RESPONSE OF CLIMATE RESILIENT WHEAT VARIETIES UNDER VARYING SOWING DATES IRRIGATION AND NITROGEN APPLICATION

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CERTIFICATE

This is to certify that the thesis entitled, *"RESPONSE OF CLIMATE RESILIENT WHEAT VARIETIES UNDER VARYING SOWING DATES IRRIGATION AND NITROGEN APPLICATION"* submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, in the partial fulfillment of the requirements for the degree of *DOCROR OF PHILOSOPHY IN AGRONOMY, embodies the result of a piece of bona fide research work carried out by MD. MASHIUR RAHMAN,* Registration No.13-05796 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated:
Place: Dhaka, Bangladesh

(Prof. Dr. Md. Jafar Ullah)
Chairman
Advisory Committee

DEDICATED

TO

MY PARENTS

AND

WHO WORK TO FEED THE

PEOPLE OF THE WORLD

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Abstract

Field experiments were conducted where four at Sher-e-Bangla Agricultural University, Dhaka and the rest one at at Shahpur, Charghat, Rajshahi to identify climate change resilient heat tolerant varieties, suitable sowing dates, irrigation regimes and application of supplemental N of wheat during two rabi seasons. The first experiment conducted in 2014-15 rabi season consisted of two varieties (V_1= BARI Gom 21,V_2=BARI Gom 23) four sowing dates (S_1= 10 November, S_2= 20 November, S_3= 30 November, S_4= 10 December). The second experiment implemented in 2014-15 rabi season with variety BARI Gom 26 comprised three irrigation levels (I_1 = field capacity, I_2 = 50% of the field capacity and I_3 = 25% of the field capacity), four sowing dates (S_1=10 November, S_2=20 November, S_3=30 November and S_4=10 December) and two top dressing of nitrogen at the reproductive stage (N_1 = no nitrogen application, N_2=20% N of the basal as top dressing). Third experiment carried out in 2014-15 rabi season with BARI Gom 25 focused on four sowing dates (S_1=10 November, S_2= 20 November, S_3= 30 November and S_4=10 December), three irrigation levels (I_1=Irrigation at heading stage, I_2=Irrigation after 10 days of I_1, I_3=Irrigation after 10 days of I_2) and two supplemental N application at the post heading stage (N_0= no supplemental N application and N_1=application of 20% supplemental N). The fourth and fifth experiments were implemented during rabi 2016-17 season at SAU and Rajshahi, respectively to examine phenology, chlorophyll, canopy temperature, growth and yield as influenced by sowing dates (S_1= November 20, S_2= November 30, S_3= Dec 10, S_4= Dec 20, S_5= Dec 30) and varieties (V_1= BARI Gom 25,V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29, V_6= BARI Gom 30). In experiment 1 significantly, the highest seed yields (4.23 - 4.27 t ha^{-1}) were obtained with variety BARI Gom 23 when sown on November 10 and November 20. In experiment 2 significantly the highest grain yields (3.2 to 4.3 t ha^{-1}) were obtained with November 10 and November 30 sowing treatments. Irrigation keeping the soil at field capacity level showed significantly highest grain yield (3.95 t ha^{-1}). In this experiment the combination treatment $I_1S_2N_2$ had the highest grain yield (4.81 t ha^{-1}) which was significantly different than other combination treatments. This was attributed to the significantly higher number of grain $spike^{-1}$ (50.83) and 1000 seed weight (50.57 g) of the treatment $I_1S_2N_2$compared to the lowest grain $spike^{-1}$ (46.83), 1000 seed weight

(48.90 g) when irrigated at 25% water of the field capacity . In experiment 3 November20 sowing gave the highest grain yield. Irrigation application at 10 days after heading produced the highest grain yield (3.9 t ha^{-1}) which was at par with irrigation at heading. The higher grain yield was attributed to the higher values of grains $spike^{-1}$ (43.63) and 1000 seed weight (53.90 g). The combined effect of sowing date and irrigation showed that November 20 sowing with giving irrigation either at heading or 10 days after heading had significantly the highest grain yield (4.81 t ha^{-1}). An extra irrigation 10 days after heading and supplying supplemental 20% N at post heading stage in experiment 3 had seed yields (4.6-4.81 t ha^{-1}) which was significantly higher than the lowest grain yield of November 10 sowing (3.3 t ha^{-1}) under the above conditions. The November 20 sowing with extra N application had higher grain yield (4.47 t ha^{-1}). Again the combination treatments $I_1S_2N_2$ and $I_2S_2N_2$ had significantly higher seed yields (4.480 and 4.600 tha^{-1}respectively) than other combined treatments. In Rajshahi (in experiment 4), the sowing date treatment November 30 and December 10 gave significantly higher grain yields (at or over 3.52 t/ha). While in experiment five the varieties BARI Gom 28 and BARI Gom 30 at SAU had significantly higher but identical seed yields (3.72 to 3.81 t ha^{-1}). The correlation analysis using the data of yield and yield attributes of the experiment 2 and 3 at SAU, showed that higher correlations of grain yield were found with the number of spikelet $spike^{-1}$ (r=0.820 - 0.814), 1000 seed weight (0.806-0.819), biological yield (r=0.802-0.912) and harvest index (r=0.802-0.912). The linear as well as polynomial regression showed that the higher temperature at the vegetative stage had positive impact on grain weight/plant and grain yield ha^{-1} (slope+6 to 2086, R^2=0.120 to 0.957), while at the anthesis to maturity, values of most grain yield and yield attributes decreased due the increase in ambient temperatures. The grain yield was higher at minimum and average temperature not above 15.5 and 22.5°C, respectively (R^2=0.922-0.992). The polygonal regression also revealed that for obtaining the maximum yield/ha, the maximum temperature should not be above 25.5°C before anthesis while the maximum, minimum and average temperature after anthesis should not be beyond 29.5, 15.5 and 22.5°C, respectively.

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%	= Percent
@	= At the rate
0C	= Degree Centigrade
AEZ	= Agro Ecological Zone
AGR	= Absolute Growth Rate
BARC	= Bangladesh Agricultural Research Council
BARI	= Bangladesh Agriculture Research Institute
CBR	= Cost Benefit Ratio
CIMMYT	= International Wheat and Maize Research Institute
cm	= Centimeter
CV	= Coefficient of Variance
cv.	= Cultivar
DAS	= Days after sowing
df	= Degrees of freedom
DM	= Dry matter
DMP	= Dry matter production
et al.	= and others (**et alia**)
etc.	= etcetera
FAO	= Food and Agriculture Organization
G	= gram
HI	= Harvest Index
i.e.	= That is
kg	= Kilogram
$Kgha^{-1}$	= Kilogram per hectare
LSD	= Least Significance Difference
m	= Meter
PH	= Hydrogen ion conc.
MOP	= Muriate of Potash
R	= Regression
r	= Correlation coefficient
SRDI	= Soil Resource and Development Institute
tha^{-1}	= Ton pre hectare
TSP	= Triple Super Phosphate
Viz.	= Namely
WRC	= Wheat Research Centre

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CHAPTER 1

INTRODUCTION

Wheat has contributed more calories and protein to the world's diet than any other food crop (Hanson *et al*., 1982).It is one of the most important cereal crops cultivated all over the world across the exceptionally diverse range of environments is an important food crop (WRC, 2009). Wheat accounts for a fifth of humanity's food and is second only to rice as a source of calories in the diets of consumers in developing countries and is first as a source of protein (Braun *et al*. 2010). The total area under wheat started increasing since 1961 (125.6thousand ha), spurred in 1970s because of introduction of modern seed-water-fertilizer technologies (Rahman, 2009) and then reached at pick during 2000 (832.2 thousand ha) in the country. Thereafter its production declined sharply in 2006 (479 thousand ha) although the world production had a record pick in 2008/09 which was attributed to farmer's positive attitudes due to a record rise in wheat prices (Allen, 2008).

1.1 Constraints of wheat production in Bangladesh

It was revealed that a host of natural as well as managerial factors are affecting wheat the reduction in wheat yield was estimated at late seeding at the rate of 1.3% per day of delay after November 30th (Ahmed and Meisner, 1996). Wheat yield with recommended package is 3.2 t/ha whereas actual production at farm level varies between 1.3 to 1.9 t/ha. Nevertheless, best practice farmers can produce 2.8 t/ha when compared with 1.9 t/ha by the average farmer, thereby, revealing a 29% yield gap (Hasan, 2005).

1.2 Botany

The cultivated wheat falls under the Kingdom Plantae (Plants), Subkingdom, racheobionta (Vascular), plants, Super division Spermatophyta (Seed plants), Division, Magnoliophyta (Flowering plants), Class Liliopsida (Monocotyledons), Subclass Commelinidae, Order Cyperales, Family Poaceae(Grass family), Genus *Triticum* L., Species *Triticum aestivum* L. (common wheat).

The plants bear this edible grain in dense spikes. The culm of the mature wheat plant is a hollow, jointed cylinder that comprises 3-6 nodes and internodes. The wheat leaf consists of the sheath, blade, ligules and auricle. The leaf sheaths normally enclose the lower 2/3 of culm. A maximum of 5-7 seminal roots may function throughout the life of the wheat plant.

Tillers arise from the axils of the basal leaves. At anthesis, only some of the tillers that have developed survive to produce an ear. Others die and may be difficult to find in the mature plant.

The seed, grain or kernel of wheat (more pedantically, the caryopsis) is a dry indehiscent fruit. The dorsal side (with respect to the spikelet axis) is smoothly rounded, while the ventral side has the deep crease. The embryo or germ is situated at the point of attachment of the spikelet axis, and the distal end has a brush of fine hairs. The embryo is made up of the scutellum, the plumule (shoot) and the radicle (primary root). The scutellum is the region that secretes some of the enzymes involved in germination and absorbs the soluble sugars from the breakdown of starch in the endosperm. Surrounding the endosperm is a metabolically active layer of cells or the aleurone layer, the testa or seed coat and the pericarp or fruit coat. In the plumule region of the embryo, the coleoptile, about four leaf primordia and the shoot apex or dome can be distinguished.

1.2 Usefulness

Wheat grain is the main staple food for about two third of the total population of the world. (Hanson et. al.,1982). It supplies more nutrients compared with other food crops. Wheat grain is rich in food value containing 12% protein, 1.72% fat, 69.60% carbohydrate and 27.20% minerals (BARI, 2006).Generally wheat supplies carbohydrate (69.60%), protein (12%), fat (1.72%), minerals (16.20%) and also other necessary nutrients in trace amount (BARI, 1997).It supplies more nutrients compared with other food crops which contain 12% protein, 1.72% fat, 69.60% carbohydrate and 27.20% minerals (BARI, 2006).

1.3 World cultivation statistics

Wheat production was increased from 592 mil metric tons in 1990/91 to 759.75 mil metric tons in 2017/18 which once upon a time was ranked below rice and maize in case of production (FAO, 2015;Statista, 2018). In the developing world, need for wheat will be increased 60 % by 2050 (Rosegrant and Agcaoili 2010). The International Food Policy Research Institute projections revealed that world demand for wheat will increase from 552 million tons in 1993 to 775 million tons by 2020 (Rosegrant *et al*.1997).China leads world, in terms of area under wheat cultivation, followed by India, Russia and USA (World Atlas, 2018). The largest area of wheat cultivation in the warmer climates exists in the South-East Asia (Dubin and Ginkel, 1991).Wheat production was increased 22% from 2000 to 2013 which was ranked below rice and maize in case of production (FAO, 2015).

1.5 Bangladesh scenario in respect of wheat area and production

Bangladesh, although nearing to self-sufficiency in rice production at present, was traditionally a food deficit country dominated by rice production, depended on wheat imports immediately after independence in 1971 which continued well into the late 1980s (Rahman, 2009). Such a resulted in a gradual change in dietary habits of Bangladeshi people. During the 1980s, the stagnation occurred due to natural constraints such as high temperature during the growing period of wheat and pre-monsoon rainfall before harvesting which badly affected the enthusiasm of the farmers previously observed in the 1970s (Ahmed and Meisner, 1996).

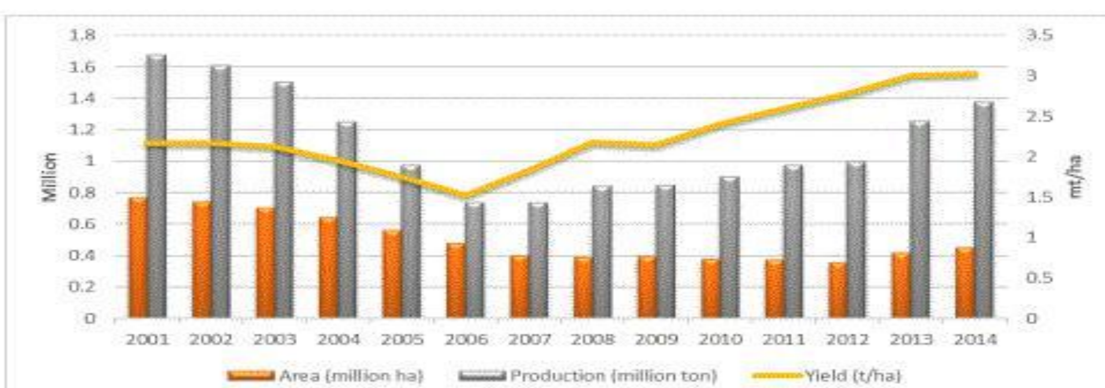

Fig. 1.1. Area, production and yield of wheat cultivation in the period 2001-14

In terms of production, Bangladesh ranked third after India, contributing together 30% of total wheat production of the world and 67% of Asia (Tang *et al,* 2013). It contributes to the national economy by reducing the volume of import of cereals for fulfilling the food requirements of the country (Razzaque *et al.*, 1992). Generally wheat supplies carbohydrate (69.60%) and reasonable amount of protein (12%), fat (1.72%), and also minerals (16.20%) and other necessary nutrients (BARI, 1997). In Bangladesh, wheat is the second most important cereal crop (FAO, 1997).

Its acreage shrank starting from 2002 continuing to 2012 again started to rise from 2013 mostly due to farmer's choice. However its productivity has been increasing from the massive drop since 2006 (1.5 t/ha) and continuing till to date (over 3 t/ha) (Rashi and Hossain, 2016). In 2017/18 growing season as many farmers switched to rice to profit from its high prices the acreage dropped again to its lowest compared to those of the recent years standing at 3.49 lakh hectares, down 79 percent year-on-year. Besides, wheat cultivation was discouraged in the southwestern districts due to blast infection. The consequence of which Bangladesh has to import 56.90 lakh tons of wheat in fiscal 2016-17. Wheat production declined 3 percent year-on-year to 13.11 lakh tons in fiscal 2016-17 on account of lower acreage, according to the Bangladesh Bureau of Statistics (The Daily Star, Feb 09, 2018).

Bangladesh has developed and disseminated 42 wheat varieties to the farmers since 1973 among which the most disseminated ones are BARI Gom 24 (Prodip), BARI Gom 21 (Shatabdi), BARI Gom 26, BARI Gom 23 (Bijoy), BARI Gom 25, BARI Gom 19 (Sourav), BARI Gom 18 (Protiva), and BARI Gom 27 etc. Among those adopted varieties, BARI Gom 24 (Prodip) was highly adopted variety (41.03%) followed by Shatabdi (24.97%), BARI Gom 26 (11.43%), Bijoy (11.06%) and BARI Gom 25 (4.45%). Others varieties such as Sourav, Protiva, and BARI Gom 27 etc. occupied 7.07% of the total wheat areas in Bangladesh. However, due the temperature rise some heat tolerant varieties has become popular such as BARE Gom 25, BARI Gom 26, BARI Gom 27, BARE Gom 29 and BARIGom 30 (Rashid and Hossain, 2016).

1.6 Problems of wheat production in Bangladesh

The yield per hectare of wheat in Bangladesh is lower than other wheat growing countries in the world due to various problems. World wheat production will reduce owing to global warming and developing countries like Bangladesh will be adversely affected (IPCC, 2007; CIMMYT-ICARDA, 2011, CGIAR, 2009 and Andarzian *et al*., 2008). In Bangladesh wheat is sown after the harvest of T. aman starting from November in the northern districts and December in the southern districts, the both of region undergoes a high temperature during the grain filling stage leading to yield losss.

1.7 Climatic demand

Wheat is grown under a wide range of climatic and soil conditions ranging from humid to arid, subtropical to temperate zone, best chose in clayey loam soils in areas of well distributed rainfall between 40 and 110 cm which is congenial for its growth. Depending on variety and weather conditions, 100-120 days are required from sowing to harvest (Banglapedia).

Photosynthesis in wheat remains maximum between 22 and 25^0C (Kobza and Edwards, 1987) and decreases sharply above 35^0C (Al-Khatib and Paulsen, 1990) which happens in February to March in Bangladesh. The optimum temperature for wheat anthesis and grain filling ranges from 12 to 22°C.

High temperature not only hastens the phenological stages of crop development but also reduces duration of grain filling (Farooq *et al*, 2011) and affects reproductive mechanisms which ultimately results in yield reduction (Innes *et al*, 2015). There is a report that high temperature decreases yield by 50% at 37.6 and 37.2^0C at anthesis and booting stages under well watered conditions, respectively (Alghabari *et al.*, 2015). Wheat yield losses due to heat stress and dry stress average 1.28% per annum in China (Chen *et al*., 2016) and the negative trend of decreasing wheat yields was found by Gourdji *et al*. (2013) across Central and South Asia and South America, for recent decades (1980–2011). Resistance to heat stress is one of the research priorities of various wheat crop improvement programmes.

1.8 Agronomy of wheat production

Yield and quality of seeds of wheat are very low in Bangladesh. The low yield of wheat in Bangladesh however is not an indication of low yielding potentiality of this crop, but may be attributed to a number of reasons viz. unavailability of quality seeds of high yielding varieties, delayed sowing after the harvest of transplanted aman rice, fertilizer management, disease and insect infestation and improper or limited irrigation facilities (Ahmed and Meisner, 1996).

Variety

For better production of wheat proper variety selection is very important. Under optimum sown condition, differences among the genotypes were found to be significant in respect of grain yield, biomass at anthesis, ground cover at 4-5 leaf stage, days to anthesis, maturity and flag leaf emergence, plant height, grain filling duration and 1000-grain weight, and insignificant for biomass at final harvest, ground cover at anthesis, chlorophyll content of the flag leaf (Rahman *et al*., 2009; Alam and Rahman, 2008). Significant variations among the genotypes were observed for grains spike, 100-grain weight and grain yield main spike. Varietal characters may apply mechanisms to cope with heat stress.

Different varieties respond differently to sowing time and the prevailing environment condition during the growing season. Recently, efforts were taken to increase the yield of wheat in Bangladesh by releasing a number of high yielding varieties. In Bangladesh although some varieties have been identified for late sowing condition (Islam *et al*., 1993 and Ahmed *et al*. 1989).

Irrigation need

Irrigation plays an imperative role for optimum growth and development of wheat. Idris *et al*. (1983) stated that uneven distribution is responsible for foiling synchronization with water requirement of wheat in the entire plain of the country. Water requirement for a crop depends on the variation in climatic conditions all over the growing season (Doorenbos and Pruitt, 1977). The difference between available moisture and irrigation requirements lies in the losses in conveyance, evaporation and seepage, which must be considered when reckoning the irrigation requirements (Prasad *et al*., 1988). Irrigation frequency also has a significant influence on growth and yield of wheat (Khajanij and Swivedi, 1988; Ahmed and Elias, 1986). However, irrigation at the reproductive stage has not been well studied especially under drought prone situation.

Sowing dates

In Bangladesh best time of sowing of wheat ranges from15 to 30 November, but it can be sown up to 7 December in Northern part of Bangladesh due to cold weather compared to other parts of the country. Farmers can't sow seeds in optimum time as they have to sow this crop after harvesting of transplanted (T) aman rice. For this reason this crop is even sown in delay up to January in some areas (BARI, 2006). Too early sowing makes plant weak having poor root system due to too cold weather after sowing. In late sowing condition, wheat crop experiences high temperature stress resulting in irregular germination, death of embryo and decomposition of endosperm for increasing activities of bacteria or fungi and ultimately reduced yield reducing number of tillers, number of grains spike-1and grain yield (Ansary *et al*., 1989; Rajput and Verma, 1994). Indexmundi (2011) reported that heat is the greatest threat to food security in Bangladesh where major wheat area under rice-wheat cropping system (Badruddin *et al*., 1994). To avoid the effect of heat stress the alternative way is to find heat tolerant varieties and sowing wheat in such a time so as to avoid heat flux during the grain filling period.

1.9 Objectives of this research work

Keeping the above points in view, the present investigation was carried out with the following objectives:

(i) To detect appropriate sowing time preferable for the heat tolerant wheat varieties so as to set climate resilient management.

(ii) To identify short duration heat tolerant late variety(ies)of wheat in Bangladesh so as to increase wheat productivity under the ever increasing temperature at the reproductive stage.

(iii) To evaluate the amount and timing of irrigation so as to cope with the soil moisture depletion under increased ambient temperature especially at the reproductive stage of wheat.

(iv) To investigate the effect of extra nitrogen application at post anthesis stage of the late varieties of wheat.

(v) To find relationships between ambient temperature with the growth, phenology and yield attributes.

CHAPTER 2

REVIEW OF LITERATURE

In this chapter approach has been made to review the relevant research information of wheat cultivation taking consideration of both the world and Bangladesh aspects. Literature on the influence of varieties, irrigation, sowing time and nitrogen application on growth and yield of wheat especially in the short duration late planting varieties have been given importance while reviewing.

2. 1 Sowing time

The optimum time is one of the major non-monitory inputs for enhancing wheat production. Yield of crop is the function of some yield contributing parameters. Sowing time has a remarkable effect on yield of wheat. The yield and yield parameters of wheat varied from location to location due to the prevailing weather situation during pre-antesis and post-anthesis development. Haider (2002) conducted an experiment on wheat and observed that plants of all cultivars of wheat sown in 15 November became taller than December 5 sown plants under each irrigation regimes. Chowdhury (2002) also observed that plant height was reduced due to late sowing. Highest plant height was obtained in plant sown in first November at the final harvest. But at 60 DAS highest plant height was observed in plants sown on 15 December.

Twelve wheat genotypes were tested by Sial *et al*. (2005) for yield and quality parameters at two levels of sowing dates i.e., normal (18^{th} November) and late sowing (11^{th} December). They observed that with the delayed planting, the development of plant organs and transfer from source to sink were remarkably affected, which was reflected by overall shortening of plant heights. Growth and yield response of three wheat varieties (Suliman-96, Chakwal-97 and Inqalab-91) to various sowing times was studied by Qasim *et al*. (2008)at Karakoram Agricultural Research Institute, (Northern Areas) Gilgit, Pakistan under three sowing dates viz., November 15, November, 30 and December, 15. In that study it was found that the early planted crop had maximum plant heights (79.81 cm).

In order to optimize time of sowing of wheat variety Hashim-8, an experiment was conducted by Baloch *et al*. (2010) at the Agricultural Research Institute, Dera Ismail Khan on different sowing dates viz. October-25, November-10, November-25, December-10 and December-25 with different seeding rates. Data indicated that sowing wheat on October-25 and November-10 produced the highest plant height, which subsequently decreased with successive sowing dates. Another field experiment was conducted by Zia-Ul-Hassan *et al*. (2014) to evaluate the response of high yielding varieties against varying sowing dates under rainfed conditions at Adaptive Research Farm, Bhaun, Chakwal. Treatments were four sowing dates, viz. D_1 (October 15), D_2 (October 30), D_3 (November 15), D_4 (November 30), and five varieties, viz. GA 2002, Chakwal 50, Farid 2006, Wafaq 2001 and Sehar 2006). The results showed that sowing dates were significant in respect of having difference in plant height.

Chowdhury (2002) observed that average tillers plant^{-1} became higher when wheat was sown in 15 November and the second highest number were produced from November 30 sown plants. The lowest number of tillers plant^{-1}was obtained when sown on 15 December. Ahmed *et al*. (2006) reported that number of tiller per plant enhanced significantly with early sowing (30 November) in all varieties in the consecutive two years as compared to the later sowings. Twelve wheat genotypes of wheat were assessed by Sial *et al*. (2005)for yield and quality parameters at two levels of sowing dates i.e., normal (18th November) and late sowing (11th December). It was revealed that with delayed planting, the development of plant organs and transfer from source to sink were remarkably affected, which was reflected by overall reduction of yield components.

A field experiment was conducted by Ahmed *et al.* (2006) at Farming System Research and Development (FSRD) site, Chabbishnagar, Godagari, Rajshahi under rainfed condition during rabi seasons to find out the suitable variety and sowing time (30 November, 15 December and 30 December). They concluded that number of tiller increased significantly with early sowing (30 November) in all varieties in two consecutive years.

A study was undertaken by Mohsen *et al*. (2013) to determine the effects of sowing dates on growth and yield components of different wheat cultivars in Iran. Five sowing dates i.e. October 31, November 15 and 30, December 15 and 30 were in main plots, whereas five wheat cultivars were in sub plots. Results showed that the effect of sowing date was significant on all parameters.

A field experiment was conducted by Aslam *et al*. (2013)at Adaptive Research Farmin Pakistan. Effect of four planting dates i.e. 25th October, 5th November, 15th November and 25th November was studied on yield and yield components of wheat. Average of two years data showed that 5th November sowing significantly produced maximum tillers (359 m^{-2}) followed by 15th November sowing. The data further indicated that 25th October sowing produced minimum tillers (232 m^{-2}) due to high temperature, not suitable for growth of wheat plant.

Field experiments were conducted by Suleiman *et al*. (2014) at the Demonstration Farm of College of Agriculture, University of Bahri to assess the performance of different wheat cultivars under different sowing dates. The experiment comprised of four dates of sowing, namely 1st November, 15th November, 1st December and 15th December and five wheat cultivars. The sowing dates showed significant effect on yield components that decreased

with delay in sowing dates and the highest values were obtained when cultivars sown on 1st November and 15th November.

Haider (2007) carried out an experiment with three different sowing dates on growth of four varieties of wheat that crop growth rate (CGR), relative leaf growth rate (RLGR) and specific leaf area (SLA) were higher in the early sown plants compared to late sown ones.

Ram *et al*., (2012) conducted a field experiment at Ludhiana (Punjab) using seven sowing dates (October 25, November 5, November 15, November 25, December 5, December 15 and December 25) with six varieties and reported that October 25 sowing recorded the highest grain yield which was statistically at par with November 5, whereas December 25 gave thelowest yield. Early sowing resulted in better development of the grains due to longer growing period, as timely planted wheat had more time for the dry matter accumulation to produce the higher grain yield.

Aslam *et al*. (2013) conducted an experiment at Adaptive Research Farm, of Pakistan during winter seasons. Effect of four planting dates i.e. 25^{th} October, 5^{th} November, 15^{th} November and 25^{th} November was studied on yield and yield components of wheat. Average of two years data showed that 5^{th} November sowing significantly increase in yield was associated with progressive increase in all growth components. Zia-Ul-Hassan *et al*. (2014) conducted a field experiment to evaluate the response of high yielding varieties against varying sowing dates under rainfed conditions at Adaptive Research Farm, Bhaun, Chakwal. The treatments of the experiment were four sowing dates, viz. D_1 (October 15), D_2 (October 30), D_3 (November 15), D_4 (November 30), and five varieties. The results showed that sowing dates remained significant on spike length, spikelets spike^{-1} and grains spike^{-1} and early sowing produced the best one.

A study was undertaken by Mohsen *et al*. (2013)to determine the effects of sowing dates on growth and yield components of different wheat cultivar in Iran. Five sowing dates i.e. October 31, November 15 and 30, December 15 and 30 were in main plots, whereas five wheat cultivars were in sub plots. Results showed that the effect of sowing date was significant on all parameters.

Alam *et al*. (2013) conducted an experiment at Ranchi (India) with two dates of sowing (November 20 and December 20) and five wheat varieties (Raj 4229, K

0906, K 0307, HD 2733 and DBW39) and concluded that November 20 sown crop resulted in significantly higher plant height, dry matter, leaf area index, days to maturity and total tillers m^{-2} than

December 20 sown crop. Accumulation of maximum growing degree days (2236) were recorded for early sowing date (September 23), resulted in the highest plant height and growth of wheat crop and grain growth parameters decreased to 1398 for late sowing. The December 11 sowing date accounted for lowest growing degree days (1398) from sowing to maturity stage.

Mumtaz *et al*. (2015) conducted an experiment at Bahawalpur (Pakistan) in which six selected varieties were sown at six different sowing date (November 1, November 11, November 21, December 1, December 11, December 21) and concluded that wheat sown on November 11 performed better with respect to days taken to booting, heading, anthesis and maturity, germination count/m2, number of tillers m^{-2}, plant height, number of grains/spike, 1000 grains weight and grain yield. It was also revealed that late sowing of wheat caused reduction in these attributes.

Pyare *et al.,* (2015) conducted an field experiment at Kanpur using three dates of sowing (December 15, December 25 and January 5) and revealed that December 15 gave significantly higher growth attributes viz., plant height, fresh weight, dry weight, number of tillers m^{-2}, productive tillers m^{-2} and unproductive tillers m^{-2}over rest of the sowing dates during both the years of experiment.

Sattar *et al*. (2015) in an experiment at Faisalabad (Pakistan) found that November 10 sown crop took maximum days and growing degree days to anthesis, grain filling and maturity, heat use efficiency was also higher in November 10 sown crop. From the above discussion it can be said that timely sown conditions have favorable effect on the growth of wheat crop. Early sowing of wheat resulted in better growth parameters like plant height, tillers and more days to booting, heading and maturity, fresh weight and dry weight. Timely sowing also resulted in higher growing degree days, chlorophyll content index (%) and canopy temperature than late sown conditions.

Suleiman *et al*., (2014) studied four dates of sowing of wheat (November 1, November 15, December 1 and December 15) on five wheat varieties at Bahri (Sudan) and revealed that highest tillers/m2, days to 50% heading and days to 95 % maturity were recorded under November 15 sowing crop, which was statistically at par with November 1 sowing but significantly higher than late sown conditions.

In a similar experiment conducted by Hossain *et al.,* (2011) in Bangladesh, using eight dates of sowing (November 8, November 15, November 22, November 29, December 6, December 13, December 20 and December 27) and eight wheat varieties and concluded that highest days to physiological maturity and harvest maturity were recorded under November 8 sowing crop which were significantly higher than late sown conditions.

Rahman (2009) reported that grain yield, biomass at anthesis, ground cover at 4-5 leaf stage, days to anthesis, maturity and flag leaf emergence, plant height, grain filling duration and 1000-grain weight were obtained significantly due to sowing in optimum time (November among genotypes Whereas because of the late sown condition (December 21) grain yield, biomass at anthesis, ground cover at 4-5 leaf stage were influenced non-significantly owing to differences among the treatments.

A study was undertaken by Mohsen *et al*. (2013)to determine the effects of sowing dates on growth and yield components of different wheat cultivar in Iran. Five sowing dates i.e. October 31, November 15 and 30, December 15 and 30 were in main plots, whereas five wheat cultivars were in sub plots. Results showed that the effect of sowing date was significant on all parameters.

Seven wheat varieties were evaluated at four sowing dates and found that early sowing maximized the baking quality and productivity of wheat at Parana, Brazil (Silva *et al.,* 2014). From the above discussion it can be concluded that late sown conditions improve the protein content in grain, as compared to early sown conditions due to higher thermal conditions at reproductive stage of late sown wheat. However, hectoliter weight, chlorophyll content, membrane thermo stability index and 1000-grain weight was higher in case of early sown conditions. Changing the sowing time influenced the amount of total protein and leaf chlorophyll content, probably driven by the differential thermal conditions prevailing during the grain filling period **(**Jat *et al*., 2013**).** Kaur *et al*., (2010) conducted an experiment at Hisar (Haryana) with three dates of sowing (November 15, December 5 and December 25) and found that December 25 sown crop gave the highest protein and gluten content, whereas hectoliter weight and grain yield was higher in case of November 15 sown crop. November 20 sown crop resulted in higher chlorophyll content, membrane thermo stability index and 1000-grain weight, in an experiment conducted by Singh *et al.,* (2014) at Varanasi (India). Subedi *et al*., (2007) conducted an experiment at Ottawa (Canada) using three dates of sowing (10 days interval starting from last week of April) and revealed that grain protein content increased by 6 to 17% in all late planting dates than the early plantings, whereas grain yield was reduced by 15 to 45% in three out of four site-years.

Rahman *et al*. (2009) reported that the mean chlorophyll content index (%) continued to increase up to 60 days after sowing and then it declined towards maturity. Different sowing dates significantly influenced the chlorophyll content index (%) at all crop growth stages. The reason for highest chlorophyll content index in timely sowing i.e. D1 (45th MW) may be the enhanced vegetative development of crop. At 60 days after sowing genotype G6 (AKAW-3931-2) recorded significantly higher chlorophyll content index (%). Genotype G11 (LOK-1) recorded significantly lower chlorophyll content index (%). Twelve wheat genotypes bred at this Institute were assessed by Sial *et al*. (2005)for yield and quality parameters at two levels of sowing dates i.e., normal (18^{th} November) and late sowing (11^{th} December). With delayed planting, the development of plant organs and transfer from source to sink were remarkably affected, which was reflected by overall reduction yield components.

Zende *et al*. (2005) showed that the growth, yield and yield attributes, except for the spike length significantly increased when durum wheat crops were sown on 15 November compared with those sown on 1 December and 15 December.

A study conducted by El-Gizawy (2009) at Egypt with three dates of sowing (November 1, November 15 and November 30). In another study, October 20 sowing resulted in significantly higher plant height, 1000 grain weight, biological yield and grain yield, was found by Khan *et al.*, (2015) at Dera Ismail Khan, Pakistan.

Field experiments were conducted by Suleiman *et al*. (2014) at the Demonstration Farm of College of Agriculture, University of Bahri to assess the performance of different wheat cultivars under different sowing dates. The experiment comprised of four dates of sowing, namely 1st November, 15th November, 1st December and 15th December and five wheat cultivars. The sowing dates that used in this experiment shown significant effect on yield components that decreased with delay in sowing date and the highest values were obtained when cultivars sown on 1st November and 15th November. This indicated that late sowing shortened the development phases of wheat and adversely affected the grain development and yield contributing characters.

Hakim *et al*. (2012) showed that all genotypes were significantly influenced by high temperature stress in late and very late sowing conditions shortening days to heading and maturity resulting in lowering yield of wheat. They also reported that genotype 'E-8' obtained maximum yield (6245 kg ha-1) whereas lowest yield was observed in late (5220 kg ha-1) and very late sowing (4657 kg ha-1) conditions. Hossain *et.al*. (2011) observed that highest yield was obtained wheat sown in November 22 to December 20 compared to November 08, 15 and December 27.

Suleiman *et al*. (2014) observed that yield and yield components were reduced due to delay in sowing date and when cultivars were sown on 1st November and

15th November, the highest values were observed. They also showed that late sowing curtailed the development phases of wheat and adversely influenced the grain development and ultimately the grain yield.

Saunders (1988) observed that yield is decreased in 1.2% ha-1 day-1 for delayed wheat sowing after December 1 compared to optimum time (November 15 to 1st week of December) for potential yield. Shafiq (2004) revealed that early sowing increased germination per unit area, plant height, spikelets spike $^{-1}$, grains per spike and 100-grain weight compared to late sowing. Hossain *et al*. (1990) observed that maximum grain yield was obtained when the wheat was sown November 20 due to higher number of grains spike-1 and the highest 1000-grain weight. To study the effect of planting time on quality characteristics of wheat varieties, Inqilab-91 and AS-2002, an experiment was carried out by Abdullah *et al.* (2007) at Wheat Research

Institute, Faisalabad. The crop was sown from 25th October to 10th January with 15 days interval. Characters such as 1000-grain weight declined progressively with delayed sowing.

These had shown maximum value in first planting date i.e. 25th October and minimum value in the last planting date i.e. 10th January. Atikulla (2013) conducted an experiment that out of 3 different sowing dates including November 19, 2012 (S_1), November 29, 2012 (S_2) sowing and December 9 sowing date (S_3) the highest biological yield (8.94 t ha^{-1}) was observed from S_1, while the lowest biological yield (8.25 t ha^{-1}) was recorded from S_3 which was statistically similar with S_2 (8.38 t ha^{-1}). Ahmed *et al*. (2006) found that grain and straw yields augmented significantly with early sowing (30 November) in all varieties. The highest grain (2.55 t ha^{-1}) and straw yield (4.28 t ha^{-1}) produced due to early sowing (30 November), whereas the lowest grain yield (1.23 t ha^{-1}) and straw yield (3.21 t ha^{-1}) was obtained from delay sowing.

A field experiment was conducted by Chowdhury (2002) at four sowing dates viz. sown at November 1, November 15, November 30 and December 15 and reported that the highest grain yield was recorded in November 15 sown plants and the next highest value was recorded in November 30 sown plants and the lowest yield was recorded in December 15 sown plants. Haider (2002) conducted experiment with two sowing dates and reported that November 15 sown plants produced significantly higher grain yield in both the years for all the irrigation regimes and varieties of wheat and the lowest yield was recorded in December 5 sown plants. Twelve wheat genotypes bred at this Institute were assessed by Sial *et al*. (2005)for yield and quality parameters at two levels of sowing dates i.e., normal (18th November) and late sowing (11th December). With delayed planting, the development of plant organs and transfer from source to sink were remarkably affected, which was reflected by overall reduction of yield. A field experiment was conducted by Ahmed *et al.* (2006) at Farming System Research and Development (FSRD) site, Chabbishnagar, Godari, Rajshahi under rainfed condition during rabi seasons to find out the suitable variety and sowing time (30 November, 15 December and 30 December). They concluded that grain and straw yields increased significantly with early owing (30 November) in all varieties. The results show that early sowing (30 November) gave the highest grain (2.55 t ha^{-1}) and straw yield (4.28 t ha^{-1}), whereas the lowest grain yield (1.23 t ha^{-1}) and straw yield (3.21 t ha^{-1}) was obtained from delay sowing.

To evaluate the effect of planting time on the quality characteristics of spring wheat varieties, Inqilab-91 and AS-2002, an experiment was carried out by Abdullah *et al.* (2007) at Wheat Research Institute, Faisalabad. The crop was sown from 25th October to 10th January with 15 days interval. Characters such as flour yield declined progressively with delayed sowing. These had shown maximum value in first planting date i.e. 25th October and minimum value in the last planting date i.e. 10th January.

Growth and yield response of three wheat varieties (Suliman-96, Chakwal-97 and Inqalab-91) to various sowing times was studied by Qasim *et al*. (2008)at Karakoram Agricultural Research Institute, (Northern Areas) Gilgit, Pakistan.

Three sowing dates viz., November 15, November, 30 and December, 15 were tested. Early planted wheat yielded maximum grain yield (4165.7 kg ha^{-1}) and straw yield (6814.2 kg ha^{-1}).

Refay (2011) conducted an investigation aimed to study the influences of genotypes, sowing dates and their interaction on grain yield and yield component characters of bread wheat. Two promising lines and introduce cv. Yecora Rojo, as well as two planting dates (November, 21 and December, 21) were selected. Result revealed that delayed sowing is associated with substantial losses in grain yield estimated by 7.98% as compared with early sowing. The present study support the use of early sowing dates for obtaining maximum yield.

The study was conducted by Anwar *et al*. (2011) to determine the proper time of sowing for promising wheat genotypes and to compare their yield behavior with already approved cultivars. Four already approved varieties of wheat and eight new promising lines were sown at six sowing dates with 10 days interval, i.e. 01 November, 10 November, 20 November, 30 November, 10 December, and 20 December. The grain yield of most of the genotypes was highest on the sowing date 20 November, except genotypes V-03094 and V-04022 which gave highest yield on 10 November and genotypes V-03138 and V-04178 which produced highest yield on sowing date of 01 November.

A study was designed by Said *et al*. (2012) to investigate the effects of various sowing dates and seeding rates on the yield and yield components of wheat. The experiment included four planting dates (1^{st} November, 15^{th} November, 1^{st} December and 15^{th} December) and three seeding rates. Significant differences were found among the planting dates for biological yield and grain yield. Maximum biological yield (11953 kg ha^{-1}) and grain yield (4134 kg ha^{-1}) were produced from 1^{st} to 15^{th} November followed by biological yield (6824 kg ha^{-1}) and grain yield (2336 kg ha^{-1}) were produced from late sowing (15^{th} December).A field experiment was conducted by Aslani and Mehrvar (2012) at Seed and Plant Improvement Institute, Karaj (Iran), on farmer's fields to investigate the effect of two sowing dates; optimum sowing date (1st November) and late sowing date (20th November) on yield and yield components of eight wheat genotypes. The results showed that the optimum sowing produced higher grain and biomass yields compared to late sowing. A study was undertaken by Mohsen *et al*. (2013) to determine the effects of sowing dates on growth and yield components of different wheat cultivar in Iran. Five sowing dates i.e. October 31, November 15 and 30, December 15 and 30 were in main plots, whereas five wheat cultivars were in sub plots. Results showed that the highest seed yield of 10.15 t ha^{-1} gave for sowing date at Nevember15, while the lowest seed yield of 6.1 t ha^{-1} gave at December 30 sowing date.

Rita Costa *et al*. (2013) conducted a study to determine the effects of sowing date and seeding rate on grain yield and test weight of fifteen bread wheat varieties and five advanced lines at two locations of Southeast Portugal. Two seeding rates as 26 October and 21 December were compared in two different sowing dates. At Elvas, higher yield was obtained with sowing date 21.

Field experiments were conducted by Suleiman *et al*. (2014) at the Demonstration Farm of College of Agriculture, University of Bahri to assess the performance of different wheat cultivars under different sowing dates. The experiment comprised of four dates of sowing, namely 1st November, 15th November, 1st December and 15th December and five wheat cultivars. The sowing dates shown significant effect on yield that decreased with delay in sowing date and the highest values were obtained when cultivars sown on 1st November and 15th November. This indicated that late sowing shortened the development phases of wheat and adversely affected the grain development and thus the grain yield.

Ram *et al.,* (2012) conducted a field experiment at Ludhiana (Punjab) using seven sowing dates (October 25, November 5, November 15, November 25, December 5, December 15 and December 25) and six varieties and revealed that October 25 took maximum calendar days, growing ground coverage, photo-thermal units and canopy temperature for earing and maturity which got reduced significantly with subsequent delay in sowing time and recorded lowest value in December 25 sown crop.

Ehdaie *et al.* (2001) reported that early sowing decreased harvest index. They reported that greater N supply increased shoot biomass by 29%, grain yield by 16% and protein by 5% but decrease harvest index by 10%.

A study was conducted by Mohsen *et al*. (2013) to determine the effects of sowing dates on growth and yield components of different wheat cultivar. Five sowing dates i.e. October 31, November 15 and 30, December 15 and 30 were used in the experiment. Results showed that the effect of sowing date was significant on all parameters excluding harvest index.

Wheat sown on different dates showed that the highest grain yield (10.15 t ha^{-1}) was recorded with November15 sowing date and the lowest grain yield (6.1 t ha^{-1}) was with December 30 sowing date. The study was conducted in Lorestan provience of Iran (Lak *et al.,* 2013). In another study it was revealed that the early planting may avoid terminal heat stress so that grain filling occurs during cooler temperatures (Sial *et al.,* 2005b) overlate sowing planting.

Jat *et al.,* (2013) conducted an experiment in Varanasi (Uttar Pardesh) and reported that ear length, grains/ear, ear weight and test weight were influenced significantly by the dates of sowing, the highest ear length, grains/ear, ear weight and test weight were recorded in November 20 sown wheat, followed by December 6 and December 23 sown crop, lower grain yield in late-sown wheat could be due to less favorable period for grain filling, high temperature and hot winds resulted in forced maturity of the crop and shortening of maturation period. Delayed sowing decreased the plant height, dry matter accumulation, grains/ear, effective tiller/m2 and 1000-grain weight in West Bengal (Mukherjee, 2012). In an experiment at Sokoto (Nigeria), it was found that length of spike, number of spikelet per spike, number of grains per ear and grain yield were decreased with delay in sowing from November 21 to January 2 (Sokoto and Singh 2013).

In another experiment at El-Arish (Egypt), using three sowing dates (November 16, December 1 and December 16) it was also concluded that 1000-grain weight, grain protein content, flag leaf area, plant height, spike length and grain yield was higher in December 1 sowing date whereas December 16 sowing date resulted in lowest yield(EI-Sarag and Ismaeil, 2013).

Craigie *et al.*, (2015) conducted a field experiment at Leeston (New Zealand) using four sowing dates (February 20, March 10, March 28 and April 23) and concluded that wheat sown at the last three dates gave yields which were statistically at par but was significantly better compared to that of February 20. In another study it was observed that the November 5 and November 20 sown crop resulted in higher grain yield, straw yield and harvest index compared to the late sown ones(Amrawat *et al*., 2013). The trial was made at Udaipur testing four dates of sowing (November 5, November 20, December 5 and December 20), three wheat varieties and two nitrogen levels.

El-Nakhlawy *et al*., (2015) studied five wheat varieties under four planting dates (November 15, December 01, December 16 and December 31) at Saudi Arabia, and revealed that December 16 plantation brought an overall increment of 20% for plant height, 17% for productive tillers, 33% for spike length, 75% for spikelet per spike,85% for grain weight per plant, 7% for 1000-grain weight, 21% for grain yield per hectare and 15% for harvest index over rest of the planting dates. It can be concluded that early date of sowing increases the number of effective tillers, 1000-grain weight, ear length, number of grains per spike, spikelet per spike, grain yield and harvest index, due to favorable growing conditions and allocation of more period and favorable temperature at reproductive stage of wheat crop , as compared to late sown conditions.

2.2 Varieties

Alam *et al.,* (2013) conducted an experiment in Ranchi (Chhattisgarh) with two dates of sowing (November 25 and December 20) and five wheat varieties (Raj 4229, K 0906, K 0307, HD 2733 and DBW39) and concluded that K 0307 variety produce significantly higher total tillers/m2 , leaf area index and crop growth rate than other varieties of wheat whereas higher dry matter was produced by K 0307 which was statistically at par with K 0906 and HD 2733 but significantly higher than Raj 4229 and DBW 39. Plant height, root length, tillers per plant, leaves per plant, chlorophyll a and b was found to significantly higher in Bakhtawar 92 variety.

An experiment conducted by Jamal *et al.,* (2011) in Peshawar (Pakistan) with seed priming (30 mM NaCl), six wheat varieties (Tatara 96, Ghaznavi 98, FakhriSarhad, Bakhtawar 92, Pirsabaq 2004 and Auqab 2000) under four salinity levels (0, 40, 80 and 120 mM). They found more grain growth under optimum sowing over late sown condition and they also reported that canopy temperature occurs higher in late sown wheat genotypes than optimum sowing condition.

Basu *et al*., (2012) conducted an experiment with three sowing dates and five wheat varieties (PBW 343, HD 2733, HW 2045, PBW533 and K 9107) in Nadia (West Bengal) and found that K 9107 recorded the minimum growing degree days values during vegetative and reproductive phases and under West Bengal situation, this variety may be recommended for better productivity.

On the basis of heat susceptibility index values, BARI Gom 26 and Shatabdi were highly tolerant to early heat stress and moderately tolerant to extremely late heat stress while Sufi was highly tolerant to extremely late heat stress and moderately tolerant to early heat stress. All other varieties were susceptible to heat stress, among which Gourab was the most susceptible followed by Sourav, Prodip, BARI Gom 25 and Bijoy varieties of wheat in Dinajpur, Bangladesh (Hossain *et al*., 2013).

Khatun *et al*., (2015) conducted an experiment at Bangladesh using three wheat varieties (BARI Gom 25, BARI Gom 26, and Pavon 76) concluded that at high temperature, due to high leaf temperature and low transpiration rate, maximum reduction of seedling growth was recorded in Pavon 76 (17%) as compared to minimum in BARI Gom 26 (5%). Cool varieties showed better agronomic performance, deeper root system and extraction of 35% more water under heat and drought stress, out of five cool and five hot varieties, was found by Pinto and Reynolds (2015) in Adelaide, Australia.

Salazar-Gutierrez *et al*., 2013 as reported by the researchers, varieties with ability to tolerate high temperature, higher growing degree day accumulation, more tillers m^{-2}, plant height, root length, chlorophyll content and leaf area index perform better than the other varieties of wheat under different agronomical conditions.

Sulewska (2004) carried out an experiment with 22 wheat genotypes for comparing vegetation period, plant height, number of stems and spikes, yield per spike. He noticed a tallest plant due to variety. He also reported that the variety Waggershauser, Hohenh, Weisser, Kolben gave the tallest plant.

Qasim *et al*. (2008) reported the growth and yield response of three wheat varieties (Suliman-96, Chakwal-97 and Inqalab-91) to various sowing times when they studied an experiment at Karakoram Agricultural Research Institute, (Norther Areas) Gilgit, Pakistan and reported that plant height varied for different cultivars of wheat.

A study was undertaken by Khokhar *et al*. (2010)to determine the effects of planting dates on growth and yield of different wheat genotypes in Sindh. Four sowing dates and six wheat genotypes (V-7001, V-7002, V-7004, MPT-6, Abadgar-93, and Anmol-91) were used. Better plant growth was recorded in for wheat genotype, V-7002.

A study was undertaken by Mohsen *et al*. (2013)to determine the effects of sowing dates on growth and yield components of different wheat cultivar in Iran.

Five sowing dates and five wheat cultivars (Pishgam, Parsi, Bahar, Sivand and Pishtaz) were used in this experiment. Results showed that the effect of cultivars was significant on all parameters.

Iranian winter wheat cultivars and their response to delay sowing date were investigated as a field experiment by Yajam and Madani (2013). The experiment designed with four winter wheat cultivars namely B.C. Roshan, Alvand, Amirkabir and Shahriar and six sowing date from very early to very late sowing time. The results showed significant differences between cultivars the first in relation to plant height.

A field experiment was conducted by Zia-Ul-Hassan *et al*. (2014)to evaluate the response of high yielding varieties against varying sowing dates under rainfed conditions at Adaptive Research Farm, Bhaun, Chakwal. Treatments were four sowing dates and five varieties, viz. GA 2002, Chakwal 50, Farid 2006, Wafaq 2001 and Sehar 2006). The results showed that varieties remained significant in consideration of plant height.

Growth and yield response of three wheat varieties (Suliman-96, Chakwal-97 and Inqalab-91) to various sowing times was studied by Qasim *et al*. (2008)at Karakoram Agricultural Research Institute, (Northern Areas) Gilgit, Pakistan and recorded the maximum tillers were in Inqalab-91 (302.17).

A study was undertaken by Khokhar *et al*. (2010)to determine the effects of planting dates on growth and yield of different wheat genotypes in Sindh. Four sowing dates and six wheat genotypes (V-7001, V-7002, V-7004, MPT-6, Abadgar-93, and Anmol-91) were used. Better tillering, were recorded in for wheat genotype V-7002 in comparison with other genotypes.

A pot experiment was carried out by Al-Musa *et al*. (2012) at Patuakhali Science and Technology University to study the performance of some BARI wheat varieties under the coastal area of Patuakhali. Four wheat varieties viz. BARI ghom-23, BARI ghom-24, BARI ghom-25 and BARI ghom-26 were planted in the field to evaluate their comparative performance. Among the BARI varieties, BARI ghom-26 produced the maximum effective tillers $hill^{-1}$ (18.08).

Yajam and Madani (2013) investigated as a field experiment with Iranian winter wheat cultivars and their response to delay sowing date. The experiment design was split plot completely randomized with three replications where the main plots were four winter wheat cultivars namely B.C. Roshan, Alvand, Amirkabir and Shahriar and Sub plots were six sowing date from very early to very late sowing time. The results showed significant differences between cultivars the first.

Islam *et al.* (1993) evaluated the performance of the existing (Sonalika) and released wheat varieties (Ananda, Kanchan, Barkat, Akbar, Aghrani) seeded from 1 November to 15 January at 15 days interval. Spike/m^2, grain/spike and 1000-grain weight were significantly affected by variety.

WRC (2003) of Bangladesh conducted an experiment in the Wheat Research Centre Nashipur, Dinajpur to examine the performance of genotypes among various tillage operations and to understand the effects of interaction between genotypes and tillage operations. Two cultivation methods were applied in the main plot and 10 wheat genotypes (Kanchan, Gourav, Shatabdi, Sourav, BAW 1008, BAW 1006, BAW 1004, BAW 969, BAW 968 and BAW 966) were tested in the sub plots. The genotypes showed a wide range of variation for yield related characters. Variety Shatabdi produced maximum grain $spike^{-1}$ and 1000 grain weight. Sulewska (2004) carried out an experiment with 22 wheat genotypes for comparing vegetation period, plant height, number of stems and spikes, yield per spike. He reported that the variety Waggershauser, Hohenh, Weisser, Kolben gave the longest spike.

A study was undertaken by Khokhar *et al*. (2010) to determine the effects of planting dates on growth and yield of different wheat genotypes in Sindh. Four sowing dates and six wheat genotypes (V-7001, V-7002, V-7004, MPT-6, Abadgar-93, and Anmol-91) were used. Better number of grain per unit area and grain weight were recorded in for wheat genotype, V-7002. A pot experiment was carried out by Al-Musa *et al*. (2012) at Patuakhali Science and Technology University to study the performance of some BARI wheat varieties under the coastal area of Patuakhali. Four wheat varieties viz. BARI ghom-23, BARI ghom-24, BARI ghom-25 and BARI ghom-26 were planted in the field to evaluate their comparative performance. Among the BARI varieties, BARI ghom-26 produced the maximum grains spike^{-1} (38.52) and higher weight of 1000-grains (49.38 g).

Iranian winter wheat cultivars and their response to delay sowing date were investigated as a field experiment by Yajam and Madani (2013). The experiment designed with four winter wheat cultivars namely B.C. Roshan, Alvand, Amirkabir and Shahriar and sub plots were six sowing date from very early to very late sowing time. The results showed significant differences between cultivars the first. A study was undertaken by Mohsen *et al*. (2013)to determine the effects of sowing dates on growth and yield components of different wheat cultivar in Iran. Five sowing dates and five wheat cultivars (Pishgam, Parsi, Bahar, Sivand and Pishtaz) were in sub plots. Results showed that the effect of cultivars was significant on all parameters excluding 1000 grain weight. Maximum number of grain spike^{-1} related to Pishtaz cultivar.

