hand sprayer until all leaves were completed wetted.

3.12 Data collection

5 plants were selected randomly and tagged from each plot at anthesis. The data were recorded on the following parameters:

3.12.1 SPAD value

The SPAD (Soil Plant Analyses Development) value was taken from middle portion of the youngest fully expanded leaflet of the 5 tagged plants at 8 days after anthesis using self-calibrating Minolta chlorophyll meter (Model: SPAD-502, Minolta Co. Ltd, Japan) and the average of the ten values were recorded.

3.12.2 Canopy temperature

A hand held infra-red thermometer (Model: Crop TRAC item no. 29551-Spectrum Technologies, Inc.) was used to measure canopy temperature. Canopy temperature was recorded at 8 days after anthesis during noon period under bright sunlight and less wind.

3.12.3 Plant height (cm)

Plant height was measured in centimetres from the base of the plant to the tip of the spike excluding the awn. The height of five tagged plants from each plot at harvest was measured using a measuring tape, and the mean was calculated.

3.12.4 Spike length (cm)

Spike length was measured in centimetres from the base of the spike to the tip of the spike excluding the awn. Spike length was taken by a centimetre scale from the five tagged plants from each plot at harvest, and the mean was calculated.

3.12.5 Number of spikelets spike^{-1}

The number of spikelets per spike was counted manually by hand from the five tagged plants of each plot, and the mean was calculated.

3.12.6 Number of spikes m^{-2}

A 1m×1m section was selected from the middle of each plot, and the spike number was counted manually by hand, and the mean was calculated.

3.12.7 Number of grains $spike^{-1}$

Grains were separated manually from the spikes of the five tagged plants of each plot and counted, and the mean was calculated.

3.12.8 Thousand grain weight (g)

1000 grains were taken randomly from each plot and weighed using an electronic balance.

3.12.9 Above ground biological weight (t ha^{-1})

Weight of all the plants of each unit plot was measured using an electronic balance and converted into t ha^{-1}.

3.12.10 Grain yield (t ha^{-1})

Total grain obtained from each unit plot were sun-dried and weighed carefully. The grains were weighed using an electronic balance and converted into t ha^{-1}.

3.13 Data analysis technique

The data obtained from the experiment on various parameters were statistically analysed in Statistix 10 computer program. The mean values for all the parameters were calculated and the analysis of variance was performed. The mean differences were compared by Tukey's Test at $p \leq 5\%$ level.

CHAPTER IV
RESULTS AND DISCUSSION

This chapter contains the findings of the study in the form of several tables and figures. Appropriate discussion and possible interpretation wherever suitable have been provided in this chapter.

4.1 SPAD value

A quick and non-destructive method for measuring chlorophyll concentration (greenness) in field can be achieved by using a SPAD meter. The chlorophyll content in leaves indicates photosynthetic activity and the yield potential in plants. The SPAD reading (Figure 1) was taken from the middle portion of flag leaf at 8 days after anthesis in fully expanded flag leaf. SPAD value was not significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions. Reduction in SPAD value was observed in BARI Gom 30 and BARI Gom 33 under late sown condition. Interestingly, BARI Gom 28 showed higher SPAD value in late sowing condition compared to normal growing condition. Ristic *et al*. (2007) studied 12 cultivars of winter wheat and concluded that heat stress reduced chlorophyll contents in all the cultivars by damaging thylakoid membranes and photosystem II. Nitrobenzene had a better impact on BARI Gom 30 in minimizing the chlorophyll content loss than that of GA_3. In BARI Gom 28 and BARI Gom 33, GA_3 had a better result in minimizing chlorophyll content loss than that of Nitrobenzene.

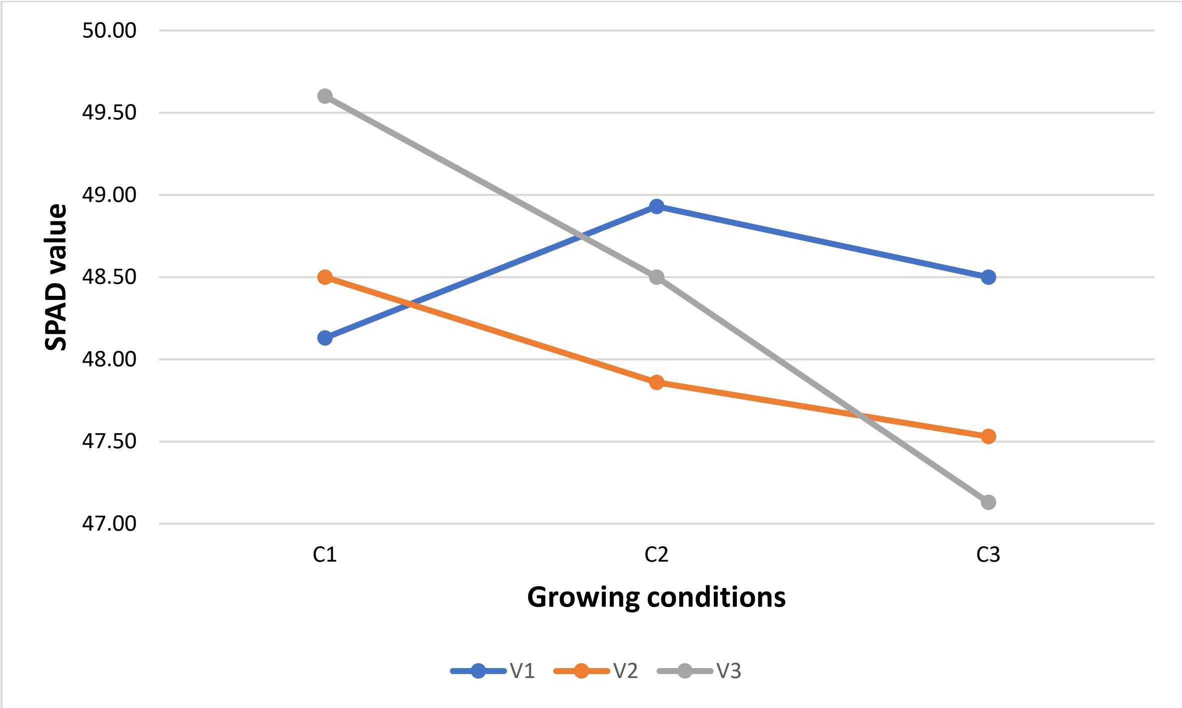

Figure 1. Combined effect of growing conditions and wheat varieties on Flag leaf SPAD value at 8 days after anthesis.

V1 indicates BARI Gom 28

V2 indicates BARI Gom 30

V3 indicates BARI Gom 33

C1 indicates normal growing condition

C2 indicates late sown with GA_3 application

C3 indicates late sown with Nitrobenzene application

4.2 Canopy temperature (°C)

Canopy temperature at 8 days after anthesis was significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 1). In late sown condition, increase in canopy temperature was observed in all the wheat varieties. The highest canopy temperature (34.16°C) was found in BARI Gom 28 under late sown with Nitrobenzene condition, whereas the lowest canopy temperature (29.7°C) was found in BARI Gom 33 under normal condition. Heat stress reduces stomatal conductance in plants, soil moisture deficit reduces normal transpiration rate, which in turn increases canopy temperature (Rebetzke *et al.* 2012). Moreover, late sown plants were exposed to higher air temperature compared to timely sown plants, leading to the increase in canopy temperature. Figure 2 shows temperature report during growing season.

Table 1. Interaction effect of varieties and growing conditions on canopy temperature at 8 days after anthesis

Wheat varieties	Growing conditions	Canopy temperature (°C)	% change over normal
BARI Gom 28	Normal	30.03d	-
	Late sown with GA_3	34.10a	+13.55
	Late sown with Nitrobenzene	34.16a	+13.75
BARI Gom 30	Normal	29.9d	-
	Late sown with GA_3	33.60abc	+12.37
	Late sown with Nitrobenzene	33.90ab	+13.38
BARI Gom 33	Normal	29.7d	-
	Late sown with GA_3	32.80c	+10.44
	Late sown with Nitrobenzene	33.03bc	+11.21
Level of significance		*	
CV (%)		1.08	
Standard error		0.28	
Critical value		1.01	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
* indicates significant at 5% level of probability

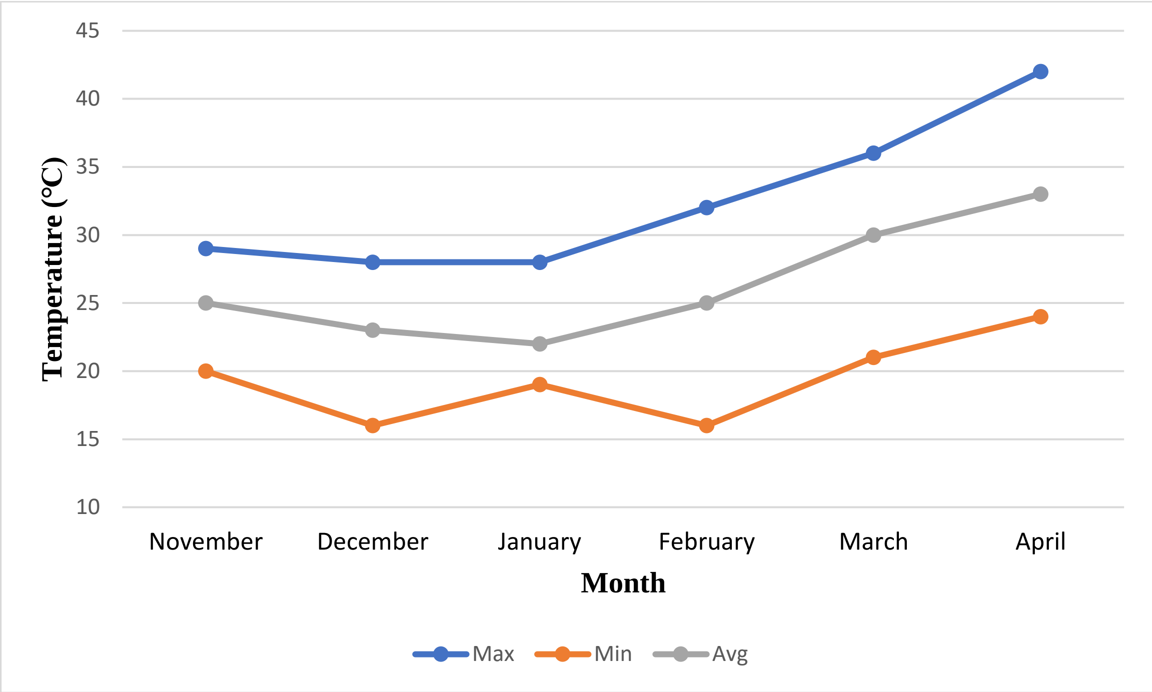

Figure 2. Temperature during growing season.

4.3 Plant height (cm)

Plant height of wheat at harvest was significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 2). The highest plant height (81.66cm) was found in BARI Gom 33 under late sown with Nitrobenzene condition which was significantly similar to plant height found in Bari Gom 33 under both normal and late sown with GA_3 condition. The lowest plant height (69.66cm) was found in BARI Gom 30 under late sown with GA_3 condition. Foliar application of GA_3 increased plant height by (2.54%) in BARI Gom 28. This might be due to application of GA_3, stimulated rapid cell division and elongation in stems and shoots (Turner 1963). Foliar application of Nitrobenzene increased plant height by (4.41%) in BARI Gom 28 and (1.32%) in BARI Gom 33. Hossain *et al*. (2020) found 22.96% increase in plant height at harvest in rice due to foliar application of Nitrobenzene. In late sown condition, Bari Gom 30 and BARI Gom 33 showed reduction in plant height due to heat stress. Abiotic stress leads to alteration in phytohormones levels and decreased plant growth (Alhaithloul *et al.* 2021). Late sown plants were exposed to different temperatures and photoperiods during their life cycle compared to timely sown plants, which was a deviation from standard requirement and as a result there was a reduction in plant height (Nagar *et al.* 2021).

Table 2. Interaction effect of varieties and growing conditions on plant height of wheat at harvest

Wheat varieties	Growing conditions	Plant height (cm)	% change over normal
BARI Gom 28	Normal	72.56cd	-
	Late sown with GA_3	74.40c	+2.54
	Late sown with Nitrobenzene	75.76bc	+4.41
BARI Gom 30	Normal	72.53cd	-
	Late sown with GA_3	69.66d	-3.96
	Late sown with Nitrobenzene	70.33d	-3.03
BARI Gom 33	Normal	80.60a	-
	Late sown with GA_3	78.80ab	-2.23
	Late sown with Nitrobenzene	81.66a	+1.32
Level of significance		*	
CV (%)		1.55	
Standard error		0.95	
Critical value		3.38	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.