A field experiment was conducted by Zia-Ul-Hassan *et al*. (2014)to evaluate the response of high yielding varieties against varying sowing dates under rainfed conditions at Adaptive Research Farm, Bhaun, Chakwal. Treatments were four sowing dates and five varieties, viz. GA 2002, Chakwal 50, Farid 2006, Wafaq 2001 and Sehar 2006). The results showed that varieties remained significant on spike length, spikelets per spike and grains per spike.

Field experiments were conducted by Suleiman *et al*. (2014)at the Demonstration Farm of College of Agriculture, University of Bahri to assess the performance of different wheat cultivars under different sowing dates. The experiment comprised of four dates of sowing and five wheat cultivars namely, Al Nilein, Debiera, Imam, Sasaraib, and Wad el Neil in subplots. The cultivar Imam and Wad el Neil scored the first rank in number of grains spike^{-1}.

Ram *et al*., (2013) conducted an experiment at Ludhiana (Punjab) using three wheat varieties (PBW 550, PBW 343 and DBW 17) with four seed rates and found that highest grains/ear were recorded in variety PBW 550 which was significantly higher than PBW 343 and DBW 17 but highest ears/m2 was recorded in case of PBW 343.

Nawaz *et al.*, (2013) studied ten wheat varieties (Mairaj 2008, C 591, Uqab 2000, BARS 2009, Dharabi 2011, Chakwal 50, Sehr 2006, Shafaq 2006, Faisalabad 2008 and Lasani 2008) and concluded that variety Mairaj 2008 stayed green and took more duration for grain filling which resulted in the maintenance of grain weight and number of grains per spike under stress conditions thus showed more grain yield and water use efficiency, whereas in heat sensitive varieties (Shafaq, 2006), the imposition of heat increased the grain filling rate with a substantial decrease in grain filling duration.

In another experiment, 18 varieties and four controls were selected for screening the best heat tolerant variety at three different locations in Bangladesh and found that varieties E 61, E 64, E 75 and E 77 produced higher number of grains per spike in all three locations than checks in optimum and late seeding condition under heat stress (Islam *et al*., 2013).

An experiment conducted by Hossain *et al*., (2013) at Dinajpur (Bangladesh) including eight spring wheat varieties (Sourav, Gourab, Shatabdi, Sufi, Bijoy, Prodip, BARI Gom 25 and BARI Gom 26) under three heat stress conditions, results indicate that stress did not negatively affect flag leaf area in Prodip and Sufi, flag leaf dry matter partitioning in Prodip, BARI Gom 26 and Shatabdi, above ground dry matter partitioning in Shatabdi and BARI Gom 26, seedling emergence in Sufi and BARI Gom 26 and tiller production in Sufi and BARI Gom 26.

Four wheat varieties namely S 24, Saher 2006, Lasani and AARI 10 were subjected to high temperature and found that variety BARI 10 performed better in growth and physiological attributes under heat stress applied at different phenological stages (Javedv *et al*., 2014).

Kumar *et al., (*2013) in Ranchi (Chhattisgarh) with two dates of sowing and five wheat varieties (Raj 4229, K 0906, K 0307, HD 2733 and DBW39) and found that grains/ear, grain yield, net returns and benefit: cost ratio was higher in K 0307 variety which was statistically at par with K 0906 and HD 2733 but significantly better than other two varieties of wheat.

Due to heat stress under late sown conditions (December 27), the highest yield reduction was observed in Sourav (46%) followed by Sufi (43%) and lowest reduction was in Shatabdi (27%) followed by Bijoy (32%) and Prodip (35%). When the phenological, growth and yield attributes took into consideration, Shatabdi performed best under heat stress followed by Bijoy and Prodip, while Sourav and Sufi were sensitive to heat stress in Dinajpur, Bangladesh (Hossain *et al*., 2012).

Heat occured five days prior to anthesis caused grain number to decline by 0.21% per °C increase in temperature above 32°C for variety Scout, for variety Yitpi, there was no effect of pre-anthesis heat on yield components, although there was a consistent trend of increasing kernel size across both varieties (Nuttall *et al.*, 2015).

2.3 Sowing time and variety

Ram *et al.,* (2012) conducted an experiment in Ludhiana (Punjab) with seven dates of sowing and six varieties of wheat and concluded that timely sown wheat varieties like PBW 621, BW 343, DBW 17 and WH 542 took highest calendar days, growing degree days, helio-thermal unit, photo thermal unit and pheno-thermal index for earing and maturity. However, in edium duration varieties like PBW 550 the significant reduction in grain yield was noticed when sowing was delayed beyond November 25, variety PBW 550 recorded the highest in grain yield at November 15 sowing as compared to all other sowing dates. Interaction effect of sowing date and varieties on grain yield of wheat showed that the highest grain yield (11.43 t ha^{-1}) was with November 15 sowing date and the lowest grain yield (7.44 t ha^{-1}) was with December 15 sowing date for Pishgam variety, however, for Pishtaz variety gave highest grain yield (9.97 t ha^{-1}) when sown at October 31 and lowest grain yield (7.66 t ha^{-1}) when sown at December 30(Lak *et al.*, 2013).

Bahar variety in Lorestan province (Iran) gave the highest grain yield (10.89 t/ha) when sown at December 15 and lowest grain yield (8.64 t ha^{-1}) when sown at November 30 and Sivand variety gave highest and lowest grain yield when sown at October 31and December 30 respectively (Lak *et al*., 2013).Basu *et al*. (2014) in Nadia (West Bengal) concluded that late sown wheat crop experienced highest canopy temperature, varieties of K 9107 and HW 2045 recorded lowest and highest canopy temperature at late sown conditions, respectively and grain yield reduced significantly which was negatively correlated with canopy temperature Wenda-Piesik *et al*., (2016) in Bydgoszcz (Poland) using four different varieties of wheat (OstkaSmolicka, Monsun, Bombona and Tybalt) under two sowing conditions (autumn and spring) and found that variety Bombona gave higher ear density m^{-2} in spring sowing than autumn sowing whereas kernels ear^{-1} and ear length of Tybalt variety was higher autumn sowing. Interaction for thousand grain weight and grain yield was non-significant.

Rascio *et al.,* (2015) conducted an experiment at Italy using two old wheat varieties (Cappelli and Timila) and one new variety (Claudio) under two different sowing conditions (December 19 and March 3) and found that yield of Cappelli and Claudio varieties were decreased under late sown conditions but yield of variety Timila was not affected at all under both conditions. However Claudio variety performed significantly better than both old varieties under both the sowing conditions. Suleiman *et al* (2014) studied four dates of sowing of wheat (November 1, November 15, December 1 and December 15) on five wheat varieties (Al Nilein, Debiera, Imam, Sasaraib and Wadel Neil) at Bahri (Sudan) and found that variety Al Nilein performed better under November 1 sown conditions whereas Imam and Wadel Neil variety performed better under November 15 sown conditions.

In a similar experiment conducted by Hossain *et al*., (2011) in Bangladesh, using eight dates of sowing (November 8, November 15, November 22, November 29, December 6, December, December 20 and December 27) with eight wheat varieties (Sourav, Gourab, Shatabdi, Sufi, Bijoy, Prodip, BARI Gom 25 and BARI Gom 26) and concluded that the highest 1000-grain weight was recorded by Prodip variety sown under November 29, the highest grain yield was recorded by Shatabdi variety under November 29 and December 6 sown conditions whereas Bijoy and Prodip varieties showed highest grain yield under December 13 sowing.

In an experiment conducted by Costa *et al.*, (2013) at two locations (Elvas and Beja of Portugal) with two dates of sowing (December 5 and December 21 for Elvas and October 26 and November 29 for Beja), two seeding rate and fifteen advanced wheat varieties and revealed that Nabao variety gave the highest test weight at both the dates of sowing, but the highest grain yield was given by Flycatcher at 5 December sowing and Ingenio at 21 December at Elvas, whereas at Beja highest test weight was given by Roxa and the highest grain yield was given by Nogal variety at both dates of sowing and at both seeding rate.

Yajam and Madani (2013) in Iran, in an experiment with four winter wheat varieties (Roshan, Alvand, Amirkabir and Shahriar) and six sowing dates (September 23, October 9, October 24, November 10, November 25 and December 11) and found that maximum grain yield for late sowing date was obtained by Shahriar variety (3.7 t ha^{-1}). The maximum grain yield by 5.3 t ha^{-1} was obtain at September 23 sowing date by Shahriar variety. The results showed that the Roshan (0.9 t ha^{-1}) and Alvand (1.1 t ha^{-1}) varieties had lowest grain yield for delay in sowing time on December 24.

Hossain *et al*., (2015) conducted an experiment at Bangladesh with three wheat varieties (BAW 1051, BARI Gom 27 and BARI Gom 28) with normal (November 25) and late sown (December 10, December 25 and January 10) conditions and concluded that in late sowing conditions, the grain yield was reduced by 4.5-17.8% in BARI Gom 28, 0.4-30.9 % in BARI Gom 27 and 5.8-20.4% in BAW 1051. It was also observed that grain yield was found to be reduced by about by 8.6-12.6% in BARI Gom 28, 12.8-13.5% in BARI Gom 27and 13.6-15.8% in BAW 1051 from irrigated timely sowing condition for each 1°C rise in average mean air temperature during booting to maturity.

The above findings suggested that long duration varieties with lower ability to tolerate high thermal conditions performed better under early sowing conditions. Medium duration varieties like PBW 550 were suitable for sowing in mid of the season, but sowing after that also result in reduction in yield of these varieties. Variety with ability to tolerate thermal conditions also performs well under late sowing conditions.

2.4 Irrigation

Mekkei and Haggan (2014) conducted two field experiment in the successive winter seasons 2011/2012 and 2012/2013 at the Agricultural Experiment and Research Station, Faculty of Agriculture, Cairo University to study the effect of irrigation regime (I_1: full irrigation 5 irrigation, I_2: skipping 2nd irrigation, I_3: skipping 3rd irrigation, I_4: skipping 4th irrigation and I_5: skipping 5th irrigation) on yield and quality of five wheat cultivars. Results showed that skipping irrigation at various growth stages had significant effect on days to heading, days to maturity and days from heading to maturity. Skipping the second or the third irrigation led to early heading and early maturity. Results also showed that skipping irrigation at various growth stages significantly decreased plant height, number of tillers m^{-2}, number of spikes m^{-2}, spike length, 1000-kernel weight, grain, straw and biological yields and harvest index in both seasons.

Zarea and Ghodsi (2004) conducted an experiment and revealed that grain yield declined due to increasing irrigation intervals. When a 20 and 30-day irrigation intervals were given in field yield was increasing. Wheat has different critical growth stages of water stress. These stages are tillering shooting, booting, heading, flowering and grain filling.

Monwar (2012) reported that the two irrigations one at crown root initiation (CRI) and on at grain filling stage (GF) showed the best performance by wheat crop. Asif *et al.* (2012) conducted an experiment to study the effect of different levels of irrigation on growth and radiation use efficiency of wheat crop. The results exhibited that the Crop growth rate (g $m^{-2}d^{-1}$), leaf area index, leaf area duration, number of grains $spike^{-1}$ and harvest index.

Rajput and Pandey (2007) experiented that grain yield, ear length, number of grains per ear, 1000- grain weight, water use efficiency, leaf area index, crop growth rate, relative growth rate, net assimilation rate were highest with 55% soil moisture.

Khan *et al*. (2013) rumored that the higher yield of wheat the crop may be irrigated after five weeks interval. Excessive and earlier irrigation time can be harmful for the optimum yield of wheat if seasonal rainfall is >330mm.

Chaudhary and Dahatonde (2007) detected the performance of wheat on the effects of irrigation frequency (irrigation at CRI [crown root initiation], jointing, flowering and milk stages or I_4; I_4 + irrigation at the tillering stage or I_5; and I_5 + irrigation at the dough stage) and quantity (irrigation at 100, 75 or 50% of the net irrigation requirement), and kaolin (0 or 6% kaolin sprayed at 50 days after sowing).Irrigation frequency exaggerated grain yield insignificantly. Irrigation at 100% of the net irrigation requirement produced the highest grain yield (27.32 quintal/ha). Water consumption augmented with the rise in irrigation frequency and quantity. Water use efficiency was obtained higher under I_5 (87.74 kg ha^{-1}

cm-^{1}) and irrigation at 100% of the net irrigation requirement (85.29 kg ha-^{1} cm-^{1}).

Jana and Mitra (2004) expressed that irrigation enhanced plant height, number of effective tillers, ear plant-1 and grain and straw yields when applied irrigation irrigation at crown root initiation, tillering, flowering and dough stages.

Shuquin *et al*. (2006) reported that the effect of irrigation on yield and quality of various gluten wheat cultivars. They also added that enhancing the number of irrigation increased yield, quality and water use efficiency whereas the yield and quality decreased when applied least number of irrigation.

Kabir *et al.*(2009) showed that the highest plant height (82.33 cm), spike length (8.37 cm),filled grain spike-^{1} (31.90), effective tillers plant-^{1} (3.31), grain yield (3.30 t ha-^{1}), straw yield (4.09 t ha-^{1}), biological yield (7.39 t ha-^{1}) and harvest index (44.47%) were obtained from single irrigation applied at CRI stage.

Jiamin *et al.* (2005) expressed that three irrigation schedules, pre-sowing irrigation only, pre-sowing irrigation and irrigation at booting stage, and also pre-sowing irrigation, irrigation at booting stage and flowering stages were selected. Pre-sowing irrigation, irrigation at booting stage and flowering stages were advised for winter wheat cultivation in the North China Basin.

Mushtaq and Muhammad (2005) reported that taller plants and maximum number of fertile tillers per unit area were obtained when five irrigations were applied at crown root + tiller + boot + milk + grain development stages. It was not significantly superior to 4 irrigations given at crown root + boot + milk + grain development stages for number of grains per spike, 1000-grain weight and grain yield. Plant height, 1000-grain weight and wheat grain yield were attained higher under 4 irrigations given at crown root + boot + grain development and crown root + boot stages of plant growth, respectively. Grain yield was declined 6.63 and 12.20% and enhanced 1.45% when applied 3, 2 and 5 irrigations respectively over 4 irrigations.

Islam *et al*. (2015) conducted an experiment with four irrigation stages viz. I_0: No irrigation; I_1: Irrigation at crown root initiation (CRI) stage (18 DAS); I_2: Irrigation at pre-flowering stage (45 DAS) and I_3: Irrigation at both CRI and pre-flowering stage. Maximum number of tiller hill^{-1} (5.2), CGR (6.7gm-2day-^{1}), RGR (0.03gg-^{1}day-^{1}), dry matter content (28.7%), number of spikes hill^{-1} (4.5), number of spikeletsspike^{-1} (19.0), ear length (17.5), filled grains spike^{-1} (30.8), total grains spike^{-1} (32.9), weight of 1000-grains (47.1 g), grain yield (3.9 t ha-^{1}), straw yield (4.9 t ha-^{1}), biological yield (8.8 t ha-^{1}) and harvest index (45.9%) were obtained from I_3 whereas lowest occurred in I_0. They also stated that early flowering (70.6 days), maturity (107.2 days) and minimum number of unfilled grains spike^{-1} (2.1) were also obtained from I_3.

Wang *et al*. (2009) reported that the possessions of different irrigation levels on spring wheat growth characteristics, water consumption and grain yield on recently reclaimed sandy farmlands with an accurate management system with irrigation systems. Water utilization enhanced due to irrigation. Water consumption in high irrigation treatment was enhanced by 16.68% and 36.88% rather than intermediate irrigation treatment and low irrigation treatment respectively.

Atikulla (2013) evaluated that irrigation hastened the maturity period of wheat and as a result maturity of 121.56 days was found for no irrigation (I_0) and that of 115.33 days was found for at 20 DAS (I_1) treatment. Rasol (2003) carried out an experiment that irrigation water amount significantly affected yield, the high yields were obtained from 500 and 600 whereas the lowest was obtained from the 300 mm treatment. Atikullah, *et al.* (2014) showed that maximum dry matter content (18.8g/plant), crop growth rate (CGR) (13.5 g m^{-2}day^{-1}), relative growth rate (RGR) (0.024 g m-^{2}day-^{1}) were obtained from I_1 which was statistically same as I_2 while lowest obtained from I_0. They also reported that Plant height (80.7 cm), number of tiller (4.9/hill), number of spike (4.7/hill), number of spikelets (18.5/spike), spike length (19.2 cm), filled grains (29.3/spike), total grains

(31.3/spike), 1000-grains weight (44.4 g), yield (grain 3.4 t/ha, straw 5.7 t/ha and biological 9.1 t/ha) and harvest index were observed better in $I_{1.}$

Mueen-ud-din *et al.* (2015) were conducted a field experiment to study the response of wheat to different irrigation levels at Adaptive Research Farm, Vehari. Four irrigations @ 4 acre-inch, 3 acre-inch, and 2 acre-inch and farmers practice were applied. Results revealed that application of different irrigation levels to wheat affected number of grain spike^{-1}, 1000 grain weight, and grain yield (kg ha^{-1}) significantly. Maximum grain yield (4232.5 kg ha^{-1}), no. of grains spike^{-1} (51), 1000 grain weight (46.5 g) were recorded from the plots where 3 acre inch water was applied. Highest water use efficiency of 20, 19.89 kg ha^{-1}/mm was observed from the plots where 2 acre inch water was applied.

Zhang-XuCheng *et al*. (2011) reported that water supplied at booting to heading stages promoted both spike and grain development.

Khan *et al*. (2013) reported that for the maximum yield of wheat the crop may be irrigated after five weeks interval. Excessive and earlier irrigation interval can be harmful for the optimum yield of wheat if seasonal rainfall is >330mm.Chaudhary and Dahatonde (2007) observed the performance of wheat on the effects of irrigation frequency (irrigation at CRI [crown root initiation], jointing, flowering and milk stages or I4; I4 + irrigation at the tillering stage or I5; and I5 + irrigation at the dough stage) and quantity (irrigation at 100, 75 or 50% of the net irrigation requirement), and kaolin (0 or 6% kaolin sprayed at 50 days after sowing). Irrigation frequency affected grain yield insignificantly. Irrigation at 100% of the net irrigation requirement produced the highest grain yield (27.32 quintal ha^{-1}). Water consumption augmented with the rise in irrigation frequency and quantity. Water use efficiency was obtained higher under I5 (87.74 kg ha^{-1} cm^{-1}) and irrigation at 100% of the net irrigation requirement (85.29 kg ha^{-1} cm^{-1}).

Waraich *et al*. (2009) observed that the Reduction in grain yield under less irrigation treatment is the result of a significant reduction in number of effective tillers. Pal and Upasani (2007) reported that different irrigation levels (2, 3 or 4 times) applied at critical growth stages (crown-root initiation, highest tillering, booting and milking). As four irrigations were applied at the crown root initiation, highest tillering, booting and milking stages, highest yield obtained. Non-irrigation at the highest tillering stage declined yield (34.7%), followed by water stress at the milking (25.9%), booting (12.8%) and crown root initiation stage (6.8%). Reduction in the values of spike dry matter accumulation, grain growth rate and duration were lessened due to the non-irrigation at the time of the highest tillering, milking and booting stage.

Ali and Amin (2007) Irrigation treatments were given as: no irrigation, control (T0); one irrigation at 21 DAS (T_1); two irrigations at 21 and 45 DAS (T_2); three irrigations at 21, 45 and 60 DAS (T_3); and four irrigation at 21, 45,60 and 75 DAS (T_4). Plant height, number of effective tillers per hill, spike length, number of spikelets spike^{-1}, filled grains per spike obtained significantly by applying irrigation at different levels. The growth, yield attributes and yield of wheat increased significantly when two irrigations were given at 21 and 45 DAS over the other treatments.

Sarkar *et al*. (2009) wheat with five irrigation treatments which were Io (No irrigation), I1 (17-21 DAS), I2 (17-21 DAS+50-55 DAS), I3 (17-21 DAS+50-55 DAS+75-80 DAS) and I_4 (17-21 DAS+35-40 DAS+50-55 DAS+75-80 DAS).They reported that on an average 33,43,52 and 51 percent higher yield were obtained over farmer’s practice at I1,I2,I3 and I4 irrigation levels, respectively. Quayyum and Kamal 2003) identified three stages of crown root initiation, maximum tillering and grain filling stages. Kanwar *et al*. (2008) expressed that greater density, dry weight and nutrient uptake obtained higher applying irrigation 5 times (21, 45, 65, 85 and 105 DAS) over twice or three times. Sultana (2013) stated that increasing water stress declined the plant height, nos. of effective tillers per hill, grain yield and straw yield and maximum grain yield was obtained for the variety BARI Gam-26 that was 2.96 t ha^{-1}.Tomic *et al*. (2012) stated that the irrigation and drainage are essential for grain yield. Grain yield increases with the increase of irrigation levels at different critical levels. Shirazi *et al*. (2014) observed that maximum grain yield of 2.27 t ha^{-1} by the application of 200mm irrigation treatment.

Tahir *et al* (2009) observed that higher grain yield (4289.54 kg ha^{-1}) was attained as wheat was sown on 1st December as well as lowest grain yield (2109.50 kg ha^{-1}) obtained because of late sowing(30th December). Atikulla (2013) observed that each of the 3 different dated irrigated plots showed better performance than that of the non-irrigated plot in all the parameters studied. Among the 3 different dates of irrigation, irrigation at crown root initiation stage (I_1), recorded the highest values in all the parameters studied but it was statistically similar with irrigation at flowering (I_2) and irrigation at grain filling stage of wheat (I_3).

Zhai *et al*. (2003) reported that winter wheat to determine water stress on the growth, yield contributing characters and yield of wheat and they reported that water stress significantly inhibited the number of tillers of winter wheat. Wang *et al*. (2002) stated that the effects of water deficit and irrigation at different growing stages of winter wheat and observed that water deficiency retarded plant growth.

Chouhan *et. al*. (2015) observed that water saving of about 28.42% higher when drip irrigation was applied rather than the border irrigation system. They also stated that water productivity of drip irrigated wheat was 24.24% higher compared with the border irrigated wheat. But there was a slightly reduction of 10.8% in the grain yield because of severe water deficit during the growing stages.

Ahodorrahmani *et al*. (2005) observed that dry matter production, crop growth rate and relative growth rate were decreased due to drought stress. All but the number of grains per ear and harvest index was influenced by water deficit. Gupta *et al*. (2001) conducted an experiment that plant height reduced to a greater extent when water stress was imposed at the anthesis stage while imposition of water stress at booting stage caused a greater reduction in plant height. Among the yield attributes plant height were positively correlated with grain and biological yield irrigation at the anthesis stage.

Wang *et al*. (2009) reported that the effects of different irrigation levels on spring wheat growth characteristics, water consumption and grain yield on recently reclaimed sandy farmlands with an accurate management system with irrigation regimes.

Atikulla (2013) reported that irrigation hastened the maturity period of wheat and as a result maturity of 121.56 days was found for no irrigation (I_0) and that of 115.33 days was found for irrigation at 20 DAS (I_1) treatment. Wu *et al*. (2011) revealed the effect of compensation irrigation on the yield and water use efficiency of winter wheat in Henan province and found that the effect of irrigation on plant height, the combinative treatment of irrigation in the former stage and medium irrigation compensation in the latter were better. The wheat yield was increased by 2.54%-13.61% compared to control and the treatments, irrigation of 900 m^3 ha^{-1} at the elongation stage and of 450 m^3 ha^{-1} at the booting stage or separate irrigation of 900 m^3 ha^{-1}at the two stage were the highest.

Wang *et al.* (2012) reported that a significant irrigation effect was observed on grain yield, kernel numbers and straw yield. The highest levels were achieved with a high irrigation supply, although WUE generally decreased linearly with increasing seasonal irrigation rates in 2 years. The low irrigation treatment (0.6 ET) produced significantly lower grain yield (20.7 %), kernels number (9.3 %) and straw yield (12.2 %) compared to high irrigation treatment (1.0 ET). The low irrigation treatment had a higher WUE (4.25 kg ha^{-1} mm^{-1}) rather than that of 3.25 ha^{-1} mm^{-1} with high irrigation over the 2 years.

Baser *et al*. (2004) found that the influence of water deficit on yield and yield components of winter wheat under Thrace conditions (Turkey). The treatments included an unstressed control (S_0), water stress at the late vegetative stage (S_1), at the flowering stage (S_2), or at the grain formation stage (S_3) and full stress (non-irrigation S_4). The effects of water stress treatments on yield components were statistically significant compared with non-stressed conditions.

Zarea and Ghodsi (2004) observed that twenty bread wheat cultivars were subjected to irrigation at 10, 20 and 30-day intervals in Iran and found that number of spike/m2 and 1000-kernel weight decreased with increasing irrigation intervals. When a 20 and 30-day irrigation interval were applied, number of spike/m^2 were higher in cultivars C-75-14 and C-75-9. Fang *et al*. (2006) expressed that grain yield and its components of wheat declined when exposed to drought stress condition.

BARI (1993) conducted an experiment that maximum grain and straw yields were obtained applying three irrigations at CRI, maximum tillering and grain filling stages. Yadav *et al*. (1995) conducted an experiment that two irrigations scheduled at CRI (Crown Root initiation) and milk stages gave the maximum plant height (1.026 m), maximum number of grain ear^{-1} (65), straw weight (4500 kg ha^{-1}) and grain yield (3158 kg ha^{-1}) of wheat.

Islam (1996) conducted an experiment that irrigation significantly affected the plant heights, number of effective tillers $plant^{-1}$, grain and straw yields but it had no effect on grains per ear and 1000-grain weight. Grain yield (3.71 t ha^{-1}) became highest with three irrigations (25, 45 and 60 DAS) and became lowest with no irrigations (2.61 t ha^{-1}).

Naser (1996) conducted an experiment that the effect of different irrigations on yield and yield contributing characters were statistically significant. Two irrigations at 30 and 50 DAS significantly increased grain and straw yields over control. Maximum number of tillers per plant, highest spike length, maximum number of grains $spike^{-1}$, highest grain yield and straw yields were obtained, when two irrigations were applied. The lowest result was observed in all plant parameters under control.

Mueen-ud-din *et al*. (2015) conducted an experiment that maximum grain yield (4232.5 kg ha^{-1}), no. of grains spike-1(51), 1000 grain weight (46.5 g) were observed due to application of 3 acre inch water and highest water use efficiency of 20, 19.89 kg ha^{-1} mm^{-1} was obtained where 2 acre inch water was given. Debelo *et al*. (2001) reported that plant height and thousand-kernel weight showed positive and strong association with grain yield, indicating considerable direct or indirect contribution to grain yield under low moisture conditions.

Adjetey *et al*. (2001) revealed that grain yield response was greatly dependent on soil moisture or rainfall. Water availability at this time determined kernel weight and hence grain yield, even sufficient grain number had been found.

Khajanij and Swivedi 2007) reported that the growth and yield of wheat affected by irrigation frequency as well as the grain yield of wheat can be raised by increasing irrigation frequencies. Banker (2008) observed that the values of growth characters were observed higher when applied five irrigations (at crown root initiation, tillering, jointing, flowering and milking stages).

Sarkar *et al*. (2008) carried out an experiment at Wheat Research Centre (WRC), Nashipur, Dinajpur for detecting irrigation scheduling of wheat based on cumulative pan evaporation (CPE). Irrigation water was given to wheat using IW: CPE ratios of 0.60, 0.85 and 1.10 applied at 17-21 days after sowing (DAS), 45-50 DAS, 75-80 DAS respectively where highest grain of Maqsood *et al*. (2002) observed that three irrigations at critical growth stages provided the maximum number of productive tillers, number of grains per spike, 1000 grain weight and grain yield.

Wang *et al*. (2002) stated that water deficiency checked plant growth due to the effects of water deficit and irrigation at different growing stages of winter wheat. Rasol, H. O. A. (2003) carried out an experiment that irrigation water amount significantly affected yield, the high yields were obtained from 500 and 600 mm whereas the lowest was obtained from the 300

Zhai *et al*. (2003) showed that water stress significantly inhibited the yield of winter wheat. Faruque (2002) showed that the plant growth which relied partly on turgor pressure to sustain cell enlargement, was more sensitive to water applied grain yield were higher in cultivars C-75-14 and C-75-9.

Wang *et al*. (2002) observed that irrigation increased yield of wheat significantly than under control condition. Atikullah, *et. Al* (2014) showed that maximum dry matter content (18.8 g/plant), crop growth rate (CGR) (13.5 g m-2day-1), relative growth rate (RGR) (0.024 g m-2day-1) were obtained from I_1 which was statistically same as I_2 whereas lowest obtained from I_0. They also reported that Plant height (80.7 cm), number of tiller (4.9/hill), number of spike (4.7/hill), number of spikelets (18.5/spike), spike length (19.2 cm), filled grains (29.3 $spike^{-1}$), total grains (31.3 $spike^{-1}$), 1000-grains weight (44.4 g), yield (grain 3.4 t ha^{-1}, straw 5.7 t $ha^{-1}$and biological 9.1 t ha^{-1}) and harvest index were observed better in I_1.

Mangan *et al*. (2008) showed that grain yield of wheat varieties were significantly influenced under water stress conditions. Grain yield increased from 373 kg ha-1 in single irrigation treatment to 3931 kg ha-1 in four irrigations. Sarkar *et al*. (2009) expressed that an average 33,43,52 and 51 percent higher yield were achieved at I_1,I_2,I_3 and I_4 irrigation levels respectively where five irrigation treatments were I_o (No irrigation), I_1 (17-21 DAS), I_2 (17- DAS+50-55 DAS), I_3 (17-21 DAS+50-55 DAS+75-80 DAS) and I_4 (17-21 DAS+35-40 DAS+50-55 DAS+75-80 DAS).

Wu *et al*. (2011) reported that the effect of compensation irrigation was observed on the yield and water use efficiency of winter wheat in Henan province as well as the wheat yield was increased by 2.54%-13.61% compared to control. Ngwako *et al*.(2013) showed that irrigation significantly affected days to maturity, number of tillers, number of grains per spike and grain yield. Irrigation throughout the growth stages increased number of tillers, number of grains per spike, grain yield, harvest index and grain protein by 20.58%, 26.07%, 42.72%, 16.71% and 3.31% respectively over no irrigation.

Zarea and Ghodsi (2004) carried out an experiment in Iran and showed that harvest index reduced due to increasing irrigation intervals. Harvest index were higher in cultivars C-75-14 and C-75-9 by applying irrigation at 20 and 30 day interval. From reviewed information it was found that in the case of wheat, high water deficit occurred during the early stages and irrigation during these stages was the most beneficial for the crop. One water application during the tillering stage allowed the yield to be lower only than that of the treatment with three irrigations. Irrigation during the stage of grain filling caused the kernel weight to be as high as under three irrigations.

2.5 Nitrogen top dressing at grain filling stage

Nitrogen constantly cycles among different forms in the environment (Jones *et al.*, 2013). The major forms of N include nitrate ($NO3^-$), ammonia (NH_3(d)) dissolved in water, mmonia gas (NH_3(gas), ammonium (NH^4+), organic N (the N in organic matter and icrobes), and N gas (N_2(gas). Only nitrate and ammonium are considered to be "plant available. By minimizing the loss of these plant-available forms to the air or water, crop yields and efficient fertilizer use will be maximized.

Possible losses of N from fields include "denitrification" (conversion of nitrate to N_2 gas), leaching (downward movement of nitrate out of the root zone), plant uptake and removal in arvested portions of the crop, and ammonia volatilization (from soils and plants). All ammonium and ammonia-based fertilizers have the potential to volatilize. Urea fertilizers generally volatilize more than other N fertilizers. Most volatilization from urea typically occurs during a two- to three-week period after application. Volatilization depends on the rate of urea hydrolysis, and the rate at which the ammonium is then converted to ammonia gas that volatilizes if use near the soil surface. Warm temperatures increase the rate of urea hydrolysis and ammonium conversion to ammonia gas, and therefore volatilization. For example, an increase in temperature from 45°F to 60°F can double volatilization loss when moisture content is kept the same (Ernst, 1960; Fan *et al*. 2011).

Nitrogen assimilation or redistribution during the seed filling period is a limiting factor for seed production in crops. During seed filling period, a large amount of nitrogen is redistributed from vegetative organs, but this process could induce the leaf senescence (Donnison *et al*., 2006), decline the photosynthetic activity (Sinclair and Horie, 1989; Angus and Fisher, 1992), shorten the duration of seed filling period, and finally limit the seed yield. Plant responses to N can be regulated directly by nitrate, or less directly via downstream metabolites (Stitt *et al*. 2002). Early season nitrogen application results in accumulation of dry matter by enhanced tiller number and larger photosynthetic surface (Morgan 1988). Late application of nitrogen at or after the emergence of flag leaf do not increase the leaf area but increase nitrogen contents of vegetative parts and prolongation of leaf area duration is the major cause for the increase in yield (Pearman *et al*. 1979; Sinclair and Amir, 1992).

Plants deficient in nitrogen will have lower photosynthetic rates, accumulate less dry matter, and produce lower yields (Delden 2001). The photosynthetic rate per unit area of leaf depends on the development and maintenance of the photosynthetic system including energy transferring components (e.g. thylakoid membranes), on enzymes of the photosynthetic carbon reduction (PCR) cycle (e.g. ribulose bisphosphate carboxylase oxygenase RuBPCO) and enzymes of nitrogen assimilation (Farquhar *et al*. 1980). Longevity of leaf and regulation of breakdown of RuBPCO is an important factor in grain production.

Some other experiments showed that high N regimes before floral initiation increased spikelet number, but generally did not affect the time of spike development (Whingwiri and Kemp 1980). Nitrogen deficiency decreased spikelet number and delayed time of double ridge and terminal spikelet (Longnecker *et al*. 1993). Changing nitrogen supply levels at the end of floret initiation and at anthesis showed (Steer *et al*. 1984) that seed number was determined by nitrogen supply before floret initiation (Whingwiri and Stern 1982). It was found in the experiment of Kumari (2011) that nitrogen influx at post anthesis stage might help in the development of florets formed at or after terminal spikelet formation and contribute in increased grain number and grain N content.

2.6 Irrigation at grain filling stage

N top dressing at grain filling stage need to be followed by a light irrigation (as during this stage no precipitation occurs in Bangladesh) so that the dressed N gets into the root zone.

Under this moisture supply, pre-anthesis assimilate reserves in the stems and sheaths of wheat (*Triticum aestivum*) contribute 10–40% of the final grain weight (Rawson & Evans, 1971; Gallagher *et al*., 1976; Bidinger *et al*., 1977; Schnyder, 1993; Gebbing & Schnyder, 1999). Moreover, remobilization of reserves to the grain is critical for grain yield if the plants are subjected to water stress (unfavorable to the point of being stressful (Yoshida, 1972; Nicolas *et al*., 1985a,b; Palta *et al*., 1994; Ehdaie & Waines, 1996; Asseng & van Herwaarden, 2003; Plaut *et al*., 2004).

There is strong evidence for sink limitation in modern wheat cultivars under post-anthesis drought stress, and it appears that post-anthesis nitrogen supply increases grain yield by decreasing sink limitation, and not by increasing source strength (BRUCKNER; FROHBERG, 1991).

Madani *et al*. (2010) set an experiment imposing post-anthesis drought stress; before anthesis, all the experimental units were irrigated uniformly when the water soil content reached 75% of field capacity (FC)-welting point (WP). After anthesis, control and under-water stress plots were irrigated when the soil water content decreased to 75 and 25% of field capacity (FC) - welting point (WP), respectively. Post-anthesis nitrogen deficiency treatments were also imposed; in all three nitrogen deprivation levels, a quarter of total nitrogen was top dressed at planting and a quarter of it at tillering. In N1, N2 and N3, 0, 25 and 50% of remaining needed nitrogen was applied at anthesis, respectively. Results showed that post-anthesis nitrogen supply increases grain yield through decrease in sink limitation, rather than increase in source strength. It seems that a higher rate of nitrogen availability, nitrogen taken up from the soil is immediately used by developing the grains rather than first being incorporated into leaf photosynthetic proteins.

In an experiment where stress and N was imposed during flowering and grain-filling, the grain yield plant^{-1} varied significantly with both N and water supplies (Muhammad, 1993). The interaction between N and water treatments on grain yield was also significant and was due primarily to their significant interaction on mean kernel weight. The major determinant of grain yield was tillers/plant at harvest. Both N and water supplies affected kernels/ear and N stress caused a reduction of 12% in both fertile spikelets ear^{-1} and kernels per fertile spikelet.

Nitrogen fertilization and irrigation practices can affect durum [*Triticum turgidum* subsp. *Durum* (Desf.) Husn.] grain quality, especially protein content **(**Ottman *et al*., 2000). The purpose of the study of Ottman *et al*. was to determine if irrigation frequency during grain fill influences the effectiveness of N applied near anthesis in increasing durum grain quality. Durum was grown with recommended amounts of N fertilizer

Until anthesis when 0, 3.4, and 6.7 g N m^{-2} were applied and irrigation based on 30, 50, and 70% depletion of plant-available soil water was initiated. Nitrogen application near anthesis of 0, 3.4, and 6.7 g N m^{-2} resulted in grain protein contents of 115, 127, and 140 g kg^{-1} in 1995 and 132, 141, and 151 g kg^{-1} in 1996, respectively. Nitrogen application near anthesis increased grain protein yield and HVAC in both years of the study and increased grain yield, grain volume weight, and kernel size in 1995.

CHAPTER 3

MATERIALS AND METHODS

The experiment was conducted to find out the effect of some heat tolerant variety, sowing dates, post anthesis nitrogen top dressing and irrigation on the growth and yield of wheat. The details of the materials and methods followed in this study have been presented below under the following headings:

3.1 Location of experimental sites and weather parameters

Location of experimental sites and weather parameters are presented in appendix I.

3.1.1 Location of experimental sites

The location is presented in appendix 1 a. The present investigation was conducted both at SAU, Dhaka and on farm at Shahpur, Charghat, Rajshahi during rabi season 2016-17 for experiment 4 and 5 and 1, 2 & 3 experiment started from 2013-14, 2014-15 and 2015-16.

SAU is located on $23^{0}74^{/}$N latitude and $90^{0}35^{/}$E longitude with an elevation of 8.2 meter from sea level while that of the Rajshahi 24^{0} 3' N latitude and 38^{0} 2' E longitude with a height of 18 m above the sea level (Appendix I a). Geographical location has been shown in appendix 1 b.

3.1.2 Weather data

The weather parameters are presented in appendix II. Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. In general, maximum summer temperatures range between 30°C and 40°C. April is the warmest month in most parts of the country. January is the coldest month, when the average temperature for most of the country is about 10°C.

Temperature

Average temperature in Bangladesh was showed in appendix **1. (b).** Temperature in Bangladesh decreased to 18.44^0C in December from 23.08^0C in November of 2015. Temperature increased in every year in Bangladesh due to its climate changes and averaged temperature 24.82^0C and reaching an all time high of 32.79^0C in May and a record low of 14.79^0C in January (Appendix II).

Maximum and minimum temperature

Growing period maximum and minimum temperature was showed in appendix I b. for Rajshahi. It was estimated that the lowest average minimum temperature happens in January (3.4°C) which continue to increase from this month of March reaching the highest (42.8°C) in May and starts decreasing from June. Maximum average temperature was also found in higher in the month of May (42.5°C) which continue to decrease up to the month of October and the lowest average maximum temperature (12.3°C) was also found in January and again increase from the month of March and up to the month of May. But the growing season of wheat from November to March in our country that time the average maximum temperature were 5.3-35.7°C in Rajshahi.

Growing period maximum and minimum temperature was showed in appendix table II in SAU, Dhaka. It was estimated that the lowest average minimum temperature happens in January (13.4°C) which continue to increase from this month of March reaching the highest (32.4°C) in May and starts decreasing from June. Maximum average temperature was also found in higher in the month of May (38.5°C) which continue to decrease up to the month of October and the lowest average maximum temperature (18.3°C) was also found in January and again increase from the month of March and up to the month of May. But the growing season of wheat from November to March in SAU that time the average maximum temperature were 15.3-32.7°C in SAU, Dhaka which hampers on wheat growing season.

Rainfall

Heavy rainfall is characteristic of Bangladesh (appendix I c). With the exception of the relatively dry western region of Rajshahi, where the annual rainfall is about 1600 mm, most parts of the country receive at least 2000 mm of rainfall per year. Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest, the regions in northeastern Bangladesh receives the greatest average precipitation, sometimes over 4000 mm per year. About 80 percent of Bangladesh's rain falls during the monsoon season.

Growing period average rainfall showed in appendix 1(c) and 1 (j) which 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. The average annual rainfall was about 800-950 mm in Rajshahi where as average annual rainfall was 1200-1800 mm in SAU, Dhaka which was received during the monsoon period from July to September in both the location and it was uneven distribution in all the years. However a few showers were received during winter season also.

Monthly sunshine hours

The average maximum and minimum monthly bright sunshine hours showed in appendix 1 d). The sunshine hour's duration were recorded 5.8 to 9.4 hrs; respectively during the period of investigation in both the location but maximum sun shine hours occurs in Rajshahi over Dhaka to its longitudinal effect and it increase wheat yield in Rajshahi than Dhaka

Relative humidity

The weekly maximum relative humidity showed in appendix 1 (e) which ranges from 55 to 94% and weekly minimum relative humidity varied from 52 to 86% during the period of experimentation in both the location but it was higher in Dhaka than Rajshahi. As a results, yield was increased in Rajshahi over in Dhaka.

Solar radiation

The average solar radiation showed in appendix 1 (f) which was mostly occurs in December to February was maximum in Rajshahi and January to February was maximum in Dhaka but solar radiation was higher in Rajshahi than Dhaka. As a results, maximum yield was also higher in Rajshahi over Dhaka.

3.1.3 Soil characteristics

Soil characteristics of the Rajshahi and SAU site have been presented in appendix IV, V and VI. 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.

The farm belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. The experimental area was flat having available irrigation and drainage system. The land was above flood level and sufficient sunshine was available during the experimental period. Soil samples from 0-15 cm depths were collected from experimental field. The analyses were done by Soil Resources and Development Institute (SRDI), Dhaka. The physicochemical properties of the soil are presented in AppendixV.

3.2 Treatments

3.2.1. Experiment 1. Performance of wheat varieties as influenced by different sowing time

The following treatments were included in this experiment.

Factor A. Variety: 2 (BARI Gom 21 and BARI Gom 23)

Factor B. Time of sowing: 4

S_1= 1st sowing at 10 November

S_2= 2nd sowing at 20 November

S_3= 3rd sowing at 30 November

S_4= 4th sowing at 10 December

3.2.2 Experiment 2. Effect of irrigation, sowing date, post anthesis supplemental nitrogen application on the performance of wheat

Variety: BARI Gom 26 was used in this experiment. The following treatments were included in this experiment.

Factor A: Irrigation: 3 (Main plot)

- Irrigation at field capacity, coded as I_1
- Irrigation at 1/2 of the field capacity , coded as I_2
- Irrigation at 1/4th of the field capacity , coded as I_3

Factor B. Time of sowing:4 (Sub plot)

S_1= 1st sowing at 10 November

S_2= 2nd sowing at 20 November

S_3= 3rd sowing at 30 November

S_4= 4th sowing at 10 December

C. Nitrogen top dressing at the reproductive stage: 2 (Sub-sub plot)

N_1 = no nitrogen application at the reproductive stage

N_2 = 20% N top dressing of the recommended dose of N

As such there were 12 treatment combinations of irrigation (I) and sowing time (S) such as; I_1S_1, I_1S_2, I_1S_3, I_1S_4, I_2S_1, I_2S_2, I_2S_3, I_2S_4, I_3S_1, I_3S_2, I_3S_3 and I_3S_4. Irrigation (I) x sowing time (S) and nitrogen top dressing (N) had the treatment combinations of $I_1S_1N_0$, $I_1S_2N_0$, I_1S_3 N_0, I_1S_4 N_0, I_2S_1 N_0, I_2S_2 N_0, I_2S_3 N_0, I_2S_4 N_0, I_3S_1 N_0, I_3S_2 N_0, I_3S_3 N_0 and I_3S_4 N_0; $I_1S_1N_{20}$, $I_1S_2N_{20}$, $I_1S_3N_{20}$, $I_1S_4N_{20}$, $I_2S_1N_{20}$, $I_2S_2N_{20}$, $I_2S_3N_{20}$, $I_2S_4N_{20}$, $I_3S_1N_{20}$, $I_3S_2N_{20}$, $I_3S_3N_{20}$ and $I_3S_4N_{20}$.

3.2.3. Experiment 3. Effect of sowing dates, supplemental irrigation and nitrogen application on the performance of wheat

Variety: BARI Gom 25 was used in this experiment

A. Main plot (Irrigation at reproductive stage): 3

1. I_1=Irrigation at heading stage
2. I_2=Irrigation after 10 days
3. I_3=Irrigation after 20 days

B. Sub-plot (sowing time -7):

1. S_1= 1st sowing at 10 November
2. S_2= 2nd sowing at 20 November
3. S_3= 3rd sowing at 30 November
4. S_4= 4th sowing at 10 December

C: Sub-sub plot (Nitrogen top dressing at the reproductive stage – 2)

1. N_1 = no nitrogen application at the reproductive stage
2. N_2 = 20% N top dressing of the recommended dose of N

As such there were 12 treatment combinations of irrigation (I) and sowing time (S) such as I_1S_1, I_1S_2, I_1S_3, I_1S_4, I_2S_1, I_2S_2, I_2S_3, I_2S_4, I_3S_1, I_3S_2, I_3S_3 and I_3S_4. Interaction treatments of Irrigation (I) x sowing time (S) and nitrogen top dressing (N) had the treatment combinations of $I_1S_1N_0$, $I_1S_2N_0$, I_1S_3 N_0, I_1S_4 N_0, I_2S_1 N_0, I_2S_2 N_0, I_2S_3 N_0, I_2S_4 N_0, I_3S_1 N_0, I_3S_2 N_0, I_3S_3 N_0 and I_3S_4 N_0; $I_1S_1N_{20}$, $I_1S_2N_{20}$, $I_1S_3N_{20}$, $I_1S_4N_{20}$, $I_2S_1N_{20}$, $I_2S_2N_{20}$, $I_2S_3N_{20}$, $I_2S_4N_{20}$, $I_3S_1N_{20}$, $I_3S_2N_{20}$, $I_3S_3N_{20}$ and $I_3S_4N_{20}$.

3.2.4. Experiment 4. Phenology, chlorophyll, canopy temperature, growth and yield of wheat varieties as influenced by sowing dates in northern Bangladesh

The field experiment was laid out in split plot design keeping sowing dates in main plots and variety levels in sub plots with three replication.

Factor A. Main plots (5 sowing dates)

S_1= Nov 20

S_2= Nov 30

S_3= Dec 10

S_4= Dec 20

S_5= Dec 30

Factor B: Sub plots (6 wheat varieties)

V_1= BARI Gom 25

V_2= BARI Gom 26

V_3= BARI Gom 27

V_4= BARI Gom 28

V_5= BARI Gom 29

V_6= BARI Gom 30

There were 30 treatment combinations such as S_1V_1, S_1V_2, S_1V_3, S_1V_1, S1V4, S1V5, S1V6, S2V1, S2V2, S2V3, S2V4, S2V5, S2V6, S3V1, S3V2, S3V3, S3V4, S3V5, S3V6, S4V1, S_4V_2, S_4V_3, S_4V_4, S_4V_5, S_4V_6, S_5V_1, S_5V_2, S_5V_3, S_5V_4, S_5V_5 and S_5V_6.

Irrigation was applied in three times at three growing stages: crown root initiation, flowering and grain filling stage. Each treatment combination was replicated three times and as such there were 90 unit plots in the study.

3.2.5 Experiment 5.Growth, yield attributes and yield of wheat as influenced by sowing dates and varieties in central Bangladesh (SAU)

Factor A. Main plots (5 sowing dates)

S_1= Nov 20

S_2= Nov 30

S_3= Dec 10

S_4= Dec 20

S_5= Dec 30

Factor B: Sub plots (6 wheat varieties)

V_1= BARI Gom 25

V_2= BARI Gom 26

V_3= BARI Gom 27

V_4= BARI Gom 28

V_5= BARI Gom 29

V_6= BARI Gom 30

There were 30 treatment combinations such as S_1V_1, S_1V_2, S_1V_3, S_1V_1, S1V4, S1V5, S1V6, S2V1, S2V2, S2V3, S2V4, S2V5, S2V6, S3V1, S3V2, S3V3, S3V4, S3V5, S3V6, S4V1, S_4V_2, S_4V_3, S_4V_4, S_4V_5, S_4V_6, S_5V_1, S_5V_2, S_5V_3, S_5V_4, S_5V_5 and S_5V_6. Irrigation was applied in three times at three growing stages: crown root initiation, flowering and grain filling stage. Each treatment combination was replicated three times and as such there were 90 unit plots in the study.

3.3 Materials

Characteristics of the wheat varieties tested

BARI Gom 21 (Satabdi)

- Semi-dwarf with good tillering habit
- Plant height 90-100 cm
- Number of tiller plant^{-1} 4-6
- Grain spike^{-1} 40-45
- 1000 grain weight 46-48 g
- Crop duration 105 days
- Sowing time November 15-30
- The seed yield ranges from 3.6-5 tha^{-1}

BARI Gom 23 (Bijoy)

- Developed by BARI during 2005
- Semi-dwarf high yielding potential variety.
- Plant height 95-105 cm.
- Number of tiller plant^{-1} 4-5
- Crop duration 103-112 days.
- Sowing time November 15-30 and for late planting up to December 15 -20.
- This variety yields in the range of 4.3-5 t ha^{-1}.

BARI Gom 25

- Grain yield higher than Shatabdi (3.8-5.0 t ha^{-1}) resistant to Bacterial leaf blight and leaf rust
- Give higher yield in saline soil (8-10 ds m^{-1})
- Early mature and short than Shatabdi Better in bread making and taste good
- White grain and large size (54-58 g 1000 $grain^{-1}$)

BARI Gom 26

- High yielding (4.0-5.2 t ha^{-1})
- Resistant to Bacterial leaf blight and leaf rust specially UG 99 tolerant Life cycle 102-110 day
- Early mature and shorter than Shatabdi Better in bread making and taste good
- White grain and large size (42-48 g 1000 $grain^{-1}$)

BARI Gom 27

- High yielding (3.5-5.4 t ha^{-1})
- Resistant to Bacterial leaf blight and leaf rust specially UG 99 tolerant Life cycle 105-112 day
- Early mature and shorter than Shatabdi Better in bread making and taste good
- White grain and large size (35-40 g 1000 $grain^{-1}$)

BARI Gom 28

- High yielding (4.0-5.5 t ha^{-1})
- Resistant to Bacterial leaf blight and leaf rust Life cycle 100-105 day
- Early mature and shorter than Shatabdi, height (95-100 cm) Better in bread making and taste good
- White grain, bright and medium large size (43-48 g 1000 $grain^{-1}$) Heat tolerant and late sowing

BARI Gom 29

- High yielding (4.0-5.0 t ha^{-1})
- Height (92-96 cm) and less lodging tolerant Resistant to Bacterial leaf blight and leaf rust Life cycle 105-110 day
- Early mature and 7-10 days shorter than Shatabdi Better in bread making and taste good
- White grain, bright and medium large size (44-48 g 1000 $grain^{-1}$)
- Heat tolerant and late sowing

BARI Gom 30

- High yielding (4.5-5.5 t ha^{-1})
- Height (95-100 cm) and less lodging tolerant Resistant to Bacterial leaf blight and leaf rust Life cycle 105-110 day
- Early mature and 7-10 days shorter than Shatabdi Better in bread making and taste good
- White grain, bright and medium large size (44-48 g 1000 $grain^{-1}$)
- Heat, drought and blast tolerant and late sowing

3.4. Methods

3.4.1 Experimental design and layout at SAU, rabi 2014-15

The experiment 1 was set in split plot distributing the sowing time in the main plot whereas the varieties in the subplot. There were three replications. Likewise the experiment 2 and 3 were also laid out in a split-split plot design with three replications distributing irrigation in the main plot, sowing time in the sub plot and the top dressing of N in the sub-sub plot. The size of each plot was 4.0 m × 2.5 m. The distance maintained between two blocks and two plots were 1.0 m and 0.5 m, respectively.

Rabi 2016-17

The experiment 4 and 5 were carried out at two different sites; SAU and Rajshahi during Rabi season 2016-17. The experimental design was split plot with three replications arranging sowing time in the main plot whereas, the varieties in the sub plot. The treatments were randomly arranged in a unit plot of having size 5m x 3m. The layouts of all the experiments are shown in Appendix V.

3.4.2 Determination of Field Capacity (FC) in Expt. 2 at SAU

Field capacity was first calibrated for 1 m^2 area in one corner of the research field. One sq. meter area was marked by putting wooden stick in the four corners of the square. Some watering can each of five liters were filled with water (W1) and then water from the watering can was poured on to the square to wet it and this wetting was done until the poured water started to deposit on the soil surface. The left water in the watering can was measured (W2) the measured and subtracted from the initial volume (W1) and the amount of water needed to moist one 1 m^2 was considered to be the water of field capacity (W2-W1).

As such 10 liters of water was required to obtain field capacity of 1 m^2area .According to this, 10 liters of water was given in the field to wet 1 m^2 area at field capacity level, 5 liters of water was given at attain 1/2 of field capacity and 2.5 liters of water was given to attain at 1/4 of field capacity.

3.4.3 Growing crops

Collection of seeds

The seeds of different wheat varieties were collected from Bangladesh Agricultural Research Institute (BARI), Joydevpur, Gazipur prior to commencing the experimental works**.**

Preparation of experimental land

The piece of land selected for the experiment was opened with a power tiller, and exposed to the sun for a week after that the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubble were removed and finally a desirable tilth of soil was obtained for sowing of seeds. Fertilizers and manures as were mixed with the soil of plot.

Fertilizer dose and methods of application

Application of fertilizers and manure

The fertilizers N, P, K and S in the form of Urea, TSP, MOP and Gypsum, respectively were applied. Cowdung was applied @ 10 t ha^{-1} 15 days before seeds sowing in the field. The entire amount of TSP, MP and Gypsum and 2/3rd of urea were applied during the final land preparation. Rest of urea was top dressed after first irrigation at crown root initiation. The dose and method of application of fertilizers are presented below in Table3.10.

Table 3.10. Doses and method of application of fertilizers in wheat field

Fertilizers	Dose (per ha)	Application (%)	
		Basal	1st installment
Urea	220 kg	66.66	33.33
TSP	180 kg	100	--
MP	50 kg	100	--
Gypsum	120 kg	100	--
Cowdung	10 ton	100	--

Source: BARI, 2016, Krishi Projukti Hatboi, Joydebpur, Gazipur

In the Expt 1 and 2, an additional amount of urea (20% of the recommended dose) was top dressed following the treatments structure. After top dressing the top dressed fields were provided a light irrigation (five liters per m^2) enough so as to wet the surface and allowing the top dressed urea getting down up to the root zone.

Seeds sowing

Furrows were made 20 cm apart by using metallic angular rods for sowing seeds when the land was in proper joe (field capacity) condition. The seeds were sown continuously (@100 kg/hectare) at the bottom of these furrows and covered by the soil on the ridge beside each furrow. During mulching (soil loosening) after the first irrigation, the extra seedlings were removed by thinning keeping plant to plant distance 5 cm within each row. Chlorpyriphos @ 4 ml was applied per kg of seed in the field prior to sowing to prevent termite infestation.

Intercultural operations

Irrigation and drainage

Three flood irrigations at early stage of crop growth (21 days after sowing (crown root initiation stage), tillering stage and heading stage following BARI were provided. Proper drainage system was also developed for draining out excess water.

However, in experiment 2 irrigation was provided as per the treatments measuring by watering can in relation to the pre estimated field capacity of the field. As such the treatments were at field capacity, 50% of field capacity and 25% of field capacity. While in experiment 3 an additional supplemental irrigation was provided at 10 and 20 days after heading along with one at heading stage (Treatments: T_1 = at heading, T_2 = at 10 days after heading and T_3 = 20 days after heading).

Weeding

During plant growth period two hand weedings were done. First weeding was done at 22 days after sowing (after first irrigation) followed by second weeding at 15 days after first weeding. Identified weeds were kakpayaghash (*Dactyloctenium aegyptium* L.), Shama (*Echinocloa crussgalli*), Durba (*Cynodon dactylon*), Arail (*Leersia hexan*dra), Mutha (*Cyperus rotundus* L.) Bathua (*Chenopodium album*) Shaknatey (*Amaranthus viridis*), Foska begun (*Physalis beterophylls*), Titabegun (*Solanum torvum*).

Plant protection measures

The crop was attacked by different kinds of insects during the growing period. Triel-20 ml 10 litre^{-1} was applied in on 05 January, 2014 and Sumithion-40 ml 20 litre^{-1} of water was applied on 30 January as plant protection measure. During the entire growing period the crop was observed carefully to take protection measures. The wheat crop was infested by Aphid. Therefore, contact insecticide (Malathion @ 22.2 mm per 10 litres of water) was given two times.

General observation of the experimental field

The field was observed time to time to detect visual difference among the treatment and any kind of infestation by weeds, insects and diseases so that considerable losses by pest was minimized.

Harvesting, threshing and cleaning

Maturity of crop was determined when 90% of the grains became golden yellow in color. Ten plants per plot were pre-selected randomly out site the central 1 m^{-2} from which different growth and yield attributes data were collected and 1 m^2 areas from middle portion of each plot was harvested separately and bundled, properly tagged and then brought to the threshing floor for recording grain and straw yield. Threshing was done by using pedal thresher. The grains were cleaned and sun dried to a moisture content of 12%. Straw was also sun dried properly. Fresh weight of wheat grain and straw were recorded plot wise from 1 m^2 area. The grains were dried, cleaned and weighed for individual plot. The weight was adjusted to a moisture content of 12%. Yields of wheat grain and straw m^{-2} were recorded and converted to t ha^{-1}.

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3.4.4 Data collection

Experimental data were recorded from 40 days of sowing and continued up to harvest. The following data were recorded during the experimentation.

Crop growth characters

i. Plant height (cm)

ii. Number of tillers $hill^{-1}$

iii. Dry weight (g) $plant^{-1}$

Yield contributing characters

i. Length of spike (cm)

ii. Number of spikelets $spike^{-1}$

iii. Number of grains $spike^{-1}$

iv. Weight of 1000 grains (g)

Yields and harvest index

i. Grain yield (t ha^{-1})

ii. Straw yield (t ha^{-1})

iii. Biological yield (t ha^{-1})

iv. Harvest index (%)

Detailed procedures of recording data

A brief outline of the data recording procedure is given below:

Crop growth characters

Plant height (cm)

Data on this parameter was recorded at maturity in the expt. 1 and 2, while on two other experiments at 30, 45, 60 and 75 DAS (Days After Sowing) and at harvest as the average of 10 plants selected at random from out site the central 1 m^{-2} of each plot that were tagged earlier. The height was measured from the ground level to the tip of the plant by a meter scale.

Tillers plant^{-1}

The number of tillers plant^{-1} was recorded at the time of tillering, booting, heading, anthesis and maturity. Data were recorded by counting tillers from each plant and as the average of 10 plants pre- demarcated plants from each plot.

Phenology of wheat crop

Days required from sowing to heading/anthesis (vegetative stage)

Days required from sowing to anthesis (50%) were recorded by calculating the number of days from sowing to starting of anthesis by eye observation of the experimental plots during the experimental period.

Days required from sowing to physiological maturity

Days required from sowing to maturity were recorded by calculating the number of days from sowing to beginning of maturity when spikes become yellow in color by eye observation of the experimental plot.

Days to physiological maturity

Each plot was observed daily for dough stage after milking. Five spike lets were taken randomly from each plot and crushed between thumb and fingers. When from four out of five spikelets, milk stops coming out and milk start solidifying in spikelet, was taken as days to dough stage.

Percentage of ground coverage

Percentage of ground coverage was measured by the automatic ground coverage machine named and Chlorophyll content determination was made by the SPAD Meter.

Periodic canopy temperature

Canopy temperature was recorded with the help of infrared thermo meter at 30, 60, 90 and 120 days after sowing of wheat crop. Infrared thermo meter was placed at height of 2 feet above the crop canopy and revolved over the plot and average value of canopy temperature given by the meter was taken as the canopy temperature of the plot. Effective tillers were counted at dough stage of crop. Tillers, which bear ear were counted from one metre row length from four different spots chosen randomly from each plot and were converted to total number of tillers per metre square area. Canopy temperature was measured by the automatic canopy temperature machine named Canopy Temp. Meter.

Ear length

Five ears were selected at random from each plot and their length was measured from tip of last spikelet to base first spikelet and then average value was calculated. Number of grains per ear

Randomly five ears were taken from each plot, ears from lodged crop were also taken on bases of percentage lodging of the plot, threshed manually, counted and averaged for number of grainsspike^{-1}.

Crop's reproductive characters

Thousand grain weight (g)

One thousand grains from produce of each plot were taken and their weight was recorded and taken as 1000-grain weight.

Straw yield

Total produce was weighed in bundles after harvesting and four days of sun drying in open. After threshing the weight of grains was subtracted from total bundle weight and remaining was straw yield, which was expressed in tha^{-1} for presentation.

Grain yield

Bundles of wheat from each plot were threshed separately and grains were collected in separate bags for each plot. After cleaning the grains were weighed and presented in quintals per hectare.

Biological yield

After harvesting and sun drying for four days before threshing wheat bundles were weighted and biological yield was expressed as tha^{-1}.

Harvest index (%)

Harvest index of each plot was calculated separately with grain yield and biological yield obtained from that plot by using the formula.

Fresh and dry weight of grain plant^{-1}

Grains from ten sample plants of each plot were collected at or after anthesis were collected and gently washed with tap water, thereafter soaked with paper towel. Then fresh weight was taken immediately after soaking by paper towel. After taking fresh weight, the sample was

oven dried at 70^0C for 72 hours. Then oven-dried samples were transferred into a desiccators and allowed to cool down to room temperature, thereafter dry weight of plant was taken and expressed in gm.

Spike length (cm):

The length of ear was measured with a meter scale from 10 selected spikes and the average value was recorded.

Number of spikes plant^{-1}

The total number of spikes plant^{-1} was recorded by calculating spikes plant^{-1}. Data on number

of spikes plant^{-1} were counted from 10 selected plants at harvest and average value was recorded.

Number of Spikelet per spike:

The total number of spikelet spike^{-1} was counted as the number of spikelet from 10 randomly selected spikes from each plot and average value was recorded.

Number of grains spike^{-1}

The total number of grains spike^{-1} was counted by adding the number of filled and unfilled grains from 10 randomly selected spikes from each plot and average value was recorded.

The number of grains spike^{-1} was counted from 5spikes and number of grains spike $^{-1}$

Filled grains spike^{-1}

The total number of filled grains spike^{-1} was counted as the number of filled grains from 10 randomly selected spikes from each plot and average value was recorded.

The total number of filled grains spike^{-1} was counted as the number of filled grains from 10 randomly selected spikes from each plot and average value was recorded.

Unfilled grains spike^{-1}

The total number of unfilled grains spike^{-1} was counted as the number of unfilled grains from 10 randomly selected spikes from each plot and average value was recorded.

Weight of 1000 grains

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

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

Grains obtained from 1.0 m^2 of each unit plot were sun-dried and weighed carefully. The dry weight of grains of central 1 m^2 area was used to record grain yield m^{-2} and this was converted into t ha^{-1} at 12% moisture basis. Grain moisture content was measured by using a digital moisture meter.

Dry weight of grain plant^{-1}

Grains from ten sample plants of each plot were collected at or after anthesis were collected and gently washed with tap water, thereafter soaked with paper towel. Then fresh weight was taken immediately after soaking by paper towel. After taking fresh weight, the sample was oven dried at 70^0C for 72 hours. Then oven-dried samples were transferred into a desiccators and allowed to cool down to room temperature, thereafter dry weight of plant was taken and expressed in gram.

Straw yield (t ha^{-1})

Straw obtained from 1.0 m^2 of each unit plot were sun-dried and weighed carefully. The dry weight of straws of central 1 m^2 area was used to record straw yield m^{-2} and was converted in to t ha^{-1}.

Biological yield:

Biological yield of a crop is defined as the sum of grain yield and straw yield. The biological yield of wheat was measured for each plot and express in tha^{-1}. The biological yield was estimated with the following formula:

Biological yield = Grain yield + Straw yield

Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated with the following formula.

$$\text{HI} = \frac{\text{Economic yield}}{Biological\ yield} \text{ X } 100$$

3.4.5 Evaluating the effect of temperature on physiological, biological and yield attributes through performing regression analysis

A number studies showed that the ambient temperature has tremendous effect on the physiological parameter of wheat. Dias and Lidon (2009) exposed some wheat genotypes to heat stress after anthesis, to correlate and evaluate grain filling traits and grain weight to the increased temperature. Results showed that high temperatures significantly affected the rate (on a growing degree day basis) and duration (on Julian day units) of grain filling.

In this study an approach has been tried to fit the regression curves (linear and polynomial) to the data collected. This was done plotting data of the maximum, minimum and average temperatures (individually) on the X axis while data of the number of grains per spike, grain weight per plant and yield per hectare were put on the Y axis individually (Table .2.2.8. in experiment 4 and 5 of Rajshahi and SAU, respectively). The fitting curves were best fit when fitted using polynomial regression as compared to the linear regression.

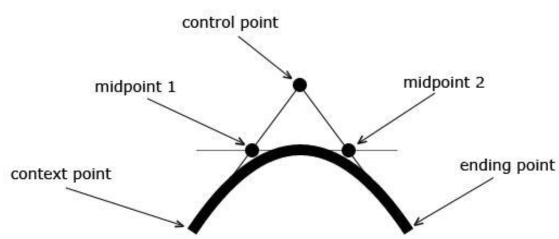
Regression[1]involves estimating the mathematical relationship between one variable called the response variable, and one or more explanatory variables.

In linear Regression, if, $y = bx + a$; the value of b is called the slope, (or gradient), of the line. It can be positive, negative or zero. If the slope is positive, *y* increases as *x* increases, and the function runs "uphill" (going left to right). If the slope is negative, *y* decreases as *x* increases and the function runs downhill. If the slope is zero, *y* does not change, thus is constant—a horizontal line. Again If x value is zero, the regression equation predicts that y value is negative.

Slope is usually expressed as an absolute value. A positive value indicates a positive slope, while a negative value indicates a negative slope. In statistics, a graph with a negative slope represents a negative correlation between two variables. This means that as one variable increases, the other decreases—and vice versa. Negative correlation represents a significant relationship between the variables *x* and *y*, which, depending on what they are modeling, can be understood as *input* and *output*, or *cause* and *effect*.

Polynomial regression is considered to be a special case of multiple linear regression and *it* used in those situations where the relationship between dependent and independent variables, curvilinear wherein the relationship between the independent variable x and the dependent variable y is modeled as an nth order polynomial. A polynomial regression can be expressed as Y' = a + b1X1 + b2X12 (Quadratic function)

In general, the polynomial equation is referred to by its degree, which is the number of the largest exponent. In the above equation, the linear equation is a polynomial equation of second degree. In the above equation the curve becomes a quadratic (Involving the second and no higher power of an unknown quantity or variable). Before examining the quadratic regression equation, it would be helpful to look at the linear equation what has been tried in this study.



Quadratic curves are defined by the context point, a control point, and an ending points as has been shown in the following picture.

The strength of the relationship between dependent and independent variable is given by the R-squared in case of regression is used to measure 'how close the data are to the fitted regression line'. It is also known as the coefficient of determination. The value of R-square (R^2) is always between 0 and 100%.0% indicates that the model explains none of the variability of the response data around its mean, while 100% indicates that the model explains all the variability of the response data around its mean. In general, the higher the R^2, the better the model fits the data.

In this study linear regression and polynomial regression line/curve were fitted to data keeping temperature (Appendix table iii) on the X axis whereas, number of grain spike^{-1}, grain weight plant^{-1} (g) and seed yield per hectare on the Y axis. The relationship between the yield and yield parameters were examined with temperatures at two different growth stages – from sowing to anthesis (before anthesis) and from anthesis to physiological maturity (Table 2.2.9). At these two growth stages (before and after anthesis) the data on yield and yield parameters were examined at three levels of temperature; maximum temperature (Tmax), minimum temperature (Tmin) and average temperature (Tave). As such the Tmax was calculated for these two stages (from sowing to anthesis and from anthesis to maturity, that is vegetative and reproductive stages respectively) by averaging the maximum temperature of the days along these two stages. Likewise the Tmin (minimum temperature) was also calculated for these two stages (before anthesis and after enthesis) by averaging the minimum temperature of the days from sowing to anthesis and again from anthesis to maturity. The average temperature of these two stages was calculated averaging the average temperature (average of daily maximum and daily minimum temperature) along these two stages, that is from sowing to anthesis and from anthesis to maturity.

In this study the regression curves (linear and polynomial) were obtained by plotting data of the maximum, minimum and average temperatures (individually) on the X axis while data of the number of grains per spike, grain weight per plant and yield per hectare were put on the Y axis individually (Table 2.2.10)in experiment 4 and 5 of Rajshahi and SAU, respectively). The regression analysis were performed using MS excel software.

While performing the regression analysis, the averages of the daily maximum, daily minimum and averages of the daily average (maximum and minimum) were calculated both from sowing to anthesis (for the vegetative stage) and also from anthesis to maturity (for reproductive stage). While calculating maximum temperature (Tmax), minimum temperature (Tmin) and average temperature (Tave), the in each cases as were undertaken by the sowing time treatments (e.g.S_1= Nov 20, S_2= Nov 30, S_3= Dec 10, S_4= Dec 20, S_5= Dec 30) were used, not the maximum, minimum and average of the month or growing season. For the calculation of average Tmax, the averages of the daily maximum temperature as was undertaken (enjoyed) by the crop sown in a particular sowing date was considered. Similar method was also followed in case of calculating average minimum temperature and the average of the average daily temperature for each sowing dates. These three categories of temperature (calculated) are presented in appendix II-III. These temperature data were fitted to the data of biological yield, number of spikelet spike^{-1}, number of grains spike^{-1}, 1000 seed weight and yield ha^{-1}.

3.4.6 Statistical analysis

The data collected on different parameters were statistically analyzed with split plot design using the MSTAT computer package program developed. Least Significant Difference (LSD) technique at 5% level of significance was used to compare the mean differences among the treatments (Gomez and Gomez, 1984).

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS

Experiment 4.1: Performance of two wheat varieties as influenced by different sowing dates

The objectives of this trial were to evaluate the performance of two heat tolerant varieties under different sowing dates**.** The experiment was conducted to find out the effect of variety and sowing dates on the growth and yield performance of wheat. Data on different yield contributing characters and yield were recorded.

4.1.1 Plant height

Wheat varieties showed statistically significant difference on plant height at 30, 45, 60, 75 DAS and harvest (Table 4.1.1). At 30, 45, 60, 75 DAS and harvest, the longest plant was found from V_2 (BARI Gom 23) which was statistically similar to V_1 (BARI Gom 21).

Different genotypes produced different plant height on the basis of their varietal characters.

4.1.1 Effect of varieties on plant height of wheat at different days after sowing (DAS) and harvest

Treatments	Plant height (cm) at				
	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
V_1	27.07	59.30	85.25	93.28	97.42
V_2	28.52	61.55	86.95	98.12	105.05
T-test	*	*	*	*	*
CV (%)	**10.23**	**11.54**	**11.52**	**11.35**	**12.58**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23

Plant height showed statistically significant differences due to different sowing dates under the present trial at 30, 45, 60, 75 DAS and harvest (Table 4.1.2). Data revealed that at 30, 45, 60, 75 DAS and harvest, the tallest plant was observed from S_2 (sowing on 20 November) which was statistically similar to S_3 (sowing on 30 November) and closely followed by S_1 (sowing on 10 November). Whereas the shortest plant was found from S_4 (sowing on 10 December). Seeds sowing at 20 November ensured the tallest plant than early and delay sowing of seeds.

Table 4.1.2 Effect of sowing dates on plant height of wheat at different days after sowing (DAS) and harvest

Sowing time	Plant height (cm) at				
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**	**Harvest**
S1	27.73	60.27	85.73	95.4	100.4
S_2	28.19	61.25	87.66	96.32	102.72
S3	26.02	57.09	81.91	90.79	96.23
S_4	27.46	58.79	84.5	93.84	98.15
LSD (0.05)	0.102	0.056	0.105	0.192	0.256
CV (%)	10.32	11.54	12.42	11.65	12.54

S_1: Sowing at 10 November, 2014’; S_2: Sowing at 20 November, 2014’ S_3: Sowing at 30 November, 2014’ S_4: Sowing at 10 December, 2014

Interaction effect of wheat varieties and sowing dates showed significant differences on plant height at 30, 45, 60, 75 DAS and harvest (Table 4.1.3). At 30, 45, 60, 75 DAS and harvest, the longest plant was observed from V_2S_2 (BARI Gom 23 and sowing on 20 November) and the shortest plant was obtained from the treatment combination V_1S_4 (BARI Gom 25 sowing and 10 December).

4.1.3. Interaction effect of varieties and sowing dates on plant height of wheat at different days after sowing (DAS) and harvest

	Plant height at				
Sowing time	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
S1	27.6	60.67	85.03	93.93	98.76
S2	28.86	63.8	89.61	98.4	107.1
S3	27.11	60.73	86.99	95.9	100.43
S4	27.34	55.88	81.29	93.35	95.31
S1	28.6	62.25	90.1	98.7	104
S2	30.3	64.22	89.75	99.11	108.65
S3	30.22	63.13	89.67	98.01	108.05
S4	23.64	55.37	81.1	89.43	90.15
LSD (0.05)	**0.205**	**0.058**	**0.211**	**0.384**	**0.512**
CV (%)	**5.65**	**10.54**	**11.25**	**12.54**	**11.25**

V_1: BARI Gom 21; V_2: BARI Gom 23; S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.2 Number of tillers plant^{-1}

Number of tillers plant^{-1} at 30, 45, 60 and 75 DAS varied significantly due to different wheat varieties under the present trial (Table 4.1.4). Data revealed that at 30, 45, 60 and 75 DAS, the maximum number of tillers plant^{-1} was recorded from V_2(3.30, 4.05, 5.88 & 6.57) and minimum tiller number (3.19, 3.98, 5.67 & 5.81) was also found from to $V_{1.}$ Although management practices influenced the number of tillers at different days after sowing but genotypes itself contributed to the number of tillers plant^{-1}.

Table 4.1.4. Effect of varieties on number of tillers plant^{-1} of wheat at different days after sowing (DAS) and harvest

Treatments	Number of tillers plant^{-1}			
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**
V_1	3.19	3.98	5.67	5.81
V_2	3.30	4.05	5.88	6.57
T-test	*	*	*	*
CV(%)	**6.58**	**4.56**	**10.54**	**3.58**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23

Different sowing dates showed statistically significant differences in terms of number of tillers plant^{-1} at 30, 45, 60 and 75 DAS (Table 4.1.5). The maximum number of tillers plant^{-1} (3.28, 4.13, 5.87 & 6.32) was found from S_2 which was statistically similar to S_4 and closely followed by S_1, while the minimum was recorded from S_3(2.98, 3.73, 5.42 & 5.73) at 30, 45, 60 and 75 DAS. Seeds sowing at 20 November ensured the maximum tiller than early and delay sowing.

Table 4.1.5 Effect of sowing dates on number of tillers plant^{-1} of wheat at different days after sowing (DAS) and harvest

Treatments	Number of tillers plant^{-1}			
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**
S1	3.22	4.08	5.70	6.08
S_2	3.28	4.13	5.87	6.32
S_3	2.98	3.73	5.42	5.73
S_4	3.05	3.93	5.53	5.88
LSD (0.05)	**0.122**	**0.065**	**0.112**	**0.045**
CV(%)	**3.24**	**5.65**	**7.87**	**5.68**

S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on number of tillers plant^{-1} at 30, 45, 60 and 75 DAS (Table 4.1. 6). At 30, 45, 60 and 75 DAS, the maximum number of tillers hill^{-1}was found from V_2S_2(3.53, 4.26, 6.16 & 6.86) whereas the minimum number of tillers plant $^{-1}$(2.76, 3.90, 5.23 & 5.43) was recorded from the treatment combination V_2S_4.

Table 4.1.6. Interaction effect of varieties and sowing dates on number of tillers plant^{-1} of wheat at different days after sowing (DAS) and harvest

Treatments		30 DAS	45 DAS	60 DAS	75 DAS
V_1	S1	3.26	4.13	5.83	6.00
	S_2	3.36	4.16	5.90	6.76
	S_3	3.30	4.13	5.80	6.13
	S_4	2.96	3.90	5.26	5.40
V_2	S_1	3.40	4.13	5.96	6.36
	S_2	3.53	4.26	6.16	6.86
	S_3	3.43	4.23	6.13	6.60
	S4	2.76	3.90	5.23	5.43
LSD (0.05)		**0.244**	**0.045**	**0.224**	**0.032**
CV(%)		**7.87**	**6.58**	**7.87**	**4.65**

V_1: BARI Gom 21; V_2: BARI Gom 23; S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.3 Dry matter content plant^{-1}

Statistically significant difference was observed due to different wheat varieties in terms of dry matter content plant^{-1} at 30, 45, 60 and 75 DAS (Table 4.1.7). At 30, 45, 60 and 75 DAS, the highest dry matter (1.10, 2.28, 3.81 & 6.01) content plant^{-1} was observed from V_2 and lowest value was also found from (1.01, 2.12, 3.58 & 5.37) V_1.

Table 4.1.7 Effect of varieties on dry matter content plant^{-1} of wheat at different days after sowing (DAS)

Treatments	Dry matter content plant^{-1} (g) at			
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**
V1	1.01	2.12	3.58	5.37
V_2	1.10	2.28	3.81	6.01
T-test	*	*	*	*
CV(%)	2.33	5.65	5.36	4.89

V_1: BARI Gom 21; V_2: BARI Gom 23

Dry matter content plant^{-1} showed statistically significant differences due to different sowing dates under the present trial at 30, 45, 60 and 75 DAS (Table 4.1.8). Data revealed that at 30, 45, 60 and 75 DAS, the highest dry matter content plant^{-1} was (1.10, 2.37, 3.89 & 5.87) attained from S_2 which was statistically similar to S_4 and closely followed by S_1, whereas the lowest was found (0.98, 1.94, 3.32 & 5.38) from S_3.

Table 4.1. 8 Effect of sowing dates on dry matter content plant^{-1} of wheat at different days after sowing (DAS)

Treatments	Dry matter content plant^{-1}(g) at			
	30 DAS	**45DA**	**60 DAS**	**75 DAS**
S_1	1.06	2.27	3.71	5.64
S_2	1.10	2.37	3.89	5.87
S_3	0.98	1.94	3.32	5.38
S4	1.01	2.08	3.44	5.58
LSD(0.05)	**0.054**	**0.729**	**0.165**	**0.205**
CV (%)	**2.34**	**5.65**	**5.36**	**3.45**

S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

Interaction effect of wheat varieties and sowing dates showed significant differences on dry matter content plant^{-1} at 30, 45, 60 and 75 DAS (Table 9). At 30, 45, 60 and 75 DAS, the highest dry matter content plant^{-1}(1.24, 2.68, 4.34 & 6.37) was found from V_2S_2, while the lowest dry matter content plant^{-1} was obtained from the treatment combination V_1S_4(0.98, 2.09, 3.46 & 5.03) at the same sampling dates.

Table 4.1.9. Interaction effect of varieties and sowing dates on dry matter content plant^{-1} of wheat at different days after sowing (DAS)

Treatments		Dry matter content plant^{-1} (g) at			
		30 DAS	**45 DAS**	**60 DAS**	**75 DAS**
V_1	S_1	1.03	2.24	3.74	5.21
	S_2	1.13	2.42	3.93	6.61
	S3	1.09	2.33	3.68	5.68
	S_4	0.98	2.09	3.46	5.03
V_2	S_1	1.07	2.34	3.92	5.85
	S_2	1.24	2.68	4.34	6.37
	S_3	1.16	2.53	4.23	6.73
	S4	0.91	1.91	3.05	4.52
LSD (0.05)		**0.057**	**0.145**	**0.331**	**0.411**
CV (%)		**3.25**	**4.54**	**5.452**	**4.352**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23; S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.4 Days to spike initiation

Different wheat varieties showed statistically significant difference on days to spike initiation (Table 4.1. 10). The highest days (66.0) to spike initiation was found from V_1 whereas the lowest days (61.5) to spike initiation was recorded from V_2. Although management practices influenced the days to starting of ear emergence but genotypes itself contributed the days to starting of ear emergence.

Statistically significant differences were observed in terms of days to spike initiationdue to different sowing dates (Table 4.1. 11). The highest days (54.1) to spike initiation was observed from S_1 which was statistically similar to S_4 and S_3, while the lowest days (62.0) to spike initiation was found from S_2 Interaction effect of wheat varieties and sowing dates showed significant differences on days to spike initiation (Table 4.1.12). The highest days (66.2) to spike initiation was observed from V_1S_4, while the lowest days (61.5) to spike initiation was obtained from the treatment combination V_2S_2.

Table 4.1.10 Effect of varieties on days to spike initiation, days to maturity, number of spikes plant^{-1} and number of spikelet spike^{-1} of wheat 4.1.5 Days to maturity

Treatments	Days to initiation spike	Days to maturity	Number of spikes plant^{-1}	Number of Spikelet spike^{-1}
V1	66.25	110.25	4.97	20.78
V_2	61.50	106.42	5.32	21.43
T-test	*	*	*	**
CV (%)	11.23	12.24	10.42	6.56

V_1 = BARI Gom 21 and V_2 = BARI Gom 23

4.1.5 Days to maturity

Days to maturity showed statistically significant difference in terms of different wheat varieties (Table 4.1.10). The highest days (110.2) to maturity was recorded from V_1 while the lowest days (106.4) to maturity was found from $V_{2.}$

Different sowing dates varied significantly in terms of days to maturity(Table 4.1.11). The highest days (111.5) to maturity was found from S_1 which was statistically similar to S_4 and S_3 whereas the lowest days (105.9) to maturity were recorded from S_2.

Days to maturity showed significant differences due to the interaction effect of wheat varieties and sowing dates (Table 12). The highest days (110.6) to maturity were found from V_1S_4 and the lowest days (103.6) to maturity were recorded from the treatment combination V_2S_2.

Table 4.1.11 Effect of sowing dates on days to spike initiation, days to maturity, number of spikes plant^{-1} and number of spikelet spike^{-1} of wheat

Treatments	Days to spike initiation	Days to maturity	Spikes plant	Spikelet spike
S1	64.09	108.25	5.04	20.92
S_2	62	105.92	5.19	21.57
S_3	66.41	111.58	4.63	19.83
S_4	64.83	109.5	4.92	20.66
LSD(0.05)	0.65	0.979	0.284	0.574
CV (%)	11.54	12.24	6.56	10.54

S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.6 Number of spikes plant^{-1}

Different wheat varieties showed statistically significant difference on number of spikes plant^{-1} (Table 4.1.10). The highest number (5.32) of spikes plant^{-1} was observed from V_2 and lowet value (4.97) was also found from similar to V_1.

Number of spikes plant^{-1} showed statistically significant differences due to different sowing dates (Table 4.1.11). The highest number (5.19) of spikes plant^{-1} was recorded from S_2 which was statistically similar to S_3 and closely followed by S_1 while the lowest number (4.63) of spikes plant^{-1} was found from S_4.

4.1.7 Number of spikelet spike^{-1}

Statistically significant variation was recorded in terms of different wheat varieties in terms of number of spikelet spike^{-1} (Table 12). The highest number (5.32) of spikelet spike^{-1} was recorded from V_2 and lowest value (4.97) was also found from V_1.

Different sowing dates showed statistically significant differences in number of spikelet spike^{-1} (Table 4.1. 20). The highest number (5.19) of spikelet spike^{-1} was observed from S_2 which was statistically similar to S_3 and S_4while the lowest number (4.63) of spikelet spike^{-1} was found from $S_{3.}$

Number of spikelet spike^{-1} varied significantly due to the interaction effect of wheat varieties and sowing dates under the present trial (Table 4.1.12). Data revealed that the highest number (22.56) of spikelet spike^{-1} was observed from V_2S_2, whereas the lowest number (19.7) of spikelet spike^{-1} was obtained from the treatment combination $V_1S_{4.}$

Table 4.1.12. Interaction effect of varieties and sowing dates on days to spike initiation, days to maturity, number of spikes plant^{-1} and number of spikelet spike^{-1} of wheat

Treatments		Days to spike initiation	Days to maturity	Spikes plant	Spikelet spike
V_1	S_1	68	110.66	5.2	20.76
	S2	62	104.33	5.36	21.86
	S_3	62	107.33	5.16	21.33
	S_4	64.33	110.66	4.43	19.73
V_2	S_1	60.66	108.66	5.43	21.93
	S_2	60	103.66	5.56	22.56
	S_3	66.33	106	5.46	21.93
	S_4	61	105.33	4.3	19.86
LSD(0.05)		**0.065**	**0.195**	**0.569**	**0.087**
CV (%)		**11.54**	**12.23**	**5.65**	**10.23**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23

4.1.8 Spike length

Different wheat varieties showed statistically significant difference on ear length (Table 4.1.13). The highest ear length (18.6) was recorded from $V_2$and lowest value (17.4) was also found from $V_{1.}$Although management practices influence the ear length of wheat but genotypes itself produced different length of ear. Spike length showed statistically significant differences due to different sowing dates (Table 4.1.14). The highest ear length (18.3) was found from S_2 which was statistically similar to S_3 and closely followed by S_1, again the lowest ear length (17.2) was recorded from S_4.

Interaction effect of wheat varieties and sowing dates showed significant differences on ear length (Table 4.1.15). The highest ear length (19.9) was observed from V_2S_2 whereas the

lowest ear length (15.4) was obtained from the treatment combination $V_1S_{4.}$

4.1.9 Filled grains spike^{-1}

Filled grains spike^{-1} varied significantly due to different wheat varieties under the present trial (Table 4.1.13). The highest filled grains (34.6) spike^{-1} was observed from $V_2$and lowest value (32.7) was found from V_1.

Statistically significant variation was recorded in terms of filled grains spike^{-1} due to different sowing dates (Table 4.1. 14). The highest filled grains (34.1) spike^{-1} was recorded from S_2 which was statistically similar to S_4 and closely followed by S_1, while the lowest filled grains (31.4) spike^{-1} was observed from S_3.

Table 4.1. 13. Effect of varieties on ear length, filled, unfilled and total grains spike^{-1} of wheat

Treatments	Spike length (cm)	Filled grains spike^{-1}	Unfilled grains spike^{-1}	Total grains spike^{-1}
V_1	17.46	32.72	3.82	36.20
V2	18.64	34.62	3.16	37.44
T-test	**	*	*	**
CV (%)	**9.56**	**10.47**	**3.25**	**10.45**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23

Wheat varieties and sowing dates showed significant differences due to their interaction effect in terms of filled grains spike^{-1} (Table 4.1.15). The highest filled grains (36.0) spike^{-1} was found from V_2S_2 and the lowest filled grains (29.8) spike^{-1} was attained from the treatment combination V_1S_4.

Table 4.1. 14. Effect of sowing dates on ear length, filled, unfilled and total grains spike^{-1} of wheat

Treatments	Spike length (cm)	Filled grains spike^{-1}	Unfilled grains spike^{-1}	Total grains spike^{-1}
S_1	17.82	33.10	3.50	36.27
S_2	18.37	34.10	3.41	37.18
S_3	16.40	31.44	3.85	34.96
S_4	17.24	32.83	3.77	36.26
LSD (0.05)	**0.211**	**0.085**	**0.161**	**0.834**
CV (%)	**8.78**	**10.23**	**6.54**	**10.58**

S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.10 Unfilled grains spike^{-1}

Different wheat varieties showed statistically significant difference on unfilled grains spike^{-1} (Table 4.1. 13). The highest unfilled grains (3.82) spike^{-1} was found from $V_2$and lowest value (3.16) was also found from V_1.

Unfilled grains spike^{-1} showed statistically significant differences due to different sowing dates (Table 4.1.14). The highest unfilled grains (3.85) spike^{-1} was observed from S_4 which was statistically similar to S_3, while the lowest unfilled grains (3.41) spike^{-1} was found from S_3which was statistically similar to S_2.

Interaction effect of wheat varieties and sowing dates showed significant differences on unfilled grains spike^{-1} (Table 4.1.15). The highest unfilled grains (4.26) spike^{-1} was observed from V_1S_4 and the lowest unfilled grains (2.96) spike^{-1} was obtained from the treatment ombination V_1S_2.

4.1.11 Total grains spike^{-1}

Total grains spike^{-1} varied significantly due to different wheat varieties under the present trial (Table 4.1.13). Data revealed that the highest total grains (37.4) spike^{-1} was observed from $V_2$and lowest value (36.2) was also found from V_1.

Total grains spike^{-1} showed statistically significant differences due to different sowing dates (Table 4.1.14). The highest total grains (37.1) spike^{-1} was recorded from S_2 which was statistically similar to S_4 and S_1, again the lowest total grains (34.9) spike^{-1} was observed from S_3.

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates in terms of total grains spike^{-1} (Table 4.1.15). The highest total grains (38.8) spike^{-1} was found from V_2S_2, while the lowest total grains (33.9) spike^{-1} was recorded from the treatment combination V_1S_4.

Table 4.1.15. Interaction effect of varieties and sowing dates on ear length, filled, unfilled and total grains spike^{-1} of wheat

Treatments		Spike length (cm)	Filled grains spike^{-1}	Unfilled grains spike^{-1}	Total grains spike^{-1}
V_1	S_1	18.10	32.63	3.70	36.00
	S_2	19.58	35.46	2.96	38.10
	S_3	18.11	34.30	3.06	37.03
	S_4	15.49	30.00	4.26	33.93
V_2	S_1	18.88	34.70	3.63	38.00
	S_2	19.97	36.06	3.10	38.83
	S_3	19.42	35.76	3.13	38.56
	S_4	15.20	29.86	3.76	33.30
LSD (0.05)		**0.422**	**0.056**	**0.323**	**0.166**
CV (%)		**8.78**	**10.54**	**8.78**	**10.25**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23; S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.12 Weight of 1000-seeds

Different wheat varieties showed statistically significant difference on weight of 1000-seeds (Table 4.1.16). The highest weight (45.2 g) of 1000-seeds was recorded from $V_2$and lowest value (43.7 g) was also found from V_1. Weight of 1000-seedsshowed statistically significant differences due to different sowing dates (Table 4.1.17). The highest weight (45.1) of 1000-seeds was found from S_2 which was statistically similar to S_3 and S_1, while the lowest weight (40.5) of 1000-seeds was observed from S_4.

Interaction effect of wheat varieties and sowing dates showed significant differences on weight of 1000-seeds (Table 4.1.18). The highest weight of 1000-seeds (46.2 g) was found from V_2S_2, while the lowest weight (43.9 g) of 1000-seeds was obtained from the treatment combination V_1S_4.

Table 4.1. 16. Effect of varieties on yield and harvest index of wheat

4.1.13 Grain yield

Treatments	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest index (%)
V_1	43.70	3.95	5.39	9.00	41.98
V_2	45.28	4.11	5.95	9.72	42.53
T-test	**	**	*	**	**
CV (%)	**10.54**	**6.56**	**3.56**	**7.68**	**11.23**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23

4.1.13 Grain yield

Statistically significant variation was observed for different wheat varieties in terms of grain yield (Table 4.1.16). The highest grain yield (4.11 t ha^{-1}) was found from V_2that means BARI Gom 23 showed good performance over BARI Gom 21. Different sowing dates showed statistically significant differences on grain yield (Table 4.1.17). The highest grain yield (4.06 t/ha) was recorded from S_2that means November 30 sowing showed better performance over others the lowest grain yield (3.59 t/ha) was observed from S_4 that means December 10 sowing.

Interaction effect of wheat varieties and sowing dates showed significant differences on grain yield (Table 4.1.18). The highest grain yield (4.27 tha^{-1}) was observed from V_2S_2 that means November 20 sowing with BARI Gom 23 showed better performance over other sowing dates whilethe lowest grain yield (3.49 t/ha) was obtained from the treatment combination V_1S_4 that means December 10 sowing with BARI Gom 21 showed less performance.

Table 4.1. 17. Effect of sowing dates on yield and harvest index of wheat

Treatments	1000-grain weight (g)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological Yield ($t\ ha^{-1}$)	Harvest index (%)
S_1	44.95	4.00	5.49	9.16	41.95
S_2	45.13	4.06	5.66	9.38	41.63
S_3	44.43	3.59	5.06	8.32	41.30
S4	40.53	3.86	5.35	8.86	41.70
LSD (0.05)	**0.542**	**0.147**	**0.132**	**0.376**	**0.559**
CV (%)	**9.87**	**5.65**	**5.48**	**6.98**	**10.23**

S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4. 1.14 Straw yield

Different wheat varieties showed statistically significant difference on straw yield (Table 4.1.16). The highest straw yield (5.95 t/ha) was found from $V_2$and lowest value (5.39 t ha^{-1}) was obtained from V_1.
Different sowing dates showed statistically significant difference on straw yield (Table 4.1.17). The highest straw yield (5.66 tha^{-1}) was found from S_2 which was statistically similar to $S_1$and lowest straw yield (5.06 t/ha) was found from $S_{3.}$
Interaction effect of wheat varieties and sowing dates showed significant differences on straw yield (Table 4.1.18). The highest straw yield was observed from V_2S_2, whereas the lowest straw yield was obtained from the treatment combination V_1S_4.

4.1.15 Biological yield

Biological yield showed statistically significant difference due to different wheat varieties (Table 4.1.16). Data revealed that the highest biological yield (9.72 t ha^{-}

^{1}) was observed from $V_2$and lowest biological yield (9.0 t ha^{-1}) was found from V_1.

Different sowing dates showed statistically significant differences in terms of biological yield (Table 4.1.17). The highest biological yield was found from S_2 (9.38 t ha^{-1}) which was closely followed by S_3 (9.16 t ha^{-1}), again the lowest biological yield (8.32 t/ha) was recorded from S_4 which was closely followed by S_1 (8.84 t ha^{-1}).

Interaction effect of wheat varieties and sowing dates showed significant differences on biological yield (Table 4.1.18). The highest straw yield (10.15 t/ha) was observed from V_2S_2, whereas the lowest straw yield (7.65 t/ha) was obtained from the treatment combination V_1S_4.

Table 4.1.18. Interaction effect of varieties and sowing dates on yield and harvest index of wheat

Treatments		1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield(t ha^{-1})	Harvest index (%)
V1	S1	44.90	4.14	5.67	9.48	41.93
	S_2	46.10	4.20	5.93	9.79	41.20
	S_3	44.20	4.17	5.59	9.43	42.55
	S_4	44.60	3.49	4.75	7.91	42.12
V_2	S_1	45.70	4.21	5.90	9.78	41.40
	S2	46.20	4.27	6.21	10.15	43.60
	S_3	44.70	4.24	6.03	9.94	41.00
	S4	43.90	3.50	4.48	7.65	40.49
LSD (0.05)		**0.045**	**0.295**	**0.078**	**0.753**	**0.325**
CV (%)		**10.23**	**6.56**	**4.65**	**7.87**	**11.21**

V_1 = BARI Gom 21 and V_2 = BARI Gom 23; S_1: Sowing at 10 November, 2014'; S_2: Sowing at 20 November, 2014' S_3: Sowing at 30 November, 2014' S_4: Sowing at 10 December, 2014

4.1.16 Harvest index

Different wheat varieties showed statistically non-significant difference on harvest index (Table 4.1.16). The highest harvest index (42.5%) was found from V_1 and the lowest harvest index (41.9%) was recorded from V_2.

Harvest index showed statistically significant differences due to different sowing dates (Table 4.1.17). The highest harvest index (43.9%) was observed from S_1 which was closely followed by S_2, whereas the lowest harvest index (41.3%) was found from S_2 which was statistically similar to S_3.

Interaction effect of wheat varieties and sowing dates showed significant differences on harvest index (Table 4.1.18). The highest harvest index (43.6%) was observed from V_2S_2, while the lowest harvest index (40.4%) was obtained from the treatment combination V_2S_4.

Experiment 2: Effect of irrigation, sowing date and post anthesis supplemental N application on the performance of wheat

4.2.1 Spike length

4.2.1.1 Impact of irrigation

Spike length of wheat significantly influenced by different treatments of irrigation (Figure 4.2.1). The figure shows that in respective of irrigation, spike length showed decreasing trend with the further providing of irrigation after the field capacity. The rate of decreasing much higher from I_1 to I_2 after that the decreasing trend much slower (I_2 to I_3). However, the longest spike was found in I_1 (31.12 cm). The smallest spike was recorded in I_3 (16.06 cm).

4.2.1.2 Impact of sowing date

Date of sowing showed significant impact on spike length of wheat (Figure 4.2.1). It can be inferred from the figure that the spike length exerted a steady increasing trend with the increases of sowing date up to S_2 after that the length reduced marginally in respective of date of sowing. However, the highest values of spike length (23.58 cm) obtained in S_2 while the lowest value (15.48 cm) was in S_1.

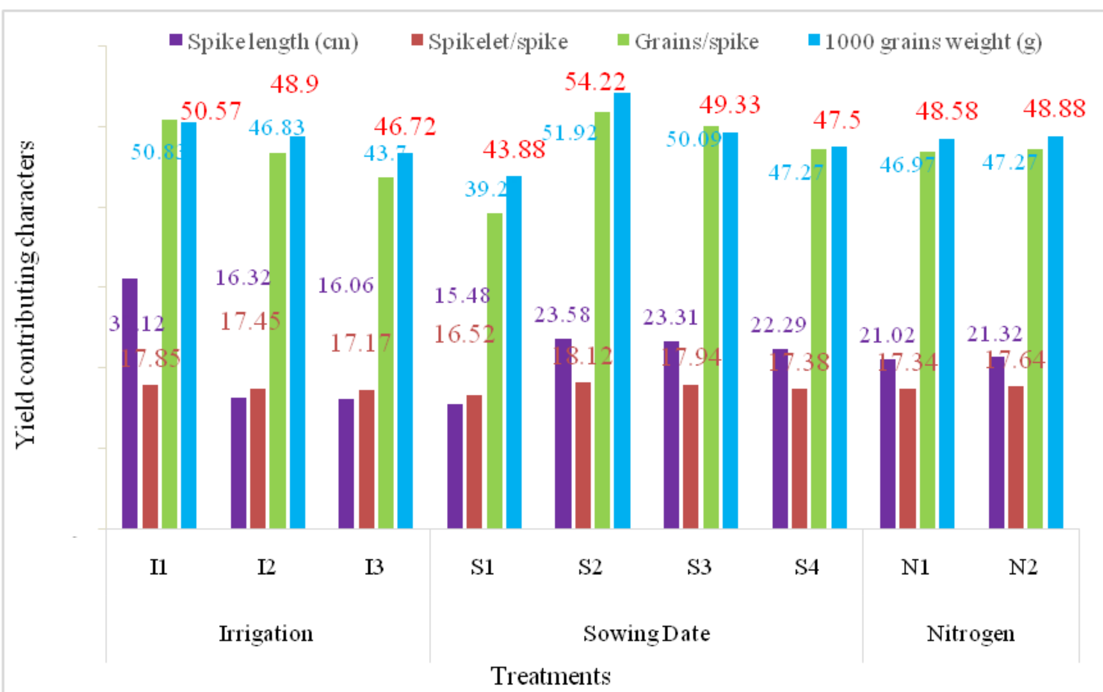


Figure 4.2.1. Effect of irrigation, date of sowing and nitrogen on yield contributing characters of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.1.3 Impact of nitrogen

The application of additional nitrogen at grain fillings stage showed significant variations on spike length of wheat (Figure 4.2.1). The longest spike (21.32 cm) was found in N_2 (application nitrogen at grain filling stage) and the smallest spike(21.02 cm) in N_1 (application nitrogen only basal dose).

4.2.1.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on spike length of wheat (Figure4.2.2 2). The highest value of spike length (37.64 cm) was found in I_1S_2 and the lowest value (15.09 cm) of the same trait was obtained in I_3S_1.

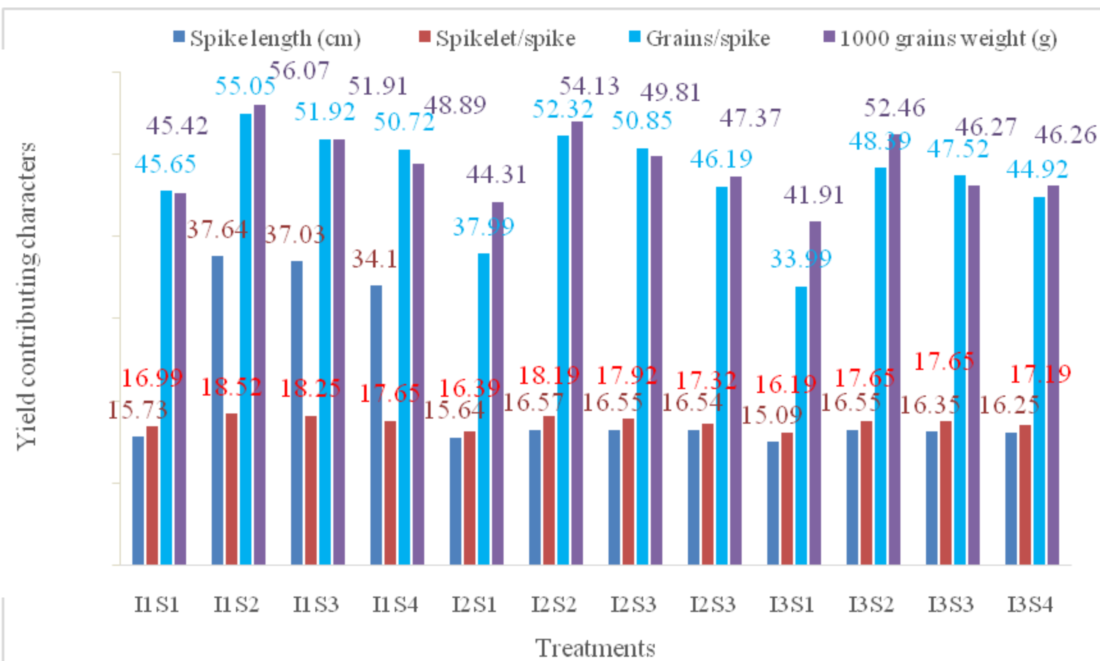


Figure 4.2.2. Combined effect of irrigation and date of sowing on yield contributing characters of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December

4.2.1.5 Combined effect of irrigation and nitrogen

The spike length of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.3). From the figure it can be demonstrated that the maximum spike length (31.27 cm) was found in I_1N_2 while the minimum spike length (15.91 cm) was recorded in I_3N_1.

4.2.1.6 Combined effect of sowing date and nitrogen

The spike length did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.4). Although having non-significant effect the longest spike (23.73 cm) was recorded in S_2N_2 and the shortest spike (15.33 cm) was found in S_1N_1.

4.2.1.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant spike length of wheat (Table 4.2.1). Table represents that, the highest spike length (37.79 cm) was recorded in $I_1S_2N_2$ and the lowest spike length (14.94 cm) was found in $I_3S_1N_1$.

4.2.2 Spikelet spike^{-1}

4.2.2.1 Impact of irrigation

The application of irrigation exerted significant impact on spikelet spike^{-1} of wheat (Figure 4.2.1). The spikelet spike^{-1} number showed decreeing trend but the rate was not so high. The maximum number of spikelet spike^{-1} was recorded in I_1 (17.84) and the lowest in I_3 (17.17).

4.2.2.2 Impact of sowing date

The date of sowing had a positive effect on spikelet spike^{-1}of wheat (Figure 4.2.1). The values showed significant impact and increasing trend up to the S_2 and then decreased slightly up to S_4. Figure demonstrated that the treatment S_2 produced maximum number of spikelet spike^{-1} (18.12) whileS_1 produced lowest number of spikelet spike^{-1} (16.52).

4.2.2.3 Impact of nitrogen

The number of spikelet spike^{-1} showed a significant variation due to effect of nitrogen at grain filling stage (Figure 4.2.1). The maximum number of spikelet spike^{-1} was recorded in N_2 (17.64) and the lowest value of the same trait was in N_1 (17.34).

4.2.2.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on number of spikelet spike^{-1}of wheat (Figure 4.2.2). The highest value of spikelet spike^{-1} (18.52) was found in I_1S_2 and the lowest value (16.19) of the same trait was obtained in I_3S_1.

4.2.2.5 Combined effect of irrigation and nitrogen

The number of spikelet spike^{-1}of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.3). From the figure it can be demonstrated that the maximum number of spikelet spike^{-1} (18.00) was found in I_1N_2 while the minimum number of spikelet spike^{-1} (17.02) was recorded in I_3N_1.

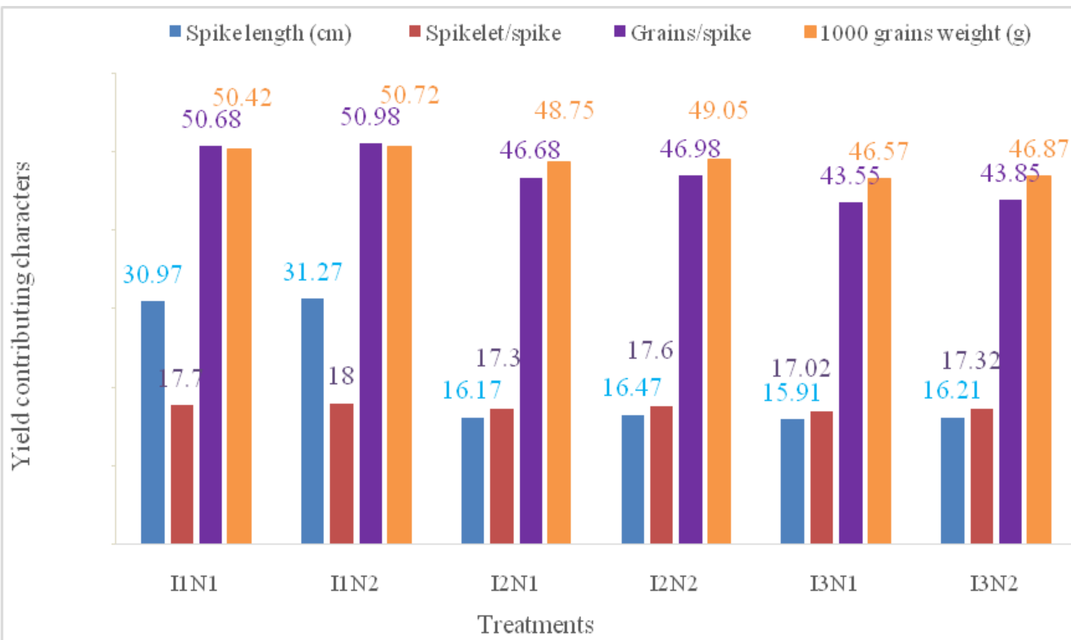


Figure 4.2.3. Combined effect of irrigation and nitrogen on yield contributing characters of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.2.6 Combined effect of sowing date and nitrogen

The number of spikelet spike^{-1} did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.4). Although having non- significant effect the highest number of pikelet spike^{-1} (18.27) was recorded in S_2N_2 and the lowest number of spikelet spike^{-1} (16.37) was found in S_1N_1.

4.2.2.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant number of spikelet spike^{-1} of wheat (Table 4.2.1). Table represents that, the highest value of number of spikelet spike^{-1} (18.67) was recorded in $I_1S_2N_2$ and the lowest number of spikelet spike^{-1} (16.04) was found in $I_3S_1N_1$.

4.2.3 Grains spike^{-1}

4.2.3.1 Impact of irrigation

The number of grains spike^{-1} of wheat influenced significantly due to irrigation treatments (Figure 4.2.1). The highest number of grains spike^{-1}was found in I_1 (50.83) the after showed decreasing trend up to the I_3. The lowest value of number of grains spike^{-1}was recorded in I_3 (46.72).

4.2.3.2 Impact of sowing date

The date of sowing showed significant impact on number of grains spike^{-1}of wheat (Figure 4.2.1). The maximum number of number of grains spike^{-1}was obtained in treatment S_2 (sowing at 20 November). The highest value of number of grains spike^{-1} (51.92) obtained in S_2while the lowest value of number of grains spike^{-1} (43.88) was in S_1.

4.2.3.3 Impact of nitrogen

The application of additional nitrogen at grain filling stage showed significant variations on number of grains spike^{-1}(Figure 4.2.1). Figure represents that the highest value of number of grains spike^{-1} (48.88) was obtained in N_2 (application nitrogen at grain filling stage) while the lowest value (48.58) of this trait was in N_1(application nitrogen only basal dose).

4.2.3.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on number of grains spike^{-1}of wheat (Figure 4.2.2). The highest value of number of grains spike^{-1}(55.05) as found in I_1S_2 and the lowest value (33.99) of the same trait was obtained in I_3S_1.

4.2.3.5 Combined effect of irrigation and nitrogen

The number of grains spike^{-1}of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.3). From the figure it can be demonstrated that the maximum number of grains spike^{-1}(50.98) was found in I_1N_2 while the minimum number of grains spike^{-1}(43.55) was recorded in I_3N_1.