[*] indicates significant at 5% level of probability

4.4 Spike length (cm)

Spike length of wheat at harvest was significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 3). The longest spike length (11.88cm) was found in BARI Gom 33 under late sown with Nitrobenzene condition. The lowest spike length (9.91cm) was found in BARI Gom 30 under late sown with GA_3 condition. Foliar application of GA_3 improved the spike length by (0.87%) in BARI Gom 28. Islam *et al*. (2014) found that 100ppm and 200ppm concentration of GA_3 increased the panicle size by 15.38 and 18.88% respectively over control condition (no GA_3) in wheat. Foliar application of Nitrobenzene improved the spike length by (2.34%) in BARI Gom 28 and (1.28%) in BARI Gom 33. Hossain *et al*. (2020) found 12.61% increase in spike length in rice due to foliar application of Nitrobenzene. Late sowing reduced the spike length in BARI Gom 30 and it might be due to reduction in cell division and cell elongation process hampered by heat stress (Punia *et al.* 2011). Reduction in spike length due to heat stress induced by late sowing of wheat was also observed by (Jaiswal *et al.* 2018 and Sattar *et al.* 2010).

Table 3. Interaction effect of varieties and growing conditions on spike length of wheat at harvest

Wheat varieties	Growing conditions	Spike length (cm)	% change over normal
BARI Gom 28	Normal	11.53ab	-
	Late sown with GA_3	11.63ab	+0.87
	Late sown with Nitrobenzene	11.80ab	+2.34
BARI Gom 30	Normal	10.23c	-
	Late sown with GA_3	9.91c	-3.13
	Late sown with Nitrobenzene	9.96c	-2.64
BARI Gom 33	Normal	11.73ab	-
	Late sown with GA_3	11.51b	-1.88
	Late sown with Nitrobenzene	11.88a	+1.28
Level of significance		*	
CV (%)		1.10	
Standard error		0.10	
Critical value		0.35	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
[*] indicates significant at 5% level of probability

4.5 Number of spikelets spike^{-1}

The number of spikelets spike^{-1} of wheat was not significantly influenced by the interaction effect of varieties and growing conditions (Table 4). Heat stress induced by late sown reduced the number of spikelets spike^{-1} in all wheat varieties. Reduction in spikelets spike^{-1} due to late sowing is also observed by (Sattar *et al.* 2010). Heat stress speeds up the development of spikes, leading to the reduction of spikelet number per spike (Porter and Gawith 1999). Bányai *et al*. (2014) also found reduction in spiklets number per spike due to heat stress.

The highest spikelets spike^{-1} (16.23) was found in BARI Gom 28 under normal condition. Among the wheat varieties, BARI Gom 30 had the highest reduction in number of spikelets spike^{-1}; the lowest of spikelets spike^{-1} (13.93) was found in BARI Gom 30 under late sown with Nitrobenzene condition.

Table 4. Interaction effect of varieties and growing conditions on number of spikelets spike^{-1} of wheat at harvest

Wheat varieties	Growing conditions	Number of spikelets spike^{-1}	% change over normal
BARI Gom 28	Normal	16.23a	-
	Late sown with GA_3	15.13a	-6.78
	Late sown with Nitrobenzene	15.40a	-5.11
BARI Gom 30	Normal	15.10a	-
	Late sown with GA_3	14.00a	-7.28
	Late sown with Nitrobenzene	13.93a	-7.75
BARI Gom 33	Normal	15.80a	-
	Late sown with GA_3	14.93a	-5.51
	Late sown with Nitrobenzene	15.30a	-3.16
Level of significance		NS	
CV (%)		5.86	
Standard error		0.72	
Critical value		2.57	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
NS indicates not significant

4.6 Number of spikes m^{-2}

Number of spikes m^{-2} of wheat at harvest was not significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 5). The highest number of spikes m^{-2} (225) was found in BARI Gom 28 under late sown with Nitrobenzene condition, whereas the lowest number of spikes m^{-2} (220) was found in BARI Gom 28 under late sown with GA_3 condition. Reduction in spike number was seen in BARI Gom 30 for late sown condition which probably because of late sown wheat were exposed to higher temperature and which may have interfered with the formation of spike number. Interestingly, there was an increase in spike number in BARI Gom 33 under late sown condition. BARI Gom 28 under late sown with Nitrobenzene showed an increase of (1.66%) over normal condition. Almubarak *et al*. (2008) also found a significant increase in the number of spikes m^{-2} in barley (*Hordium vulgare*).

Table 5. Interaction effect of varieties and growing conditions on number of spikes m^{-2} of wheat

Wheat varieties	Growing conditions	Number of spikes m^{-2}	% change over normal
BARI Gom 28	Normal	221.33a	-
	Late sown with GA_3	220.00a	-0.60
	Late sown with Nitrobenzene	225.00a	+1.66
BARI Gom 30	Normal	224.00a	-
	Late sown with GA_3	221.33a	-1.19
	Late sown with Nitrobenzene	220.33a	-1.64
BARI Gom 33	Normal	220.33a	-
	Late sown with GA_3	220.67a	+0.15
	Late sown with Nitrobenzene	220.67a	+0.15
Level of significance		NS	
CV (%)		1.33	
Standard error		2.41	
Critical value		8.58	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
NS indicates not significant

4.7 Number of grains spike^{-1}

The number of grains spike^{-1} of wheat was significantly influenced by varieties (Figure 3.1). The highest number of grain spike^{-1} was found in BARI Gom 30 which was statistically similar to BARI Gom 33 and the lowest grains spike^{-1} of wheat was found in BARI Gom 28.

The growing conditions did not significantly affect the number of grains spike^{-1} of wheat (Figure 3.2).

The number of grains spike^{-1} of wheat was significantly influenced by the interaction effect of varieties and growing conditions (Table 6). The highest number of grains spike^{-1} (42.33) was found in BARI Gom 33 under late sown with Nitrobenzene condition whereas the lowest of grains spike^{-1} (36.66) was found in BARI Gom 28 under late sown with Nitrobenzene condition. Reduction in number of grains per spike due to late sowing of wheat was also observed by (Sattar *et al.* 2010). Heat stress speeds up the development of spikes, leading to the reduction of spikelet number per spike, hence the reduction in number of grains per spike (Porter & Gawith, 1999). Bányai *et al*. (2014) also found reduction in spiklets number per spike due to heat stress. Foliar application of GA_3 improved grains spike^{-1} in BARI Gom 30 by (3.17%), and foliar application of Nitrobenzene improved grains spike^{-1} in BARI Gom 30 and BARI Gom 33 by (3.95%) and (6.49%) respectively. Islam *et al*. (2014) studied the impact of different concentration of GA_3 on wheat and found that 100ppm and 200ppm increased the grains per spike by 9.44% and 13.99% respectively over control condition (no GA_3).