4.2.3.6 Combined effect of sowing date and nitrogen

The number of grains spike^{-1}did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.4). Although having non-significant effect the maximum number of grains spike^{-1}(52.37) was recorded in S_2N_2 and the minimum number of grains spike^{-1}(39.06) was found in S_1N_1.

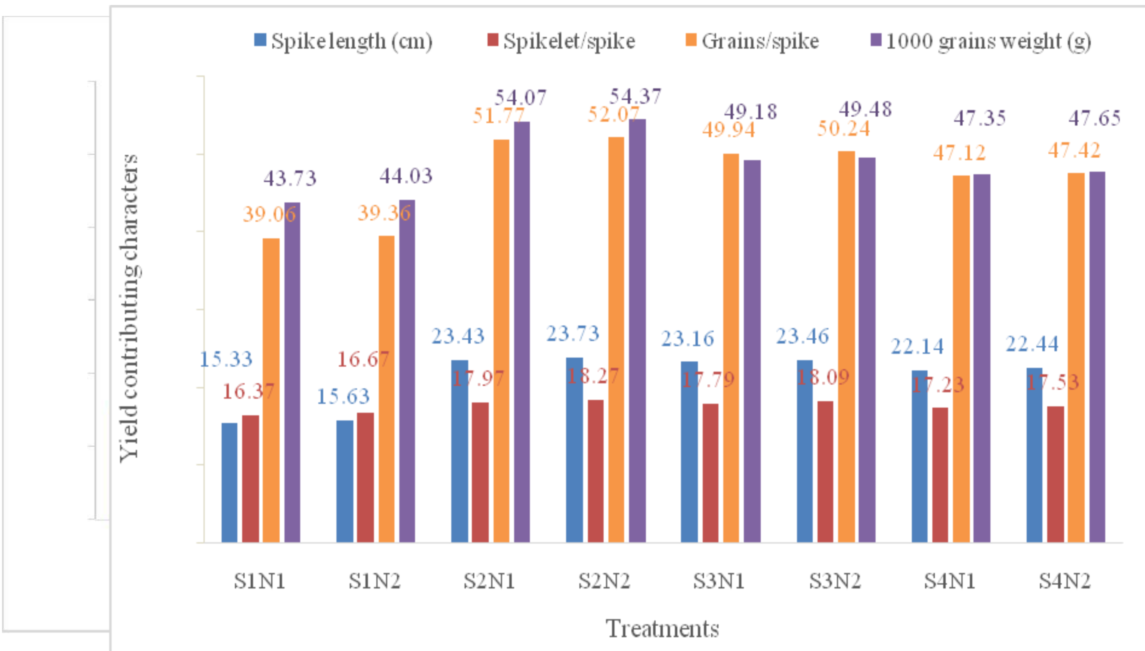


Figure 4.2.4. Combined effect of date of sowing and nitrogen on yield contributing characters of wheat

S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.3.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant value of number of grains spike^{-1} of wheat (Table 4.2.1). Table represents that, the highest number of grains spike^{-1} (55.20) was recorded in $I_1S_2N_2$ and the lowest number of grains spike^{-1} (33.84) was found in $I_3S_1N_1$.

4.2.4 The 1000 grains weight

4.2.4.1 Impact of irrigation

The irrigation treatments showed significant effect on 1000 grains weight of wheat (Figure 4.2.1). The highest 1000 grains weight (50.57 g) was recorded in I_1 and the lowest value of 1000 grains weight (46.72 g) in I_3 which indicated that irrigation at filed capacity condition produced heaver grain than further irrigation at ½ of field capacity and 1/4 of field capacity conditioned plots.

4.2.4.2 Impact of sowing date

The date of sowing had a positive effect on 1000 grains weight of wheat (Figure 4.2.1). The figure showed an increasing trend with an advancement of date of sowing up to the S_2 treatment. A further advancement of date of sowing reduced the 1000 grains weight slightly. However, the treatment S_2 produced highest 1000 grains weight (54.22 g) where S_1 produced lowest 1000 grains weight (43.88 g) compared to other treatments.

4.2.4.3 Impact of nitrogen

The 1000 grains weight showed significant impact due to the effect of nitrogen at grain filling stage (Figure 4.2.1). Figure demonstrated that the highest value of 1000 grains weight was recorded in N_2 (48.88 g) while the lowest value of this trait was in N_1 (48.58 g).

4.2.4.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on 1000 grains weight of wheat (Figure 4.2.2). The highest value of 1000 grains weight (56.07 g) was found in I_1S_2 and the lowest value (41.91 g) of the same trait was obtained in $I_3S_{1.}$

4.2.4.5 Combined effect of irrigation and nitrogen

The 1000 grains weight of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.3). From the figure it can be demonstrated that the maximum 1000 grains weight (50.72 g) was found in I_1N_2 while the minimum 1000 grains weight (46.57 g) was recorded in I_3N_1.

4.2.4.6 Combined effect of sowing date and nitrogen

The 1000 grains weight did not influence significantly by the combined effect of date and nitrogen. Although having non-significant effect the highest 1000 grains weight (54.37 g) was recorded in S_2N_2 and the lowest 1000 grains weight (43.73 g) was found in S_1N_1.

4.2.4.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant 1000 grains weight of wheat (Table 4.2.1). Table represents that, the highest 1000 grains weight (56.22 g) was recorded in $I_1S_2N_2$ and the lowest 1000 grains weight (41.76 g) was found in $I_3S_1N_1$.

Table 4.2.1. Combined effect of irrigation, sowing date and nitrogen on yield contributing characters of wheat

Treatments	Spike length (cm)	Spikelet spike^{-1}	Grains spike^{-1}	1000 grains weight (g)
$I_1S_1N_1$	15.58	16.84	45.50	45.27
$I_2S_1N_1$	15.49	16.24	37.84	44.16
I3S1N1	14.94	16.04	33.84	41.76
$I_1S_2N_1$	37.49	18.37	54.90	55.92
$I_2S_2N_1$	16.42	18.04	52.17	53.98
$I_3S_2N_1$	16.40	17.50	48.24	52.31
I1S3N1	36.88	18.10	51.77	51.76
$I_2S_3N_1$	16.40	17.77	50.70	49.66
I3S3N1	16.20	17.50	47.37	46.12
$I_1S_4N_1$	33.95	17.50	50.57	48.74
$I_2S_4N_1$	16.39	17.17	46.04	47.22
I3S4N1	16.10	17.04	44.77	46.11
$I_1S_1N_2$	15.88	17.14	45.80	45.57
$I_2S_1N_2$	15.79	16.54	38.14	44.46
$I_3S_1N_2$	15.24	16.34	34.14	42.06
$I_1S_2N_2$	37.79	18.67	55.20	56.22
I2S2N2	16.72	18.34	52.47	54.28
$I_3S_2N_2$	16.70	17.80	48.54	52.61
$I_1S_3N_2$	37.18	18.40	52.07	52.06
$I_2S_3N_2$	16.70	18.07	51.00	49.96
$I_3S_3N_2$	16.50	17.80	47.67	46.42
$I_1S_4N_2$	34.25	17.80	50.87	49.04
I2S4N2	16.69	17.47	46.34	47.52
$I_3S_4N_2$	16.40	17.34	45.07	46.41
CV (%)	**1.85**	**2.25**	**0.83**	**0.81**
LSD (0.05)	**0.66**	**0.66**	**0.66**	**0.66**

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.5 Grain yield

4.2.5.1 Impact of irrigation

Grain yield of wheat showed significant influences by the application of irrigation (Figure 4.2.5). The highest grain yield was found in I_1 (3.97 t ha^{-1}). The lowest grain yield was recorded in I_3 (3.43 t ha^{-1}) which indicated that the irrigation at field capacity condition put yielded higher than irrigation at ½ of field capacity and ¼ of the field capacity.

4.2.5.2 Impact of sowing date

The date of sowing showed significant impact on grain yield of wheat (Figure 4.2.5). Grain yield values showed a gradual increasing trend with the advancement of date of sowing up to S_2 treatment after that the value reduced marginally. Among the sowing dates grain yield ranges from 3.43 to 4.18 t $ha^{-1}$the highest yield was obtained with S^2. It can be infrared from the data that S_2 treatment showed higher yield over other treatments.

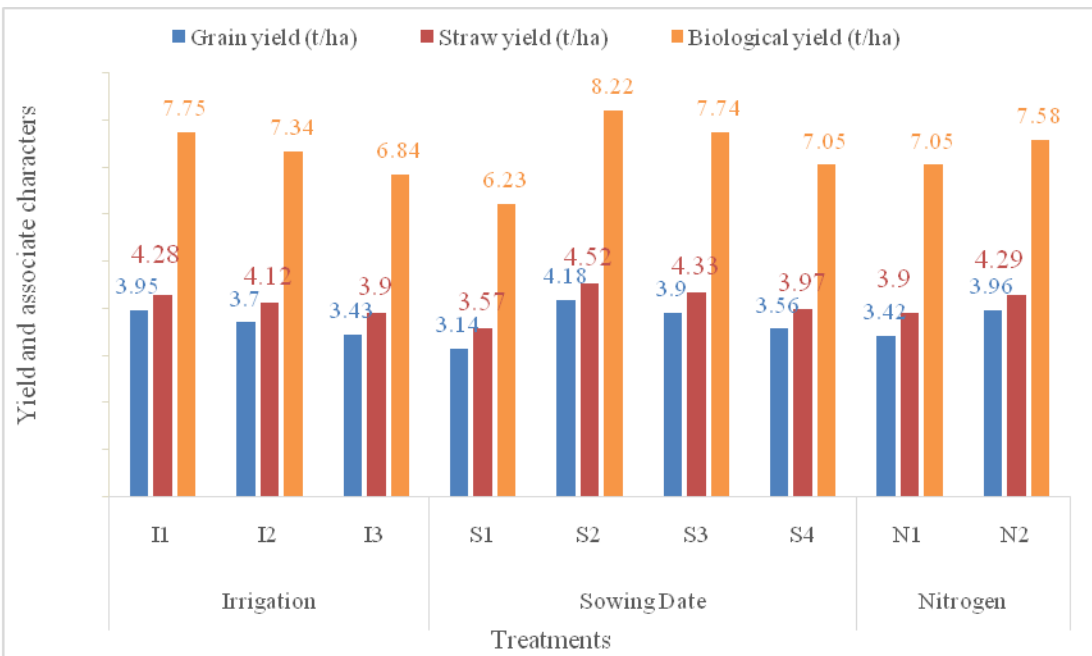


Figure 4.2.5. Combined effect of irrigation, sowing date and nitrogen on yield contributing characters of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.5.3 Effect of nitrogen

The effect of additional nitrogen at grain filling stage showed significant impact on grain yield of wheat (Figure 4.2.5). The highest grain yield was found in N_2 (3.96 t ha^{-1}) while the lowest yield was in N_1 (3.42 t ha^{-1}).

4.2.5.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on grain yield of wheat (Figure 4.2.6). The highest value of grain yield (4.54 t ha^{-1}) was found in I_1S_2 and the lowest value (2.87 t ha^{-1}) of the same trait was obtained in I_3S_1.

4.2.5.5 Combined effect of irrigation and nitrogen

The grains yield of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.7). From the figure it can be demonstrated that the highest grain yield (4.22 t ha^{-1}) was found in I_1N_2 while the minimum grain yield (3.16 t ha^{-1}) was recorded in $I_3N_{1.}$

4.2.5.6 Combined effect of sowing date and nitrogen

The grain yield did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.8). Although having non-significant effect the highest grain yield (4.45 t ha^{-1}) was recorded in S_2N_2 and the lowest grain yield (2.87 t ha^{-1}) was found in S_1N_1.

4.2.5.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant grain yield of wheat (Table 4.2.2). Table represents that, the highest grain yield (4.81 t ha^{-1}) was recorded in $I_1S_2N_2$ and the lowest grain yield (2.60 t ha^{-1}) was found in $I_3S_1N_1$.

4.2.6 Straw yield

4.2.6.1 Impact of irrigation

The application of irrigation showed significant impact on straw yield of wheat (Figure 4.2.5). The highest straw yield was recorded in I_1 (4.28 t ha^{-1}) and lowest in I_3 (3.90 t ha^{-1}).

4.2.6.2 Impact of sowing date

Sowing date had a significant effect on straw yield of wheat (Figure 4.2.5). The treatment S_2 produced the highest straw yield (4.52 t ha^{-1}) where S_1 produced the lowest straw yield (3.57 ha^{-1}).

4.2.6.3 Impact of nitrogen

The straw yield showed significant impact due to effect of application an additional nitrogen at grain filling stage (Figure 4.2.5). The figure represent that the highest straw yield was recorded in N_2 (4.29 t ha^{-1}) and the lowest straw yield was recorded in N_1 (3.90 t ha^{-1}).

4.2.6.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on straw

yield of wheat (Figure 4.2.6). The highest value of straw yield (4.80 t ha^{-1}) was found in I_1S_2 and the lowest value (3.36 t ha^{-1}) of the same trait was obtained in I_3S_1.

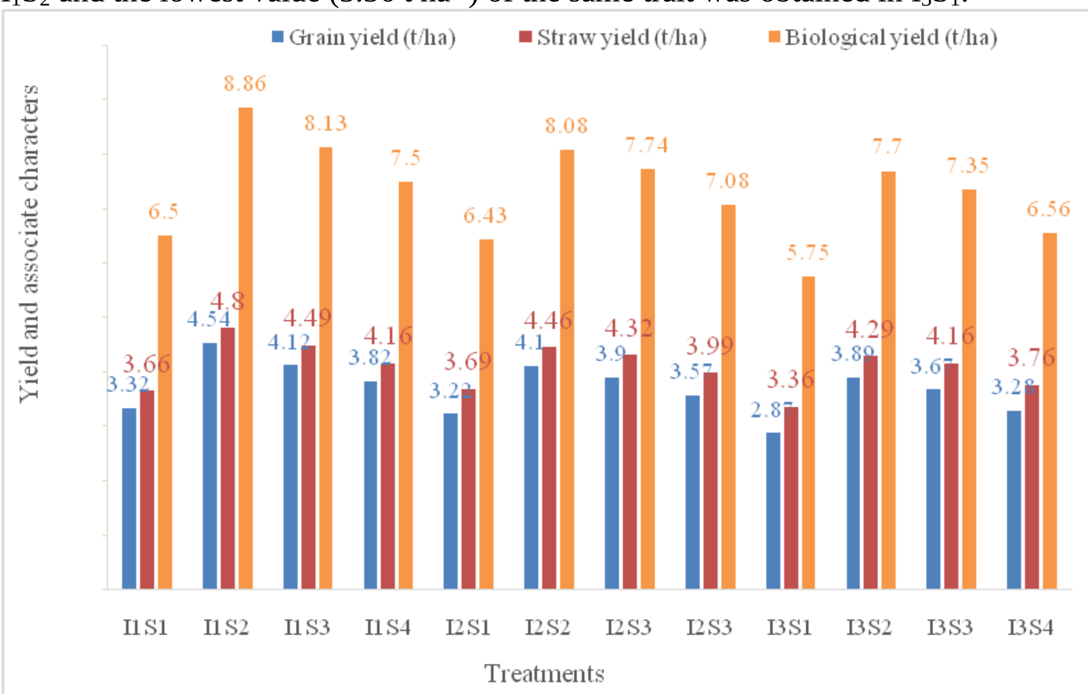


Figure 4.2.6. Combined effect of irrigation and sowing date on yield and yield attributing characters of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December

4.2.6.5 Combined effect of irrigation and nitrogen

The straw yield of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.7). From the figure it can be demonstrated that the highest straw yield (4.48 t ha^{-1}) was found in I_1N_2 while the minimum grain yield (3.70 t ha^{-1}) was recorded in I_3N_1.

4.2.5.6 Combined effect of sowing date and nitrogen

Th straw yield did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.8). Although having non-significant effect the highest straw yield (4.72 t ha^{-1}) was recorded in S_2N_2 and the lowest straw yield (3.38 t ha^{-1}) was found in S_1N_1.

4.2.5.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant straw yield of wheat (Table 4.2.2). Table represents that, the highest straw yield (5.00 t ha^{-1}) was recorded in $I_1S_2N_2$ and the lowest grain yield (3.17 t ha^{-1}) was found in $I_3S_1N_1$.

4.2.7 Biological yield

4.2.7.1 Impact of irrigation

The biological yield of wheat showed significant influences by the application of different types of irrigation (Figure 4.2.5). The highest biological yield was found in I_1 (7.75 t ha^{-1}). The lowest biological yield was recorded in I_3 (6.84 t ha^{-1}) which indicated that the irrigation at field capacity condition put biological yielded higher than irrigation at 50% of field capacity and 25% of the field capacity.

4.2.7.2 Impact of sowing date

The date of sowing showed significant impact on biological yield of wheat (Figure 4.2.5). The biological yield values showed a gradual increasing trend with the advancement of date of sowing up to S_2 treatment and after that the value reduced marginally. Among the sowing dates biological yield ranges from 6.23 t ha^{-1} to 8.22 t ha^{-1}. It can be infrared from the data that S_2 treatment showed higher biological yield over other treatments.

4.2.7.3 Effect of nitrogen

The effect of additional nitrogen at grain filling stage showed significant impact on biological yield of wheat (Figure 4.2.5). The highest biological yield was found in N_2 (7.58 t ha^{-1}) while the lowest yield was in N_1 (7.05 t ha^{-1}).

4.2.7.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on biological yield of wheat (Figure 4.2.6). The highest value of biological yield (8.86 t ha^{-1}) was found in I_1S_2 and the lowest value (5.75 t ha^{-1}) of the same trait was obtained in I_3S_1.

4.2.7.5 Combined effect of irrigation and nitrogen

The biological yield of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.7). From the figure it can be demonstrated that the highest biological yield (8.02 t ha^{-1}) was found in I_1N_2 while the minimum biological yield (6.58 t ha^{-1}) was recorded in I_3N_1.

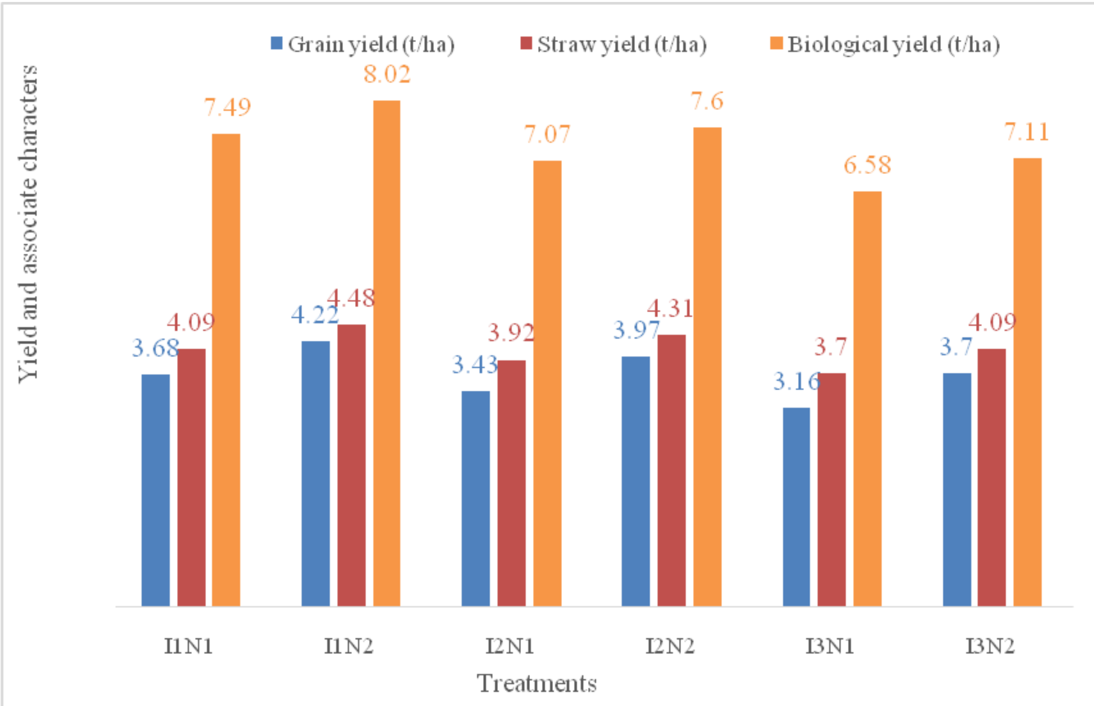


Figure 4.2.7. Combined effect of irrigation and nitrogen on yield and yield attributing characters of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.7.6 Combined effect of sowing date and nitrogen

The biological yield did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.8). Although having non-significant effect the highest biological yield (8.48 t ha^{-1}) was recorded in S_2N_2 and the lowest biological yield (5.97 t ha^{-1}) was found in S_1N_1.

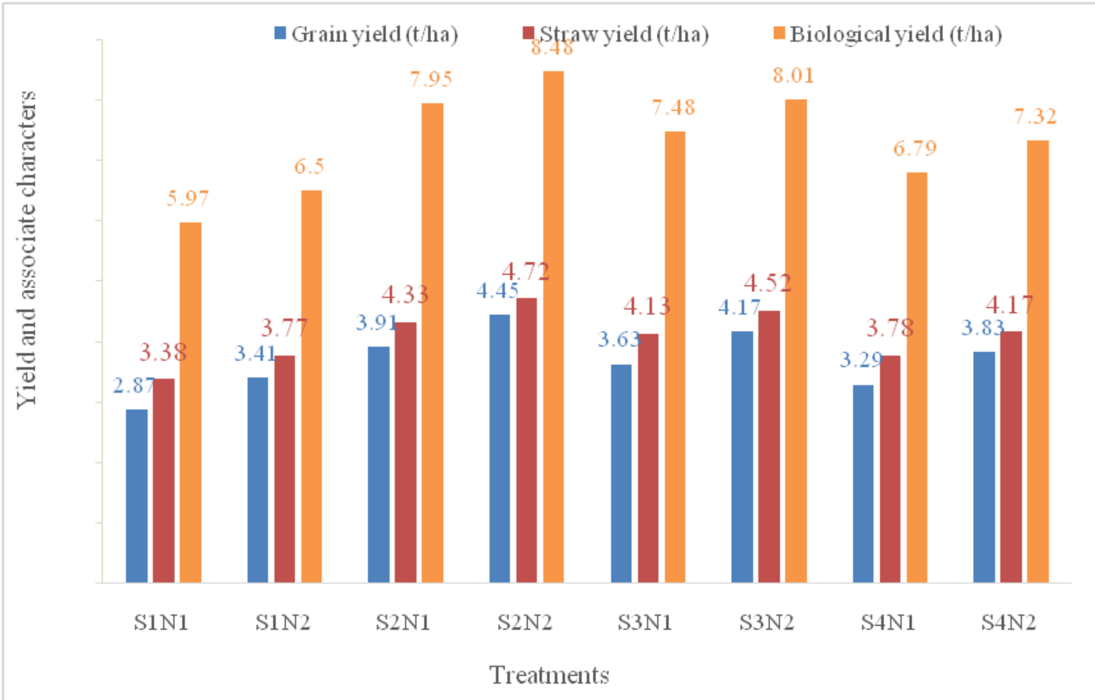


Figure 4.2.8. Combined effect of sowing date and nitrogen on yield and yield attributing characters of wheat

S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.7.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant biological yield of wheat (Table 4.2.2). Table represents that, the highest biological yield (9.13 t ha^{-1}) was recorded in $I_1S_2N_2$ and the lowest biological yield (5.49 t ha^{-1}) was found in $I_3S_1N_1$.

4.2.8 Harvest index

4.2.8.1 Impact of irrigation

Harvest index of wheat influenced significantly by the application of irrigation at different field capacity condition (Figure 4.2.9). The highest value (47.64%) of harvest index was found in I_1 treatment. The lowest value (46.16%) of this trait was recorded in I_3.

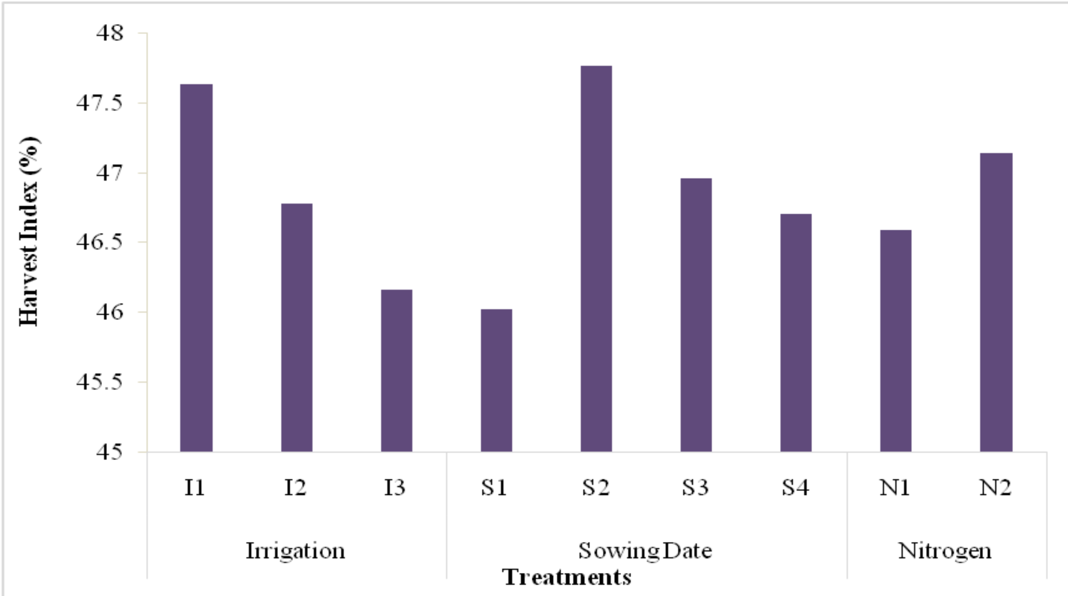


Figure 4.2.9.Effect of irrigation, sowing date and nitrogen on harvest index of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.8.2 Impact of sowing date

The different sowing date showed significant impact on harvest index of wheat (Figure 4.2.9). The figure indicated that S_2 treatment (sowing date 20 November) produced highest harvest index (47.77%). The sowing date earlier and later than S_2 treatment reduced the value harvest index. Though the date of sowing later than S_2 treatment showed a gradual decreasing trend but the lowest decrease (46.02%) was found in S_1 (sowing date 10 November).

4.2.8.3 Effect of nitrogen

The additional application of nitrogen at grain filling stage produced significant harvest index of wheat (Figure 4.2.9). The highest value of harvest index was found in N_2 (47.14 %) and the lowest was in N_1 treatment (46.59%).

4.2.8.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on harvest index of wheat (Figure 4.2.10). The highest value of harvest index (48.49%) was found in I_1S_2 while the lowest value (45.22%) of the harvest index was obtained in I_3S_1.

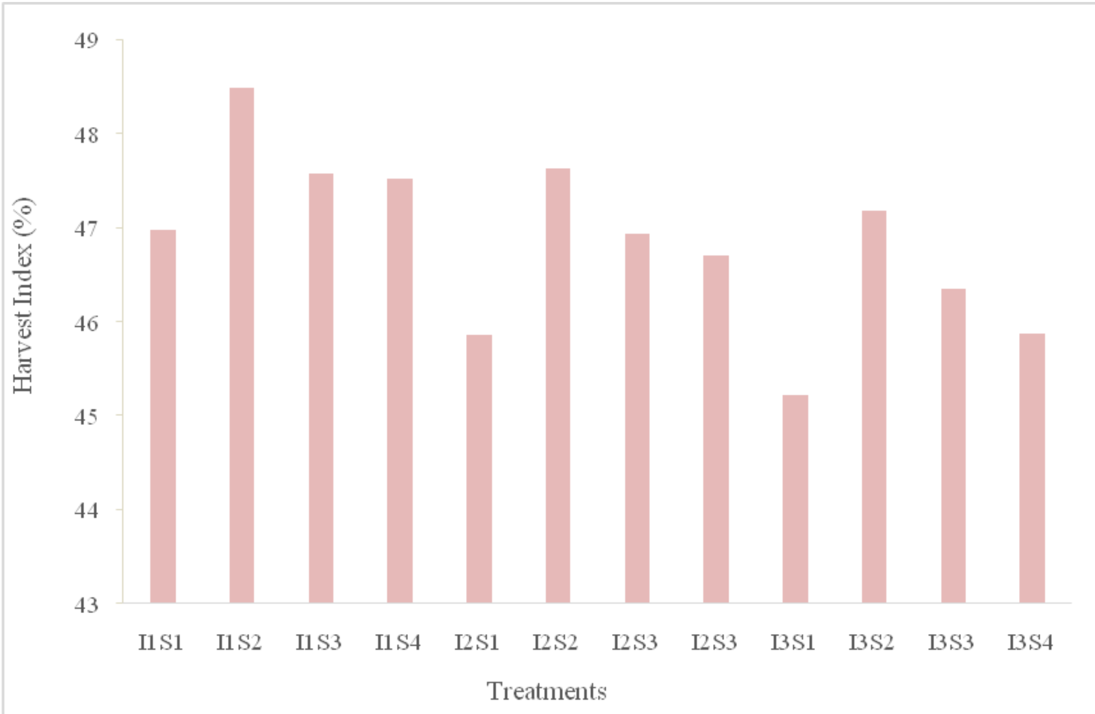


Figure 4.2.10.Combined effect of irrigation and sowing date on harvest index of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December

4.2.8.5 Combined effect of irrigation and nitrogen

The harvest index of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.2.11). The figure demonstrated that the highest value of harvest index (47.92%) was found in I_1N_2 while the minimum harvest index (45.89%) was recorded in I_3N_1.

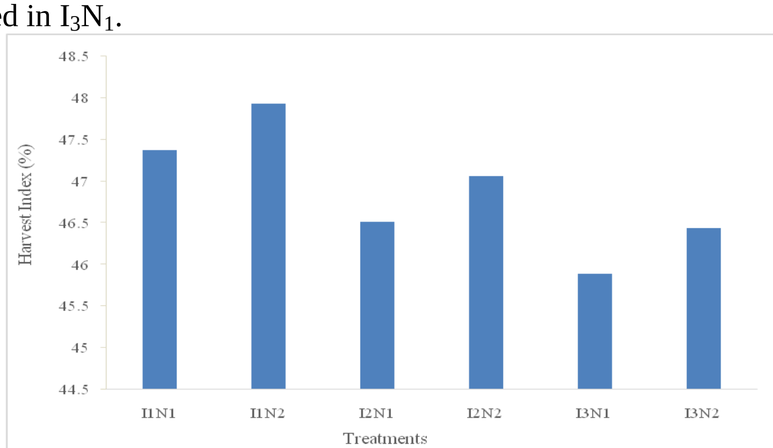


Figure 4.2.11.Combined effect of irrigation and nitrogenon harvest index of wheat

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.8.6 Combined effect of sowing date and nitrogen

The harvest index did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.2.12). Although having non-significant effect the highest harvest index (48.04%) was recorded in S_2N_2 and the lowest harvest index (45.75%) was found in S_1N_1.

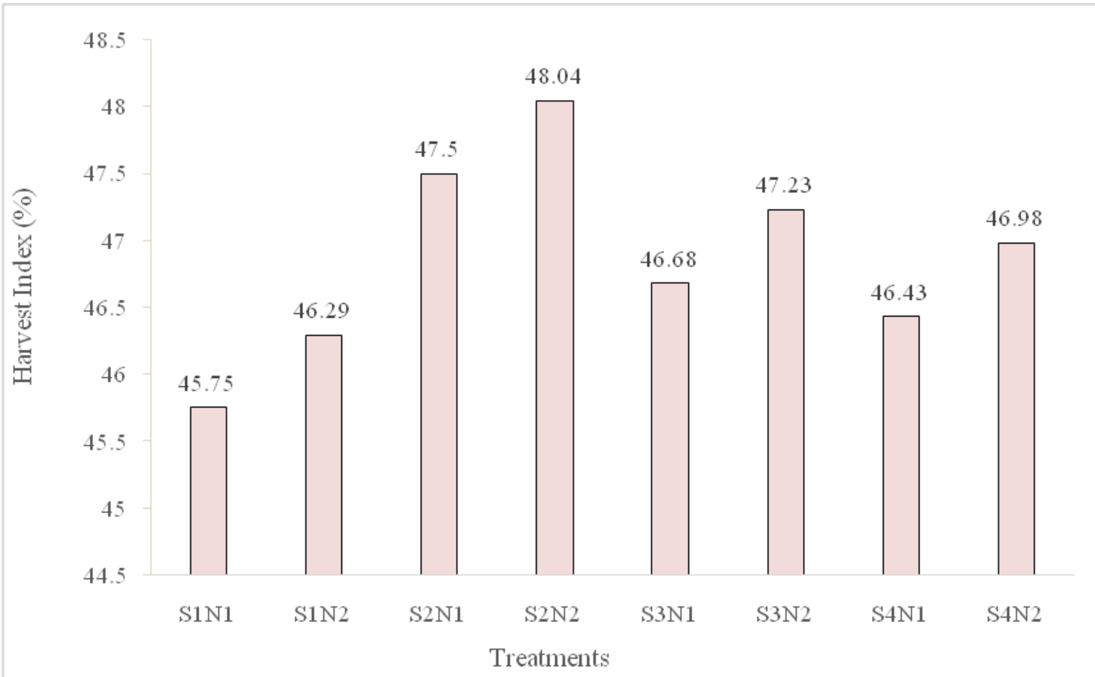


Figure 4.2.12.Combined effect of irrigation and nitrogen on harvest index of wheat
S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.8.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant harvest index of wheat (Table 4.2.2). Table represents that, the highest harvest index (48.76%) was recorded in $I_1S_2N_2$ and the lowest value of harvest index(44.95%) was found in $I_3S_1N_1$.

Table 4.2.2. Combined effect of date of sowing and nitrogen on yield and yield attributing characters of wheat

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest Index (%)
$I_1S_1N_1$	3.05	3.47	6.24	46.71
$I_2S_1N_1$	2.95	3.50	6.17	45.59
$I_3S_1N_1$	2.60	3.17	5.49	44.95
I1S2N1	4.27	4.61	8.60	48.22
I2S2N1	3.83	4.27	7.82	47.36
$I_3S_2N_1$	3.62	4.10	7.44	46.92
$I_1S_3N_1$	3.85	4.30	7.87	47.31
$I_2S_3N_1$	3.63	4.13	7.48	46.67
$I_3S_3N_1$	3.40	3.97	7.09	46.08
I1S4N1	3.55	3.97	7.24	47.26
$I_2S_4N_1$	3.30	3.80	6.82	46.44
$I_3S_4N_1$	3.01	3.57	6.30	45.61
$I_1S_1N_2$	3.59	3.86	6.77	47.25
$I_2S_1N_2$	3.49	3.89	6.70	46.13
$I_3S_1N_2$	3.14	3.56	6.02	45.49
$I_1S_2N_2$	4.81	5.00	9.13	48.76
$I_2S_2N_2$	4.37	4.66	8.35	47.90
$I_3S_2N_2$	4.16	4.49	7.97	47.46
$I_1S_3N_2$	4.39	4.69	8.40	47.85
$I_2S_3N_2$	4.17	4.52	8.01	47.21
$I_3S_3N_2$	3.94	4.36	7.62	46.62
$I_1S_4N_2$	4.09	4.36	7.77	47.80
$I_2S_4N_2$	3.84	4.19	7.35	46.98
$I_3S_4N_2$	3.55	3.96	6.83	46.15
CV (%)	6.13	2.54	2.95	0.50
LSD (0.05)	0.38	0.17	0.36	0.39

I_1=irrigation at field capacity condition, I_2=irrigation at ½ of field capacity condition, I_3=irrigation at ¼ of field capacity; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.2.9 Correlation analysis among yield attributes

In expt. 2 (sowing time with variety BARI GOM-26) at SAU correlation was made among the yield and yield attributes (Table 4.2.3). Results showed that all the attributes were significantly correlated at 1% level of probability (correlation coefficient, r=0.530-0.966). However, higher correlation coefficient was observed between grain yield/ha with number of spikelet/spike (r=0.814), 1000 grain weight (0.819, straw yield (r=0.945), biological yield (r=0.912) and harvest index (r=0.912).

Table.4.2.3.Pierson correlation for experiment 2

	Spike length	Spikelet/spike	Grains/spike	1000 grains weight	Grain yield	Straw yield	Biological yield	HI
Spike length	1							
Spikelet/spike	0.530**	1						
Grains/spike	0.587**	0.853**	1					
1000 grains weight	0.563**	0.823**	0.885**	1				
Grain yield	0.560**	0.814**	0.792**	0.819**	1			
Straw yield	0.534**	0.762**	0.790**	0.815**	0.945**	1		
Biological yield	0.614**	0.842**	0.886**	0.912**	0.966**	0.946**	1	
HI	0.665**	0.785**	0.874**	0.868**	0.912**	0.852**	0.909**	1

** means correlation is significant at 1% level

4.3. Experiment 3. Effect of sowing dates supplemental irrigation water and N application on the performance of wheat

4.3.1 Spike length

4.3.1.1 Impact of irrigation

Spike length of wheat significantly influenced by different treatments of irrigation (Figure 4.3.1). The figure shows that in respective of irrigation, spike length showed decreasing trend with the further providing of irrigation at the heading stage. The rate of decreasing much higher from I_1 to I_2 after that the decreasing trend much slower (I_2 to I_3). However, the longest spike was found in I_1 (15.37 cm). The smallest spike was recorded in I_3 (15.15 cm).

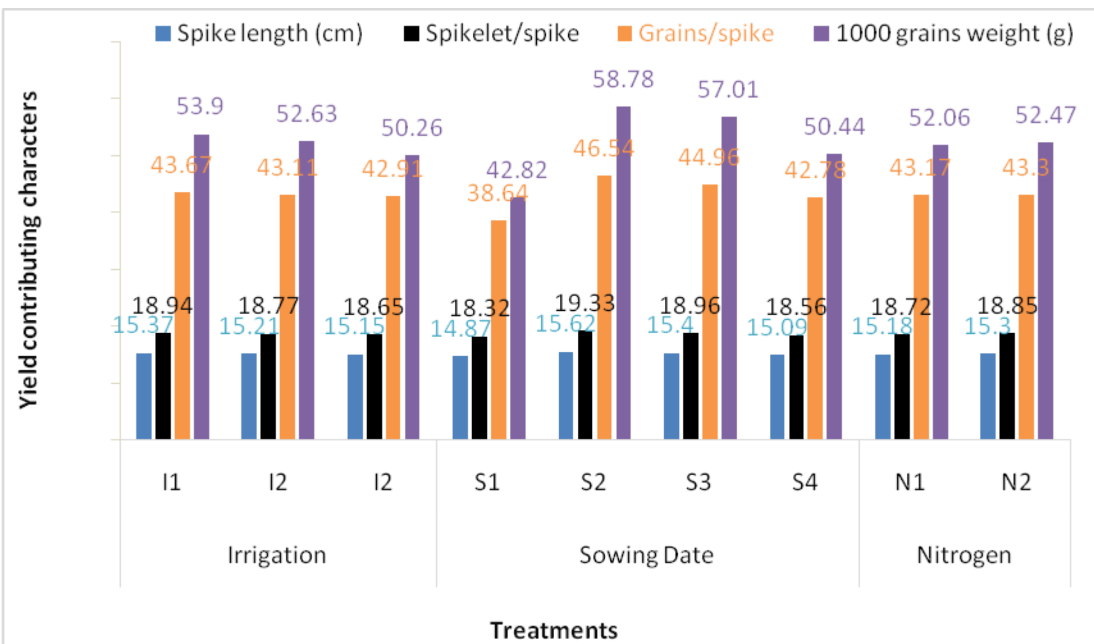


Figure 4.3.1.Effect of irrigation, date of sowing and nitrogen on yield contributing characters of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.1.2 Impact of sowing date

Date of sowing showed significant impact on spike length of wheat (Figure 4.3.1). It can be inferred from the figure that the spike length exerted a steady increasing trend with the increases of sowing date up to S_2 after that the length reduced marginally in respective of date of sowing. However, the highest values of spike length (15.62 cm) obtained in S_2 while the lowest value (14.87 cm) was in S_1.

4.3.1.3 Impact of nitrogen

The application of additional nitrogen at grain fillings stage showed significant variations on spike length of wheat (Figure 4.3.1). The longest spike (15.30 cm) was found in N_2(application nitrogen at grain filling stage) and the smallest spike (15.18 cm) in N_1 (application nitrogen only basal dose).

4.3.1.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on spike length of wheat (Figure 4.3.2). The highest value of spike length (16.06 cm) was found in I_1S_2 and the lowest value (14.74 cm) of the same trait was obtained in I_3S_1.

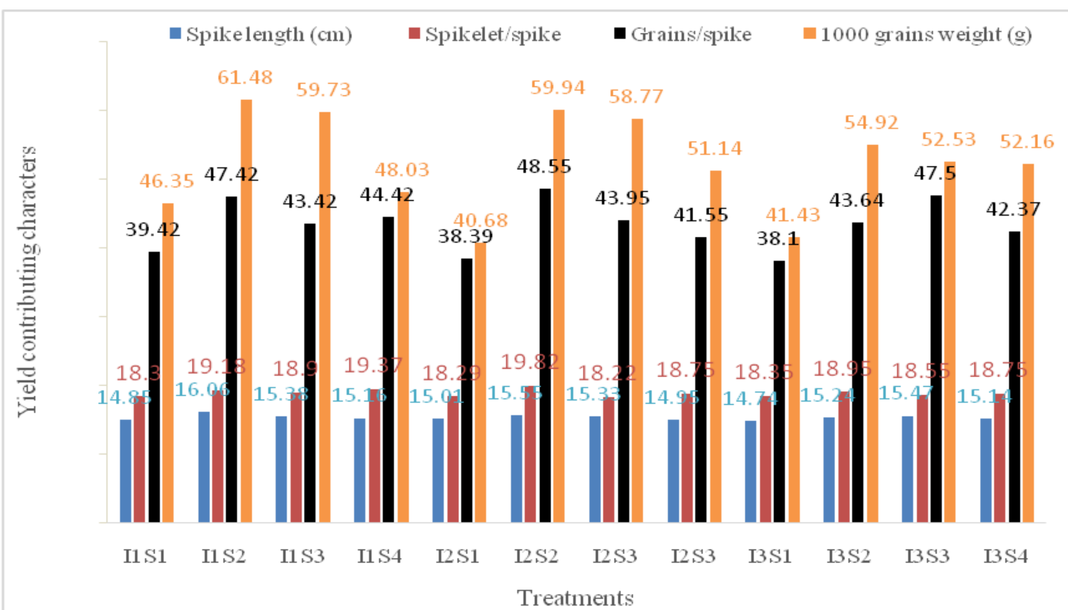


Figure 4.3.2.Combined effect of irrigation and date of sowing on yield contributing characters of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December

4.3.1.5 Combined effect of irrigation and nitrogen

The spike length of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.3). From the figure it can be demonstrated that the maximum spike length (15.44 cm) was found in I_1N_2 while the minimum spike length (15.10 cm) was recorded in I_2N_1but it was non-significant.

4.3.1.6 Combined effect of sowing date and nitrogen

The spike length did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.4). Although having non-significant effect the longest spike (15.68 cm) was recorded in S_2N_2 and the shortest spike (14.81 cm) was found in S_1N_1.

4.3.1.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant spike length of wheat (Table 4.3.1). Table represents that, the highest spike length (16.27 cm) was recorded in $I_1S_2N_2$ and the lowest spike length (14.44 cm) was found in $I_3S_1N_1$.

4.3.2 Spikelet spike^{-1}

4.3.2.1 Impact of irrigation

The application of irrigation exerted significant impact on spikelet spike^{-1} of wheat (Figure 4.3.1). The spikelet spike^{-1} number showed decreeing trend but the rate was not so high. The maximum number of spikelet spike^{-1} was recorded in I_1 (18.94) and the lowest in I_3 (18.65).

4.3.2.2 Impact of sowing date

The date of sowing had a positive effect on spikelet spike^{-1} of wheat (Figure 4.3.1). The values showed significant impact and increasing trend up to the S_2 and then decreased slightly up to S_4. Figure demonstrated that the treatment S_2 produced maximum number of spikelet spike^{-1} (19.33) while S_1 produced lowest number of spikelet spike^{-1} (18.32).

4.3.2.3 Impact of nitrogen

The number of spikelet spike^{-1} showed a non-significant variation due to the effect of nitrogen at grain filling stage (Figure 4.3.1). The maximum number of spikelet spike^{-1} was recorded in N_2 (18.85) and the lowest value of the same trait was in N_1 (18.72).

4.3.2.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on number of spikelet spike^{-1} of wheat (Figure 4.3.2). The highest value of spikelet spike^{-1} (19.82) was found in I_2S_2 and the lowest value (18.22) of the same trait was obtained in I_2S_3.

4.3.2.5 Combined effect of irrigation and nitrogen

The number of spikelet spike^{-1} of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.3). From the figure it can be demonstrated that the maximum number of spikelet spike^{-1} (19.11) was found in I_1N_2 while the minimum number of spikelet spike^{-1} (18.64) was recorded in I_3N_1.

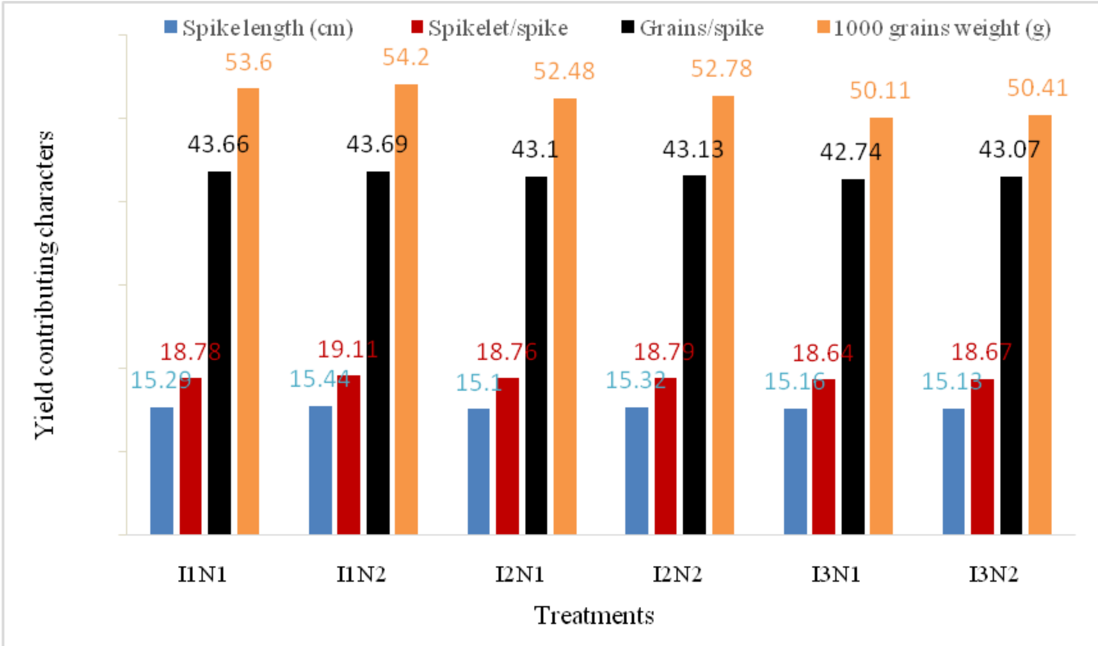


Figure 4.3.3.Combined effect of irrigation and nitrogen on yield contributing characters of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.2.6 Combined effect of sowing date and nitrogen

The number of spikelet spike^{-1} did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.4). Although having non-significant effect the highest number of spikelet spike^{-1} (19.39) was recorded in S_2N_2 and the lowest number of spikelet spike^{-1} (18.25) was found in S_1N_1.

4.3.2.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant number of spikelet spike^{-1} of wheat (Table 4.3.1). Table represents that, the highest value of number of spikelet spike^{-1} (19.84) was recorded in $I_2S_2N_2$ and the lowest number of spikelet spike^{-1} (18.14) was found in $I_1S_1N_1$.

4.3.3 Grains spike^{-1}

4.3.3.1 Impact of irrigation

The number of grains spike^{-1} of wheat influenced significantly due to irrigation treatments (Figure 4.3.1). The highest number of grains spike^{-1} was found in I_1 (43.67) then after showed decreasing trend up to the I_3. The lowest value of number of grains spike^{-1} was recorded in I_3 (42.91).

4.3.3.2 Impact of sowing date

The date of sowing showed significant impact on number of grains spike^{-1} of wheat (Figure 4.3.1). The maximum number of number of grains spike^{-1} was obtained in treatment S_2 (sowing at 20 November). The highest value of number of grains spike^{-1} (46.54) obtained in S_2 while the lowest value of number of grains spike^{-1} (38.64) was in S_1.

4.3.3.3 Impact of nitrogen

The application of additional nitrogen at grain filling stage showed non-significant variations on number of grains spike^{-1}(Figure 4.3.1). Figure represents that the highest value of number of grains spike^{-1} (43.30) was obtained in N_2 (application nitrogen at grain filling stage) while the lowest value (43.17) of this trait was in N_1(application nitrogen only basal dose).

4.3.3.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on number of grains spike^{-1}of wheat (Figure 4.3.2). The highest value of number of grains spike^{-1}(47.50) was found in I_2S_1 and the lowest value (38.39) of the same trait was obtained in I_3S_1.

4.3.3.5 Combined effect of irrigation and nitrogen

The number of grains spike^{-1}of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.3). From the figure it can be demonstrated that the maximum number of grains spike^{-1}(43.69) was found in I_1N_2 while the minimum number of grains spike^{-1}(42.74) was recorded in I_3N_1.

4.3.3.6 Combined effect of sowing date and nitrogen

The number of grains spike^{-1}did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.4). Although having non-significant effect the maximum number of grains spike^{-1}(46.61) was recorded in S_2N_2 and the minimum number of grains spike^{-1}(38.58) was found in S_1N_1.

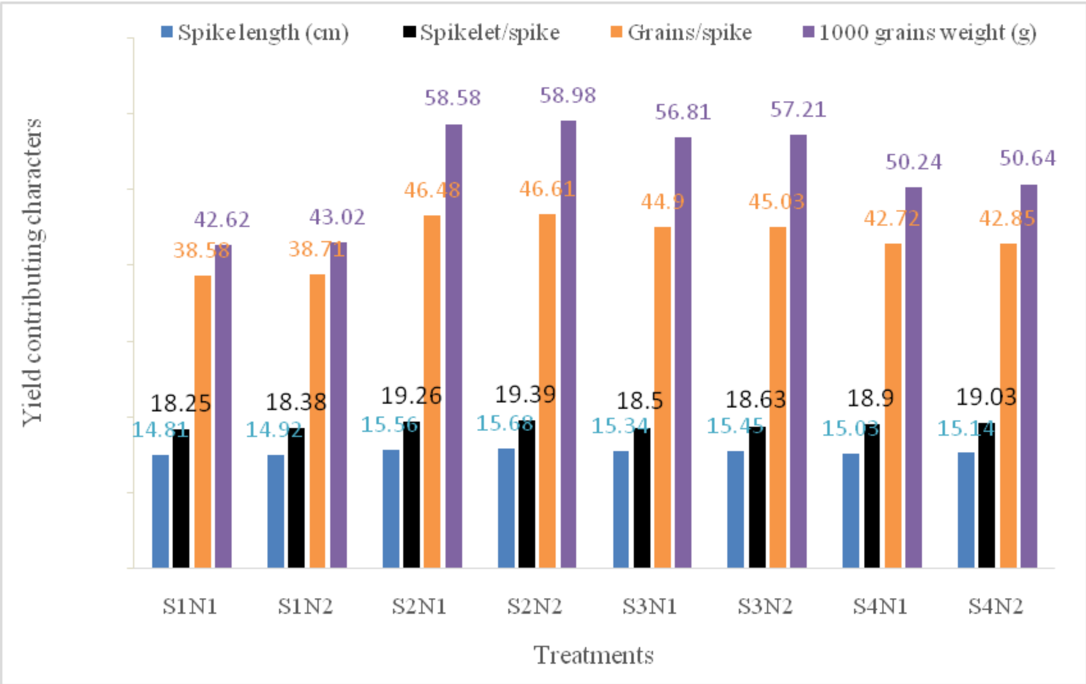


Figure 4.3.4.Combined effect of date of sowing and nitrogen on yield contributing characters of wheat

S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.3.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant value of number of grains spike^{-1} of wheat (Table 4.3.1). Table represents that, the highest number of grains spike^{-1} (48.57) was recorded in $I_2S_2N_2$ and the lowest number of grains spike^{-1} (37.94) was found in $I_3S_1N_1$.

Table 4.3.1. Combined effect of date of sowing and nitrogen on yield contributing characters of wheat

Treatments	Spike length (cm)	Spikelet spike^{-1}	Grains spike^{-1}	1000 grains weight (g)
$I_1S_1N_1$	14.98	18.14	39.41	46.05
$I_2S_1N_1$	15.01	18.28	38.38	40.53
$I_3S_1N_1$	14.44	18.34	37.94	41.28
I1S2N1	16.24	19.02	47.41	61.18
I2S2N1	14.84	19.81	48.54	59.79
$I_3S_2N_1$	15.61	18.94	43.48	54.77
$I_1S_3N_1$	15.11	18.74	43.41	59.43
I2S3N1	15.53	18.21	43.94	58.62
$I_3S_3N_1$	15.38	18.54	47.34	52.38
$I_1S_4N_1$	14.84	19.21	44.41	47.73
I2S4N1	15.04	18.74	41.54	50.99
I3S4N1	15.21	18.74	42.21	52.01
$I_1S_1N_2$	14.72	18.47	39.44	46.65
$I_2S_1N_2$	15.01	18.31	38.41	40.83
I3S1N2	15.04	18.37	38.27	41.58
I1S2N2	15.89	19.35	47.44	61.78
I2S2N2	16.27	19.84	48.57	60.09
$I_3S_2N_2$	14.87	18.97	43.81	55.07
$I_1S_3N_2$	15.66	19.07	43.44	60.03
$I_2S_3N_2$	15.14	18.24	43.97	58.92
$I_3S_3N_2$	15.56	18.57	47.67	52.68
I1S4N2	15.49	19.54	44.44	48.33
I2S4N2	14.87	18.77	41.57	51.29
$I_3S_4N_2$	15.07	18.77	42.54	52.31
LSD (0.05)	ns	ns	0.28	0.17
CV (%)	1.57	1.27	0.55	0.27

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.4 The 1000 grains weight

4.3.4.1 Impact of irrigation

The irrigation treatments showed significant effect on 1000 grains weight of wheat (Figure 4.3.1). The highest 1000 grains weight (53.90 g) was recorded in I_1 and the lowest value of 1000 grains weight (50.26 g) in I_3 which indicated that irrigation at filed capacity condition produced heaver seed than further irrigation at ½ of field capacity and 1/4 of field capacity conditioned plots.

4.3.4.2 Impact of sowing date

The date of sowing had a positive effect on 1000 grains weight of wheat (Figure 4.3.1). The figure showed an increasing trend with an advancement of date of sowing up to the S_2 treatment. A further advancement of date of sowing reduced the 1000 grains weight slightly. However, the treatment S_2 produced highest 1000 grains weight (58.78 g) where S_1 produced lowest 1000 grains weight (42.82 g) compared to other treatments.

4.3.4.3 Impact of nitrogen

The 1000 grains weight showed significant impact due to the effect of nitrogen at grain filling stage (Figure 4.3.1). Figure demonstrated that the highest value of 1000 grains weight was recorded in N_2 (52.47 g) while the lowest value of this trait was in N_1 (52.06 g).

4.3.4.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on 1000 grains weight of wheat (Figure 4.3.2). The highest value of 1000 grains weight (61.48 g) was found in I_1S_2 and the lowest value (40.68 g) of the same trait was obtained in I_2S_1.

4.3.4.5 Combined effect of irrigation and nitrogen

The 1000 grains weight of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.3). From the figure it can be demonstrated that the maximum 1000 grains weight (54.20 g) was found in I_1N_2 while the minimum 1000 grains weight (50.11 g) was recorded in I_3N_1.

4.3.4.6 Combined effect of sowing date and nitrogen

The 1000 grains weight did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.4). Although having non-significant effect the highest 1000 grains weight (58.98 g) was recorded in S_2N_2 and the lowest 1000 grains weight (42.62 g) was found in S_1N_1.

4.3.4.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant 1000 grains weight of wheat (Table 4.3.1). Table represents that, the highest 1000 grains weight (61.78 g) was recorded in $I_1S_2N_2$ and the lowest 1000 grains weight (40.53 g) was found in $I_2S_1N_1$.

4.3.5 Grain yield

4.3.5.1 Impact of irrigation

Grain yield of wheat showed significant influences by the application of irrigation (Figure 4.3.5). The highest grain yield was found in I_1 (3.90 t ha^{-1}). The lowest grain yield was recorded in I_3 (3.81 t ha^{-1}) which indicated that the irrigation at after 10 days of heading stage put yielded higher than irrigation at 20 days after heading stage and 30 days after heading stage.

4.3.5.2 Impact of sowing date

The date of sowing showed significant impact on grain yield of wheat (Figure 4.3.5). Grain yield values showed a gradual increasing trend with the advancement of date of sowing up to S_2 treatment after that the value reduced marginally. Among the sowing dates grain yield ranges from 3.40 t ha^{-1} to 4.33 t ha^{-1}. It can be infrared from the data that S_2 treatment showed higher yield over other treatments.

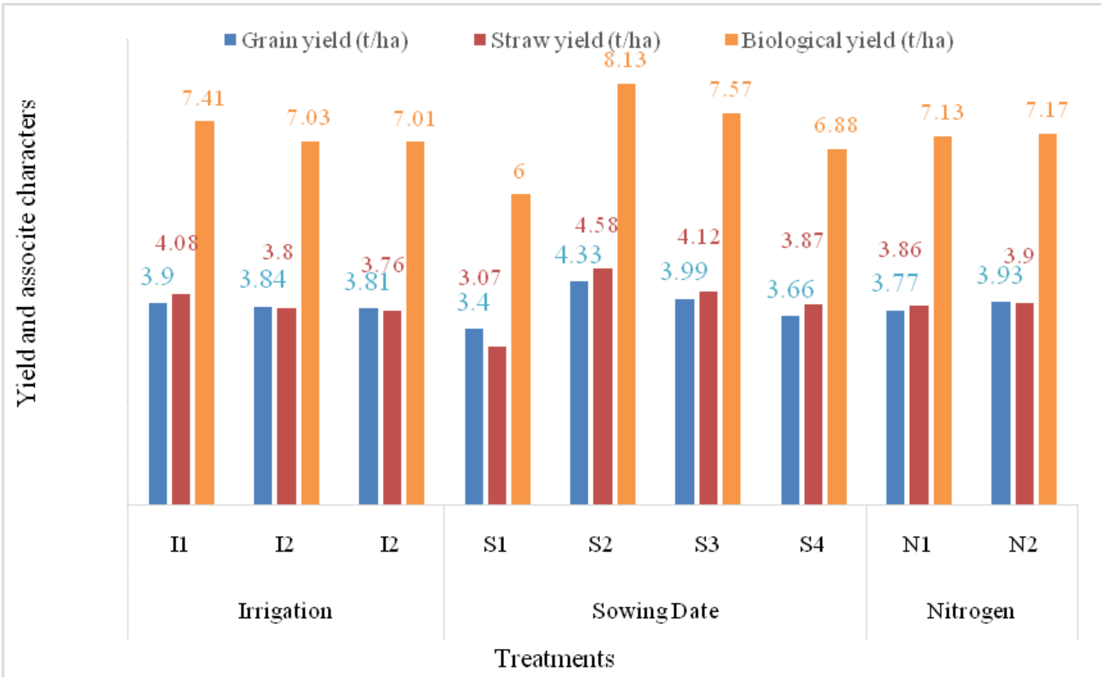


Figure 4.3.5.Combined effect of irrigation, sowing date and nitrogen on yield contributing characters of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.5.3 Effect of nitrogen

The effect of additional nitrogen at grain filling stage showed non-significant impact on grain yield of wheat (Figure 4.3.5). The highest grain yield was found in N_2 (3.93 t ha^{-1}) while the lowest yield was in N_1 (3.77 t ha^{-1}).

4.3.5.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on grain yield of wheat (Figure 4.3.6). The highest value of grain yield (4.46 t ha^{-1}) was found in I_1S_2 and the lowest value (3.32 t ha^{-1}) of the same trait was obtained in I_3S_1.

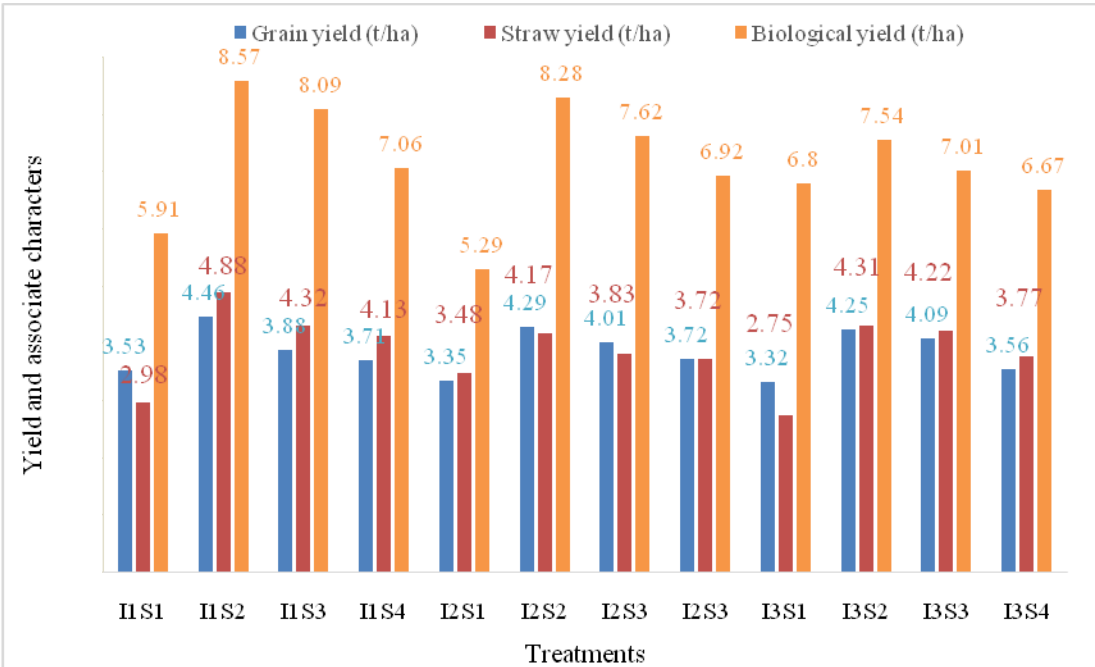


Figure 4.3.6.Combined effect of irrigation and sowing date on yield and associate characters of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December

4.3.5.5 Combined effect of irrigation and nitrogen

The grains yield of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.7). From the figure it can be demonstrated that the highest grain yield (3.99 t ha^{-1}) was found in I_2N_2 while the minimum grain yield (3.69 t ha^{-1}) was recorded in I_2N_1.

4.3.5.6 Combined effect of sowing date and nitrogen

The grain yield did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.8). Although having nonignificant effect the highest grain yield (4.48 t ha^{-1}) was recorded in S_2N_2 and the lowest grain yield (3.38 t ha^{-1}) was found in S_1N_1.

4.3.5.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant grain yield of wheat (Table 4.3.2). Table represents that, the highest grain yield (4.48 t ha^{-1}) was recorded in $I_1S_2N_2$ and the lowest grain yield (3.30 t ha^{-1}) was found in $I_3S_1N_1$.

4.3.6 Straw yield

4.3.6.1 Impact of irrigation

The application of irrigation showed significant impact on straw yield of wheat (Figure 174.3.5). The highest straw yield was recorded in I_1 (4.08 t ha^{-1}) and lowest in I_3 (3.76 t ha^{-1}).

4.3.6.2 Impact of sowing date

Sowing date had a significant effect on straw yield of wheat (Figure 4.3.5). The treatment S_2 produced the highest straw yield (4.58 t ha^{-1}) where S_1 produced the lowest straw yield (3.07 ha^{-1}).

4.3.6.3 Impact of nitrogen

The straw yield showed non-significant impact due to effect of application additional nitrogen at grain filling stage (Figure 4.3.5). The figure represent that the highest straw yield was recorded in N_2 (3.90 t ha^{-1}) and the lowest straw yield was recorded in N_1 (3.86 t ha^{-1}).

4.3.6.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on straw yield of wheat (Figure 4.3.6). The highest value of straw yield (4.88 t ha^{-1}) was found in I_1S_2 and the lowest value (2.75 t ha^{-1}) of the same trait was obtained in I_3S_1.

4.3.6.5 Combined effect of irrigation and nitrogen

The straw yield of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.7). From the figure it can be demonstrated that the highest straw yield (4.10 t ha^{-1}) was found in I_1N_2 while the minimum grain yield (3.74 t ha^{-1}) was recorded in I_3N_1.

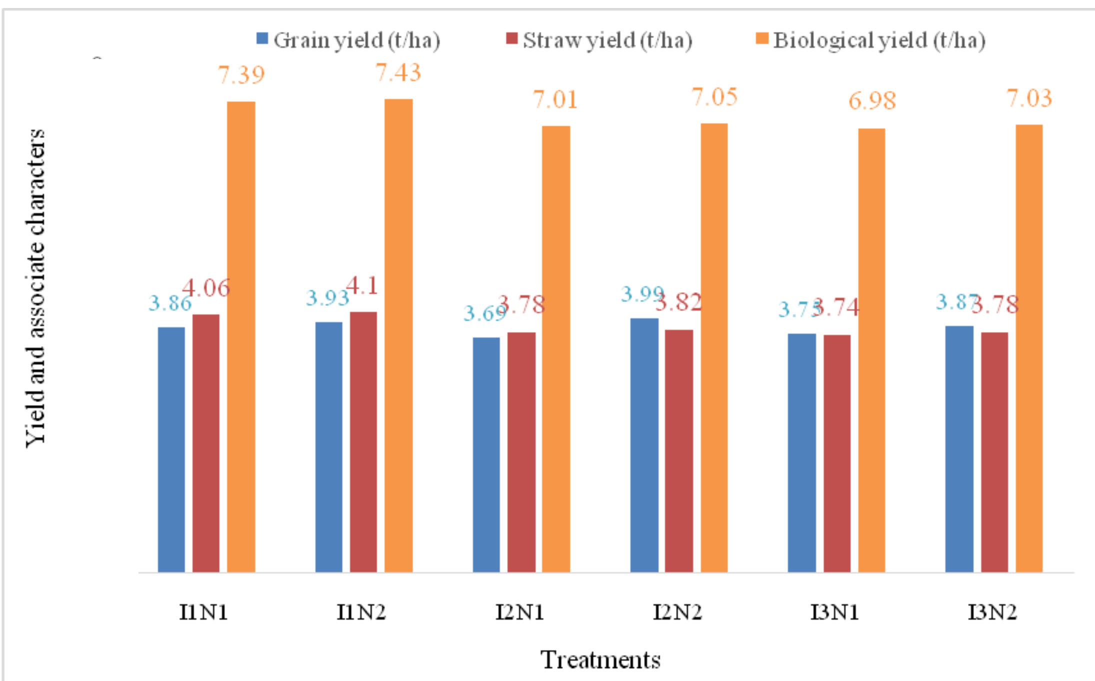


Figure 4.3.7.Combined effect of irrigation and nitrogen on yield and associate characters of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.5.6 Combined effect of sowing date and nitrogen

The straw yield did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.8). Although having non-significant effect the highest straw yield (4.48 t ha^{-1}) was recorded in S_2N_2 and the lowest straw yield (3.05 t ha^{-1}) was found in S_1N_1.

4.3.5.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-

significant straw yield of wheat (Table 4.3.2). Table represents that, the highest straw yield (4.90 t ha^{-1}) was recorded in $I_1S_2N_2$ and the lowest grain yield (2.73 t ha^{-1}) was found in $I_3S_1N_1$.

4.3.7 Biological yield

4.3.7.1 Impact of irrigation

The biological yield of wheat showed significant influences by the application of different types of irrigation (Figure 4.3.5). The highest biological yield was found in I_1 (7.41 t ha^{-1}). The lowest biological yield was recorded in I_3 (6.84 t ha^{-1}) which indicated that the irrigation at 10 days after heading put biological yielded higher 20 days after heading and 30 days after heading.

4.3.7.2 Impact of sowing date

The date of sowing showed significant impact on biological yield of wheat (Figure 4.3.5). The biological yield values showed a gradual increasing trend with the advancement of date of sowing up to S_2 treatment and after that the value reduced marginally. Among the sowing dates biological yield ranges from 6.00 t ha^{-1} to 8.13 t ha^{-1}. It can be infrared from the data that S_2 treatment showed higher biological yield over other treatments.

4.3.7.3 Effect of nitrogen

The effect of additional nitrogen at grain filling stage showed non-significant impact on biological yield of wheat (Figure 4.3.5). The highest biological yield was found in N_2 (7.17 t ha^{-1}) while the lowest yield was in N_1 (7.13 t ha^{-1}).

4.3.7.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on biological yield of wheat (Figure 4.3.6). The highest value of biological yield (8.57 t ha^{-1}) was found in I_1S_2 and the lowest value (5.29 t ha^{-1}) of the same trait was obtained in I_2S_1.

4.3.7.5 Combined effect of irrigation and nitrogen

The biological yield of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.7). From the figure it can be demonstrated that the highest biological yield (7.43 t ha^{-1}) was found in I_1N_2 while the minimum biological yield (6.98 t ha^{-1}) was recorded in I_3N_1.

4.3.7.6 Combined effect of sowing date and nitrogen

The biological yield did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.8). Although having non-significant effect the highest biological yield (8.15 t ha^{-1}) was recorded in S_2N_2 and the lowest biological yield (5.98 t ha^{-1}) was found in S_1N_1.

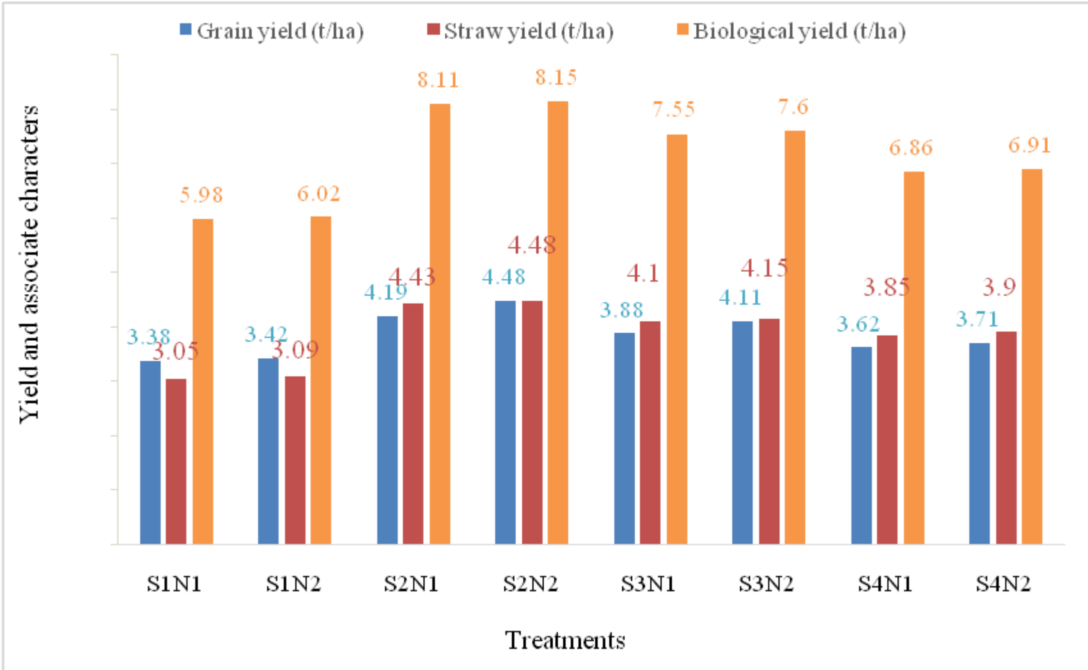


Figure 4.3.8 Combined effect of sowing date and nitrogen on yield and associate characters of wheat

S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.7.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically nonsignificant biological yield of wheat (Table 4.3.2). Table represents that, the highest biological yield (8.59 t ha^{-1}) was recorded in $I_1S_2N_2$ and the lowest biological yield (5.27 t ha^{-1}) was found in $I_2S_1N_1$.

Table 4.3.2. Combined effect of date of sowing and nitrogen on yield and associate characters of wheat

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest Index (%)
$I_1S_1N_1$	3.51	2.96	5.89	46.26
I2S1N1	3.33	3.46	5.27	47.34
I3S1N1	3.30	2.73	6.78	44.33
$I_1S_2N_1$	4.44	4.86	8.55	52.06
$I_2S_2N_1$	3.98	4.15	8.26	52.10
I3S2N1	4.15	4.29	7.52	53.35
$I_1S_3N_1$	3.82	4.30	8.07	51.87
$I_2S_3N_1$	3.75	3.81	7.60	48.43
$I_3S_3N_1$	4.07	4.20	6.99	49.24
$I_1S_4N_1$	3.69	4.11	7.04	48.31
$I_2S_4N_1$	3.70	3.70	6.90	47.57
$I_3S_4N_1$	3.48	3.75	6.65	45.46
I1S1N2	3.55	3.00	5.93	46.30
$I_2S_1N_2$	3.37	3.50	5.31	47.38
$I_3S_1N_2$	3.34	2.77	6.82	44.37
$I_1S_2N_2$	4.48	4.90	8.59	52.10
$I_2S_2N_2$	4.60	4.19	8.30	52.14
$I_3S_2N_2$	4.36	4.33	7.56	53.39
$I_1S_3N_2$	3.95	4.34	8.11	51.91
$I_2S_3N_2$	4.26	3.85	7.64	48.47
$I_3S_3N_2$	4.11	4.24	7.03	49.28
$I_1S_4N_2$	3.73	4.15	7.08	48.35
$I_2S_4N_2$	3.74	3.74	6.94	47.61
$I_3S_4N_2$	3.65	3.79	6.69	45.50
LSD (0.05)	**0.13**	**0.13**	**0.13**	**0.13**
CV (%)	**2.62**	**2.95**	**1.60**	**0.23**

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.8 Harvest index

4.3.8.1 Impact of irrigation

Harvest index of wheat influenced significantly by the application of irrigation at different field capacity condition (Figure 4.3.9). The highest value (49.65%) of harvest index was found in I_1 treatment. The lowest value (48.12%) of this trait was recorded in I_3.

4.3.8.2 Impact of sowing date

The different sowing date showed significant impact on harvest index of wheat (Figure 4.3.9). The figure indicated that S_2 treatment (sowing date 20 November) produced highest harvest index (52.52%). The sowing date earlier and later than S_2 treatment reduced the value of harvest index. Though the date of sowing later than S_2 treatment showed a gradual decreasing trend but the lowest value (46.00%) was found in S_1 (sowing date 10 November).

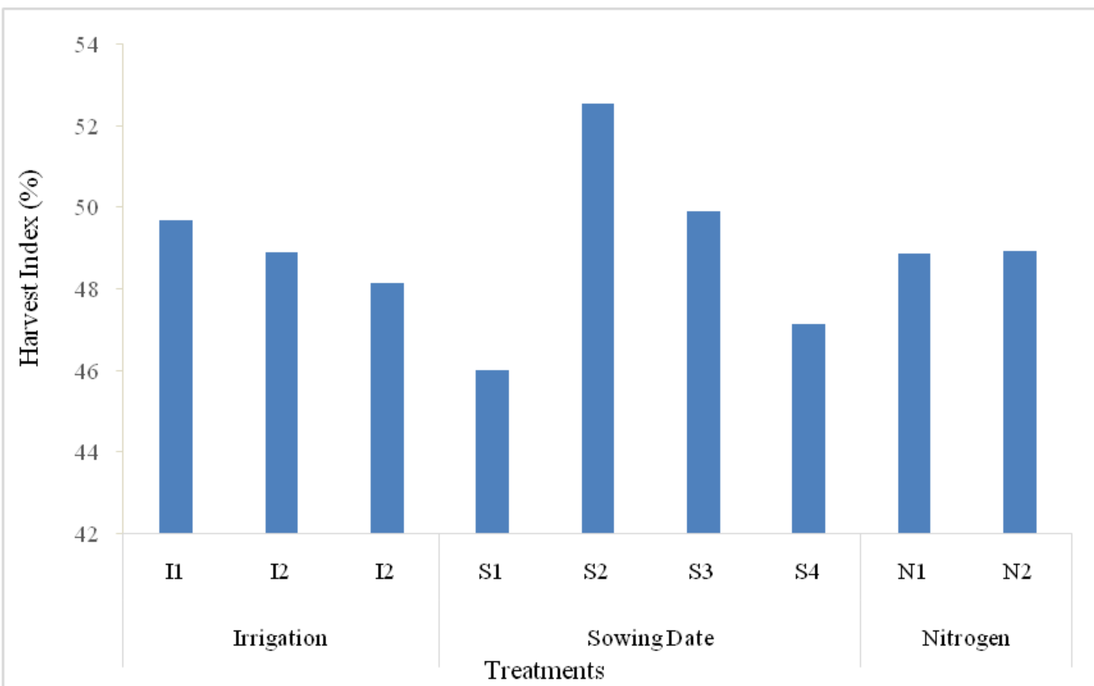


Figure 4.3.9 Effect of irrigation, sowing date and nitrogen on harvest index of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.8.3 Effect of nitrogen

The additional application of nitrogen at grain filling stage produced non-significant harvest index of wheat (Figure 4.3.9). The highest value of harvest index was found in N_2 (48.90%) and the lowest was in N_1 treatment (48.86%).

4.3.8.4 Combined effect of irrigation and sowing date

The combined effect of irrigation and date of sowings showed significant effect on harvest index of wheat (Figure 4.3.10). The highest value of harvest index (53.37%) was found in I_3S_2 while the lowest value (44.35%) of the harvest index was obtained in I_3S_1.

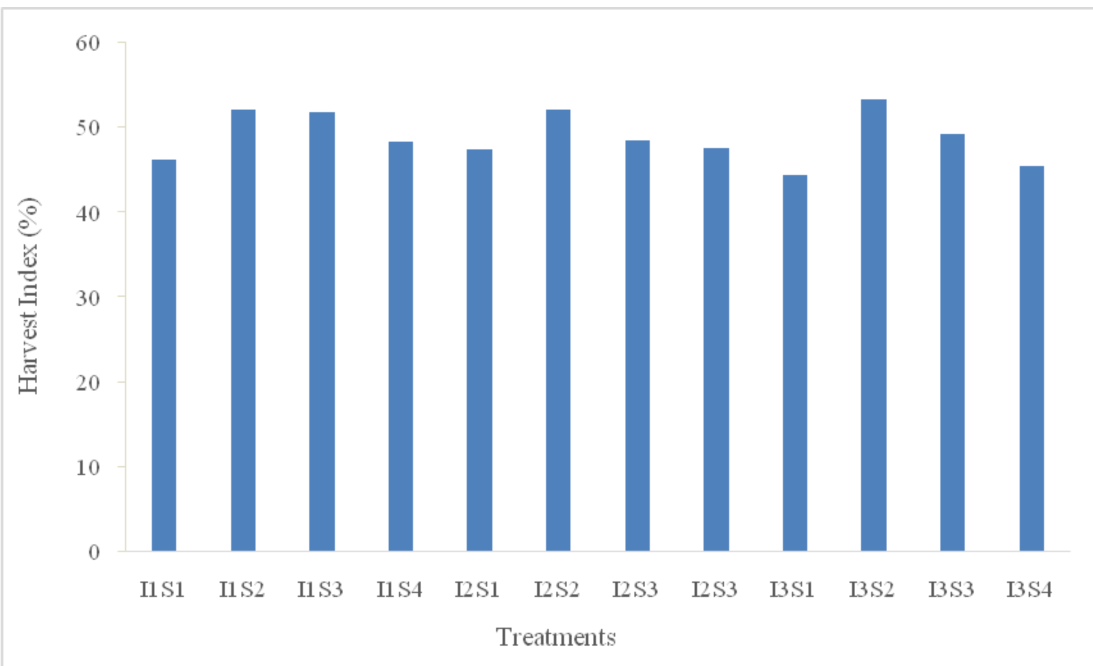


Figure 4.3.10.Combined effect of irrigation and sowing date on harvest index of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December

4.3.8.5 Combined effect of irrigation and nitrogen

The harvest index of wheat showed a wide range of variation due to combined effect of irrigation and nitrogen (Figure 4.3.11). The figure demonstrated that the highest value of harvest index (49.67%) was found in I_1N_2 while the minimum harvest index (48.09%) was recorded in I_3N_1.

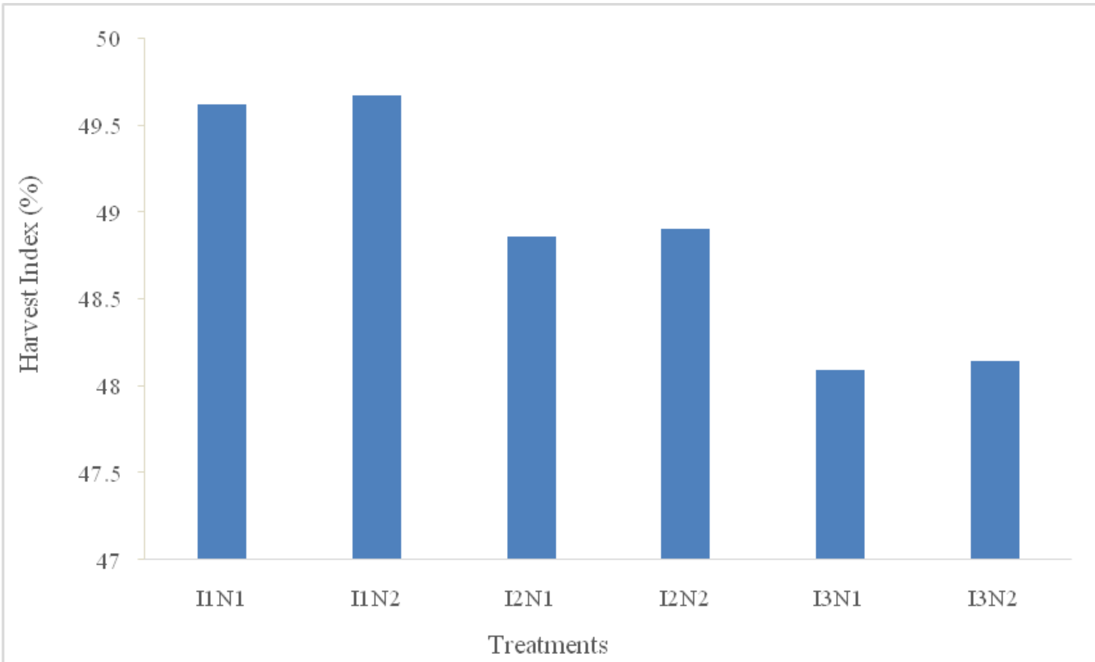


Figure 4.3.11.Combined effect of irrigation and nitrogenon harvest index of wheat

I_1=irrigation at heading, I_2=irrigation at 10 days after heading, I_3=irrigation at 20 days after heading; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.8.6 Combined effect of sowing date and nitrogen

The harvest index did not influence significantly by the combined effect of date of sowing and additional nitrogen at grain filling stage (Figure 4.3.12). Although having non-significant effect the highest harvest index (52.55%) was recorded in S_2N_2 and the lowest harvest index (45.98%) was found in S_1N_1.

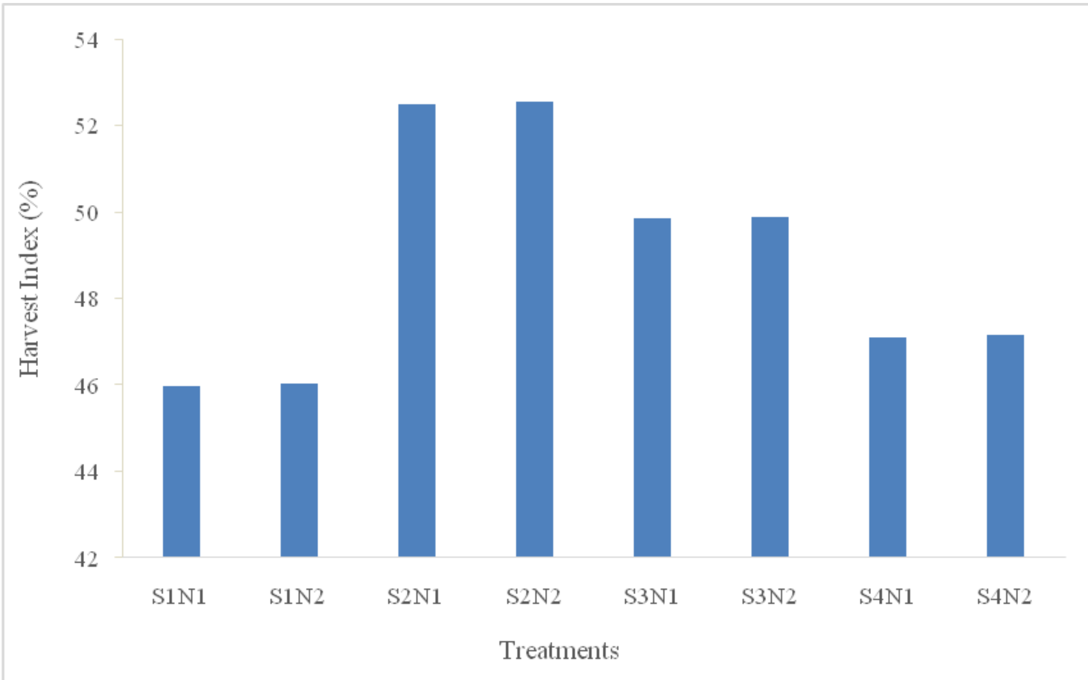


Figure 4.3.12.Combined effect of irrigation and nitrogen on harvest index of wheat

S_1=sowing date at 10 November, S_2=sowing date at 20 November, S_3=sowing date at 30 November, S_4=sowing date at 10 December; N_1= no nitrogen at grain filling stage, N_2=nitrogen at grain filling stage

4.3.8.7 Combined effect of irrigation, sowing date and nitrogen

The combined effect of irrigation, sowing date and nitrogen produced statistically non-significant harvest indexof wheat (Table 4.3.13). Table represents that, the highest harvest index(53.39%) was recorded in $I_3S_2N_2$ and the lowest value of harvest index(44.33%) was found in $I_3S_1N_1$.

4.3.8.8 Correlation analysis among yield attributes

In expt 3 (sowing time, irrigation and extra N with variety BARI GOM-25) at SAU correlation was made among the yield and yield attributes (Table 4.3.13). Results showed that all the attributes were significantly correlated at 1% level of probability (correlation coefficient, r=0.495-0.887). However, higher correlation coefficient was observed between grain yield/ha with number of spikelet/spike (r=0.820), 1000 seed weight (0.806, biological yield (r=0.802) and harvest index (r=0.802).

Table. 4.3.13 Pierson correlation for experiment 3.

	Spike length	Spikelet/spike	Grains/spike	1000 grains weight	Grain yield	Straw yield	Biological yield	HI
Spike length	1							
Spikelet/spike	0.505**	1						
Grains/spike	0.625**	0.654**	1					
1000 grains weight	0.590**	0.495**	0.802**	1				
Grain yield	0.706**	0.577**	0.820**	0.806**	1			
Straw yield	0.687**	0.637**	0.830**	0.785**	0.811**	1		
Biological yield	0.582**	0.628**	0.771**	0.887**	0.784**	0.737**	1	
HI	0.536**	0.576**	0.709**	0.756**	0.802**	0.828**	0.724**	1

** means correlation is significant at 1% level

Expt. 4: Phenology, canopy chlorophyll content and temperature, growth and yield of wheat as influenced by sowing dates and varieties at Rajshahi

4.1 Phenological stages

4.1.1 Sowing date effect

Days to booting

Booting is one of the most important growth stages of wheat plant. Swollen base of flag leaf is called boot and spike emerges out of boot. Days taken to booting are strongly influenced by the prevailing environmental conditions and varieties grown. Data on days taken to booting have been presented in Table 4.4.1. Significantly higher number of days was taken by November 30 sown crop to booting than November 20, December 10, December 20 and December 30 sowing. November 30 sown crop took 3-5 days more than November 20 and December 10-30 sown crop.

Days to heading

Environment conditions prevailing at the heading significantly influence the yield and yield attributes of wheat. According to Slafer and Savin (1991) suitable temperature for heading was 24.3^0C. Date of sowing significantly influenced the days taken to heading. November 30 sown crop took maximum calendar days to heading 60 which was significantly higher than November 20 and December 10-30 sown crop. November 30 sown crop took one and nine more days than November 20 and December 10-30 sowing, respectively.

Days to anthesis

Anthesis is the most important stage of wheat crop. Anthesis determines the number of grains setting in the ear. Fertilization is very sensitive to environmental conditions prevailed at that time, because pollen grains are highly sensitive to temperature and other environmental conditions. Data on days taken to anthesis have been presented in Table 4.4.1. November 20 sown crop took maximum calendar days to anthesis, which was statistically at par with November 20 but significantly higher than December 10-30 sowing. Early onset of anthesis in December 10 was due high temperature conditions prevailed at the time of anthesis.

Days to physiological maturity

Physiological maturity is the stage at which yield of crop is almost determined but grains still contains more moisture than required for harvesting and threshing. The data on days taken to physiological maturity have been presented in Table 4.4.1. November 30 sowing took maximum number of days to physiological maturity, which was significantly higher than November 20 and December 10-30 sowing. Crop sown on November 30 took 5.4 and 12.8% higher days to physiological maturity as compared to November 20 and December 5-30 sowing, respectively. Lower number of days to physiological maturity in December 30 sown crops was due to sudden rise in temperature late in the season (Appendix II). Regression analysis of the days to maturity with the average temperature from anthesis to maturity showed that that the maturity became delay below the average temperature 22.5^{0}C and beyond which it was shortened (Fig.4.4.1).

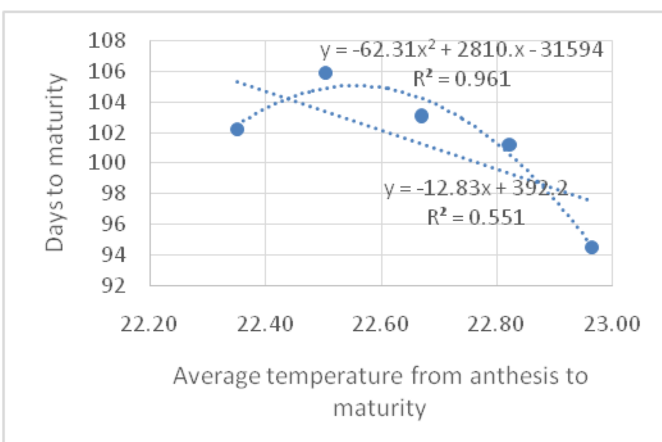


Fig.4.4.1 Relationship between the average temperature from anthesis to maturity with the days to physiological maturity.

Table 4.4.1Effect of sowing date on phenological parameters at different stage

Sowing time	Booting days	Heading days	Anthesis days	Physiological maturity days
S_1	54.1	59.2	64.6	102.2
S_2	55.3	62.3	67.8	105.9
S_3	54.1	60.7	66.2	103.1
S4	52.7	58.4	64.3	101.2
S_5	47.7	53.2	59.4	94.5
LSD(0.05)	**0.572**	**0.635**	**0.429**	**0.627**
% CV	**11.23**	**9.89**	**11.45**	**7.78**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties on the phenological stages of wheat

Days to booting

Varieties also differed significantly with respect to days taken to booting shown as table 4.4.2. BARI Gom 25 took more number (54.8) of days to booting and BARI Gom 30 took lower number (50.5) of days to booting.

Days to heading

Varieties were also differ significantly with respect to days taken to heading shown as table 4.4.2. BARI Gom 25 took more number (62.4) of days to heading and BARI Gom 30 took lower number (57.0) of days to heading. Variety PBW 677 took significantly more number of days to heading than WH 1105.

Days taken to anthesis

Varieties differ significantly in relations to days taken to anthesisshown as table 4.4.2. BARI Gom 25 took more number (68.7) of days to anthesis and BARI Gom 30 took lower number (64.0) of days to anthesis.

Days to physiological maturity

Varieties also differ significantly in relation to days taken to physiological maturity shown as table 4.4.2. BARI Gom 25 took more number of days (102.0) to physiological maturity and BARI Gom 30 took lower number (98.6) of days to physiological maturity.

Table 4.4.2. Effect of variety on phenological parameters at different stage of wheat

Variety	Booting days	Heading days	Anthesis days	Physiological maturity days
V1	54.8	62.47	68.73	102
V2	54.4	61.6	68.07	101.27
V_3	51.87	58.6	64.73	100
V_4	52.33	58.93	65.07	100.4
V_5	53	60.2	66.27	101.93
V_6	50.53	57.07	64	98.6
LSD (0.05)	**0.627**	**0.695**	**0.47**	**0.687**
% CV	**11.25**	**8.97**	**10.52**	**12.45**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and BARI GOM-30

Interaction effect of sowing date and variety on phenological stages

Days taken to booting

Booting is one of the most important growth stages of wheat plant. Swollen base of flag leaf is called boot and spike emerges out of boot. Days taken to booting are strongly influenced by the prevailing environmental conditions and varieties grown. Data on days taken to booting on interaction effect have been presented in Table 4.6. Interaction effect significantly higher number of days was taken by November 30 sown crop with BARI Gom 25 variety to booting than November 20, December 10, December 20 and December 30 sowing over other varieties. November 30 sown crop with BARI Gom 25 took 3-5 days more than November 20 and December 10-30 sown crop. Late sowing with BARI Gom 30 variety took minimum days of booting. November 30 sown crop took highest number of days to booting due to lower canopy temperature (Table 4.4.3).

Days to heading

Mean highest temperature of four days at heading of November 20, November 30 and December 10-30 sown crop was 24^0, 25.2-27^0 C, respectively (Appendix II). Data on days taken to heading have been presented in Table 4.4.3. Interaction effect of sowing date and variety significantly influenced by days taken to heading. November 30 sown with BARI Gom 25 variety took maximum calendar days to heading 60 which was significantly higher than November 20 and December 10-30 sown crop. November 30 sown with BARI Gom 25 variety took 2-5 days more than November 20 and December 10-30 sowing, respectively. November 30 sown crop took the highest number of days to heading due to lower canopy temperature of November 20 sown crop at 90 DAS (Table 4.4.3).

Days to anthesis

Data on days taken to anthesis have been presented in Table 4.4.3. November 30 sown with BARI Gom 25 took maximum calendar days (71.0) to anthesis, which was statistically at par with November 20 (68.7) but significantly higher than December 10-30 sowing. Late sowing with BARI Gom 30 variety took minimum days (60.0) of anthesis.

Days to Physiological maturity

Physiological maturity is the stage at which yield of crop is almost determined but grains still contains more moisture than required for harvesting and threshing. The data on days taken to physiological maturity have been presented in Table 4.4.3.November 30 sowing with BARI

Gom 25 took maximum number of days to physiological maturity, which was significantly higher than November 20 and December 10-30 sowing. Crop sown on November 30 with BARI Gom 25 took 5.4 and 12.8% higher days to physiological maturity as compared to November 20 and December 5-30 sowing, respectively. Late sown with BARI Gom 30 variety took minimum days of physiological maturity. Lower number of days to physiological maturity in December 30 sown crops was due to sudden rise in temperature late in the season (Appendix II).

Table 4.4.3. Interaction effect of sowing date and variety on phenological parameters

Sowing days	Variety	Booting days	Heading days	Anthesis days	Physiological maturity days
S_1	V_1	51.33	60.67	68.67	105.67
	V2	48.00	56.67	65.33	101.33
	V_3	46.00	53.00	59.33	100.33
	V4	47.00	53.33	60.33	102.33
	V_5	49.00	56.67	64.00	105.33
	V6	45.33	51.67	60.33	98.33
S_2	V_1	56.33	64.00	71.00	103.33
	V_2	55.33	62.33	69.33	104.00
	V_3	50.00	56.00	63.67	100.67
	V_4	50.33	56.67	63.67	100.33
	V_5	53.33	60.00	66.00	104.67
	V_6	48.00	55.00	60.67	98.67
S_3	V_1	55.67	62.33	69.00	102.33
	V_2	55.67	62.00	69.00	101.00
	V_3	54.00	60.67	67.67	101.33
	V_4	53.67	60.00	67.00	100.00
	V_5	53.67	61.33	68.33	102.00
	V6	50.00	56.00	63.00	96.00
S_4	V_1	55.33	63.00	67.00	101.67
	V_2	56.67	64.67	68.67	103.00
	V_3	54.33	62.00	65.67	100.67
	V_4	53.00	62.62	66.13	97.33
	V_5	54.00	61.67	65.67	99.67
	V_6	52.00	58.65	64.67	95.00
S5	V1	55.67	61.37	67.00	97.00
	V_2	56.33	62.35	68.00	96.00
	V_3	55.00	61.13	66.30	95.00
	V_4	53.67	59.00	65.00	94.00
	V_5	54.00	61.30	66.23	95.00
	V_6	49.33	56.00	61.30	93.00
LSD (0.05)		**1.402**	**1.555**	**1.051**	**1.536**
	% CV	**11.54**	**10.54**	**9.86**	**10.54**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30

4.2 Biochemical parameter

Chlorophyll content in leaves

Effect of sowing date

Statistically significant variation was recorded on the effect of sowing dates on percent ground coverage at different growth stage (Fig.4.4.2). Chlorophyll content percentage was increased to increase at anthesis stage but decreased when late sown at this stage. Maximum chlorophyll content percentage (45.33%) was found from S_3 that mean December 10 sowing at all stage followed by (45.03%) was found from S_2 at said stage and statistically significant from (44.01%) from S_1 whereas the minimum chlorophyll content percentage (67.17%) at all booting, heading and anthesis stage was recorded from the treatment S_5 that mean late sown condition.

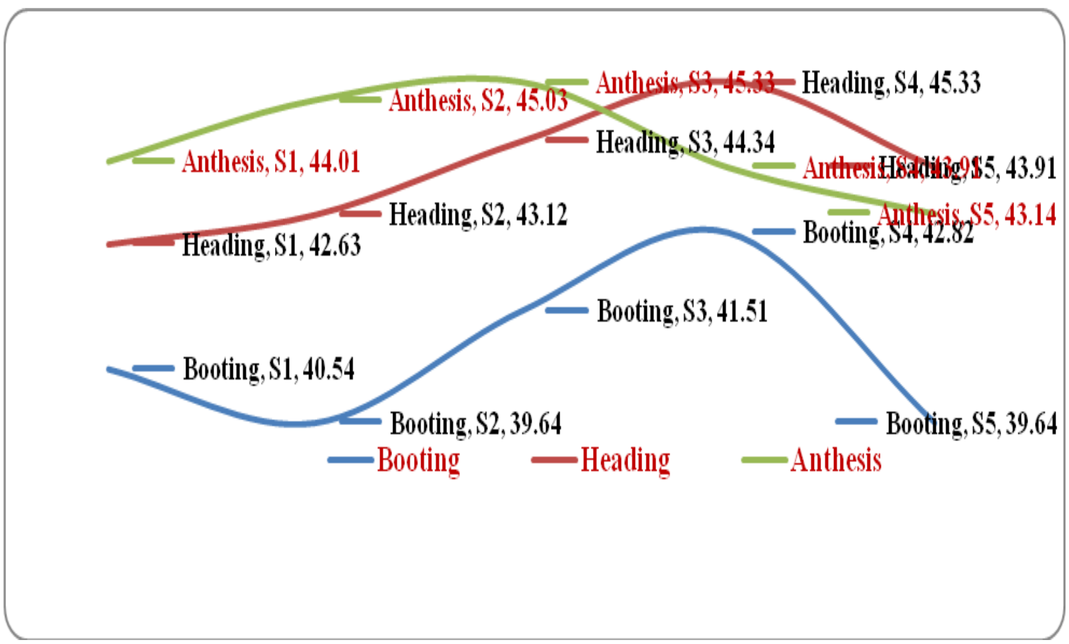


Fig.4.4.2.Chlorophyll content pattern of wheat as influence by sowing dates (S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30) at different phenotypic stages (bootingtoanthesis) at Rajshahi during rabi 2016-17

Table 4.4.4. Effect of sowing date on chlorophyll content at different stage (SPAD Meter)

Sowing days	Booting	Heading	Anthesis
S_1	40.54	42.63	44.01
S2	39.64	43.12	45.03
S_3	41.51	44.34	45.33
S_4	42.82	45.33	43.91
S5	39.64	43.91	43.14
LSD (0.05)	**1.530**	**1.521**	**1.390**
% CV	**11.54**	**10.31**	**7.87**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties

Statistically significant variation was recorded on the effect of wheat variety on percent chlorophyll content at different stage (Table 4.4.5). Chlorophyll content percentage was increased to increasing at anthesis stage and then decrease up to maturity stage. The maximum chlorophyll content (47.52%) was found from V_3 that mean BARI Gom 27 at anthesis stage followed by (44.75%) was found from V_2 at anthesis stage and statistically significant from (44.16%) from V_6 whereas the minimum chlorophyll content (41.39%) at anthesis stagewas recorded from the treatment V_1 that mean BARI Gom 25.

Table 4.4.5. Effect of variety on chlorophyll content (%) at different stage of wheat

Variety	Booting	Heading	Anthesis
V_1	38.85	41.02	41.39
V2	40.56	44.37	44.75
V_3	44.98	47.15	47.52
V4	41.12	44.17	43.65
V_5	38.87	42.37	44.24
V_6	40.61	44.13	44.16
LSD (0.05)	**1.676**	**1.666**	**1.522**
% CV	**10.52**	**9.97**	**10.56**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29, BARI Gom30

Interaction effect of sowing time and varieties on chlorophyll content

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on percent chlorophyll content at different growth stage (Table 4.4.6). Different sowing dates significantly influenced the chlorophyll content (%) at all crop growth stages. Chlorophyll content percentage was increased to increasing at anthesis stage and decreases at maturity stage. The maximum chlorophyll content (50.90%) was found from V_3S_3 at anthesis stage followed by (47.60%) was found from V_3S_1 and statistically significant (47.07%) from V_3S_2 at same stage whereas the minimum chlorophyll content (38.97%) was recorded from the treatment combination V_1S_5 at same stage.

Table 4.4.6. Interaction effect of sowing date and variety on chlorophyll content (%) at different stages

Sowing days	Variety	Booting	Heading	Anthesis
S_1	V_1	39.33	39.93	40.03
	V_2	39.57	42.87	44.33
	V3	47.10	47.00	47.60
	V4	42.40	43.23	44.50
	V5	37.27	42.23	44.87
	V_6	37.60	40.53	42.70
S_2	V_1	39.93	40.73	43.63
	V_2	37.60	44.73	44.53
	V_3	43.40	44.80	47.07
	V_4	36.57	42.03	44.37
	V_5	38.47	42.13	46.30
	V_6	41.90	44.30	44.30
S_3	V_1	37.70	39.73	41.63
	V2	43.10	44.03	46.60
	V_3	46.83	49.13	50.90
	V_4	41.67	45.27	43.47
	V_5	40.17	42.90	43.37
	V6	39.60	44.97	46.03
S4	V1	40.83	43.90	42.67
	V_2	41.13	44.60	42.97
	V_3	44.97	47.80	46.00
	V_4	44.13	45.27	41.97
	V_5	41.83	43.80	45.30
	V_6	44.00	46.60	44.53
S_5	V_1	36.47	40.80	38.97
	V_2	41.40	45.63	45.33
	V_3	42.60	47.00	46.03
	V_4	40.83	45.03	43.93
	V5	36.60	40.77	41.37
	V_6	39.97	44.23	43.23
LSD (0.05)		**3.749**	**3.72652**	**3.405**
% CV		**5.65**	**10.54**	**11.35**

S_1= Nov 20, S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29, BARI Gom30

Relations of chlorophyll content with the ambient temperature

The chlorophyll content (at anthesis) decreased with the increase of the ambient maximum temperature. The relationship was linearly but negative both in linear regression (slope - 0.629) and the R2=0.86).Fig.4.4.2

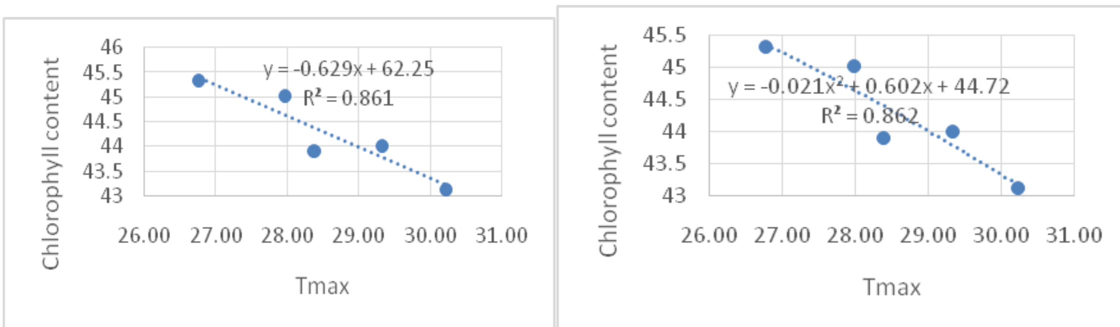


Fig.4.4.2. Relations of chlorophyll content with the ambient temperature

Like with the maximum ambient temperature, the chlorophyll content (at anthesis) decreased with the increase of the ambient minimum temperature. The relationship was linearly but negative (slope -1.222 in linear) with R2=0.625 at polynomial). Fig.4.4.3

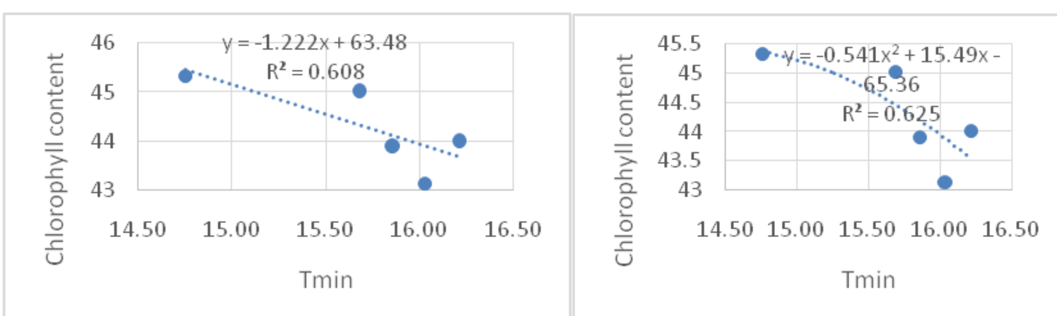


Fig.4.4.3. Relations of chlorophyll content with the ambient temperature

Like with the maximum and minimum ambient temperature, the chlorophyll content (at anthesis) decreased with the increase of the ambient average temperature. The relationship was linear but negative (slope -0.882 in linear) with R2=0.846 at polynomial)(Fig.4.4.3).

The regression analysis showed that the synthesis of chlorophyll (at anthesis) was negatively related with all levels of temperature (maximum, minimum and average from sowing to anthesis (vegetative stage), that is the chlorophyll content of the leaves decreased with increase of the ambient temperature.

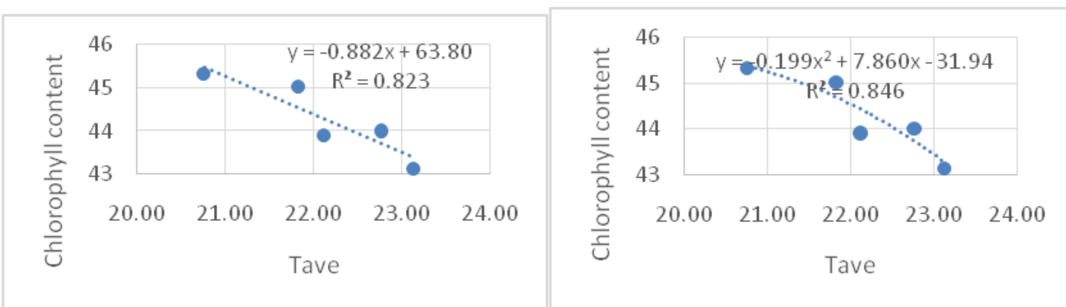


Fig.4.4.4. Relations of chlorophyll content with the ambient temperature

In both the sites the maximum temperature was higher at the reproductive stage (29.44 to 29.91^{0}C at Rajshahi and 31.88-32.91^{0}C) than that of the vegetative stage (24.85-26.97^{0}C at Rajshahi and 27.98-30.21^{0}C at SAU).