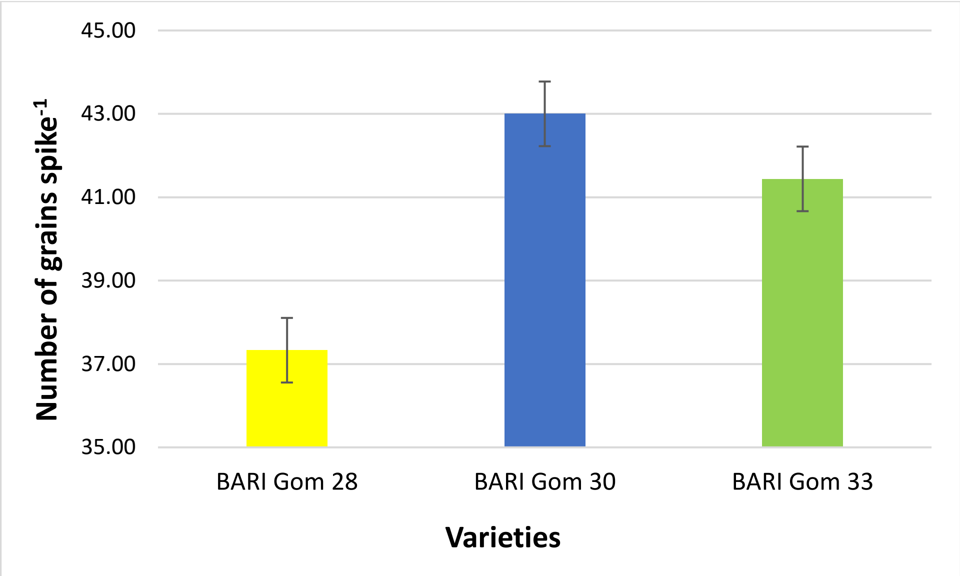

Figure 3.1 Effect of different varieties on number of grains spike^{-1}

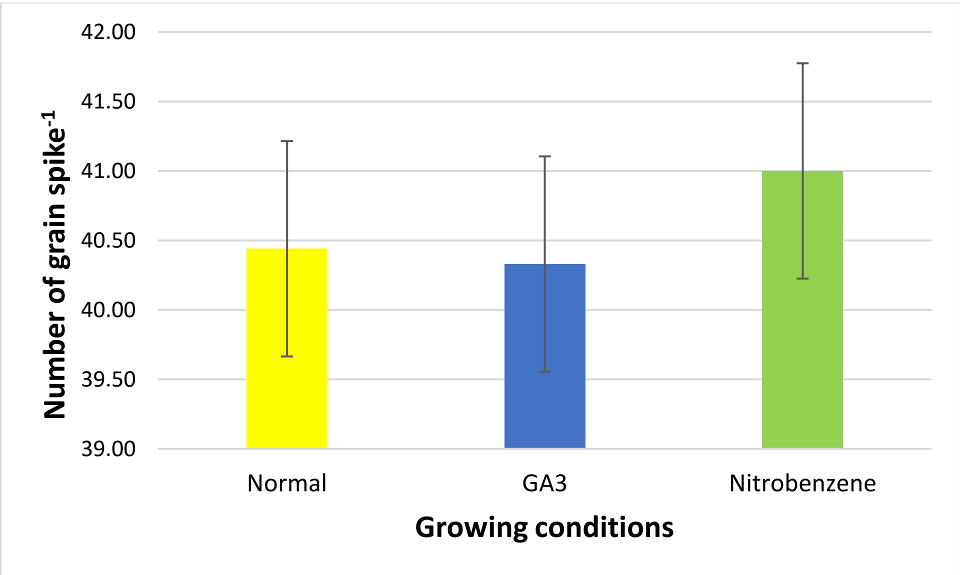

Figure 3.2 Effect of different growing conditions on number of grains spike^{-1}

Table 6. Interaction effect of varieties and growing conditions on number of grains spike^{-1} of wheat

Wheat varieties	Growing conditions	Number of grains spike^{-1}	% change over normal
BARI Gom 28	Normal	38.33bc	-
	Late sown with GA_3	36.66c	-4.36
	Late sown with Nitrobenzene	37.00c	-3.47
BARI Gom 30	Normal	42.00ab	-
	Late sown with GA_3	43.33a	+3.17
	Late sown with Nitrobenzene	43.66a	+3.95
BARI Gom 33	Normal	41.00abc	-
	Late sown with GA_3	41.00abc	-
	Late sown with Nitrobenzene	42.33ab	+6.49
Level of significance		*	
CV (%)		4.05	
Standard error		1.34	
Critical value		4.77	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
NS indicates not significant

4.8 Thousand grain weight (g)

Thousand grain weight of wheat was significantly influenced by varieties (Figure 4.1). The highest 1000 grain weight of wheat was found in BARI Gom 33, whereas the lowest 1000 grain weight of wheat was found in BARI Gom 28.

The growing conditions significantly affected the 1000 grain weight of wheat (Figure 4.2). The highest 1000 grain weight of wheat was found in Nitrobenzene condition, whereas the lowest 1000 grain weight of wheat was found in Normal condition which is statistically similar to GA_3 condition.

Thousand grain weight of wheat was significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 7). The highest 1000 grain weight of wheat (44.14g) was found in BARI Gom 33 under late sown with Nitrobenzene condition, whereas the lowest 1000 grain weight of wheat (40.07g) was found in BARI Gom 28 under late sown with GA_3 condition. Late sowing reduced the 1000 grain weight of wheat in BARI Gom 28. Reduction in 1000 grain weight of wheat due to late sowing was also observed by (Sattar *et al.* 2010). High temperature increased the rate of development, but at the same time, reduced the duration of crop growth and grain filling which led to a reduction in 1,000 grain weight (Reynolds *et al.* 2012). Foliar application of GA_3 improved 1000 grain weight by (1.06%) in BARI Gom 30 and (1.09%) in BARI Gom 33. Foliar application of GA_3 could improve the grain-filling process (Lu *et al*. 2022) leading to the increase in grain weight. Islam *et al.* (2014) studied the impact of different concentration of GA_3 on wheat and found that 100ppm and 200ppm increased the 1000 grain weight by 12.00% and 13.75% respectively over control condition (no GA_3).

Foliar application of Nitrobenzene improved 1000 grain weight by (1.80%) in BARI Gom 30 and (2.11%) in BARI Gom 33. Hossain *et al*. (2020) found that, application of Nitrobenzene increased grain weight by 7.49% in rice.