Minimum temperature

At Rajshahi the average minimum temperature from sowing to anthesis ranged from 12.96-13.05^{0}C, while from anthesis to maturity from 15.26-16.02^{0}C. That is the minimum temperature was higher at the reproductive stage of plants.

At SAU the average minimum temperature from sowing to anthesis ranged from 14.75-16.21^{0}C, while from anthesis to maturity from 17.47-19.02^{0}C. That is the minimum temperature was higher at the reproductive stage of plants.

In both the sites the minimum temperature was higher at the reproductive stage (12.96-13.05^{0}C at Rajshahi and 14.75-16.21^{0}C) than that of the vegetative stage (15.26-16.02^{0}C at Rajshahi and 17.47-19.02^{0}C at SAU).

Average temperature

At Rajshahi the average of the daily average temperature from sowing to anthesis ranged from 19.86-19.92^{0}C, while from anthesis to maturity from 22.35-22.96 ^{0}C. That is the average of the daily average temperature was higher at the reproductive stage of plants. At SAU the average of the daily average temperature from sowing to anthesis ranged from 20.76-23.12^{0}C, while from anthesis to maturity from 24.67-25.96 ^{0}C. That is the average of the daily average temperature was higher at the reproductive stage of plants.

In both the sites the average of the daily average temperature was higher at the reproductive stage (22.35-22.96^{0}C at Rajshahi and 24.67-25.96^{0}C) than that of the vegetative stage (19.86-19.92^{0}C at Rajshahi and 20.76-23.12^{0}C at SAU).

The average of the daily maximum, minimum and average ambient temperature undertaken by the crops sown at different dates from sowing to anthesis

From sowing to anthesis at Rajshahi Dec 30 sowing enjoyed the highest average maximum temperature (26.97^{0}C, the Nov sowings higher minimum temperature (above 13^{0}C) than others (below 13^{0}C) and the higher average of the average temperature from sowing to anthesis was maximum with Nov 20 sowing (19.92^{0}C), however there was no remarkable difference between the lowest (19.86^{0}C) of Dec 20-30 sowing.

While at SAU from sowing to anthesis, like at Rajshahi the Dec 30 sowing enjoyed the highest average maximum temperature (30.21^{0}C, the Nov 20 sowings higher minimum temperature (above 16.21^{0}C) than others (below 16^{0}C) and the higher average of the average temperature from sowing to anthesis was maximum with Dec 30 sowing (23.12^{0}C), but in comparison to Rajshahi there was a remarkable difference between the lowest average temperature (20.76^{0}C) of Dec 30 sowing and others (above 22^{0}C).

The average of the daily maximum, minimum and average ambient temperature undertaken by the crops sown at different dates from anthesis to maturity

From anthesis to maturity at Rajshahi Dec 30 sowing enjoyed the highest average maximum temperature (29.91^{0}C, the Dec 30 sowings had higher minimum temperature (above 16^{0}C) than others (below 15.26-below 16^{0}C) and the higher average of the

average temperature from sowing to anthesis was maximum with Dec 30 sowing (22.96^{0}C), however, like at sowing to anthesis, there was no remarkable difference between the lowest (22.35^{0}C) of Nov 20 sowing and that of the Dec 30 (22.96^{0}C).
While at SAU from anthesis to maturity, like at Rajshahi the Dec 30 sowing enjoyed the highest average maximum temperature (32.91 degree C. But unlike at Rajshahi the Dec 30 sowings had highest minimum temperature (19.02^{0}C) than others (below 17.47-18.44^{0}C). Like at Rajshahi the higher average of the average temperature from anthesis to maturity was maximum with Dec 30 sowing (25.96^{0}C), but in comparison to Rajshahi there was a remarkable difference between the lowest average temperature (24.67^{0}C) of Nov 20 sowing and Dec 30 (above 25.96^{0}C).

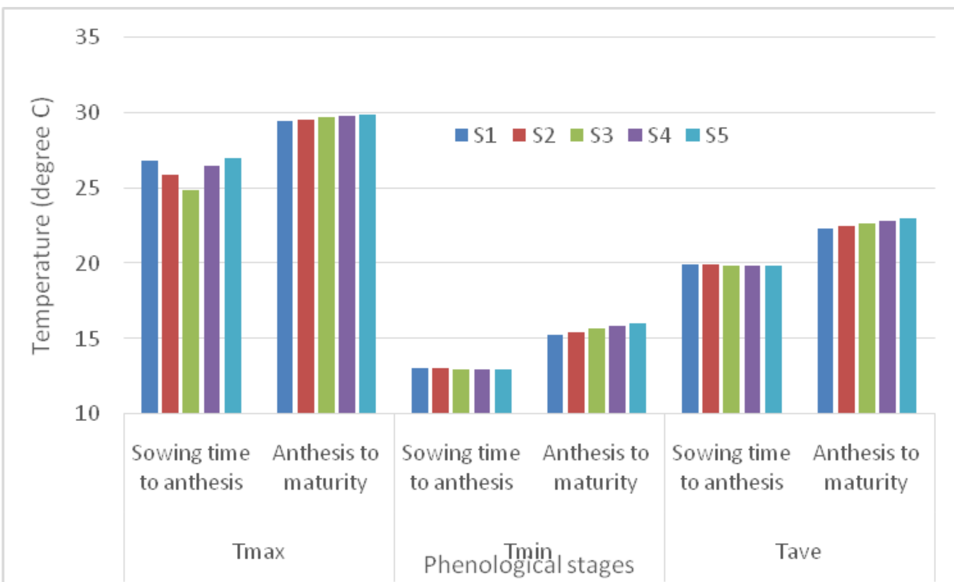


Fig. 4.4.5. Averages of daily maximum, minimum and averages temperature from sowing to anthesis at Rajshahi during rabi 2016-17 (S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30).

Canopy temperature

Effect of sowing dates

Canopy temperature is good indication of stress on the plant. Plant uses the transpiration to reduce the canopy temperature and mitigate the stress. More healthy plants were more transpiration and lower the canopy temperature. Data on canopy temperature have been presented in Table 4.4.7. Date of sowing had significant effect on canopy temperature.

At different stages, canopy temperature was fluctuated from booting to anthesis stage. Early sowing get higher canopy temperature in heading stage but lower in anthesis stage. Beside this, late sowing get lower canopy temperature in heading stage and higher in anthesis stage.

Higher canopy temperature (28.19^{0}C) was found when seed was sown in December 30 at anthesis stage but lower (18.21^{0}C) in booting stage. Wheat plant gets optimum temperature when seeds were sown in November 15 to December 10. However, December 30 recorded the highest canopy temperature at different stage.

Table.4.4.7. Effect of sowing date on canopy temperature (0c) at different stage

Sowing date	**Booting stage**	**Heading stage**	**Anthesis stage**
S_1	20.88	22.02	21.13
S_2	22.72	22.21	21.51
S3	19.03	19.77	22.45
S_4	20.16	22.92	25.86
S_5	18.51	20.64	28.19
LSD	**0.7122**	**0.641**	**0.583**
% CV	**8.58**	**10.23**	**7.78**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties

Canopy temperature is good indication of stress on the plant. Plant uses the transpiration to reduce the canopy temperature and mitigate the stress. More healthy plants were more transpiration and lower the canopy temperature. Data on canopy temperature have been presented in Table 4.4.8. Wheat varieties had significant effect on canopy temperature. At different stages, canopy temperature was fluctuated from booting to anthesis stage. Higher canopy temperature (23.06^{0}C) was found from V_6 variety at anthesis stage which is good for wheat but lower (19.95^{0}C) from V_1 in booting stage. The varieties BARI Gom 28, 29 and 30 were get optimum canopy temperature at anthesis stage.

Significant effect on canopy temperature. At different stages, canopy temperature was fluctuated from booting to anthesis stage. Early sowing get higher canopy temperature in heading stage but lower in anthesis stage. Beside this, late sowing get lower canopy temperature in heading stage and higher in anthesis stage. Higher canopy temperature (28.93^0C) was found when seed was sown in December 30 with V_5 at anthesis stage due to its long duration but lower (18.93^0C) in V_5 at anthesis stage due to its short duration. Wheat plant gets optimum temperature when seeds were sown in November 15 to December 10. However, December 30 recorded the highest canopy temperature at different stage.

Table 4.14. Effect of variety on canopy temperature (0c) at different stage

Variety	**Booting stage**	**Heading stage**	**Anthesis stage**
V_1	19.95	20.91	22.42
V_2	20.11	21.48	22.81
V_3	20.65	21.69	23.05
V_4	20.02	21.55	22.57
V_5	20.17	21.69	22.1
V6	20.64	21.73	23.06
LSD (0.05)	**0.78**	**0.702**	**0.639**
% CV	**10.32**	**9.87**	**8.78**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29

Interaction effect of sowing date and variety

Canopy temperature is good indication of stress on the plant. Plant uses the transpiration to reduce the canopy temperature and mitigate the stress. More healthy plants were more transpiration and lower the canopy temperature. Data on interaction effect of canopy temperature have been presented in Table 4.4.9. Sowing date and wheat variety had significant effect on canopy temperature. At different stages, canopy temperature was fluctuated from booting to anthesis stage. Early sowing get higher canopy temperature in heading stage but lower in anthesis stage. Beside this, late sowing get lower canopy temperature in heading stage and higher in anthesis stage. Higher canopy temperature (28.93^{0}C) was found when seed was sown in December 30 with V_5 at anthesis stage due to its long duration but lower (18.93^{0}C) in V_5 at anthesis stage due to its short duration. Wheat plant gets optimum temperature when seeds were sown in November 15 to December 10. However, December 30 recorded the highest canopy temperature at different stage.

Table 4.4.9. Interaction effect of sowing date and variety on canopy temperature (°c)

Sowing days	Variety	Booting	Heading	Anthesis
S_1	V_1	20.33	21.10	20.53
	V2	20.63	22.90	21.00
	V_3	21.50	22.37	23.37
	V_4	20.47	21.37	21.90
	V_5	21.17	22.47	16.83
	V6	21.17	21.90	23.17
S2	V1	20.93	20.93	22.40
	V_2	22.47	21.73	22.43
	V_3	23.47	22.33	22.87
	V4	22.00	22.60	22.60
	V5	23.07	22.70	22.83
	V_6	24.37	22.93	22.77
S_3	V_1	19.60	19.43	20.67
	V_2	19.33	19.77	21.67
	V_3	18.83	20.10	21.90
	V_4	18.80	20.00	21.80
	V_5	18.70	19.73	21.47
	V_6	18.90	19.57	21.53
S_4	V_1	20.37	22.27	19.70
	V_2	19.73	22.40	20.10
	V_3	20.50	22.80	19.80
	V_4	20.53	23.37	18.93
	V_5	19.73	23.27	20.43
	V_6	20.07	23.43	20.20
S5	V1	18.50	20.83	28.80
	V_2	18.40	20.60	28.83
	V_3	18.97	20.83	27.33
	V4	18.30	20.43	27.60
	V_5	18.17	20.30	28.93
	V_6	18.70	20.83	27.63
LSD (0.05)		**1.744**	**1.571**	**1.429**
	% CV	**8.87**	**10.54**	**9.78**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and BARI Gom-30

4.4 Vegetative growth parameters

Number of tillers plant^{-1}

Effect of sowing dates

Different sowing dates showed statistically significant differences in terms of number of tillers plant^{-1} at different stage (Fig. 4.4.6). The maximum number of tillers plant^{-1} (3.35, 3.52, and 3.66, respectively) was found from S_4 which was statistically similar (3.15, 3.38 and 3.64, respectively) to S_5 and closely followed (2.26, 2.39 and 3.24 respectively) by S_3, while the minimum (2.24, 2.34 and 2.74 respectively) was recorded from S_1 at different growth stage. Seeds sowing at 20 December ensured the maximum tiller than early and delay sowing. BARI (1984) reported that 10 and 20 December sowing produced the highest number of tillers plant^{-1}. Aslam *et al*. (2013) reported that that the 10thDecember sowing significantly produced maximum tillers (359 m^{-2}) followed by the 30th November sowing, the early sowing produced minimum tillers (232 m^{-2}) due to high temperature, not suitable for growth of wheat plant.

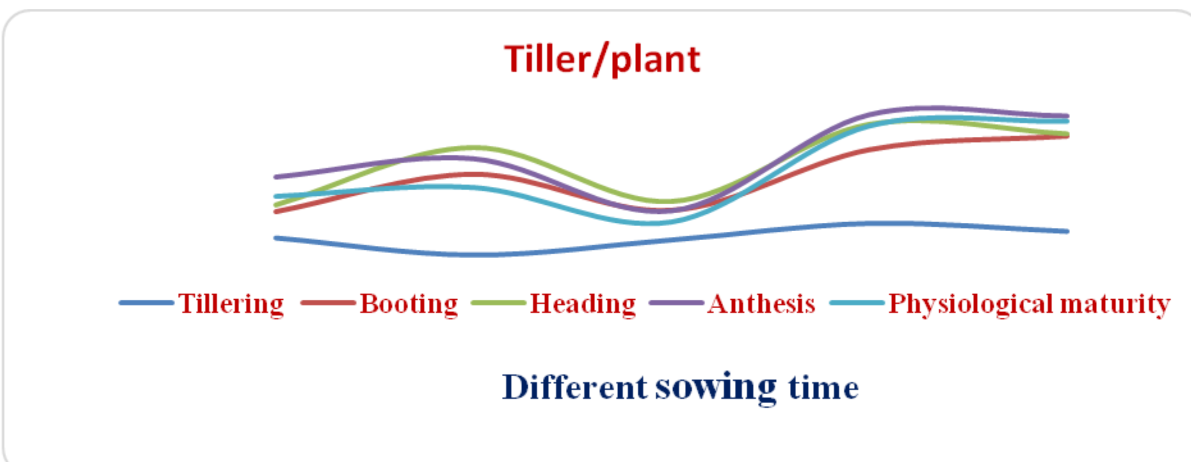


Fig.4.4.6. Trend of tiller production of wheat at different phenological stages at Rajshahi during 2016-17

Table 4.4.10. Effect of sowing date on number of tiller/plant at different stage

Sowing Days	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
S1	1.84	2.24	2.34	2.74	2.46
S2	1.58	2.79	3.18	3.01	2.59
S_3	1.81	2.26	2.39	3.24	2.08
S_4	2.06	3.35	3.52	3.66	3.5
S_5	1.94	3.15	3.38	3.64	3.57
LSD (0.05)	**0.315**	**0.427**	**0.453**	**0.486**	**0.435**
% CV	**5.36**	**7.87**	**3.65**	**6.58**	**8.25**

S_1= Nov 20, S_2= Nov 30, S_3= Dec 10, S_4= Dec 20, S_5= Dec 30

Effect of varieties on tillers

Number of tillers plant^{-1} at different stage varied significantly due to different wheat varieties under the present trial (Table4.4.11). Data revealed that at booting, heading, anthesis and physiological maturity, the maximum number of tillers plant^{-1} (2.95, 3.32, 3.47 and 3.19, respectively) was recorded from V_4 which was statistically similar (2.79, 3.13, 3.33 and 3.02, respectively) to V_3 and followed (2.70, 2.92, 2.98 and 2.80, respectively) by V_5, whereas the minimum number of tillers plant^{-1} (2.57, 2.84, 2.90 and 2.79, respectively) was observed from V_1. Although management practices influenced the number of tillers at different days after sowing but genotypes itself contributed to the number of tillers plant^{-1}.

Table 4.4.11. Effect of variety on number of tiller/plant at different stage of wheat

Variety	Tillering	Booting	Heading	Anthesis	Physiological maturity
V1	1.83	2.57	2.84	2.9	2.79
V2	1.71	2.72	3.04	3.23	2.83
V_3	1.77	2.79	3.13	3.33	3.02
V_4	1.96	2.95	3.32	3.47	3.19
V_5	2.11	2.7	2.92	2.98	2.8
V_6	1.7	2.62	2.79	2.92	2.71
LSD (0.05)	**0.345**	**0.468**	**0.496**	**0.532**	**0.476**
% CV	**5.56**	**3.65**	**7.54**	**8.45**	**6.54**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V_6= BARI Gom 30

Interaction effect of sowing dates and varieties on tiller production

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on number of tillers plant^{-1} at different growth stage (Table 4.4.12). At Booting, heading, anthesis and physiological maturity stage, the maximum number of tillers hill^{-1} (3.57, 3.90, 4.33 and 4.00 respectively) was found from V_2S_4 followed by (3.47,4.00,4.00 and 3.90 respectively) was found from V_4S_4 and statistically significant from V_4S_5 whereas the minimum number of tillers plant $^{-1}$ (1.67, 1.90, 1.77 and 1.43 respectively) was recorded from the treatment combination V_2S_3.

Table 4.4.12. Interaction effect of sowing date and variety on number of tiller/plant

Sowing date	Variety	Tillering	Booting	Heading	Anthesis	Physiological maturity
S_1	V_1	2.23	2.43	2.43	2.43	2.53
	V_2	1.77	2.47	2.57	3.23	2.57
	V3	2.1	2.77	2.77	3.43	3.2
	V4	1.53	2.00	2.00	2.53	2.43
	V5	2.00	2.00	2.20	2.43	2.00
	V_6	1.43	1.77	2.10	2.37	2.00
S_2	V_1	1.57	3.00	3.2	3.3	3.1
	V_2	1.53	2.8	3.37	3.23	2.57
	V_3	1.57	2.53	3	2.67	2.2
	V_4	1.67	3.2	3.87	3.33	2.53
	V_5	1.43	2.53	2.53	2.67	2.33
	V_6	1.7	2.67	3.1	2.87	2.8
S_3	V_1	1.43	1.9	2.03	2	1.67
	V_2	1.23	1.67	1.9	1.77	1.43
	V_3	1.77	2.57	2.67	2.8	2.8
	V_4	2.03	2.33	2.33	2	1.77
	V_5	2.47	2.77	2.87	2.43	2.67
	V6	1.90	2.33	2.57	2.47	2.13
S_4	V_1	2.00	2.77	3.77	3.90	3.77
	V_2	2.2	3.57	3.9	4.33	4.00
	V_3	1.67	2.23	2.9	3.13	2.9
	V_4	2.23	3.47	4.00	4.00	3.9.0
	V5	2.67	3.77	3.57	3.43	3.43
	V_6	1.80	3.10	3.00	3.13	3.00
S_5	V_1	1.90	2.77	2.77	2.87	2.87
	V2	2.00	3.47	3.47	3.57	3.57
	V_3	1.77	3.43	3.53	4.10	4.00
	V_4	2.33	3.77	3.9	4.00	3.8
	V_5	2.00	3.43	3.43	3.57	3.57
	V_6	1.67	3.23	3.20	3.77	3.63
	LSD (0.05)	**0.773**	**1.047**	**1.112**	**1.19**	**1.065**
	CV(%)	**3.45**	**5.65**	**4.56**	**7.54**	**6.56**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V_6= BARI Gom 30

Plant height

Effect of sowing dates

Plant height showed statistically significant differences due to different sowing dates (Table 4.4.13). The highest plant height was recorded from S_3 (88.56 cm) which was statistically similar to S_2 (86.81 cm) and closely followed by S_4 (86.08 cm), while the lowest plant height was (75.01 cm) found from S_1.

Table 4.4.13.Effect of sowing date on plant height

Sowing days	Plant height (cm)
S_1	75.01
S_2	86.81
S_3	88.56
S4	86.08
S_5	82.47
LSD (0.05)	**2.224**
% CV	**10.25**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties

Plant height showed statistically significant differences on different wheat varieties (Table 4.4.14). The highest plant height was recorded from V_1 (86.63 cm) which was statistically similar to V_2 (83.68 cm) and closely related by V_4 (86.08 cm), while the lowest plant height was (75.01 cm) found from S_1.

Table 4.4.14.Effect of varieties on number plant height

Variety	Plant height(cm)
V_1	86.63
V2	83.68
V_3	82.98
V4	82.42
V_5	85.33
V_6	81.67
LSD (0.05)	**2.436**
% CV	**10.54**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30

Interaction effect of sowing time and varieties

Plant height showed statistically significant differences due to interaction effect of sowing dates and different wheat varieties (Table 4.4.15). The highest plant height was recorded from S_3V_1 (91.43 cm) which was statistically similar to S_3V_6 (88.33 cm) and closely related by S_2V_2 (88.23 cm), while the lowest plant height was (67.90 cm) found from S_1V_6.

Table 4.4.15. Interaction effect of sowing time and varieties on plant height

Sowing days	Plant height (cm)
S_1	83.23
	75.57
	69.57
	74.13
	79.67
	67.9
S2	87.67
	88.23
	88.1
	83.77
	88.1
	85
S_3	91.43
	86.8
	88.1
	85.67
	91
	88.33
S_4	88
	85.57
	85.9
	86.1
	85.47
	85.43
S5	82.8
	82.23
	83.23
	82.43
	82.43
	81.67
LSD (0.05)	**5.447**
CV (%)	**11.25**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30;

Ground coverage

Effect of sowing dates

Statistically significant variation was recorded on the effect of sowing dates on percent ground coverage at different growth stage (Fig. 4.4.7.). Ground coverage percentage was increased to increasing up to 60 DAS and then decrease up to 90 DAS. The maximum ground coverage percentage (75.28%) was found from S_3 that mean December 10 sowing at 60 DAS followed by (74.72%) was found from S_2 at 60 DAS and statistically significant from (74.17%) from S_4 whereas the minimum ground coverage percentage (67.17%) at 60 DAS was recorded from the treatment S_1 that mean early sowing.

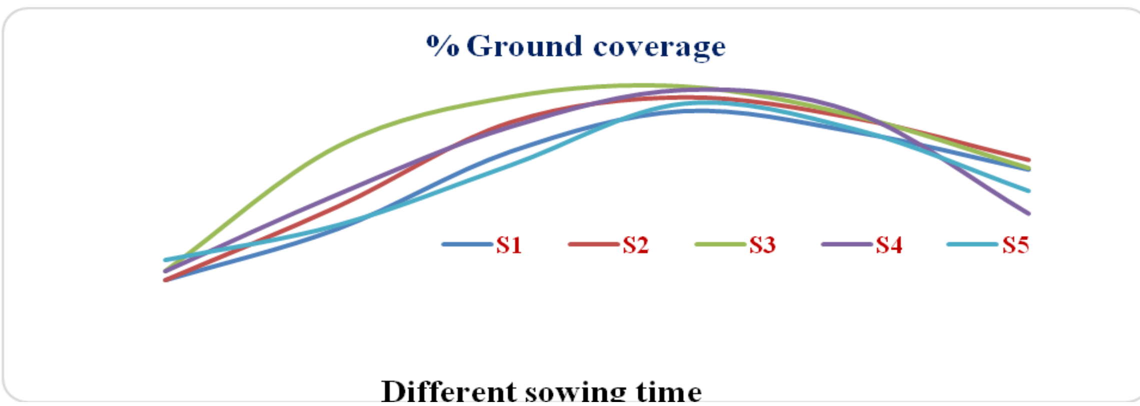


Fig.4.4.7 Showing the ground coverage pattern by the crops grown on different sowing dates at Rajshahi during rabi 2016-17

Regression analysis showed that the ground coverage (maximum of 60 DAS) was linearly but negatively related to the Tmax from sowing to anthesis, that is the ground coverage data was best fitted to the linear regression negatively (slope -2.216 with R^2=0.661). Fig.4.4.8

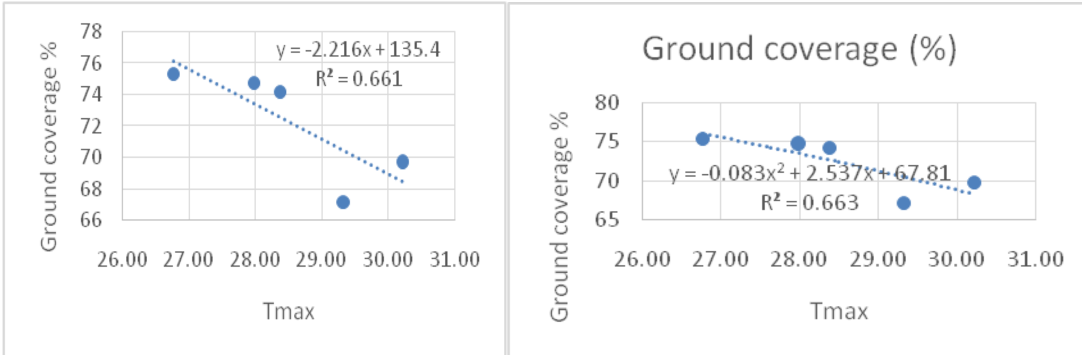


Fig.4.4.8. Relationship of ground coverage with the maximum ambient temperature

The ground coverage (maximum of 60 DAS) was also negatively related to the ambient minimum temperature from sowing to anthesis, however unlike the maximum temperature the regression analysis showed that the ground coverage was best fitted to the Tmin when polynomial regression analysis was made, that is the ground coverage data was best fitted to the polynomial regression although it was negative (slope -4682in linear, with R2=0.964 in polynomial). The higher range of ground coverage was seen at the minimum temperature of 15.5^0C. Fig.4.4.9.

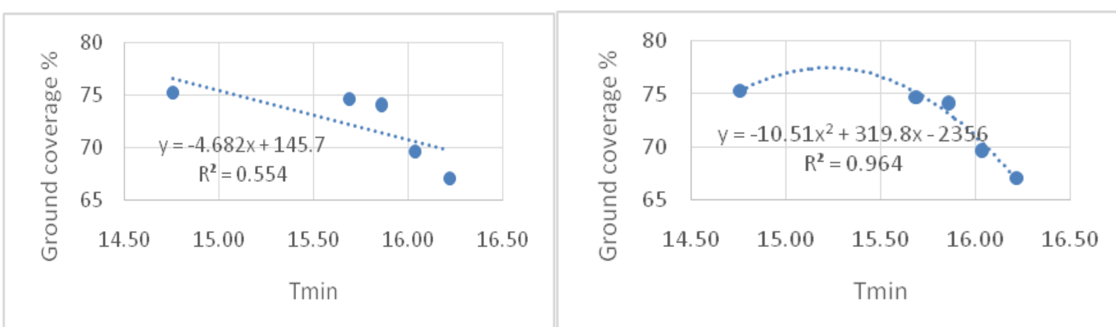


Fig.4.4.9. Relationship of ground coverage with the minimum ambient temperature

The ground coverage (maximum of 60 DAS) was also negatively related to the ambient average temperature (slope -3.179) from sowing to anthesis, however unlike the maximum temperature and like the minimum temperature, the regression analysis showed that the ground coverage was best fitted to the Tmin when polynomial regression analysis was made, that is the ground coverage data was best fitted to the polynomial regression although it was negative (with R2=0.739 in polynomial). The higher ground coverage was seen at the average temperature of 21^{0}C and with further increase the ground coverage decreased. Fig.4.4.10.

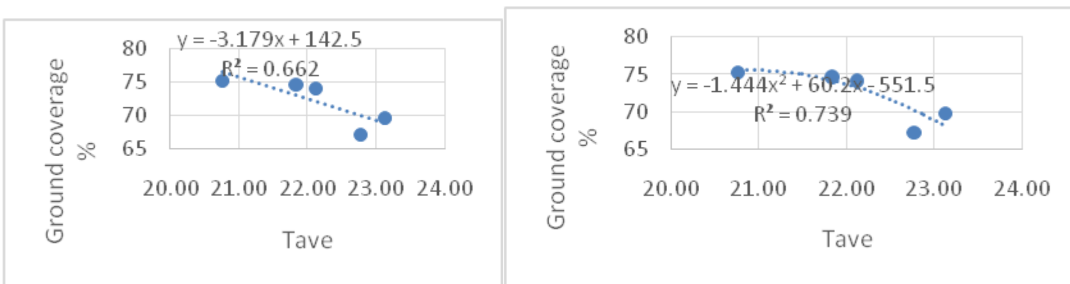


Fig.4.4.10. Relationship of ground coverage with the average ambient temperature

Effect of varieties

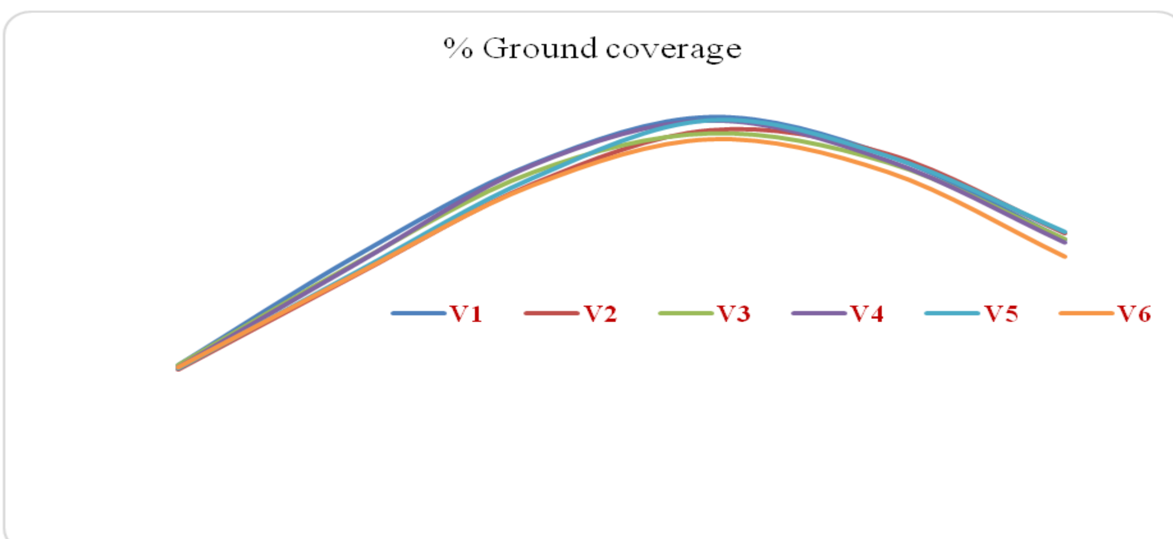


Fig.4.4.11 Ground coverage pattern of different varieties of wheat at Rajshahi duting rabi 2016-17 season

Statistically significant variation was recorded on the effect of wheat variety on percent ground coverage at different growth stage (Fig. 4.4.11). Ground coverage percentage was increased to increasing up to 60 DAS and then decrease up to 90 DAS. The maximum ground coverage percentage (78.7%) was found from V_6 that mean BARI Gom 30 at 60 DAS followed by (74.0%) was found from V_4 at 60 DAS and statistically significant from (73.9%) from V_1 whereas the minimum ground coverage percentage (70.1%) at 60 DAS was recorded from the treatment V_3 that mean BARI Gom 27.

Interaction effect of sowing dates and varieties

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on percent ground coverage at different growth stage (Table 4.4.16).

Ground coverage percentage was increased to increasing up to 60 DAS and then decrease up to 90 DAS. The maximum ground coverage percentage (78.33%) was found from V_6S_3 at 60 DAS followed by (76.69%) was found from V_1S_3 and statistically significant from V_4S_3 and V_5S_3 at 60 DAS whereas the minimum ground coverage percentage (61.17%) was recorded from the treatment combination V_6S_1 at 60 DAS.

Table 4.4.16. Interaction effect of sowing date and variety on ground coverage (%) at 15 days interval

Sowing days	Variety	15 days	30 days	45 days	60 days	75 days	90 days
S_1	V_1	13.17	34	56.17	73.5	65.5	50.5
	V_2	9.5	24.17	47.17	64.83	60.17	45.5
	V3	12.5	30.33	56	66.17	59.17	47
	V4	11.33	28.83	57.17	69.17	60.83	49.83
	V_5	10.67	27	55.33	68.17	61.83	52.33
	V6	10.17	25.17	50.83	61.17	53.83	41.83
S_2	V_1	12.33	35.5	68.17	73.83	64.5	51.17
	V_2	10.83	33.5	59.83	71.67	66.17	55.83
	V3	10.67	35.5	64.67	71	65.67	49.67
	V_4	10.5	36.33	63	71.17	62.83	51
	V_5	11.67	37.83	60.67	72.5	65.83	50.17
	V_6	11	34.83	64.33	74.17	63.5	48.17
S_3	V_1	13.5	56.83	74.33	76.67	66.17	48.17
	V_2	14.33	54.17	71	75.17	69	53.5
	V_3	15	62.5	72.83	74.17	65.83	52
	V4	14.17	52.17	71.7	76.17	65.33	47.67
	V_5	13.83	51.67	73	76.17	65.17	48.67
	V_6	14.83	56.17	68.17	78.33	61.5	39.83
S_4	V_1	14.67	44.67	64.17	74.33	65.83	31.5
	V_2	12.67	38.17	58.5	72.17	68.17	35.83
	V_3	13.83	36.17	59.5	72.5	65.17	33.5
	V_4	15.5	42.5	66.83	74.67	67.17	31.83
	V5	13	38.83	61.5	75.33	66.67	35.83
	V_6	14.83	37.33	61.5	75	66.33	30.5
S_5	V_1	17.5	31.17	50.5	71.17	61.67	40.83
	V_2	18.17	29.33	52.83	69.83	61.83	38.83
	V_3	19.33	29.5	50.67	66.83	59.83	40.83
	V4	17	32.83	52.83	72.83	61.17	38.17
	V_5	17.5	26.83	45.5	71.67	63.17	44.33
	V6	16.83	26.5	43.33	76	59	41.17
LSD (0.05)		**2.655**	**6.521**	**8.181**	**4.137**	**5.681**	**6.567**
CV (%)		**8.87**	**10.54**	**11.45**	**11.54**	**10.54**	**8.98**

S_1= Nov 20, S_2= Nov 30 S_3= Dec 10, S_4= Dec 20, S_5= Dec 30 ; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29

4.5 Reproductive growth

Grain growth on three spike

Effect of sowing date

Grain growth parameter was statistically significant on varied sowing date at different growth stage (Figure 4.4.12). Both fresh and dry weight of grain was gradually increased of days after growth stage up to 28 days after anthesis (DAA). From anthesis to 28 DAA stage, both fresh and dry weight of grain were increased to increasing significantly but grain growth weight of late sowing were decreasing. The highest grain growth was found from November 30 to December 20. Maximum fresh and dry weight of grain (12.60 g, 12.30 g and 7.60 g, 7.27 g) were found in V_6S_2 & V_4S_2 followed by (11.28 g, 10.47 g and 6.16 g, 5.35 g) were also found from S_2 and S_3 stage that mean November 30 and December 10 sowing were maximum grain growth stage. The minimum fresh and dry weight of grain (9.47 g, 9.74 g and 5.02 g, 438 g) were found from the treatment of S_1& S_5 stage that mean November 20 and December 30 sowing were minimum grain growth in all stages.

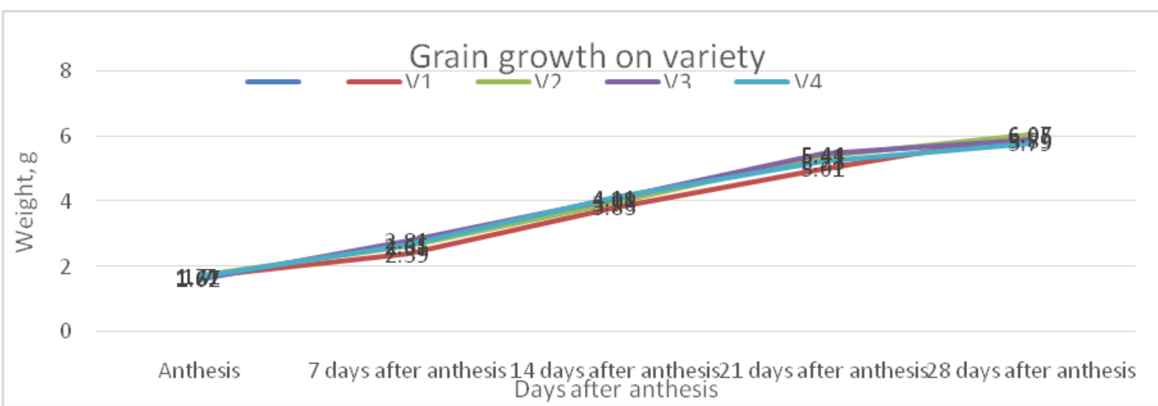


Fig.4.4.12 Effect of sowing date on dry grain growth per three spikes at different days after anthesis

Effect of varieties

Grain growth parameter was statistically significant on different wheat varieties at different growth stage (Figure). Dry weight (Fig..4.4.13) of grain was gradually increased of days after growth stage up to 28 days after anthesis (DAA). The maximum grain growth was found in BARI Gom 28, BARI Gom 29 and BARI Gom 30. Maximum fresh and dry weight of grain (12.18 g, 11.41 g and 6.12 g, 6.03 g) were found in V_6 & V_5 at 28 DAA followed by (11.45 g and 6.05 g) was also found from V_1 variety at 28 DAA. The minimum fresh and dry weight of grain (10.11 g and 5.79 g) were found from V_3 variety.

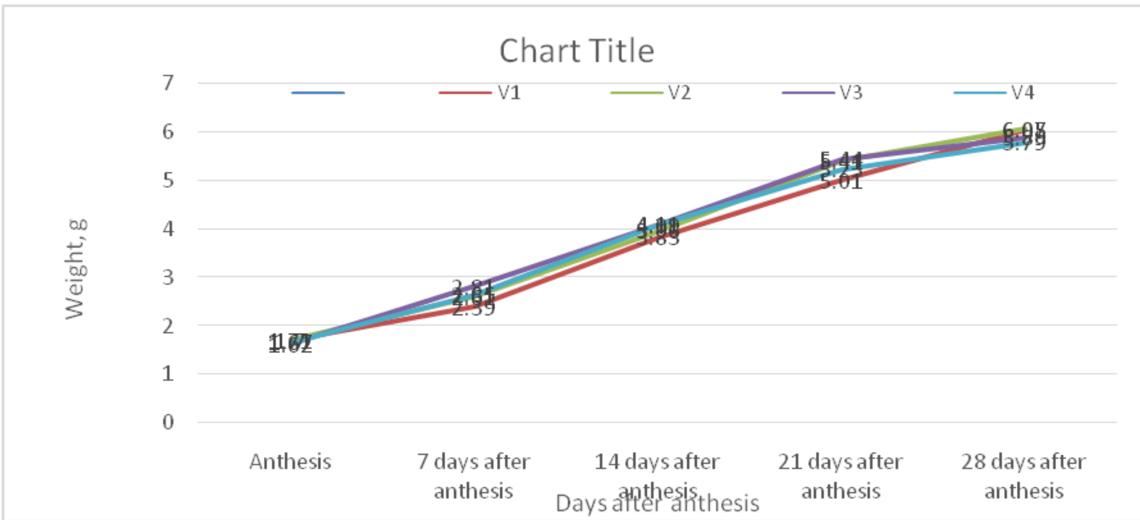


Fig.4.4.14 Effect of variety on dry grain weight at different days after anthesis

Interaction effect of wheat varieties and sowing dates on grain growth

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on grain growth parameter at different growth stage (Table 4.4.17). Both fresh and dry weight of grain was gradually increased of days after growth stage up to 28 and 28 were maximum grain growth in this stage. Besides this, in late sowing condition, BARI Gom 30 and 28 were also good performance with more grain weight and it was statistically significant from V_6S_1 whereas the minimum fresh and dry weight of grain (8.35g, 9.80 g and 4.30 g, 5.80 g) were found from treatments combination of V_3S_5 that mean December 30 sowing with BARI Gom 26 and BARI Gom 27 were minimum grain growth in all stages.

Table 4.4.17 Interaction effect of sowing date and variety on grain growth at different days after anthesis

Sowing days	Variety	Anthesis FW (g)	Anthesis DW (g)	7 DAA FW (g)	7 DAA DW (g)	14 DAA FW (g)	14 DAA DW (g)	21 DAA FW (g)	21 DAA DW (g)	28 DAA FW (g)	28 DAA DW (g)
S_1	V_1	5.6	1.6	6.3	2.5	8.83	3.87	9.27	4.03	10.87	4.5
	V_2	4.9	1.37	6.73	3	8.33	4.2	9.87	5.1	10.83	5.33
	V_3	4.47	1.2	6.33	2.5	8.1	4	9	4.47	9.2	4.8
	V_4	6.5	1.9	7.2	3.23	9.07	4.67	9.53	4.9	9.73	5.13
	V5	6.07	1.67	7.83	3.7	9.5	5.3	10.37	5.47	11.03	5.63
	V_6	6.53	1.93	7.87	3.8	10.2	5.47	10.33	5.4	11	5.4
S_2	V_1	5.7	1.83	6.67	2.03	9.7	3.3	9.5	4.43	14.37	7.83
	V_2	5	1.4	7.43	2.47	9.17	3.17	10.43	4.53	11.8	6.6
	V_3	4.77	1.3	7.1	2.37	9	3.1	10.1	4.17	11.47	6.6
	V_4	6.63	1.9	7.33	2.43	9.57	3.57	10.4	4.1	12.1	7.27
	V_5	6.2	1.77	9.13	3.07	9.83	3.4	11.03	4.57	12.37	7.37
	V6	6.7	2.4	9.2	3.2	10.03	4.23	11.33	4.87	12.6	7.6
S_3	V_1	5.57	1.73	7.27	2.33	8.93	2.6	11.57	5.3	10.53	5.77
	V_2	5.17	1.88	7.23	2.57	8.7	2.6	11.37	5.23	10.03	6.27
	V_3	5	1.67	8.07	2.67	8.53	2.27	13.13	5.93	9.23	5.3
	V_4	5.53	1.93	7.03	2.5	8.67	2.93	10.43	5.17	9.53	5.4
	V_5	5.87	2.03	7.4	2.57	9.37	3.27	12.07	5.63	10.67	6.6
	V_6	6.7	2.3	8.4	3.13	9.57	3.63	11.7	5.97	10.8	6.77
S_4	V_1	5.37	1.5	7.23	2.47	8.73	2.67	10.2	6.97	10.74	6.08
	V_2	5	1.4	8.1	2.53	8.23	2.43	9.9	6.83	10.67	6.05
	V_3	4.9	1.27	7.53	2.87	8.03	2.3	9.1	6.5	9.84	5.08
	V_4	5.3	1.4	7.63	2.77	9.03	3.67	8.97	6.63	10.64	6.15
	V_5	5.67	1.6	10.2	3.3	9.17	3.77	9.53	6.93	10.53	6.08
	V_6	6.73	2	10.6	3.93	9.4	3.93	9.3	6.23	10.74	6.78
S_5	V_1	4.57	1.93	8.53	2.63	8.63	2.73	10.23	5.34	10.34	6.1
	V_2	4.37	1.9	8.07	2.5	8.13	2.9	10.23	5.57	9.8	5.8
	V_3	4.5	1.57	7.87	2.43	8	2.4	10.23	5.04	8.35	4.3
	V_4	5.23	1.93	7.83	2.4	8.67	3.53	10.23	5.27	10.4	6
	V_5	5.6	2.03	7.6	2.3	9.1	3.3	10.23	5.24	10.53	6.04
	V_6	6.33	2.13	8.6	2.77	9.52	3.9	10.23	5.38	10.82	6.38
LSD (0.05)		**1.559**	**0.5**	**1.912**	**0.819**	**1.003**	**1.01**	**2.086**	**1**	**2.098**	**1.043**
% CV		**5.87**	**4.65**	**6.54**	**3.45**	**10.87**	**11.7**	**10.34**	**9.9**	**10.58**	**9.85**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29

4.6 Yield and yield contributing parameters

Number of spikes m^{-2}

Effect of sowing dates

Number of spikes m^{-2}showed statistically significant differences due to different sowing dates (Table 4.4.18). The highest number of spikes $m^{-2}$was recorded from S_4 (248.78) which was statistically similar to S_3 (246.83) and closely followed by S_2 (243.56), while the lowest number of spikes plant^{-1} was found from S_5 (230.22).

Effect of varieties

Number of spikes m^{-2}showed statistically significant differences on different wheat varieties (Table 4.4.19). The highest number of spikes $m^{-2}$was recorded from V_3 (263.93) which was statistically similar to V_4 (248.13) and closely followed by V_6 (235.33), while the lowest number of spikes $m^{-2}$was found from V_2 (223.73).

Interaction effect of sowing dates and variety

Number of spikes m^{-2}showed statistically significant differences due to the interaction effect of wheat varieties and sowing dates (Table 4.4.20). The highest number of spikes $m^{-2}$was recorded from S_1V_3 (289.33) which was statistically similar to S_3V_3 (284.67) and closely followed by S_1V_4 (269.67), while the lowest number of spikes $m^{-2}$was found from S_5V_5 (180.67).

Number of spikelet spike^{-1}

Effect of sowing dates

Different sowing dates showed statistically significant differences in number of spikelets spike^{-1} (Table 4.4.18). The highest number of spikelet spike^{-1} was observed from S_2 (16.81) which was statistically similar to S_3 (16.36) and S_4 (16.37), while the lowest number of spikelets spike^{-1} was found from S_4 (13.86).

Effect of varieties

Statistically significant variation was recorded in terms of different wheat varieties in terms of number of spikelet spike^{-1} (Table 4.4.19). The highest number of spikes spike^{-1}was observed from V_2 (16.53) which was statistically similar to V_1 (16.27) and followed by V_6 (15.97), while the lowest number of spikes spike^{-1}was found from V_5 (15.19).

Interaction effect of sowing dates and varieties

Number of spikelet spike^{-1} varied significantly due to the interaction effect of wheat varieties and sowing dates under the present trial (Table 4.4.20). Data revealed that the highest number of spikelet spike^{-1} was observed from V_1S_4 (18.77), whereas the lowest number of spikelet spike^{-1} was obtained from the treatment combination V_6S_1 (11.43).

Total grains spike^{-1}

Effect of Sowing dates

Number of grains per spike is important yield attribute which determine the yield potential of crop. More the number of grains per ear more will be the yield. Total grains spike^{-1} showed statistically significant differences due to different sowing dates (Table 4.4.18). Maximum grains spike^{-1} was recorded from S_2 (44.03) which was statistically similar to S_3 (44.01) and followed by S_1 (38.29), again minimum grains spike^{-1} was observed from S_5 (34.70).

Effect of varieties

Number of grains per spike is important yield attribute which determine the yield potential of crop. More the number of grains per ear more will be the yield. Total grains spike^{-1} varied significantly due to different wheat varieties under the present trial (Table 4.4.19). Data revealed that the highest total grains spike^{-1} was observed from V_6 (46.0) which was statistically similar to V_4 and V_2 (44.87 and 44.48, respectively), whereas the lowest total grains spike^{-1} was found from V_1 (38.55).

Interaction effect of sowing dates and varieties

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates in terms of total grains spike^{-1} (Table 4.4.20). The highest total grains spike^{-1} was found from V_2S_3 (52.33), while the lowest total grains spike^{-1} was recorded from the treatment combination V_6S_1 (25.00).

1000-grain weight

1000-grain weight showed statistically significant differences due to different sowing dates (Table 4.4.18). The highest 1000-seeds weight (54.32 g) was found from S_2 which was statistically similar (53.60 g and 52.19 g) from S_1& S_3, while the lowest 1000-grains weight (35.81 g) was observed from S_5. Chowdhury (2002) reported that 1000-grain weight decreased with delay in sowing time from November 15 and the lowest 1000-grain weight were recorded in December 15 sown plants.

Effect of Varieties

The 1000-grain weight is most important yield attribute, which determines the yield contribution of individual grain as well as quality appearance of grain. More the 1000-grain weight, more grain looks bolder in appearance. The 1000-grain weight determines the ability of the plant to translocate the photo assimilates to sink. Different wheat varieties showed statistically significant difference on 1000-seeds weight (Table 4.4.19). The highest 1000-grains weight (49.48 g) was recorded from V_6 which was statistically similar (49.21 g) to V_5, whereas the lowest 1000-seeds weight (41.4 g) was found from V_3 which was statistically similar (42.19 g) to V_2.

Interaction Effect of sowing dates and varieties

Interaction effect of wheat varieties and sowing dates showed significant differences on weight of 1000-grains (Table 4.4.20). The highest weight of 1000-grains (56.83 g) was found from V_6S_2, while the lowest weight of 1000-grains (32.20 g) was obtained from the treatment combination of V_3S_5.

Table 4.4.18. Effect of sowing date on yield contributing characters

Sowing days	Spike/m2	Spikelet spike^{-1}	Grains spike^{-1}	Grain weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
S_1	247	13.09	33.29	53.6	3.29	14.17	23.2
S2	233.56	15.81	44.03	54.32	3.52	11.9	29.6
S_3	236.83	16.36	44.01	52.19	3.39	10.3	32.9
S_4	248.78	17.37	44.32	41.97	3.24	10.78	30.1
S_5	200.22	16.86	42.7	35.81	2.44	8.64	28.2
LSD(0.05)	**15.093**	**0.644**	**3.036**	**2.798**	**0.124**	**0.391**	**0.234**
% CV	**10.54**	**8.35**	**5.36**	**9.56**	**5.56**	**9.87**	**7.65**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Relations of biological yield with the average canopy temperature (booting, heading and anthesis)

The regression analysis showed that the biological yield was decreased with the increase of canopy temperature, however the solpe was not so high (-0.497). But when polygonal regression was fitted it was observed that the biological yield increased when the canopy temperature increased from 20^{0}C, was maximum at about 21.5^{0}C and thereafter decreased.

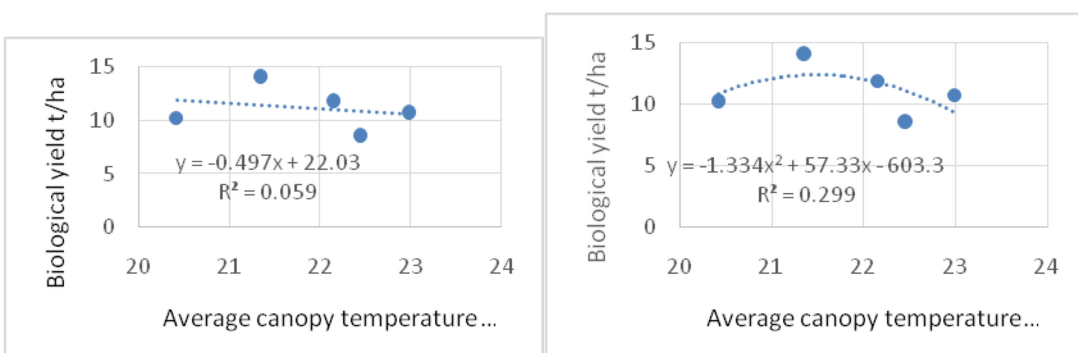


Fig.4.4.15 Relationships of the biological yield with the average canopy temperature from booting to anthesis

Table 4.4.19.Effect of variety on yield contributing characters of wheat

Variety	Spike m^{-2}	Spikelet $spike^{-1}$	Grains $spike^{-1}$	1000-Grain weight (g)	Grain yield (tha^{-1})	Biological yield (tha^{-1})	Harvest index (%)
V_1	224.53	16.97	38.55	44.97	3.41	11.3	30.2
V2	223.73	16.53	44.48	42.19	2.97	10.58	28.1
V_3	263.93	15.93	43.89	41.4	3.42	11.49	29.8
V_4	248.13	15.77	44.87	47.23	3.72	11.24	33.1
V_5	204	15.19	42.63	49.51	3.23	10.99	29.4
V_6	235.33	15.97	46	49.48	3.81	11.33	33.6
LSD(0.05)	**16.534**	**0.706**	**3.325**	**2.066**	**0.355**	**1.085**	**0.465**
CV%	**12.42**	**5.56**	**7.58**	**6.89**	**5.56**	**8.78**	**7.673**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29, V_6= BARI Gom 30

Grain yield/ha

Effect of sowing date

Grain yield is the function of effective tillers, spikem^{-2} number of grains per spike and 1000-grain weight. Data on grain yield have been presented in Table 4.4.18. Sowing date significantly affected the grain yield of wheat. Crop sown on November 20 recorded the highest grain yield which was statistically at par with November 5 sowing. Different sowing dates showed statistically significant differences on grain yield (Table 4.4.18). The highest

grain yield (3.52 t ha^{-1}) was recorded from S_2 that mean November 30 sowing which was statistically similar (3.39 t ha^{-1}) to S_3 and closely followed (3.29 t ha^{-1}) by $S_{1.}$

Effect of varieties

Statistically significant variation was observed for different wheat varieties in terms of grain yield (Table 4.4.19). The highest grain yield was found from V_6 (3.81 t ha^{-1}) BARI Gom 30 which was statistically similar to V_4 (3.72 t ha^{-1}) BARI Gom 28 due to its heat tolerant, blast disease registrant and yield potentiality and followed by V_1 (3.41 t ha^{-1}), whereas the lowest grain yield was found from V_2 (2.97 t ha^{-1}) BARI Gom 26 due to blast susceptible.

Interaction effect of sowing dates and varieties

Effect of wheat varieties and sowing dates showed significant differences on grain yield (Table 4.4.20). The highest grain yield (4.28 t ha^{-1}) was observed from V_6S_2 that mean November 30 sowing with BARI Gom 30 variety followed (3.95 t ha^{-1}) by V_4S_2 BARI Gom28 variety with December 10 sowing and statistically similar results (4.10 t ha^{-1}) was also found from V_6S_3 that mean December 10 sowing with BARI Gom 30 variety and V_4S_3 BARI Gom 28 variety with December 10. Higher grain yield under November 30 sowing was attributed to higher yield contributing characters, chlorophyll content, lower canopy temperature), number of grains per spike and 1000-grain weight. Ram *et al*., (2013) and Kaur *et al.,* (2010) also reported higher grain yield under November 15 sowing as compared to late sown conditions in Hisar (Haryana). While the lowest grain yield (2.28 t ha^{-1}) was obtained from the treatment combination V_5S_5 that mean December 30 sowing with BARI Gom 29 variety followed (2.32 t ha^{-1}) by V_1S_5 that mean December 30 sowing with BARI Gom 25 variety and statistically similar to V_3S_5 that mean December 30 sowing with BARI Gom 27 variety.

Biological yield

Effect of sowing dates

Biological yield is the total biomass produced by the plant during its life cycle. Different sowing dates showed statistically significant differences in terms of biological yield (Table 4.4.18). The highest biological yield (14.17 t ha^{-1}) was found from S_1 which was closely followed (11.90 t ha^{-1}) by S_2.

Effect of Variety

Biological yield showed statistically significant difference due to different wheat varieties (Table 4.419). Data revealed that the highest biological yield (11.49 t ha^{-1}) was observed from V_3 which was statistically similar (11.30 t ha^{-1}) to V_1 and followed (11.24

t ha^{-1}) by V_4, while the lowest biological yield (10.58 t ha^{-1}) was obtained from V_2 followed (10.99 t ha^{-1}) by V_5 sowing.

Interaction effect of sowing dates and varieties

Effect of wheat varieties and sowing dates showed significant differences on biological yield (Table 4.4.20). The highest biological yield (15.15 t ha^{-1}) was found from V_2S_1 and statistically similar biological yield (14.23 t ha^{-1}) was found from V_1S_1 followed (14.06 t ha^{-1}) by V_1S_1 and the lowest biological yield (7.98 t ha^{-1}) was obtained from the treatment combination V_6S_5 followed (8.34 t ha^{-1}) by V_1S_5 .

Harvest index

Effect of sowing dates

Harvest index is an important parameter indicating the efficiency in partitioning of dry matter to economic part of the crop. Harvest index showed statistically significant differences due to different sowing dates (Table 4.4.18). The highest harvest index (32.9) was observed from S_3 which was closely followed (30.1) by S_3, whereas the lowest harvest index (23.2) was found from S_1 which was statistically similar (28.2) to S_5.

Effect of Variety

Different wheat varieties showed statistically significant difference on harvest index (Table 4.4.19). The highest harvest index (33.6%) was found from V_6 that mean BARI Gom 30 variety followed (33.1%) from BARI Gom 28 and the lowest harvest index (28.1%) was recorded from V_3 that mean BARI Gom 26.

Interaction Effect of sowing dates and varieties

Interaction effect of wheat varieties and sowing dates showed significant differences on harvest index (Table 4.4.20). The highest harvest index (35.4%) was observed from V_6S_2 which was statistically similar (33.9%) from V_4S_2 while the lowest harvest index (20.3%) was obtained from the treatment combination V_2S_1 followed (25.0%) by $V_1S_{5.}$

Table 4.4.20.Interaction effect of sowing date and variety on yield contributing characters

Sowing days	Variety	Spike /m2	Spikelet /spike	Grains/spike	1000 grain wt (g)	Grain yield	Biological yield (t/ha)	Harvest index (%)
S_1	V_1	232	16.33	38.57	51.35	3.56	14.23	25
	V_2	232.33	12.8	34.33	52.92	3.07	15.15	20.3
	V_3	289.33	12.87	36.2	48.25	3.58	14.06	25.5
	V_4	269.67	12.67	34.1	53.9	3.54	12.44	28.5
	V_5	217.33	12.43	31.57	51.33	3.8	13.56	28
	V_6	241.33	11.43	25	53.87	3.21	12.55	25.6
S_2	V_1	227.67	15.67	33.67	51.85	3.7	12.34	30
	V_2	231.33	16.57	47	52.47	3.59	10.92	32.9
	V_3	246.67	16.23	44.57	49.07	3.65	13.52	27
	V_4	252.67	16	44.47	54.48	3.95	12.07	31.9
	V_5	201.33	15.57	42.23	52.68	3.37	11.73	28.7
	V_6	261.67	16.8	48.23	56.83	4.28	11.79	33.4
S_3	V_1	232.33	17	39.13	43.4	3.4	11.39	29.9
	V_2	218	16.87	52.33	39.28	2.82	8.72	32.3
	V_3	284.67	15.77	44.9	39.32	3.58	10.66	33.6
	V_4	253.33	16.2	45.77	45.87	3.9	10.41	36.6
	V_5	196.67	16.43	38.57	47.13	3.72	10.59	32.3
	V_6	236	15.9	43.33	48.15	4.1	10.8	34.7
S_4	V_1	235.67	18.77	40.13	41.7	3.06	11.17	27.4
	V_2	223	18.77	50.2	40.32	3.19	9.72	32.8
	V_3	275.33	17.67	49.43	41.17	3.14	10.28	30.5
	V_4	270.67	16.33	43.57	40.87	3.45	11.45	30.1
	V_5	224	16	40.8	45.48	3.29	11.1	29.6
	V_6	264	16.67	41.77	42.28	3.43	10.95	31.3
S_5	V_1	195	17.1	41.23	36.53	2.32	8.34	27.8
	V_2	214	17.67	48.53	35.97	2.5	8.38	29.8
	V_3	223.67	17.13	44.33	32.2	2.46	8.94	27.5
	V_4	194.33	17.67	46.43	34.03	2.54	9.24	27.5
	V_5	180.67	15.53	40	36.9	2.28	7.98	28.6
	V_6	193.67	16.03	35.67	39.25	2.65	8.73	30.4
LSD (0.05)		**36.972**	**1.578**	**7.436**	**3.856**	**0.264**	**1.027**	**0.365**
CV (%)		**12.23**	**9.87**	**10.54**	**8.98**	**5.56**	**8.87**	**7.86**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30; V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29, V_6= BARI Gom 30

4.7 Relationships of yield and yield attributes with the ambient temperature

Regression analysis

4.7.1 Sowing to anthesis temperature

Effect of temperature on number of grains/spike

The number of grains/spike was remarkably and reluctantly dependent on ambient maximum temperature. In the linear regression curve the slope had a negative value (-2.470), that means that as the maximum temperature of the day across from sowing to anthesis increases the number of grains per spike decreases (Fig.4.4.12). But in the polygonal curve the curve is curvilinear showing a negative relationship (slope -1.943) at the lower temperature after about 25^0C and thereafter the yield further decreases although this negative relationship was not very strong (R^2=0.222) at polygonal polygonal regression curve).

The interaction of the number of spike with the minimum temperature of the days from sowing to anthesis shows that the relationship of the grain number was a negative one (slope was negative of –72.35) (Fig 4.4.13).That is the prevailing temperature above 12.92^0C caused decrease in seed number. However the within the prevailing range of minimum temperature (12.92-13.05^0C), the highest seed number was obtained at 12.96^0C and the overall relationship was very strong (R^2=0.943).

Effect of temperature on number of grains/spike

Similar relations were also obtained with number of grains and the average temperature of the days from sowing to anthesis. In general, as the average temperature increased the grain number decreased (slope value -5.305) (Fig. 4.4.14). But the polygonal regression showed that at lower values of the average temperature (25^0C) the grain number increased slightly and again decreased (slope -0.5.84 multiplied by x^2). The coefficient of determinations at the polygonal regression was a weaker one (R^2=0.427).

Effect of temperature on 1000 grain weight, g

1000 grain weight had also weak negative relationship the maximum temperature from sowing to anthesis both at linear and polygonal analysis (Fig 4.4.15). The polygonal regression shows that there was a tendency of increasing the 1000 grain weight at maximum temperature 19.87^{0}C, showing maximum value at this temperature and the decreased 19.89^{0}C. The R2 value at linear and polygonal level were 0.753 and 0.967 respectively.

A dissimilar situation was observed in case of 1000 grain weight with the minimum temperature of the days from sowing to anthesis (Fig. 4.4.16). The 1000 grain weight increased (slope 139.89) with the increase of the minimum temperature with the R2 value of 0.659 (moderate). Similar trend was noticed while polygonal regression was made showing highest 1000 grain weight at 13 minimum temperature showing a strong fitting of the data at this polygonal model (R2=0.883).

Likewise the 1000 grain weight responded weakly (R^2 = 0.326) to the average temperature although it was an increasing trend showing a positive slope (216.33) at the linear regression curve (Fig. 4.4.17). The 1000 grain weight increased after as the average temperature increased weakly showing R^2 of 0.335 at polygonal curve.

Effect of temperature on Yield ha^{-1}

Strong negative relationship was also observed (slope -0.300) between seed yield/ha with maximum temperature (Fig. 4.4.18). The polygonal squared curve shows that from 25^{0}C the yield increased at temperature up to 26^{0}C and thereafter decreased showing the coefficient of determination value of R^2=0.727 on polygonal curve).

Like the 1000 grain weight, the minimum temperature had a positive effect on grain yield/ha (slope is positive with a value of 5.542 although it did not seem to be significant (R2=390) at the linear curve (Fig. 4.4.19). But in polygonal curve the effect seemed to be significant (R^2=0.957).Similar phenomenon happened with the average temperature although the relationship was weaker showing lower R^2 values of 0.096-0.120 at linear and polygonal level respectively (Fig. 4.4.20).

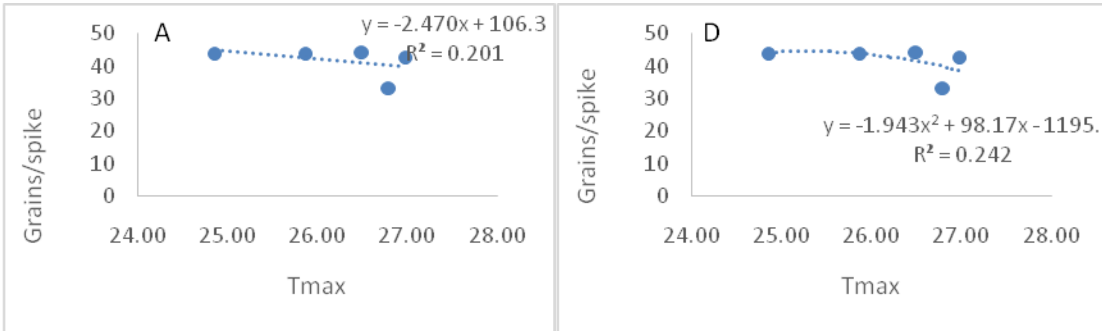


Fig. 4.4.16Regression analysis between Grain/spike at average of daily maximum temperature from sowing to anthesis at Rajshahi

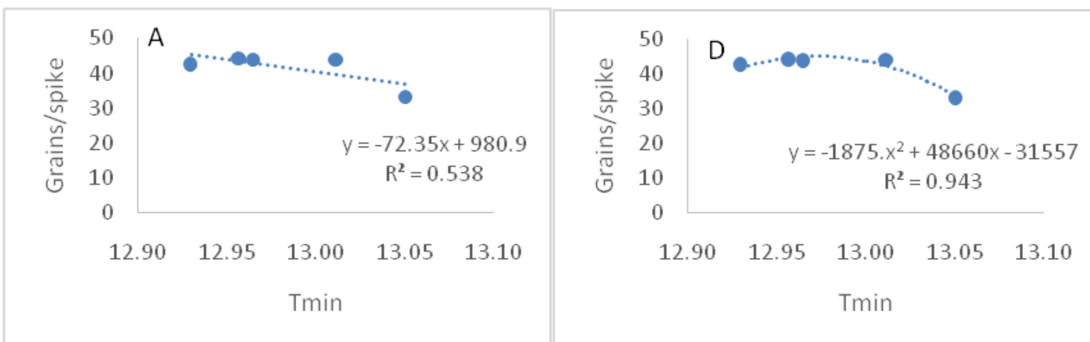


Fig. 4.4.17.Regression analysis between Grain/spike at average of daily minimum temperature from sowing to anthesis at Rajshahi

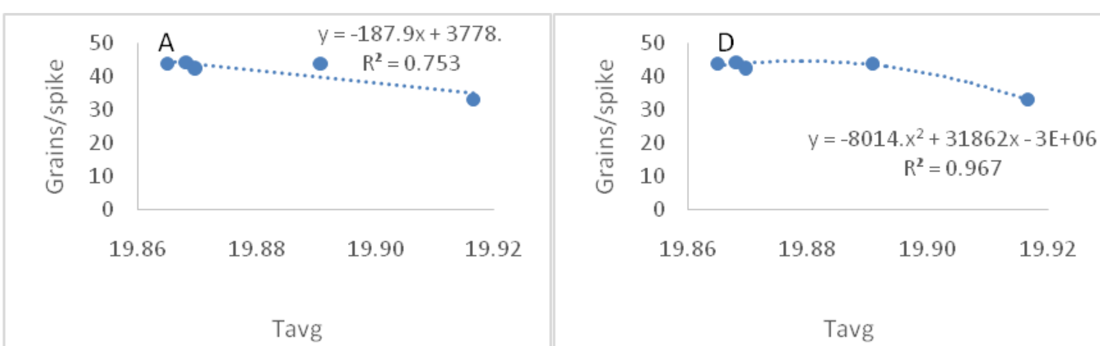


Fig. 4.4.18 Regression analysis between Grain/spike at average temperature of daily maximum and minimum temperature from sowing to anthesis at Rajshahi

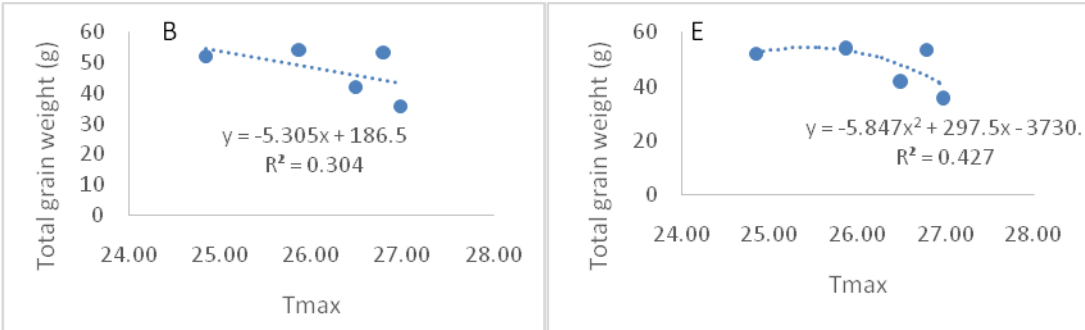


Fig. 4.4.19 Regression analysis between weight/plant at average of daily maximum temperature from sowing to anthesis at Rajshahi

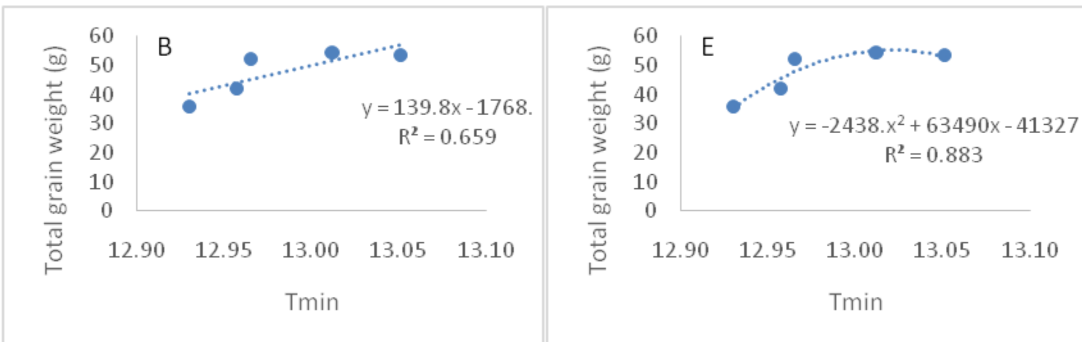


Fig. 4.4.20 Regression analysis between weight/plant at average e of daily minimum temperature from sowing to anthesis at Rajshahi

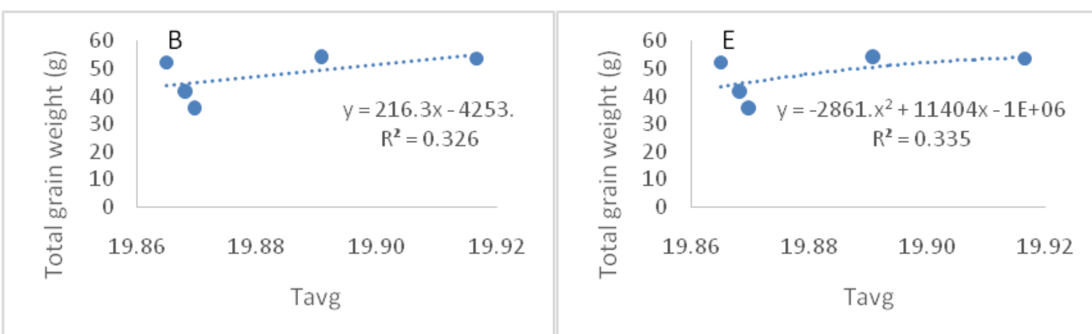


Fig. 4.4.21.Regression analysis between Grain weight/plant at average of daily maximum and minimum temperature from sowing to anthesis at Rajshahi

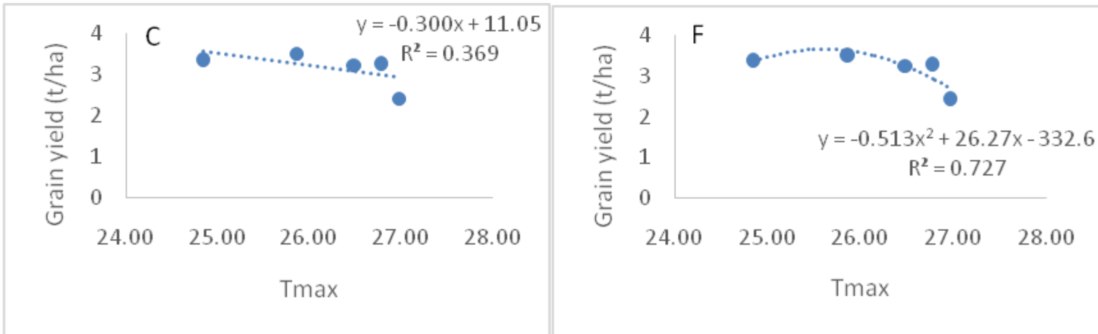


Fig. 4.4.23 .Regression analysis between grain yield/ha at average of daily maximum temperature from sowing to anthesis at Rajshahi

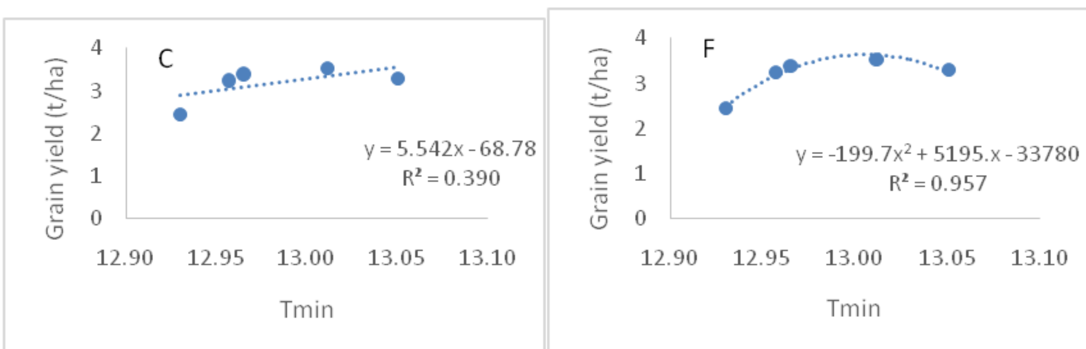


Fig. 4.4.24.Regression analysis between grain yield/ha at average of daily minimum temperature from sowing to anthesis at Rajshahi

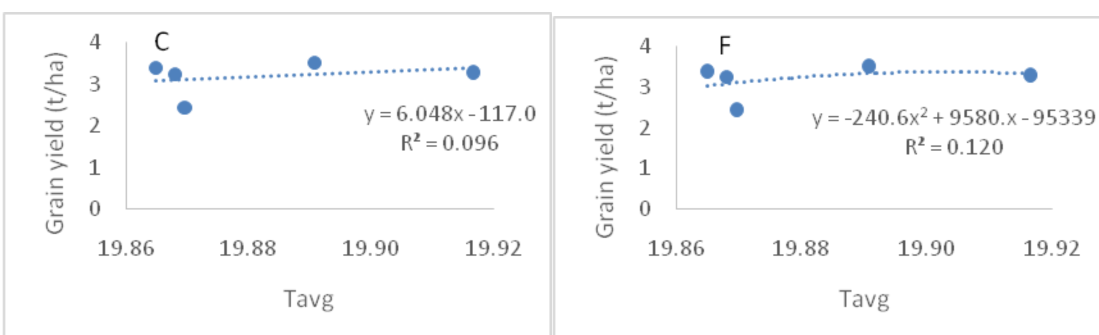


Fig. 4.4.25. Regression analysis between grain yield/ha at average of daily maximum and minimum temperature from sowing to anthesis at Rajshahi

4.7.2 Effect of temperature averaged over anthesis to maturity

Number of grains spike^{-1}

Number of grain^{-1}spike has a little positive dependence on the maximum ambient temperature with a slope 4.2778 and R^2 value 0.167 (Fig. 4.4.21). But it showed a strong relation when polygonal regression was fitted showing R^2 value of 0.832. Number of grains^{-1}spike responded positively (slope 10.193) to the ambient minimum temperature with a R^2 value 0.907 (Fig.4.4.22). Number of grain spike^{-1} had also positive relationship (slope 4.63, R^2=0.0.436 at linear regression). In the polygonal regression it increased with the increase of average temperature up to a temperature of about 22^0C and due to the further increase in temperature it tended to decrease (R^2=0.382) (Fig. 4.4.23).

1000 grain weight

1000 grain weight was strongly but negatively dependent on T max (slope -41.14) showing R2 value at linear curve of 0.832). Similar trend was also noticed in the polygonal regression, that is during anthesis to maturity the 1000 grain weight decreased as the atmospheric maximum temperature increased (R^2=0.933) (Fig. 4.4.24).

Likewise, in the daily average of the minimum temperature from anthesis to maturity, 1000 grain weight showed a better fitting to both linear and polynomial regression although with negative intercept showing R2 values of 0.826 and 0.989 respectively (Fig. 4.4.25).

Similar situation happened in this parameter showing a negative relation with average of the daily maximum and minimum ambient temperature and the relationship was strong both in linear and polygonal regression (R^2=0.831 and 0.977 on linear and polygonal curve respectively (Fig. 4.4.26)

Grain yield

The grain yield in general decreases sharply with the increases of maximum temperature (in the linear graph the slope is -1.755 on linear regression) showing R^2 values of 0.572 and 0.992 at linear and polygonal regression levels respectively (Fig. 4.4.27).

Grain yield had also a negative relationship (b or slope value in the linear graph is negative) with the minimum temperature (Fig.4.4.28). But the relationship was very strong on polygonal regression showing R^2 value 0.922. Grain yield was negatively affected by the average temperature (slope was negative -0.523) although this relationship was best fitted in the polygonal graph showing R^2 value of 0.961. That is, the effect of the average temperature was strong (Fig. 4.4.29).

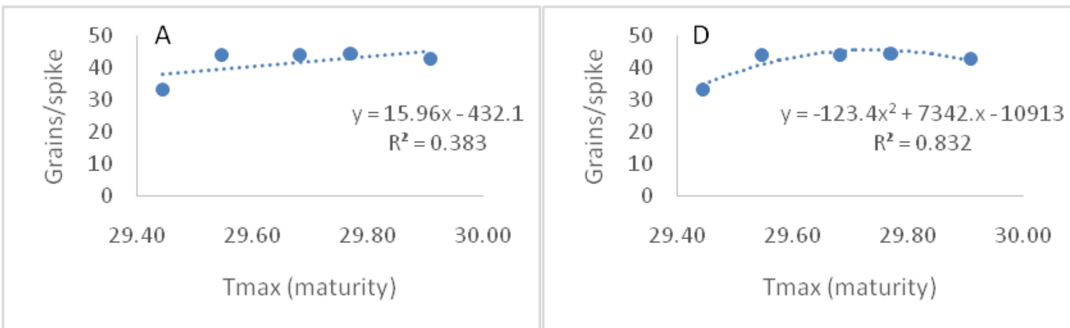


Fig. 4.4.26 Regression analysis between grain/spike at average of daily maximum temperature from anthesis to maturity at Rajshahi

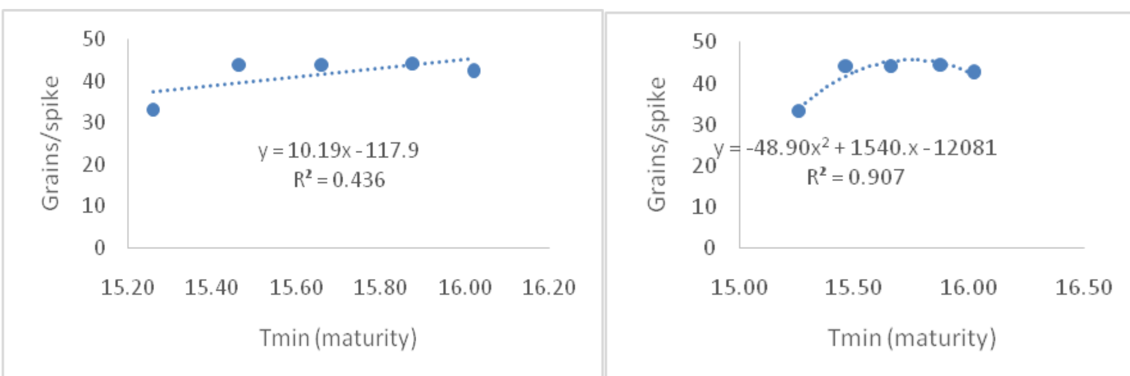


Fig. 4.4.27 Regression analysis between grain/spike at minimum of daily temperature from anthesis to maturity at Rajshahi

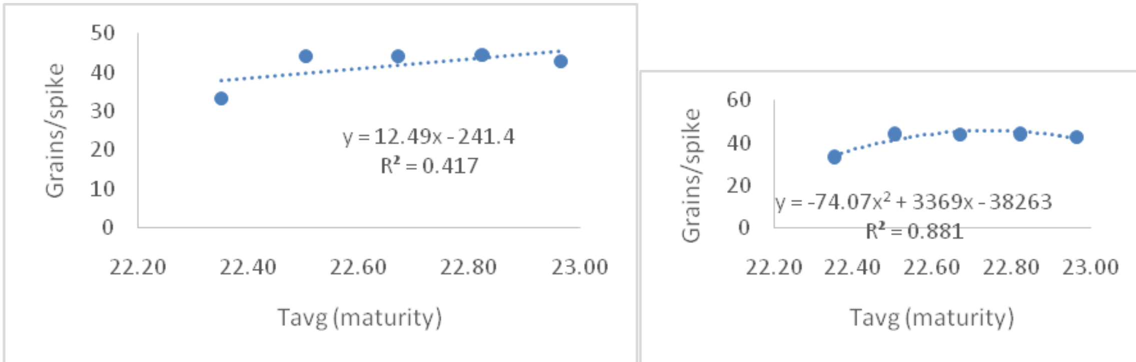


Fig. 4.4.28.Regression analysis between grain/spike at average of daily maximum and minimum temperature from anthesis to maturity at Rajshahi

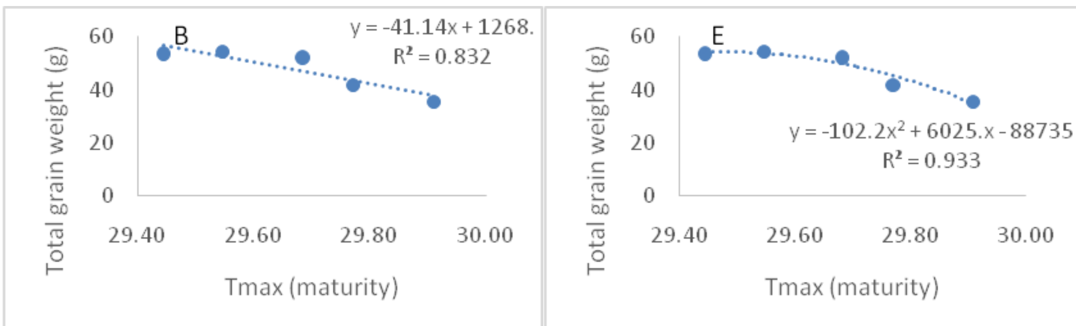


Fig.4.4.29 Regression analysis between grain weight/plant at average of daily maximum temperature from anthesis to maturity at Rajshahi

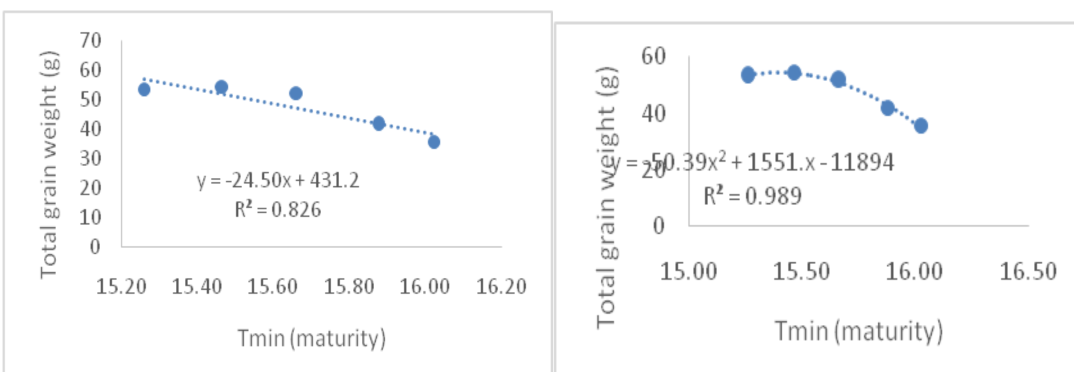


Fig. 4.4.30 Regression analysis between grain weight/plant at averages of daily minimum temperature from anthesis to maturity at Rajshahi

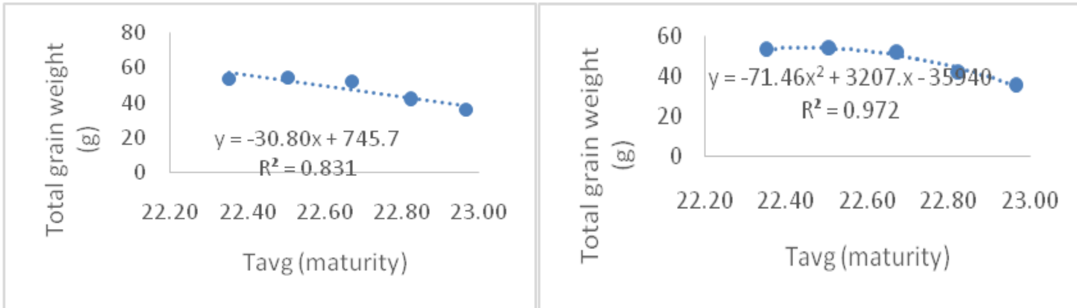


Fig. 4.4.31 Regression analysis between grain weight/plant at averages of daily maximum and minimum temperature from anthesis to maturity at Rajshahi

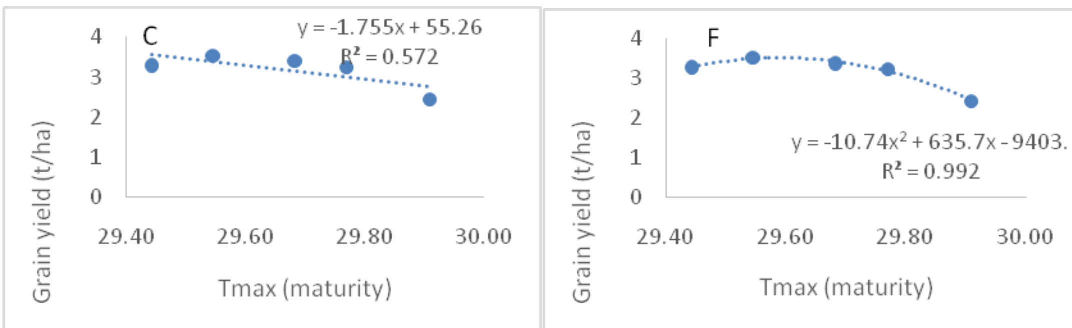


Fig.4.4.32 Regression analysis between grain yield/ha at average of daily maximum temperature from anthesis to maturity at Rajshahi

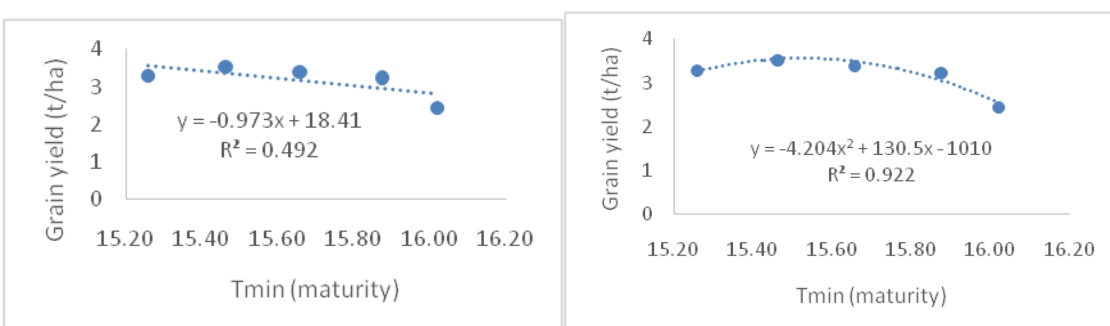


Fig. 4.4.33 Regression analysis between grain yield/ha at average of daily minimum temperature from anthesis to maturity at Rajshahi

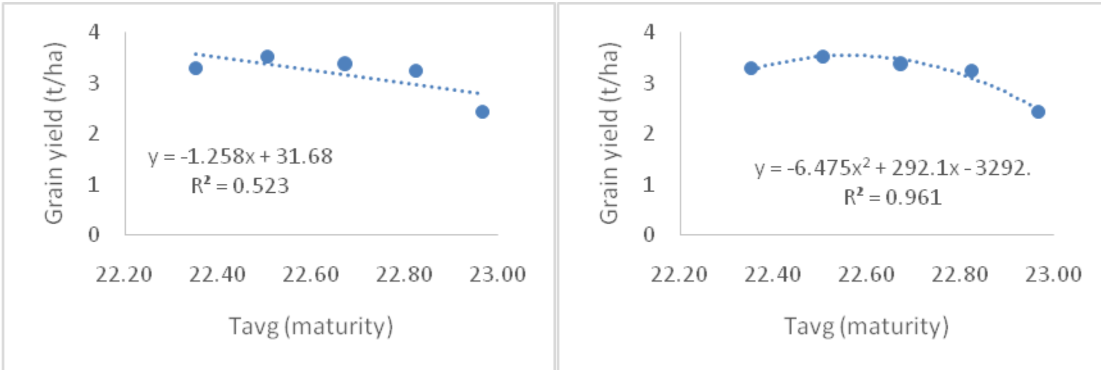


Fig. 4.4.34 Regression analysis between grain yield/ha at average of daily maximum and minimum temperature from anthesis to maturity at Rajshahi

Expt. 5: Growth, yield attributes and yields of wheat as influenced by sowing dates and varieties in central Bangladesh

4.5.1 Vegetative parameters

4.5.1.1 Number of tillers plant^{-1}

Effect of sowing dates

Sowing dates showed statistically significant in terms of number of tillers plant^{-1} at different stage shown in (Fig. 4.5.1). Tillers plant^{-1}increased up to anthesis stage then decrease. Maximum number of tillers plant^{-1} (1.56, 2.65, 3.02, 3.16 and 1.56, respectively) was found from S_4 which was statistically similar (1.44, 2.45, 288, 3.14 and 1.44, respectively) to S_5 and closely followed (1.38, 2.29, 2.68, 2.91 and 1.08 respectively) by S_2, while minimum tillers plant^{-1}(1.34, 1.74, 1.84, 2.24 and 1.34, respectively) was recorded from S_1 at different growth stage. Seeds sowing at 20 December ensured the maximum tiller than early and delay sowing. BARI (1984) reported that 10 and 20 December sowing produced the highest number of tillers plant^{-1}.

Table 4.5.1.Effect of sowing date on number of tiller/plant at different stage

Sowing Days	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
S1	1.34	1.74	1.84	2.24	1.34
S2	1.38	2.29	2.68	2.91	1.08
S_3	1.31	1.76	1.89	2.74	1.31
S_4	1.56	2.65	3.02	3.16	1.56
S_5	1.44	2.45	2.88	3.14	1.44
LSD(0.05)	**0.305**	**0.417**	**0.443**	**0.466**	**0.425**
% CV	**5.35**	**7.84**	**3.45**	**6.38**	**8.15**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties

Number of tillers plant^{-1} at different stage varied significantly due to different wheat varieties under the present trial (Fig. 4.5.2). Tillers plant^{-1}increased up to anthesis stage then decreased. Data revealed that at booting, heading, anthesis and physiological maturity, maximum number of tillers plant^{-1} (2.62, 2.89, 3.12 and 2.51, respectively) was recorded from V_6 which was statistically similar (2.55, 2.82, 3.07 and 2.49, respectively) to whereas minimum number of tillers plan served from V_3. Although management (2.31, 2.57, 2.73 and 2.42, respectively) was practices influenced the number of tillers at different days after sowing but genotypes itself contributed to the number of tillers plant^{-1}.

Table 4.5.2. Effect of variety on number of tiller/plant at different stage of wheat

Variety	Tillering	Booting	Heading	Anthesis	Physiological maturity
V_1	1.43	2.17	2.74	2.8	2.49
V_2	1.39	2.39	2.64	2.83	2.43
V_3	1.37	2.31	2.57	2.73	2.42
V_4	1.56	2.55	2.82	3.07	2.49
V_5	1.57	2.5	2.59	2.81	2.4
V_6	1.6	2.62	2.89	3.12	2.51
LSD (0.05)	**0.339**	**0.462**	**0.492**	**0.53**	**0.474**
% CV	**5.54**	**3.63**	**7.53**	**8.42**	**6.52**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30

Interaction effect of sowing dates and varieties

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates on number of tillers plant^{-1} at different growth stage (Table 4.5.3). Tillers plant^{-1}increased up to anthesis stage then decreased. At booting, heading, anthesis and physiological maturity stage, maximum number of tillers hill^{-1} (3.03, 3.27, 3.57 and 3.35 respectively) was found from V_6S_5 followed by (3.07,3.20,3.50 and 3.30 respectively) was found from V_4S_5 whereas minimum number of tillers plant $^{-1}$ (1.60, 1.77, 1.1.93 and 1.50 respectively) was recorded from the treatment combination V_5S_1.

Table 4.5.3.Interaction effect of sowing date and variety on number of tiller/plant

Sowing date	Variety	Tillering	Booting	Heading	Anthesis	Physiological maturity
S1	V1	1.73	1.93	1.93	1.97	2.03
	V2	1.27	1.97	2.07	2.73	2.07
	V3	1.6	2.27	2.27	2.43	2.7
	V_4	1.03	1.5	1.5	2.03	1.93
	V5	1.5	1.6	1.77	1.93	1.5
	V_6	1.43	1.27	1.6	2.47	1.5
S_2	V_1	1.07	2.5	2.7	2.8	2.6
	V_2	1.03	2.3	2.87	2.73	2.07
	V_3	1.07	2.03	2.5	2.17	1.7
	V_4	1.17	2.7	3.37	2.83	2.03
	V_5	0.93	2.03	2.03	2.17	1.83
	V6	1.2	2.17	2.6	2.67	2.3
S_3	V_1	0.93	1.4	1.53	1.5	1.17
	V_2	0.73	1.17	1.4	1.27	0.93
	V3	1.27	2.07	2.17	2.3	2.3
	V4	1.53	1.83	1.83	1.5	1.27
	V_5	1.97	2.27	2.37	1.93	2.17
	V_6	1.4	1.83	2.27	2.57	1.63
S_4	V_1	1.5	2.27	3.27	3.4	3.27
	V_2	1.5	3.07	3.4	3.83	3.5
	V_3	1.17	1.73	2.4	2.63	2.4
	V_4	1.73	2.97	3.5	3.5	3.4
	V_5	2.17	3.27	3.07	2.93	2.93
	V_6	1.3	2.6	2.5	2.63	2.5
S_5	V_1	1.4	2.27	2.27	2.37	2.37
	V_2	1.5	2.97	2.97	3.07	3.07
	V_3	1.27	2.93	3.03	3.6	3.2
	V_4	1.73	3.07	3.2	3.5	3.3
	V_5	1.5	2.93	2.93	3.07	3.07
	V_6	1.77	3.03	3.27	3.57	3.35
LSD (0.05)		**0.763**	**1.017**	**1.012**	**1.145**	**1.032**
CV (%)		**3.35**	**5.45**	**4.46**	**7.34**	**6.36**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30; S_1= Nov 20 S_2= Nov 30 S $_3$= Dec 10 S_4= Dec 20 S_5= Dec 30

4.5.1.2 Plant height

Effect of sowing dates

Plant height showed statistically significant differences due to different sowing dates Table 4.5.4). The highest plant height was recorded from S_3 (87.06 cm) which was statistically similar to S_2 (85.31 cm) and closely followed by S_4 (84.58 cm), while the lowest plant height was (73.51 cm) found from S_1.

Table 4.5.4.Effect of sowing date on plant height

Sowing Days	Plant height (cm)
S_1	73.51
S_2	85.31
S_3	87.06
S_4	84.58
S_5	80.97
LSD (0.05)	**2.214**
% CV	**10.15**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties

Plant height showed statistically significant differences on different wheat varieties Table 4.5.5). The highest plant height was recorded from V_1 (85.13 cm) which was statistically similar to V_5 (83.83 cm) and closely related by V_2(82.18 cm), while the lowest plant height was (80.17 cm) found from V_6.

Table 4.5.5.Effect of variety on plant height

Variety	Plant height(cm)
V1	85.13
V2	82.18
V3	81.48
V4	80.92
V5	83.83
V6	80.17
LSD (0.05)	**2.430**
% CV	**10.54**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30

Interaction effect of sowing date and varieties

Plant height showed statistically significant differences due to interaction effect of sowing dates and different wheat varieties (Table 4.21). The highest plant height was recorded from S_3V_1 (90.93 cm) which was statistically similar to S_3V_5 (90.50 cm) and closely related by S_2V_2 (87.73 cm), while the lowest plant height was (67.0 cm) found from S_1V_6.

Table 4.5.6. Interaction effect of sowing date and varieties on plant height

Sowing days	Variety	Plant height(cm)
S_1	V_1	82.73
	V_2	75.07
	V_3	69.07
	V_4	73.63
	V_5	79.17
	V6	67.4
S2	V1	87.17
	V_2	87.73
	V_3	87.6
	V_4	83.27
	V_5	87.6
	V_6	84.5
S_3	V_1	90.93
	V2	86.3
	V_3	87.6
	V_4	85.17
	V_5	90.5
	V_6	85.83
S_4	V_1	87.5
	V_2	85.07
	V_3	85.4
	V_4	85.6
	V_5	84.97
	V_6	84.93
S_5	V_1	82.3
	V_2	81.73
	V_3	82.73
	V_4	81.93
	V_5	81.93
	V_6	81.17
	LSD (0.05)	5.427
	% CV	11.15

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30; S_1= Nov 20 S_2= Nov 30 S $_3$= Dec 10 S_4= Dec 20 S_5= Dec 30

4.5.1.3 Reproductive parameters

Number of spikes m^{-2}

Effect of sowing dates

Number of spikes m^{-2} showed statistically significant differences due to different sowing dates (Table 4.4.5). The highest number of spikes $m^{-2}$was recorded from S_4 (247.28) which was statistically similar to S_3 (245.33) and closely followed by S_2 (232.06), while the lowest number of spikes plant^{-1} was found from S_5 (198.72).

Effect of varieties

Number of spikes m^{-2}showed statistically significant differences on different wheat varieties Table 4.5.6). The highest number of spikes $m^{-2}$was recorded from V_4 (246.43) which was statistically similar to V_6 (243.83), while the lowest number of spikes $m^{-2}$was found from V_5 (202.50).

Interaction effect of sowing dates and varieties

Number of spikes m^{-2}showed statistically significant differences due to the interaction effect of wheat varieties and sowing dates (Table 4.5.7). The highest number of spikes $m^{-2}$was recorded from S_2V_6 (261.17) which was statistically similar to S_2V_4 (252.17) and closely followed by S_3V_6(251.50), while the lowest number of spikes $m^{-2}$was found from S_5V_5 (180.17).

Number of spikelet spike^{-1}

Effect of sowing dates

Different sowing dates showed statistically significant differences in number of spikelet spike^{-1} (Table 4.4.5). The highest number of spikelet spike^{-1} was observed from S_2 (15.31) which was statistically similar to S_3 (14.86), while the lowest number of spikelet spike^{-1}was found from S_5(13.36).

Effect of varieties

Statistically significant variation was recorded in terms of different wheat varieties in terms of number of spikelet spike^{-1} (Table 4.5.6). Data revealed that the highest number of spikes spike^{-1}was observed from V_6 (15.47) which was statistically similar to V_4 (15.27) and followed y V_2(15.03), while the lowest number of spikes spike^{-1}was found from V_5 (13.69).

Interaction effect of sowing dates and varieties

Number of spikelet spike^{-1} varied significantly due to the interaction effect of wheat varieties and sowing dates under the present trial (Table 4.5.7). Data revealed that the highest number of spikelet spike^{-1} was observed from V_2S_3(16.37), whereas the lowest number of spikelet spike^{-1} was obtained from the treatment combination V_5S_1 (11.93).

Total grains spike^{-1}

Effect of sowing dates

Number of grains per spike is important yield attribute which determine the yield potential of crop. More the number of grains per ear more will be the yield. Total grains spike^{-1} showed statistically significant differences due to different sowing dates (Table 4.5.5). Maximum grains spike^{-1} was recorded from S_2 (42.53) which was statistically similar to S_3 (42.51) and followed by S_1 (40.79), again minimum grains spike^{-1} was observed from S_5 (36.25). Chowdhury (2002) conducted an experiment with four sowing dates and reported that grains spike^{-1} decreased with delay sowing date from November 15 and the lowest grains spike^{-1} were recorded in December 15 sown plants.

Effect of varieties

Number of grains per spike is important yield attribute which determine the yield potential of

crop. More the number of grains per ear more will be the yield. Total grains spike^{-1} varied significantly due to different wheat varieties under the present trial (Table 4.5.6). Data revealed that the highest total grains spike^{-1} was observed from V_6 (44.5) which was statistically similar to V_4 and V_2 (43.37 and 42.98, respectively), whereas the lowest total grains spike^{-1} was found from V_1 (37.05).

Interaction effect of sowing dates and varieties

Statistically significant variation was recorded due to the interaction effect of wheat varieties and sowing dates in terms of total grains spike^{-1} (Table 4.5.7). The highest total grains spike^{-1} was found from V_6S_2 (48.73), while the lowest total grains spike^{-1} was recorded from the treatment combination V_6S_1 (24.50).

1000-grains weight

Effect of sowing dates

1000-grains weight showed statistically significant differences due to different sowing dates (Table4.5.5). The highest 1000-grains weight (52.82 g) was found from S_2 which was statistically similar (50.69 g and 50.10 g) from S_3& S_1, while the lowest 1000-grains weight (34.31 g) was observed from S_5.

Table 4.5.5. Effect of sowing date on yield contributing characters

Sowing Days	Spike/m2	Spikelet/spike	Grains/spike	TGW (g)
S_1	225.5	14.59	40.79	50.10
S_2	232.06	15.31	42.53	52.82
S_3	245.33	14.86	42.51	50.69
S_4	247.28	14.07	42.82	40.47
S_5	198.72	13.36	36.25	34.31
LSD (0.05)	**15.073**	**0.634**	**3.026**	**2.758**
% CV	**10.34**	**8.15**	**5.26**	**9.36**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of varieties

The 1000-grain weight is most important yield attribute, which determines the yield contribution of individual grain as well as quality appearance of grain. More the 1000-grain weight, more grain looks bolder in appearance. 1000-grain weight determines the ability of the plant to translocate the photo assimilates to sink. Different wheat varieties showed statistically significant difference on 1000-grains weight (Table 4.5.6). The highest 1000-grains weight (47.98 g) was recorded from V_6 which was statistically similar (46.01 g) to V_5, whereas the lowest 1000-grains weight (39.9 g) was found from V_3 which was statistically similar (40.69 g) to V_2.

Table 4.5.6. Effect of variety on yield contributing characters of wheat

Variety	Spike/m^2	Spikelet/spike	Grains/spike	TGW (g)
V_1	223.03	14.47	37.05	43.47
V_2	222.23	15.03	42.98	40.69
V_3	232.43	14.43	42.39	39.9
V_4	246.63	15.27	43.37	45.73
V_5	202.5	13.69	41.13	46.01
V_6	243.83	15.47	44.5	47.98
LSD (0.05)	**16.530**	**0.704**	**3.321**	**2.062**
% CV	**12.40**	**5.52**	**7.54**	**6.82**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30

Interaction effect of sowing dates and varieties

Interaction effect of wheat varieties and sowing dates showed significant differences on weight of 1000-grains. The highest weight of 1000-grains (56.33 g) was found from V_6S_2, while the lowest weight of 1000-grains (31.70 g) was obtained from the treatment combination of V_3S_5.

Table.4.5.8. Interaction effect of sowing date and variety on yield contributing characters

Sowing days	Variety	Spike/m2	Spikelet/spike	Grains/spike	TGW (g)
S_1	V_1	231.5	15.83	38.07	50.85
	V2	231.83	12.3	33.83	52.42
	V_3	248.83	12.37	35.7	47.75
	V4	249.17	12.17	33.6	53.4
	V_5	216.83	11.93	31.07	50.83
	V_6	240.83	10.93	24.5	53.37
S_2	V_1	227.17	15.17	33.17	51.35
	V_2	230.83	16.07	46.5	51.97
	V_3	246.17	15.73	44.07	48.57
	V_4	252.17	15.5	43.97	53.98
	V_5	200.83	15.07	41.73	52.18
	V_6	261.17	15.90	48.73	56.33
S_3	V_1	231.83	16.5	38.63	42.9
	V2	217.5	16.37	51.83	38.78
	V3	244.17	15.27	44.4	38.82
	V_4	242.83	15.7	45.27	45.37
	V_5	196.17	15.93	38.07	46.63
	V_6	251.50	15.4	46.83	47.65
S_4	V_1	235.17	18.27	39.63	41.2
	V_2	222.5	18.27	49.7	39.82
	V_3	274.83	17.17	48.93	40.67
	V4	270.17	15.83	43.07	40.37
	V_5	223.5	15.5	40.3	44.98
	V_6	263.5	16.17	44.27	41.78
S_5	V_1	194.5	16.6	40.73	36.03
	V_2	213.5	17.17	48.03	35.47
	V_3	223.17	16.63	43.83	31.7
	V_4	193.83	17.17	45.93	33.53
	V_5	180.17	15.03	44.5	36.4
	V_6	193.17	15.53	35.17	38.75
LSD (0.05)		**36.475**	**1.475**	**7.335**	**3.752**
% CV		**12.15**	**9.72**	**10.32**	**8.75**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30; S_1= Nov 20 S_2= Nov 30 S $_3$= Dec 10 S_4= Dec 20 S_5= Dec 30

Grain yield

Effect of sowing date

Grain yield is the function of effective tillers, spikem^{-2} number of grains per spike and 1000-grain weight. Data on grain yield have been presented in Table 4.5.9. Sowing date significantly affected the grain yield of wheat. Crop sown on November 30 recorded the highest grain yield which was statistically at par with November 20 sowing. Different sowing dates showed statistically significant differences on grain yield(Table 4.5.9). The highest grain yield (3.02 t ha^{-1}) was recorded from S_2 that mean November 30 sowing which was statistically similar (2.99 t ha^{-1}) to S_3 and closely followed (2.79 t ha^{-1}) by S_1. The lowest grain yield (1.94 t ha^{-1}) was observed from S_5 that mean December 30.

Table 4.5.9. Effect of sowing date on grain and biomass yield

Sowing Days	Grain yield(t/ha)	Biomass(t/ha)	Harvest index (%)
S_1	2.79	13.67	20.41
S_2	3.02	11.4	26.49
S_3	2.89	9.8	29.49
S_4	2.74	10.28	26.05
S_5	1.94	8.14	23.83
LSD (0.05)	**0.121**	**1.387**	**3.452**
% CV	**5.52**	**9.83**	**10.52**

S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30

Effect of variety

Statistically significant variation was observed for different wheat varieties in terms of grain yield (Table 4.5.10). The highest grain yield was found from V_6 (3.31 t ha^{-1}) BARI Gom 30 which was statistically similar to V_4 (3.22 t ha^{-1}) BARI Gom 28 due to its heat tolerant, blast disease registrant and yield potentiality and whereas the lowest grain yield was found from V_2 (2.47 t ha^{-1}) BARI Gom 26 due to blast susceptible characters.

Interaction effect of sowing dates and variety

Grain yield affected by interaction effect of sowing time and variety

Interaction effect of wheat varieties and sowing dates showed significant differences on grain yield (Table 4.5.11). The highest grain yield (3.44 t ha^{-1}) was observed from V_6S_2 that mean November 30 sowing with BARI Gom 30 variety followed (3.35 t ha^{-1}) by V_4S_2 from BARI Gom 28 with December 10 sowing and statistically similar results (3.31 t ha^{-1}) was also found from V_4S_3 that mean December 10 sowing with BARI Gom28 variety and V_6S_3 BARI Gom 30 variety with December 10. While the lowest grain yield (1.70 t ha^{-1}) was obtained from the treatment combination V_3S_5 that mean December 30 sowing with BARI Gom 27 variety followed (1.78 t ha^{-1}) by V_5S_5 that mean December 30 sowing with BARI Gom 29 variety. Higher grain yield under November 30 sowing was attributed to higher yield contributing characters, chlorophyll content, lower canopy temperature), number of grains per spike and 1000-grain weight.

4.5.1.4 Biological yield

Effect of sowing dates

Biological yield is the total biomass produced by the plant during its life cycle. Different sowing dates showed statistically significant differences in terms of biological yield (Table 4.5.9). The highest biological yield (13.67 t ha^{-1}) was found from S_1 which was closely followed (11.00 t ha^{-1}) by S_2. Higher biomass was due to high plant height, tiller density and dry matter. Early sowing recorded higher biomass production as compared to late sowing, as reported by Khan *et al.* (2015) in Dera Ismail Khan (Pakistan). Varieties differ significantly with respect to biological yield. Again the lowest biological yield (8.14 t ha^{-1}) was recorded from S_5 which was closely followed (10.28 t ha^{-1}) by S_4.

Effect of varieties

Biological yield showed statistically significant difference due to different wheat varieties (Table 4.5.10). Data revealed that the highest biological yield (10.99 t ha^{-1}) was observed from V_3 which was statistically similar (10.83 t ha^{-1}) to V_6 and followed (10.80 t ha^{-1}) by V_1, while the lowest biological yield (10.08 t ha^{-1}) was obtained from V_2 followed (10.49 t ha^{-1}) by V_5 sowing.