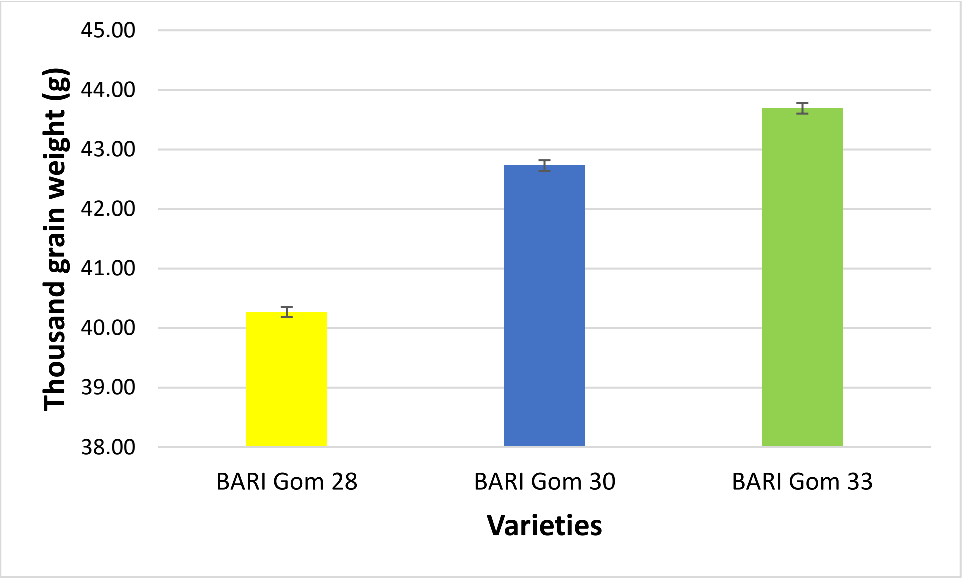

Figure 4.1 Effect of different varieties on thousand grain weight

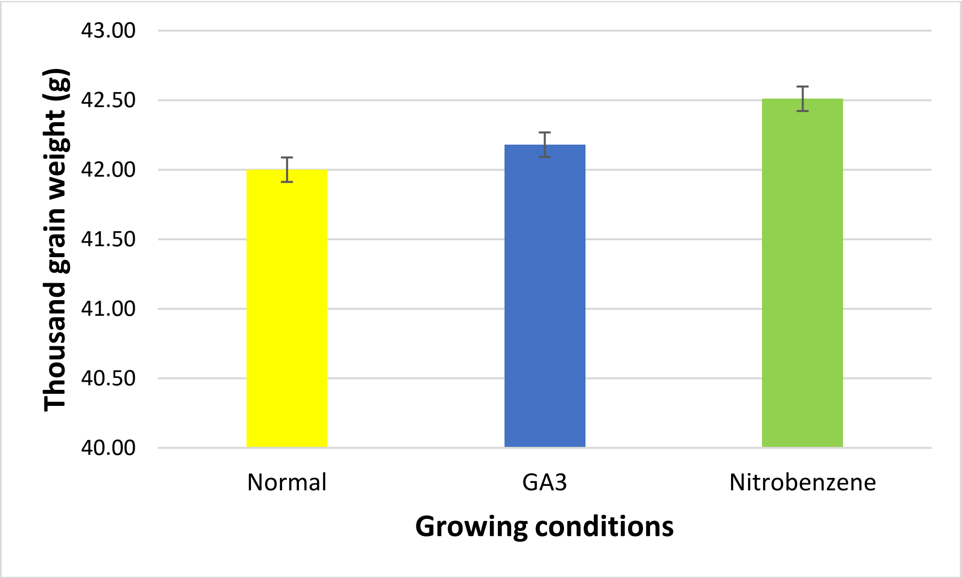

Figure 4.2 Effect of different growing conditions on thousand grain weight

Table 7. Interaction effect of varieties and growing conditions on thousand grain weight of wheat

Wheat varieties	Growing conditions	Thousand grain weight (g)	% change over normal
BARI Gom 28	Normal	40.44e	-
	Late sown with GA_3	40.07e	-0.91
	Late sown with Nitrobenzene	40.32e	-0.30
BARI Gom 30	Normal	42.33d	-
	Late sown with GA_3	42.78cd	+1.06
	Late sown with Nitrobenzene	43.09c	+1.80
BARI Gom 33	Normal	43.23bc	-
	Late sown with GA_3	43.70ab	+1.09
	Late sown with Nitrobenzene	44.14a	+2.11
Level of significance		*	
CV (%)		0.44	
Standard error		0.15	
Critical value		0.54	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
* indicates significant at 5% level of probability

4.9 Above ground biological yield (t ha^{-1})

Above ground biological yield of wheat was significantly influenced by varieties (Figure 5.1). The highest biological yield of wheat was found in BARI Gom 28, which is statistically similar to BARI Gom 30, whereas the lowest biological yield of wheat was found in BARI Gom 33.

The growing conditions significantly affected the biological yield of wheat (Figure 5.2). The highest biological yield of wheat was found in Nitrobenzene condition, whereas the lowest biological yield of wheat was found in GA_3 condition which is statistically similar to Normal condition.

Above ground biological yield of wheat was significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 8). The highest biological yield of wheat (9.30 t ha^{-1}) was found in BARI Gom 28 under late sown with Nitrobenzene condition, whereas the lowest biological yield of wheat (7.63 t ha^{-1}) was found in BARI Gom 33 under late sown with GA_3 condition. Foliar application of GA_3 improved biological yield by (1.38%) in BARI Gom 28. Islam *et al.* (2014) studied the impact of different concentration of GA_3 on wheat and found that 100ppm and 200ppm increased the biological yield by 12.33% and 16.44% respectively over control condition (no GA_3). Foliar application of Nitrobenzene improved biological yield by (6.77%) in BARI Gom 28, (6.49%) in BARI Gom 33, and (1.37%) in BARI Gom 30. Hossain *et al*. (2020) found that, application of Nitrobenzene increased biological yield by 12.25% in rice.

Heat stress reduced biological yield of wheat in BARI Gom 30 and BARI Gom 33 under late sown with GA_3 condition. Late sown plants were exposed to different temperatures and photoperiods during their life cycle compared to timely sown plants, which was a deviation from standard requirement. This reduced plant growth and development, resulting in less dry matter accumulation (Nagar *et al.* 2015) and ultimately decreased biological yield.

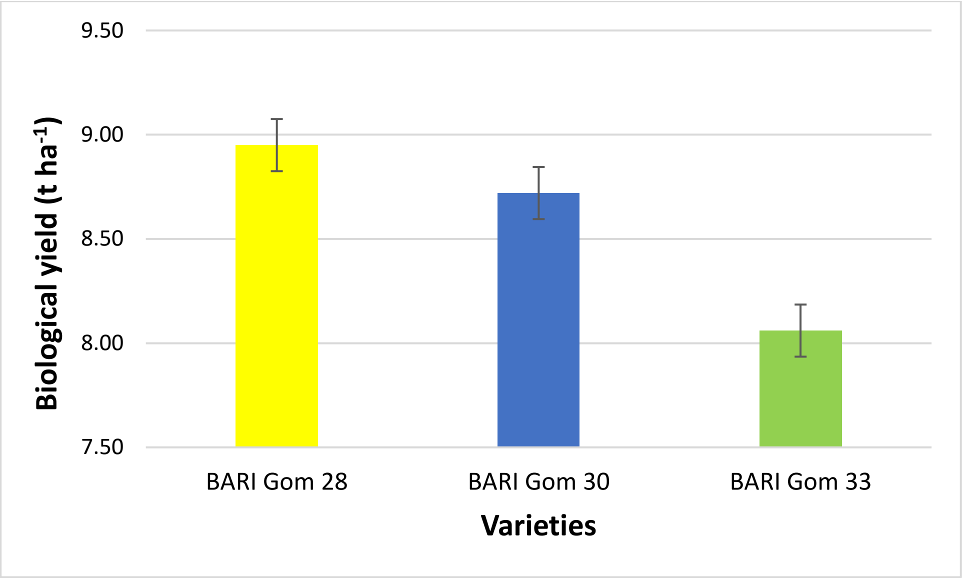

Figure 5.1 Effect of different varieties on biological yield

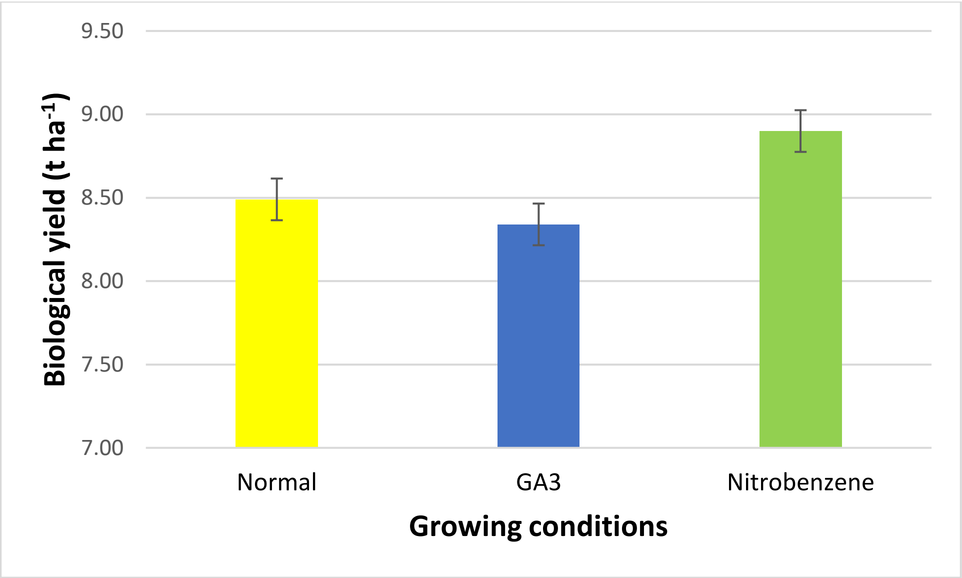

Figure 5.2 Effect of different growing conditions on biological yield

Table 8. Interaction effect of varieties and growing conditions on above ground biological yield of wheat

Wheat varieties	Growing conditions	Biological yield (t ha^{-1})	% change over normal
BARI Gom 28	Normal	8.71ab	-
	Late sown with GA_3	8.83a	+1.38
	Late sown with Nitrobenzene	9.30a	+6.77
BARI Gom 30	Normal	8.74ab	-
	Late sown with GA_3	8.56ab	-2.06
	Late sown with Nitrobenzene	8.86a	+1.37
BARI Gom 33	Normal	8.01bc	-
	Late sown with GA_3	7.63c	-4.74
	Late sown with Nitrobenzene	8.53ab	+6.49
Level of significance		*	
CV (%)		3.11	
Standard error		0.21	
Critical value		0.77	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.

* indicates significant at 5% level of probability

4.10 Grain yield (t ha^{-1})

Grain yield of wheat was significantly influenced by varieties (Figure 6.1). The highest grain yield was found in BARI Gom 33, which is statistically similar to BARI Gom 30, whereas the lowest grain yield was found in BARI Gom 28.

The growing conditions significantly affected the grain yield of wheat (Figure 6.2). The highest grain yield was found in Nitrobenzene condition, which is statistically similar to Normal condition, whereas the lowest grain weight was found in GA_3 condition, which is statistically similar to Normal condition.

Grain yield of wheat was significantly ($P<0.05$) influenced by the interaction effect of varieties and growing conditions (Table 9). The maximum grain yield of wheat (3.46 t ha^{-1}) was found in BARI Gom 33 under late sown with Nitrobenzene condition, whereas the minimum grain yield of wheat (2.95 t ha^{-1}) was found in BARI Gom 28 under late sown with GA_3 condition. Foliar application of GA_3 increased grain yield by (4.17%) in BARI Gom 30. Haque *et al.* (2022) found that foliar application of GA_3 improved grain yield by (1.47% and 1.18%) in Kanchan and BARI Gom-30, respectively under drought stress condition. Islam *et al.* (2014) studied the impact of different concentration of GA_3 on wheat and found that 100ppm and 200ppm increased the grain yield by 19.35% and 25.81% respectively over control condition (no GA_3). Foliar application of Nitrobenzene improved grain yield by (8.01%) in BARI Gom 30, (3.90%) in BARI Gom 33. Hossain *et al*. (2020) found that, application of Nitrobenzene increased grain yield by 22.66% in rice.

Reduction in grain yield observed in BARI Gom 28 under late sown condition. In BARI Gom 33, grain yield was reduced by (3.30%) under late sown with GA_3 condition. High temperature increased the rate of development, but at the same time, reduced the duration of crop growth and grain filling, number of spikes m^{-2}, ultimately leading to a significant reduction in yield (Reynolds *et al.* 2012).

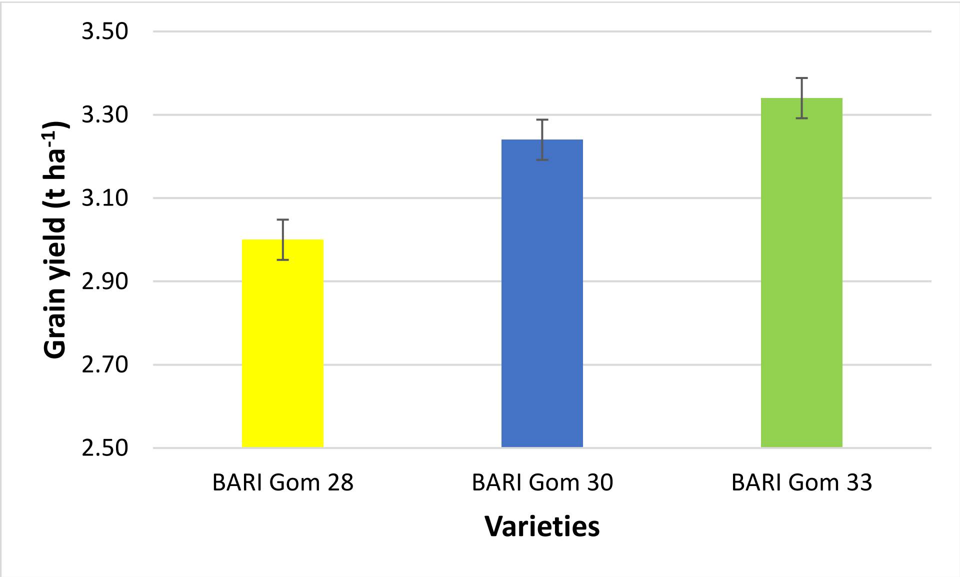

Figure 6.1 Effect of different varieties on grain yield

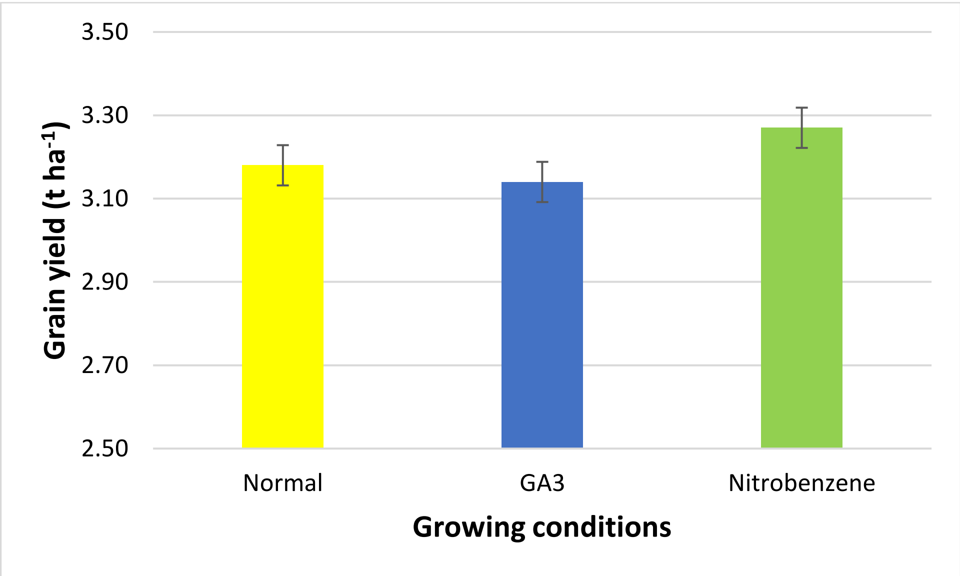

Figure 6.2 Effect of different growing conditions on grain yield

Table 9. Interaction effect of varieties and growing conditions on grain yield of wheat

Wheat varieties	Growing conditions	Grain yield (t ha^{-1})	% change over normal
BARI Gom 28	Normal	3.08bcd	-
	Late sown with GA_3	2.95d	-4.22
	Late sown with Nitrobenzene	2.97cd	-3.57
BARI Gom 30	Normal	3.12bcd	-
	Late sown with GA_3	3.25abc	+4.17
	Late sown with Nitrobenzene	3.37ab	+8.01
BARI Gom 33	Normal	3.33ab	-
	Late sown with GA_3	3.22abcd	-3.30
	Late sown with Nitrobenzene	3.46a	+3.90
Level of significance		*	
CV (%)		3.21	
Standard error		0.08	
Critical value		0.29	

In a column, values followed by similar letter(s) did not differ significantly by Tukey's test at 5% level of probability.
* indicates significant at 5% level of probability

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was conducted at the research field of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur during November 2022 to April 2023 to investigate the mitigating effect of GA_3 and Nitrobenzene on late sown wheat. The experiment was laid out in a factorial design with three replications. Two factors were used in the experiment. Factor A: three growing conditions (Normal, Foliar application of GA_3 under late sown condition, and Foliar application of Nitrobenzene under late sown condition). Factor B: three wheat varieties (BARI Gom 28, BARI Gom 30, and BARI Gom 33). Observations were made on SPAD value, canopy temperature, plant height, spike length, number of spikelets spike^{-1}, number of spikes m^{-2}, number of grains spike^{-1}, 1000-grain weight, above ground biological yield and grain yield. Interaction effect of growing conditions and wheat varieties significantly influenced the different physiological traits, yield and yield attributes of wheat except SPAD value, number of spikelets spike^{-1}, number of spikes m^{-2} .

Reduction in SPAD value was observed in BARI Gom 30 and BARI Gom 33 under late sown condition. Interestingly, BARI Gom 28 showed higher SPAD value in late sowing condition compared to normal growing condition. Highest SPAD value was found in BARI Gom 33 under normal condition and the lowest SPAD value was found in BARI Gom 33 under late sowing condition with Nitrobenzene, however they are not statistically different.

In late sown condition, increase in canopy temperature was observed in all the wheat varieties. Plants grown under normal condition maintained a cooler canopy temperature compared to late sown plants. The highest canopy temperature (34.16°C) was found in BARI Gom 28 under late sown with Nitrobenzene condition, and the lowest canopy temperature (29.7°C) was found in BARI Gom 33 under normal condition.

Reduction in plant height was observed due to late sowing in BARI Gom 30, however, foliar application of GA_3 improved plant height by (2.54%) in BARI Gom 28, foliar application of Nitrobenzene improved plant height by (4.41%) and (1.32%) in BARI Gom 28 and BARI Gom 33 respectively.

The longest spike length (11.88cm) was found in BARI Gom 33 under late sown with Nitrobenzene condition and the lowest spike length (9.91cm) was found in BARI Gom 30 under late sown with GA_3 condition. Reduction in spike length was observed due to late sowing in BARI Gom 30, however, foliar application of GA_3 improved spike length by (0.87%) in BARI Gom 28, foliar application of Nitrobenzene improved spike length by (2.34%) and (1.28%) in BARI Gom 28 and BARI Gom 33 respectively.

Late sowing reduced the number of spikelets spike^{-1} in all wheat varieties. The highest of spikelets spike^{-1} (16.23) was found in BARI Gom 28 under normal condition, and the lowest of spikelets spike^{-1} (13.93) was found in BARI Gom 30 under late sown with Nitrobenzene condition.

The highest number of spikes m^{-2} (225) was found in BARI Gom 28 under late sown with Nitrobenzene condition, whereas the lowest number of spikes m^{-2} (220) was found in BARI Gom 28 under late sown with GA_3 condition. Reduction in spike number was seen in BARI Gom 30 under late sown condition.

The highest number of grains spike^{-1} (42.33) was found in BARI Gom 33 under late sown with Nitrobenzene condition and the lowest of grains spike^{-1} (36.66) was found in BARI Gom 28 under late sown with Nitrobenzene condition. Foliar application of GA_3 improved grains spike^{-1} in BARI Gom 30 by (3.17%), and foliar application of Nitrobenzene improved grains spike^{-1} in BARI Gom 30 and BARI Gom 33 by (3.95%) and (6.49%) respectively.

The maximum 1000 grain weight of wheat (44.14g) was found in BARI Gom 33 under late sown with Nitrobenzene condition, whereas the minimum 1000 grain weight of wheat (40.07g) was found in BARI Gom 28 under late sown with GA_3 condition. Late sowing reduced the 1000 grain weight of wheat in BARI Gom 28. Foliar application of GA_3 improved 1000 grain weight by (1.06%) in BARI Gom 30 and (1.09%) in BARI Gom 33, and foliar application of Nitrobenzene improved 1000 grain weight by (1.80%) in BARI Gom 30 and (2.11%) in BARI Gom 33.

The maximum biological yield of wheat (9.30 t ha^{-1}) was found in BARI Gom 28 under late sown with Nitrobenzene condition, whereas the minimum biological yield of wheat (7.63 t ha^{-1}) was found in BARI Gom 33 under late sown with GA_3 condition. Foliar application of GA_3 improved biological yield by (1.38%) in BARI Gom 28, and foliar application of Nitrobenzene improved biological yield by (6.77%) in BARI Gom 28, (6.49%) in BARI Gom 33, and (1.37%) in BARI Gom 30. Late sowing reduced biological yield of wheat in BARI Gom 30 and BARI Gom 33.

The maximum grain yield of wheat (3.46 t ha^{-1}) was found in BARI Gom 33 under late sown with Nitrobenzene condition, and the minimum grain yield of wheat (2.95 t ha^{-1}) was found in BARI Gom 28 under late sown with GA_3 condition. Foliar application of GA_3 improved grain yield by (4.17%) in BARI Gom 30. Foliar application of Nitrobenzene improved grain yield by (8.01%) in BARI Gom 30, (3.90%) in BARI Gom 33. Reduction in grain yield observed in BARI Gom 28 under late sown condition. In BARI Gom 33, grain yield was reduced by (3.30%) under late sown with GA3 condition. BARI Gom 33 performed best among the late sown wheat varieties. Due to current cropping pattern, late sowing of wheat is somewhat inevitable in Bangladesh, and application of GA_3 and Nitrobenzene may help to mitigate the condition.

Based on the in-depth findings of this study, it may be concluded that

- Foliar application of GA_3 and Nitrobenzene improved wheat growth, yield and yield contributing characters.
- BARI Gom 33 performed best at late sown condition with Nitrobenzene.
- Foliar application of GA_3 and Nitrobenzene could be helpful for mitigating late sown wheat cultivation.

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APPENDICES

Appendix I: Characteristics of soil of the experimental site

Soil Ansalysis Report	
General characters	**Description**
Location	Crop Physiology and Ecology, HSTU, Dinajpur
AEZ	Old Himalayan Piedmont Plain (AEZ-1)
General soil type	Non-Calcareous Brown Floodplain Soil
Parent material	Piedmont alluvium
Soil series	Ranishankail
Drainage	Moderately well drained
Flood level	Above flood level
Topography	High land
Chemical characteristics	**Value**
pH	5.06
OC (%)	1.04
OM (%)	1.79
TN (%)	0.09
P (μg^{-1})	13.06
K (μg^{-1})	0.33
Mg (μg^{-1})	1.71
S (μg^{-1})	9.83
Zn (μg^{-1})	1.69
B (μg^{-1})	0.09
EC (dSm^{-1})	0.07
Salinity (dSm^{-1})	0.22

Appendix II: Analysis of variance of data on SPAD value, Canopy temperature, Plant height, Spike length and Number of spikelets spike^{-1}

Sources of variation	Degrees of freedom	Mean square				
		SPAD value	Canopy temp.	Plant height	Spike length	Number of spikelets spike^{-1}
Replication	2	0.65	0.37	1.73	0.02	0.29
Variety	2	3.68	1.99	209.05	8.11	3.91
Treatment	2	103.45	41.65	6.05	0.09	2.66
Variety × Treatment	4	3.79*	0.21*	7.36*	0.07*	0.09^{NS}
Error	16	0.43	0.12	1.35	0.01	0.78
Total	26					

^{NS} indicates non-significant
* means significant at 5% level of probability

Appendix III: Analysis of variance of data on Number of spikes m^{-2}, Number of grains spike$^{-1,}$ Thousand grain weight, Above ground biological yield and Grain yield

Sources of variation	Degrees of freedom	Mean square				
		Number of spikes m^{-2}	Number of grains spike^{-1}	Thousand grain weight	Above ground biological yield	Grain yield
Replication	2	24.51	0.03	0.00	0.03	0.01
Variety	2	12.74	77.14	27.92	1.92	0.27
Treatment	2	9.85	1.14	0.61	0.74	0.04
Variety × Treatment	4	52.14^{NS}	2.64^{NS}	0.27*	0.11*	0.03*
Error	16	139.48	2.70	0.03	0.07	0.01
Total	26					

^{NS} indicates non-significant
* means significant at 5% level of probability