Table 4.5.10. Effect of variety on grain and biomass yield of wheat

Variety	Grain yield (t ha^{-1})	Biomass (tha^{-1})	Harvest Index (%)
V_1	2.91	10.8	26.94
V_2	2.47	10.08	24.50
V_3	2.92	10.99	26.57
V_4	3.22	10.74	29.98
V_5	2.73	10.49	26.02
V_6	3.31	10.83	30.56
LSD (0.05)	**0.351**	**1.083**	**3.547**
% CV	**5.53**	**8.76**	**10.87**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30

Interaction effect of sowing dates and varieties

Interaction effect of wheat varieties and sowing dates showed significant differences on biological yield (Table 4.5.11). The highest biological yield (14.65 t ha^{-1}) was found from V_2S_1 and statistically similar biological yield (13.73 t ha^{-1}) was found from V_1S_1 followed (13.56 t ha^{-1}) by V_3S_1 and the lowest biological yield (7.44 t ha^{-1}) was obtained from the treatment combination V_3S_5 followed (7.48 t ha^{-1}) by V_5S_5 .

4.5.1.5 Harvest index (HI)

Effect of sowing dates

Harvest index is an important parameter indicating the efficiency in partitioning of dry matter to economic part of the crop. Harvest index showed statistically significant differences due to different sowing dates (Table 4.5.9). The highest harvest index (29.49) was observed from S_3 which was closely followed (26.49) by S_2, whereas the lowest harvest index (20.41) was found from S_1 which was statistically similar (23.83) to S_5.

Effect of varieties

Different wheat varieties showed statistically significant difference on harvest index (Table 4.5.10). The highest harvest index (30.56%) was found from V_6 that mean BARI Gom 30 variety followed (29.98%) from BARI Gom 28 and the lowest harvest index (24.50%) was recorded from V_2 that mean BARI Gom 26.

Interaction effect of sowing dates and varieties

Interaction effect of wheat varieties and sowing dates showed significant differences on harvest index (Table 4.5.11). The highest harvest index (33.40%) was observed from V_4S_3 which was statistically similar (31.55) from V_6S_3 while the lowest harvest index (23.22%) was obtained from the treatment combination V_3S_5 followed (23.21.0%) by V_1S_5.

Table 4.5.11. Interaction effect of sowing date and variety on grain and biomass yield

Sowing days	Variety	Grain yield (t/ha)	Biomass (t/ha)	Harvest index (%)
S_1	V_1	3.06	13.73	22.29
	V2	2.57	14.65	17.54
	V_3	3.08	13.56	22.71
	V4	3.04	11.94	25.46
	V_5	3.20	13.06	25.27
	V6	2.71	12.05	22.49
S_2	V_1	3.2	11.84	27.03
	V_2	3.09	10.42	29.65
	V_3	3.15	13.02	24.19
	V_4	3.35	11.57	28.95
	V_5	2.87	11.23	25.56
	V_6	3.44	11.29	30.47
S_3	V_1	2.9	10.89	26.63
	V_2	2.32	8.22	28.22
	V3	3.08	10.16	30.31
	V_4	3.31	9.91	33.40
	V_5	2.92	10.09	28.94
	V_6	3.25	10.3	31.55
S_4	V_1	2.56	10.67	23.99
	V_2	2.69	9.22	29.18
	V_3	2.64	9.78	26.99
	V_4	2.95	10.95	26.94
	V5	2.79	10.6	26.32
	V6	2.93	10.45	28.04
S_5	V_1	1.82	7.84	23.21
	V2	2.00	7.88	25.38
	V_3	1.70	7.44	23.22
	V_4	2.04	8.74	23.34
	V5	1.78	7.48	23.80
	V_6	2.15	8.23	26.12
LSD (0.05)		**0.235**	**1.015**	**3.215**
CV%		**5.45**	**8.68**	**10.72**

V_1= BARI Gom 25, V_2= BARI Gom 26, V_3= BARI Gom 27, V_4= BARI Gom 28, V_5= BARI Gom 29 and V6= BARI Gom 30; S_1= Nov 20 S_2= Nov 30 S $_3$= Dec 10 S_4= Dec 20 S_5= Dec 30

4.5.1. The ambient temperature

From sowing to anthesis (vegetative stage)

Maximum temperature

At SAU the average maximum temperature from sowing to anthesis ranged from 29.44 to 29.91^{0}C, while from anthesis to maturity (reproductive stage) from 31.88-32.91^{0}C. That is the maximum temperature was higher at the reproductive stage of plants (Appendix III). In both the sites the maximum temperature was higher at the reproductive stage (29.44 to 29.91^{0}C at Rajshahi and 31.88-32.91^{0}C) than that of the vegetative stage (24.85-26.97 ^{0}C at Rajshahi and 27.98-30.21 ^{0}C at SAU). Fig. 4.5.1

Minimum temperature

At SAU the average minimum temperature from sowing to anthesis ranged from 14.75-16.21 ^{0}C, while from anthesis to maturity from 17.47-19.02 ^{0}C. That is the minimum temperature was higher at the reproductive stage of plants. In both the sites the minimum temperature was higher at the reproductive stage (12.96-13.05 C at Rajshahi and 14.75-16.21^{0}C) than that of the vegetative stage (15.26-16.02 ^{0}C at Rajshahi and 17.47-19.02 ^{0}C at SAU). Fig. 4.5.1

Average temperature

At SAU the average of the daily average temperature from sowing to anthesis ranged from 20.76-23.12 ^{0}C, while from anthesis to maturity from 24.67-25.96 ^{0}C. That is the average of the daily average temperature was higher at the reproductive stage of plants. In both the sites the average of the daily average temperature was higher at the reproductive stage (22.35-22.96 ^{0}C at Rajshahi and 24.67-25.96 ^{0}C) than that of the vegetative stage (19.86-19.92 ^{0}C at Rajshahi and 20.76-23.12 ^{0}C at SAU).

From anthesis to maturity

Maximum temperature

While at SAU from anthesis to maturity, like at Rajshahi the Dec 30 sowing enjoyed the highest average maximum temperature (30.21 ^{0}C, the Nov 20 sowings, higher minimum temperature (above 16.21^{0}C) than others (below 16 ^{0}C) and the higher average of the average temperature from sowing to anthesis was maximum with Dec 30 sowing (23.12 ^{0}C), but in comparison to Rajshahi there was a remarkable difference between the lowest average temperature (20.76 ^{0}C) of Dec 30 sowing and others (above 22^{0}C. Minimum temperature While at SAU from anthesis to maturity, like at Rajshahi the Dec 30 sowing enjoyed the highest average minimum temperature (32.91^{0}C. But unlike at Rajshahi the Dec 30 sowings had highest minimum temperature (19.02 ^{0}C^{0}C) than others (below 17.47-18.44 ^{0}C).

Average temperature

Like at Rajshahi the higher average of the average temperature from anthesis to maturity was maximum with Dec 30 sowing (25.96 ^{0}C), but in comparison to Rajshahi there was a remarkable difference between the lowest average temperature (24.67 ^{0}C) of Nov 20 sowing and Dec 30 (above 25.96 ^{0}C).Fig. 4.5.1

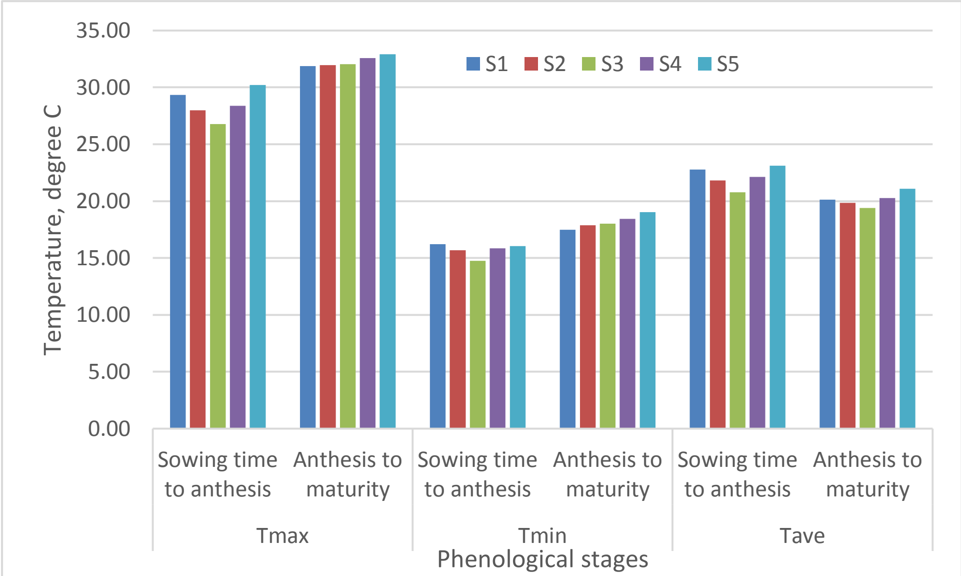


Fig.4.5.1 Averages of daily maximum, minimum and averages temperature from sowing to anthesis and anthesis to maturity at SAU during rabi 2016-17 (S_1= Nov 20 S_2= Nov 30 S_3= Dec 10 S_4= Dec 20 S_5= Dec 30).

4.5.1.7 Relationships of yield and yield attributes with the ambient temperature:

Regression analysis

5.4.1 Effect of temperature averaged over sowing to anthesis

Effect of temperature on number of grains/spike

Maximum temperature

The number of grains/spike was remarkably and reluctantly dependent on ambient maximum temperature. In the linear regression curve the slope had a negative value (-1.556), that means that as the maximum temperature of the day across from sowing to anthesis increases the number of grains per spike decreases (Fig.4.5.2). But in the polygonal curve the curve is curvilinear although showing a positive relationship (slope 569.42) at the lower temperature up to about 31^0C and thereafter the yield decreases. This negative relationship was very strong (R2=0.221 at polygonal polygonal regression curve) showing maximum value between 27^0C.

Minimum temperature

The interaction of the number of grains/spike with the minimum temperature of the days from sowing to anthesis shows that the relationship of the grain number was a negative one (slope was negative of –4.48) (Fig 4.5.3).That is the prevailing temperature above 15^0C caused decrease in grain yield. However the within the prevailing range of minimum temperature (15-16 ^{0}C), the highest grain number was obtained at $15\text{-}15.5^0$C and the overall relationship was very strong (R^2=0.819).

Average temperature

Similar relations was also obtained with number of grains and the average temperature of the days from sowing to anthesis. In general, as the average temperature increased the grain number decreased (slope value -2.464) (Fig. 4.5.4). But the polygonal regression showed that at lower values of the average temperature ($17.5\text{-}18^0$C) the grain number increased (slope 21.766), while the grain number decreased when the average temperature was further increased (slope -0.552 multiplied by x^2). The coefficient of determinations was very weak (R2=0.234).

1000 grain weight, g

Maximum temperature

1000 grain weight had also weak negative relationship the maximum temperature from sowing to anthesis both at linear and polygonal analysis having R^2 value 0.360 and 0.455 respectively, the highest value occurred at 32 ^{0}C. Fig 4.5.5.

Minimum temperature

Similar situation was observed in case of 1000 grain weight with the minimum temperature of the days from sowing to anthesis (Fig. 4.5.6). The 1000 grain weight decreased (slope -4.76) with the increase of even the minimum temperature. Both the linear and the polynomial curve shows that the relationship was weak showing R^2 values were 0.107 and 0.128 respectively.

Average temperature

Likewise the 1000 grain weight responded weakly to the average temperature (Fig. 4.5.7). The 1000 grain weight decreased as the average temperature increased showing a slope -4.8. In both the cases of linear and polygonal regression, the R2 value was 0.283 and 0.358 at linear and polygonal regression respectively.

Yield /ha

Maximum temperature

Strong negative relationship was also observed (slope -0.250) between grain yield/ha with maximum temperature (Fig. 4.5.8). From 26.77 ^{0}C the yield increased at temperature between 27 and 28 and thereafter decreased showing the coefficient of determination value of R2=0.886 on polygonal curve) showing the best temperature of 27-28 at sowing t anthesis of wheat.

Minimum temperature

However, the minimum temperature did not have significant effect on grain yield (t/ha) showing R2 value of 0.157-0.183 (Fig. 4.5.9). Similar phenomenon happened with the average temperature showing R2 values of 0.459-0.781 at linear and polygonal level respectively (Fig. 4.5.10). That is, , the average temperature did not have also great effect on the seed yield although the pattern was the similar as was observed with both the maximum temperature and minimum temperature showing R2 value at linear and polygonal level of 0.459 and 0.781 respectively.

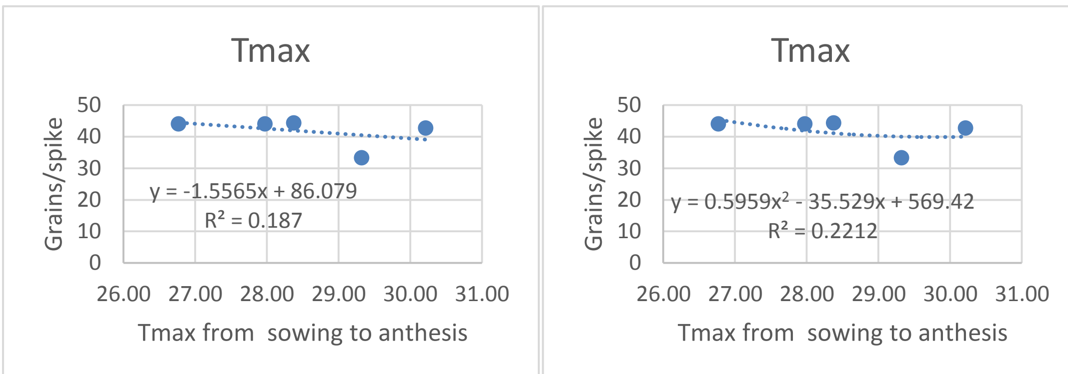


Fig. 4.5.2. Regression analysis between number of grains/spike and maximum temperature from sowing to anthesis of wheat at SAU farm

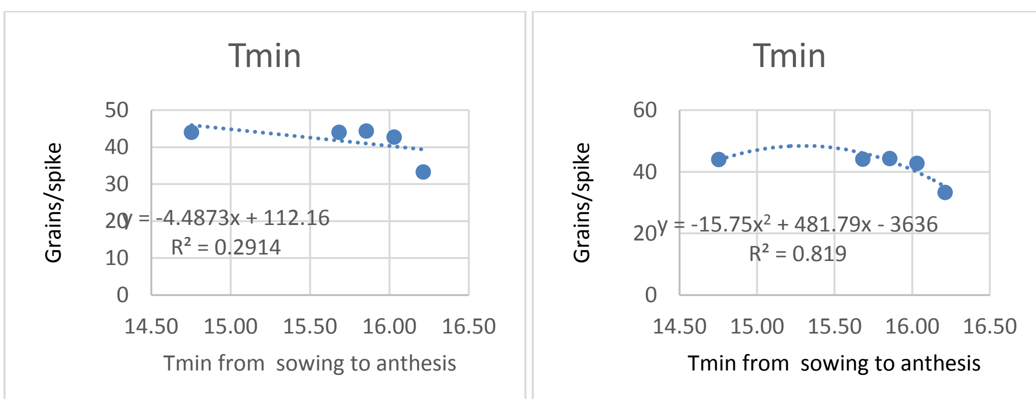


Fig. 4.5.3 Regression analysis between number of grains/spike and minimum temperature from sowing to anthesis of wheat at SAU farm

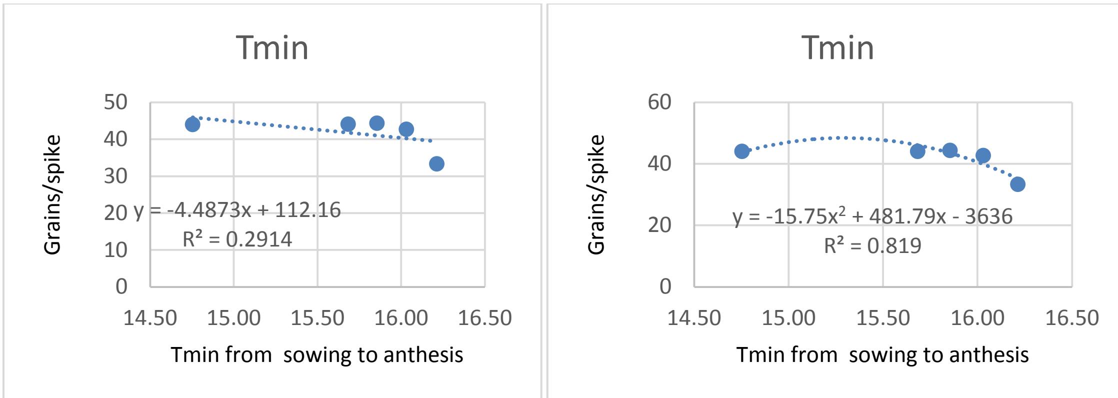


Fig. 4.5.3 Regression analysis between number of grains/spike and minimum temperature from sowing to anthesis of wheat at SAU farm

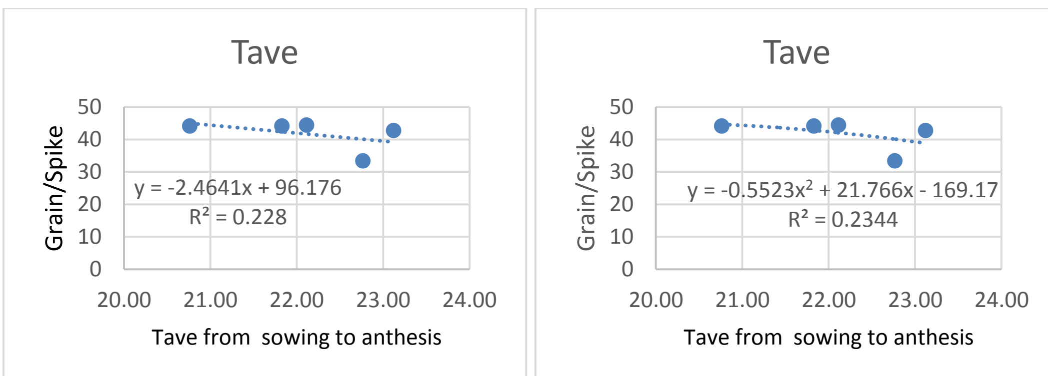


Fig. 4.5.4.Regression analysis between number of grains/spike and average temperature from sowing to anthesis of wheat at SAU farm

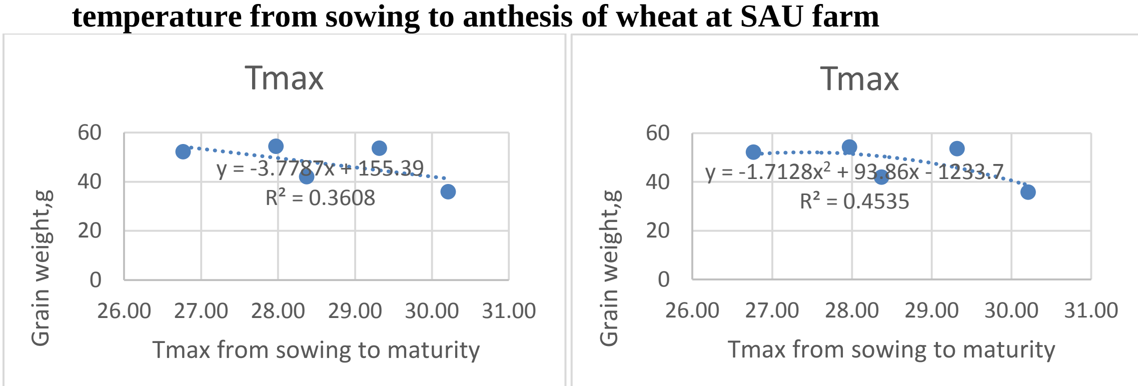


Fig. 4.5.5.Regression analysis between grains weight and maximum temperature from sowing to anthesis of wheat at SAU farm

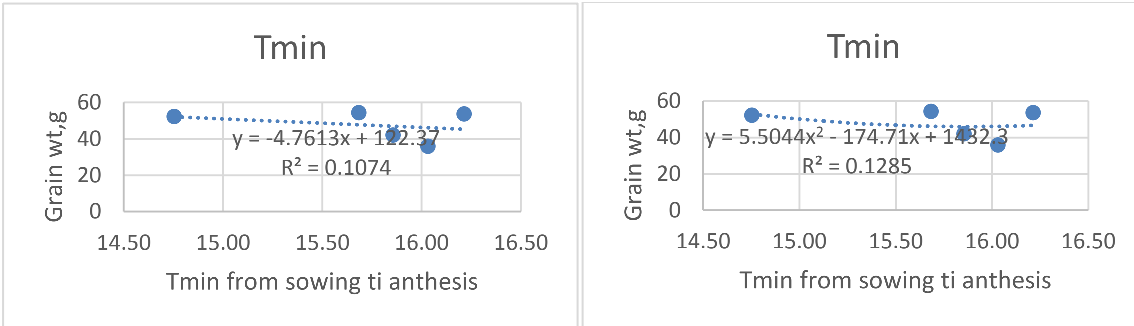


Fig. 4.5.6.Regression analysis between number of grains weight and minimum temperature from sowing to anthesis of wheat at SAU farm

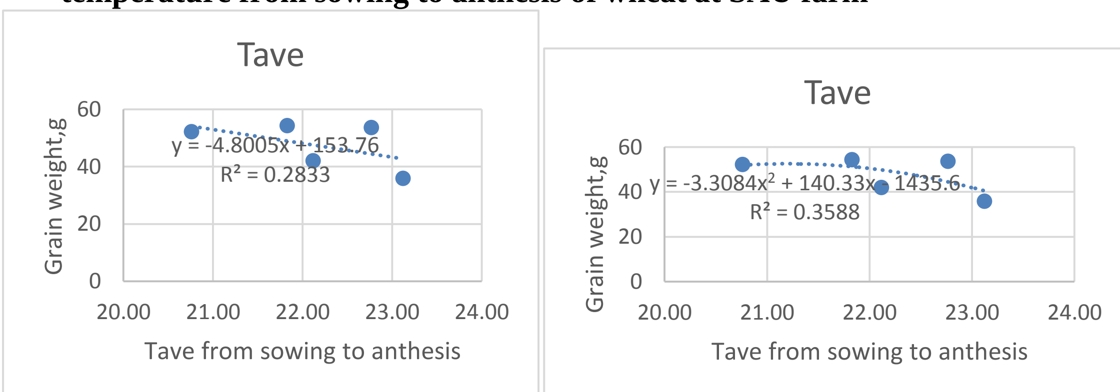


Fig. 4.5.7 Regression analysis between number of grain weight and average temperature from sowing to anthesis of wheat at SAU farm

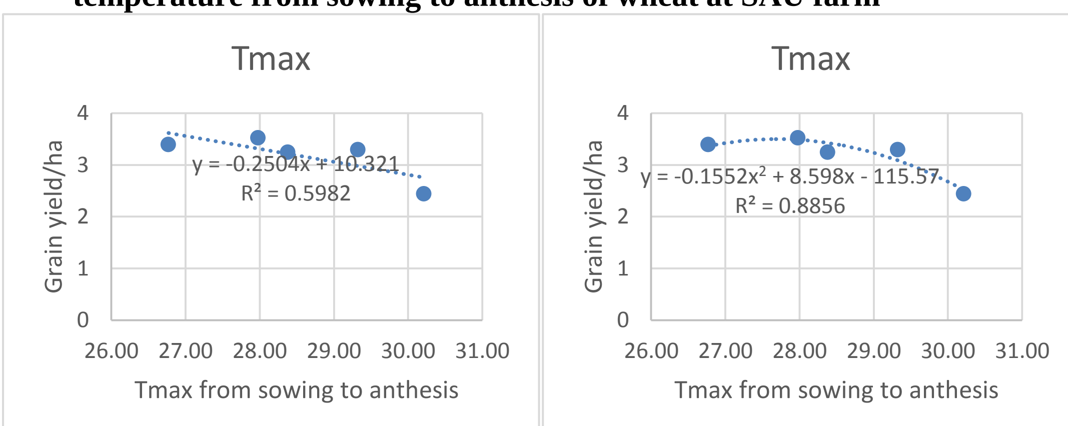


Fig. 4.5.8. Regression analysis between grain yield (t/ha) of wheat and maximum temperature averaged over that crop enjoyed at each sowing from sowing to anthesis at SAU farm

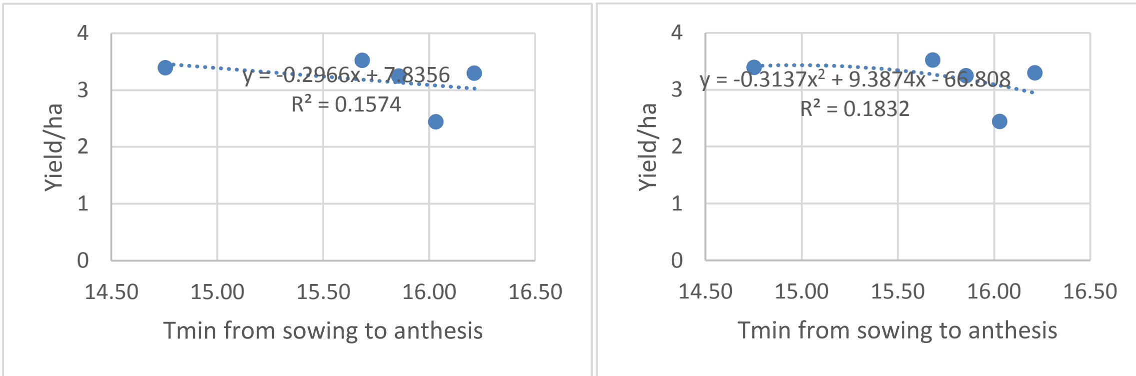


Fig. 4.5.9. Regression analysis between grain yield (t/ha) of wheat and minimum temperature from sowing to anthesis at SAU farm

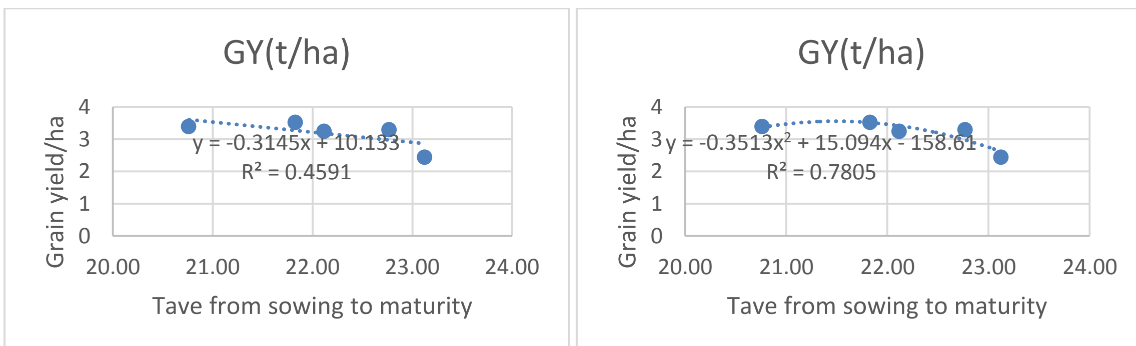


Fig. 4.5.10. Regression analysis between grain yield (t/ha) of wheat and average temperature from sowing to anthesis at SAU farm

4.5.1.8 Effect of temperature averaged over anthesis to maturity

Number of grains / spike

Maximum temperature

Number of grain/spike has little dependence on the maximum ambient temperature of anthesis to maturity although it showed a bit positive relations (slope 4.2778 with R2 value 0.167). Fig. 4.5.11. But it had a bit stronger relations when polygonal regression was fitted showing R2 value of 0.474.

Minimum temperature

Number of grains /spike responded to the ambient minimum temperature (Fig.4.5.12). This parameter was best fitted to the maximum temperature of between 18-19 ^{0}C showing R2 value 0.905 (Fig. 4.5.12).

Average temperature

Number of gr/spike had also positive relationship (slope 4.63, R2=0.257 at linear regression). However in the polygonal regression it showed negative relation with the average temperature (R2=0.791) (Fig. 4.5.13) showing the highest value at near about 25.5 ^{0}C.

1000 grain weight

Maximum temperature

1000 grain weight was strongly but negatively dependent on T max (intercept negative at polygonal regression), that is during anthesis to maturity the 1000 grain weight decreased as the atmospheric maximum temperature increased (R2=0.991 and 0.993 respectively at linear and polygonal regression) (Fig. 4.5.14).

Minimum temperature

Likewise, on minimum temperature showing a better fitting to both linear and polynomial regression although with negative intercept showing R2 values of 0.888 and 0.921 respectively proving that this parameter also decreased with increasing even the minimum temperature of the surrounding atmosphere (Fig. 4.5.15)..

Average temperature

Likewise this parameter also strongly was related to average temperature showing higher R2 values of 0.948 and 0.96 respectively in linear and polynomial regression (Fig. 4.5.16)..

Grain yield

Maximum temperature

The grain yield in general decreases sharply with the increases of maximum temperature from anthesis to maturity (in the linear graph) (Fig. 4.5.17) showing R^2 values of 0.727 and 0.966 at linear and polygonal regression levels respectively.

Minimum temperature

Grain yield was had also a negative relationship (b or slope value in the linear graph is negative) with the minimum temperature. However the relationship is very poor showing R2 value 0.183 (Fig 4.5.18) showing R2 values of 0.989 at polygonal regression.

Average temperature

Grain yield was negatively affected by the average temperature (slope was negative -0.691). However, this relationship was best fit in the polygonal graph showing R^2 value of 0.782, that is the effect of the average temperature was moderate (Fig.4.5.19).

Anthesis to maturity

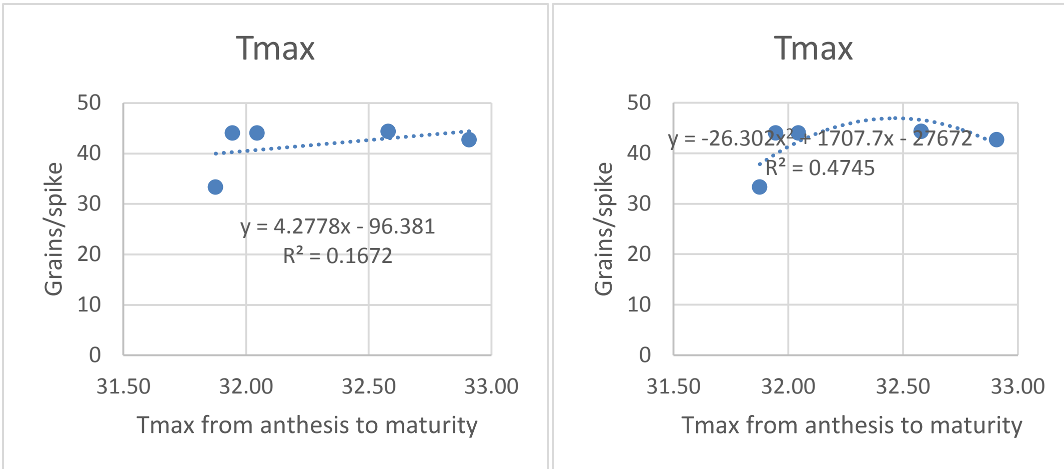


Fig. 4.5.11 Regression analysis between grain /spike of wheat and max temperature from anthesis to maturity at SAU farm

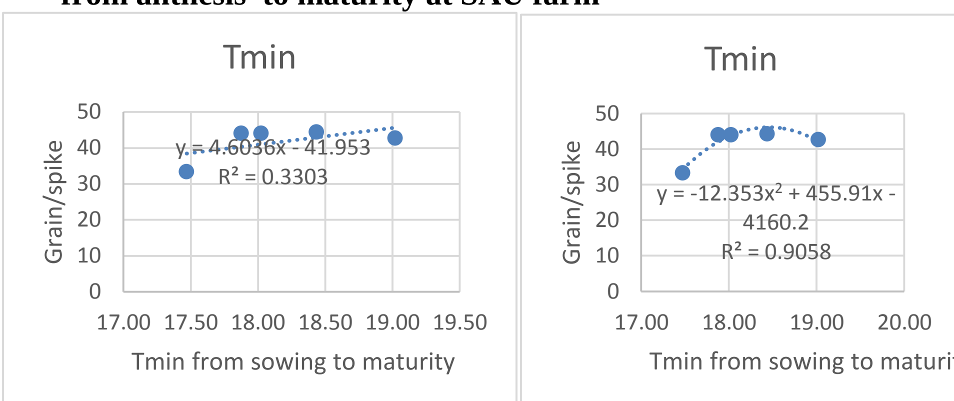


Fig. 4.5.12 Regression analysis between grain yield (t/ha) of wheat and minimum temperature from anthesis to maturity at SAU farm

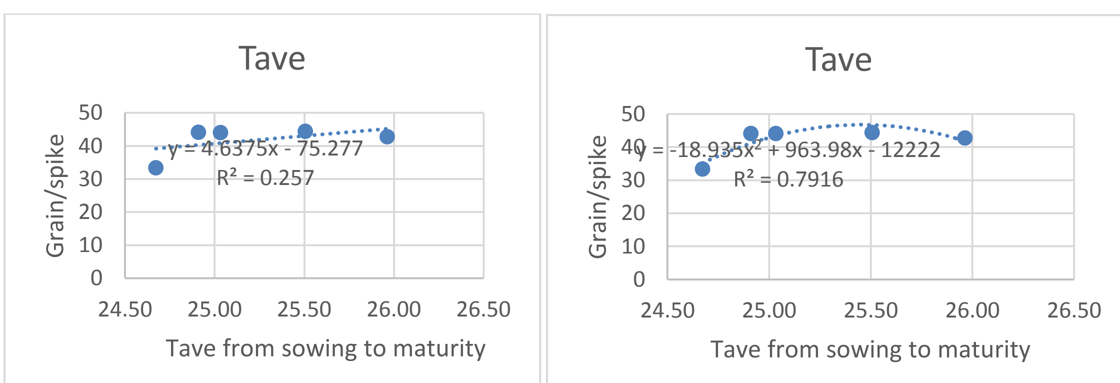


Fig. 4. 5.13 Regression analysis between number of grain/spike of wheat and average temperature from anthesis to maturity at SAU farm

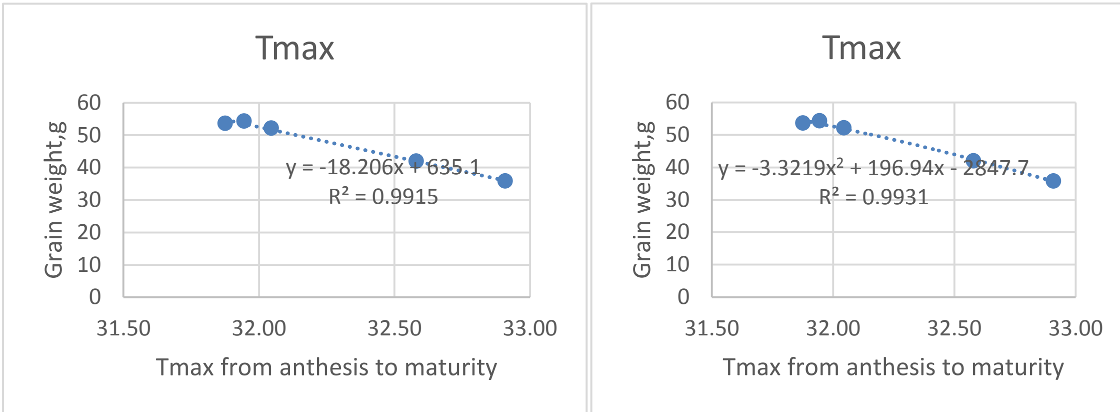


Fig. 4.5.14 Regression analysis between grain weight (g) of wheat and max temperature from anthesis to maturity at SAU farm

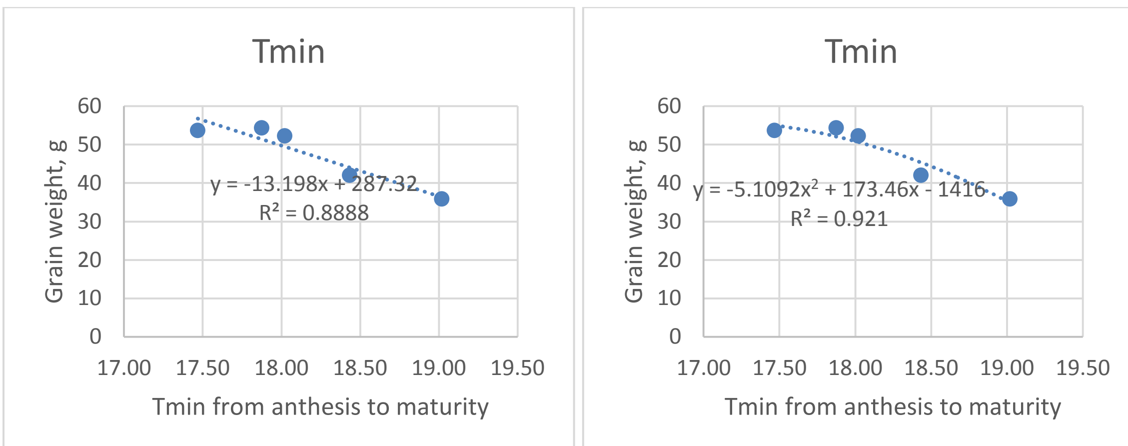


Fig. 4.5.15 Regression analysis between grain yield/spike (g) of wheat and minimum temperature from anthesis to maturity at SAU farm

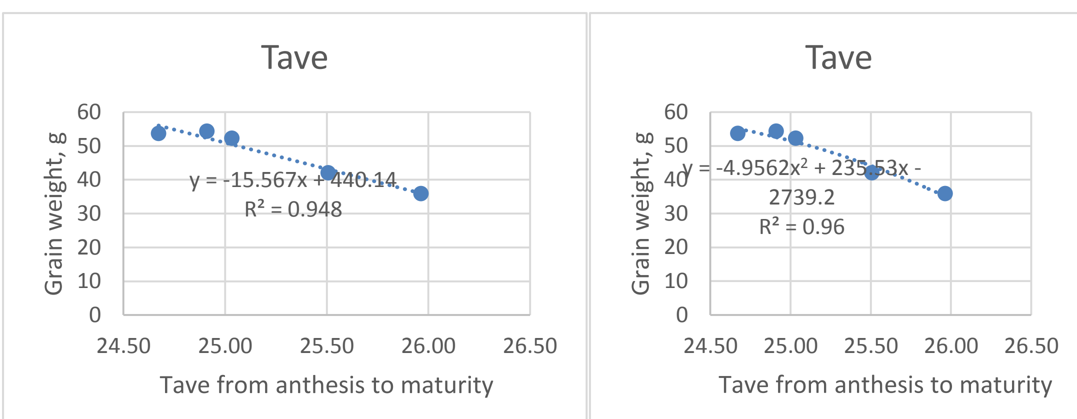


Fig. 4.5.16 Regression analysis between grain weight/spike (g) of wheat and average temperature from anthesis to maturity at SAU farm

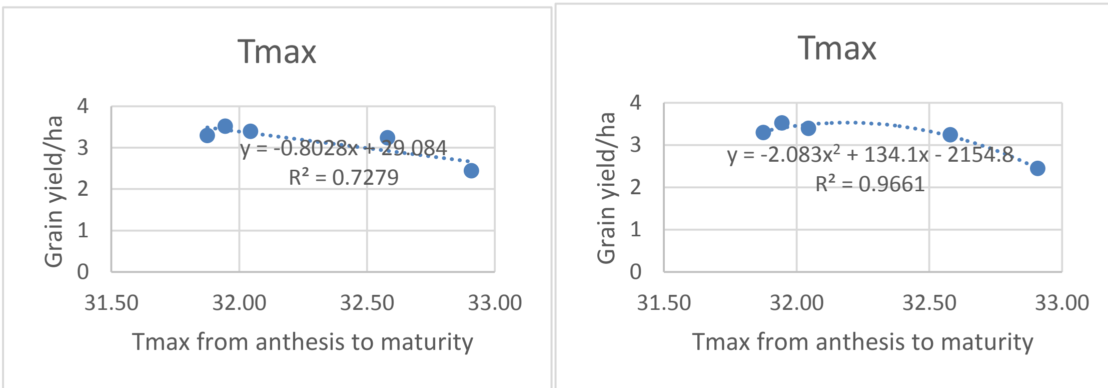


Fig. 45.17 Regression analysis between grain yield (t/ha) of wheat and maximum temperature from anthesis to maturity at SAU farm

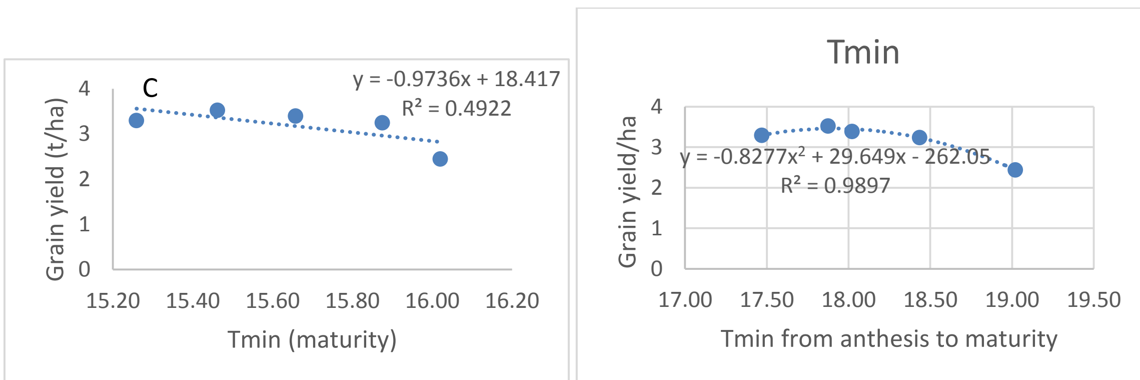


Fig. 4.5.18 Regression analysis between grain yield (t/ha) of wheat and minimum temperature from anthesis to maturity at SAU farm

DISCUSSION

Experimental findings are discussed under different heads and sub-heads as it has been presented in the *same* chapter previously. The first experiment was conducted to find out the varietal performance and sowing times. The second experiment was conducted on the effect of different sowing dates, amount of irrigation and supplemental nitrogen at reproductive stage. The third experiment was also conducted to find out the suitable sowing time with supplemental irrigation and nitrogen at post heading stage. The fourth and fifth experiments were conducted with six varieties and five sowing dates in two locations at SAU, Dhaka and farmers field of Rajshahi. Depending upon the status of five experiments the interpretation and scientific explanation of the results have been made altogether below to avoid repetition.

4.5.2.1 Sowing dates, ambient temperature, crop phenology, chlorophyll content, yield and yield attributes

Ambient temperature

It was observed that the average of the daily maximum, minimum and average temperature at both the places was higher at the reproductive stage of plants. Again the average of the daily average temperature at both the growth stages was lower at Rajshahi (12-24^{0}C) than that at SAU (18-27^{0}C).The averages of the daily maximum, minimum and average temperature were higher at SAU both at sowing to anthesis and from anthesis to maturity (respectively over 29 & 32; about 15 & 18; 22 &25^{0}C) than those at Rajshahi (respectively over 25 & 29; about 12 & 15.5; 19.9 & 22.5^{0}C) showing higher at SAU than those at Rajshahi.

Ambient temperature undertaken by the crops sown at different dates

At sowing to anthesis at Rajshahi highest maximum temperature (in^{0}C) was with Dec 30 sowing (26.97), Nov 20 had higher minimum (above 13) and higher average temperature

(19.92). While at SAU, highest maximum temperature (^{0}C) was with Dec 30 sowing (30.21), Nov 20 had higher minimum (above 16.21) and Dec 30 had highest average temperature (23.12).We may conclude that at sowing to anthesis, both at Rajshahi and SAU the higher average of the daily average maximum (26.96, 30.21) was with Dec 30, but the higher minimum was with Nov 20 (above 13),16.21), but at SAU again the Dec 20 had the higher average temperature 23.12).

From anthesis to maturityat Rajshahi Dec 30 sowing enjoyed the highest average maximum temperature (29.91^{0}C), higher minimum temperature (above 16^{0}C) and also the higher average of the average temperature (22.96^{0}C).While at SAU from anthesis to maturity, Dec 30 sowing enjoyed the highest average maximum temperature (32.91^{0}C), highest minimum temperature (19.02^{0}C) and higher average of the daily averages (23.12^{0}C).

That is at both the sites, the Dec 30 sown crops had higher maximum temperature at both the growth stages. At sowing to anthesis it was 26.97 at Rajshahi while 31.21 at SAU while at anthesis to maturity it was 29.91 at Rajshahi while 32.91 at SAU. That is, the Dec 30 sowing at SAU site had always higher maximum temperature (31.21 before anthesis and 32.91 after anthesis to maturity) than at Rajshahi (26.97 before anthesis and 29.91 after anthesis to maturity). It can be summarized that at sowing to anthesis the Nov sowing at both the sites had higher minimum temperature (about 13 at Rajshahi while at SAU 16-16-21). But after anthesis to maturity the Dec 30 sowing had higher minimum temperature at both the sites (about 16 at Rajshahi and 19^{0}C at SAU).At anthesis to maturity the higher average temperature was seen with Nov 20 at Rajshahi (19.92), while it was with Dec 30 at SAU (23.12). This Dec 30 treatment also had higher average temperature at both the sites showing 22.96 at Rajshahi and 25.96 at SAU. That is SAU had higher average temperature (23.12-25.96 with Dec30 sowing) than at Rajshahi.

4.5.2.2 Difference between 'before anthesis' and 'after anthesis' temperature

Attempt was made to calculate the difference between the temperature at the vegetative and the reproductive stages considering the higher values of all levels of temperature (maximum, minimum and average) as was received by the sowing time. This was seemed to the important as in Bangladesh higher temperature especially at from anthesis to maturity is thought to be detrimental in respect of reducing grain yield (7.8%).It was observed that at both the sites the sowing time treatment underwent higher temperature at the reproductive stage than at the vegetative. Again, the differences of maximum, minimum and average between the vegetative and reproductive stages were wider at Rajshahi (2.94, 3 and 3.04) than at SAU (1.7, 2.81 and 2.84). Moreover the difference was wider at the vegetative than at the reproductive.

At sowing to anthesis, both at Rajshahi and SAU the higher average of the daily average maximum (26.96,30.21) was with Dec 30, but at Rajshahi the higher minimum was with Nov 20 (above 13,16.21), while at SAU the Dec20 had the higher average temperature 23.12).

That is, from anthesis to maturity at both the places Dec 30 sowing undertook the highest average of the daily maximum, minimum and average temperature (at Rajshahi: 29.91,above 16, 22.96; at SAU 32.91,19.02,25.96^{0}C).

If we compare between the temperature from sowing to anthesis and from anthesis to maturely, it was observed that at the vegetative stage the Nov 20 sowing underwent the higher temperature while at anthesis to maturity the Dec 30 sowing had higher temperature compared to other sowing dates. The higher temperature at Nov 20 at the vegetative stage probably helped to increased plant growth which ultimately increased grain yield.

4.5.2.3 Sowing dates and crop phenology

Sowing dates had also effect on the phenological stages of wheat. At Rajshahi the significantly higher number of days for booting was taken by November 30 which was 3-5 days more than those of the November 20 and December 10-30 sown crops. Likewise, November 30 sown crop took maximum calendar days to heading (60 days). November 20 sown crop also took maximum days to anthesis (66 days) which was much later than that of the Dec 30 sowing. Early onset of anthesis in December 10 was due high temperature conditions prevailed at the time of anthesis. November 30 sowing took maximum number of days to physiological maturity, which was significantly higher than November 20 and December 10-30 sowing. Regression analysis of the days to maturity with the average temperature from anthesis to maturity showed that that the maturity became delay below the average temperature 22.50^0C and beyond which it was shortened.

Sowing dates influenced the phenological stages of wheat which was demonstrated by different workers. It was observed that the early sown wheat took higher number of days to heading under sub-tropical conditions of Ludhiana, Punjab (Ram *et al.*, 2012). December 30 sown crop bore early ears, which was under high temperature. Hossain *et al*. (2015) found that earlier heading was advantageous in the retention of more green leaves at anthesis which is congenial to obtain higher grain yield.

In this study November 30 sown crop took the longest days to heading and probably it happened due to lower canopy temperature of November 20 sown crop at 90 DAS. Hossain *et al*., (2015) reported early onset of anthesis under late sown conditions in Bangladesh. Crop sown early took more days to physiological maturity than the crop sown late in the season (Basu *et al.* 2014, Sattar *et al.*, 2015).

Anthesis is the most important stage of wheat crop. Anthesis determines the number of grains setting in the ear. Fertilization is very sensitive to environmental conditions prevailed at that time, because pollen grains are highly sensitive to temperature and other environmental conditions. According to Russell and Wilson (1994) and Chakrabarti *et al.*, (2011) suitable temperature for anthesis was $18\text{-}24^0$C. More the temperature early will be the onset of anthesis. Early onset of anthesis in December 10 sown crops of this study was due high temperature conditions prevailed at the time of anthesis. Hossain *et al.*, (2015) also reported early onset of anthesis under late sown conditions in Bangladesh. Crop sown early took more number of days to physiological maturity than the crop sown late in the season (Basu *et al.* 2014, Sattar *et al.*, 2015).

Dias and Lidon (2009) exposed some wheat genotypes to heat stress after anthesis, to correlate and evaluate grain filling traits and grain weight to the increased temperature. It was found that bread and durum wheat exposure to high temperatures significantly decreased grain weight and hastens physiological maturity (shortening the grain filling period).

In this study such situation also happened. Regression analysis of the days to maturity with the average temperature from anthesis to maturity showed that the maturity became delayedwhen the average temperature remained below 22.50^{0}C and beyond which it was shortened (Fig. 4.1.2). High temperatures significantly affected the rate (on a growing degree day basis) and duration (on Julian day units) of grain filling. Several studies conducted in Australia and USA (Wardlaw and Wrigley 1994) further indicated that, each year, crop production decreases about 10–15 %, mostly because of high temperatures during anthesis. Variation for tolerance to high temperature stress among genotypes has been reported in wheat (Wardlaw *et al*. 1989, Viswanathan and Khanna-Chopra 2001, Tahir and Nakata 2005).

4.5.2.4 Relations of the average canopy temperature at booting, heading and anthesis with biological yield

Regression analysis showed that the ground coverage data was best fitted to the polynomial regression although it was negative (slope -4682 in linear, with R2=0.964 in polynomial, Fig.4.4.2-4.4.3). The higher range of ground coverage (maximum of 60 DAS) was seen at the minimum temperature of 15.5^{0}C.

The relationship of ground coverage (maximum of 60 DAS) with the ambient temperature showed that the ground coverage was negatively correlated to the all level of temperature (maximum, minimum and average) indicating that the ambient temperature was higher than needed by this crop. However in all the cases the data were best fitted in polynomial regression (R^2=0.739-0.964). It was observed that the higher ground coverage was happened when the ambient minimum and average temperature was 15.5 and 21^{0}C.

The regression analysis showed that the biological yield was decreased with the increase of canopy temperature, however the slope was not so high (-0.497). But when polygonal regression was fitted it was observed that the biological yield increased when the canopy temperature increased from 20^{0}C, was maximum at about 21.5^{0}Cand thereafter decreased.

4.5.2.5 Sowing dates and leaf chlorophyll content

Relations of chlorophyll content with the ambient temperature

The regression analysis showed that the chlorophyll content of the leaves decreased with increase of the ambient temperature. That is, the chlorophyll content (at anthesis) decreased with the increase of the ambient maximum, minimum and average temperature. The relationship was linear but negative both in linear regression (slope -0.629 - (-) 1.222) and the R^2= (0.625-0.86). Fig.4.4.5

Rahman *et al*. (2009) reported that the mean chlorophyll content (%) continued to increase up to 60 days after sowing and then it declined towards maturity. Different sowing dates significantly influenced the chlorophyll content (%) at all crop growth stages. The reason for highest

chlorophyll content index in timely sowing may be the enhanced vegetative development of crop.

4.5.2.6 Sowing dates, yield and yield attributes

In the first experiment Nov 10-20 sowing produced grain yields from 4 to 4.06 t ha^{-1} across the varieties which were significantly higher and much higher than that sown on Nov30 (3.59 t ha^{-1} showing a difference of over 14%. The higher grain yield of Nov 10-20 sowing was attributed to the significantly higher number of grain per spike (33.10-34.10) and number of tiller per plant (6.08-6.32) (Table 4.1.5) of these treatments (Nov 10-20).November 10 and 20 sowing also showed significantly longer plants (100.40-102.72 cm), more tillers per plant (6.08-6.32), dry matter per plant (5.64-5.87 g), number of spikelet per spike (20.92-21.57), longer spike (17.82-18.37 cm), number of filled grains per spike (33.10-34.10), total grains per spike (36.27-37.18), 1000 grain weight (44.95-45.13 g) along with having higher straw (5.45 t ha^{-1}),and also higher harvest index (37%). The Nov20 sowing had also significantly the higher values of spike length (23.58 cm) and the biological yield (8.220 t ha^{-1}).

Likewise in the second experiment with BARI Gom 26, Nov 20 sowing produced the highest grain yield (4.180 t ha^{-1}) which was significantly higher than the values of other sowing dates treatments, showing over 33% higher grain yields over that of Nov10 sowing (3.14 t ha^{-1}). The highest grain yield of the Nov 20 sowing may be attributed to the number of grains per spike (51.92) and number of tiller per plant (43.88) which were significantly higher than those (39.21 and 43.88 respectively) of Nov10 sowing.

In the third experiment with BARI Gom 25, again the Nov20 sowing out yielded the other sowing dates showing grain yield of 4.330 t ha^{-1} which was also significantly higher than the grain yields of other sowing dates showing over 27% higher grain yield than that (3.400 t ha^{-1}) produced by Nov10 sowing. This highest grain yield of the Nov20 sowing was attributed to the higher values of number of grain per spike (46.54) and number of tiller per plant (58.78) which were significantly higher than those (38.64 and 42.82 respectively) of Nov10 sowing (Table 4.4.6). In this experiment, the Nov20 treatment also showed significantly the highest straw and biological yield (4.580 and 8.13 t ha^{-1} respectively).

In the fourth experiment, the results of Rajshahi comparatively later sowing dates, as compared to the SAU sites, of Dec 10 to 20 sowing showed significantly higher grain yields (3.39-3.52 t ha^{-1}) which were significantly higher (up to 39%) than those of other sowing dates treatments (2.44-3.24 t ha^{-1}, table..4.1.6). Dec 30 sowing had the lowest grain yield. The higher grain yields of the sowing date treatments Dec 10-20 were attributed to the number of grain per spike (44.32), number of tiller per plant (3.64-3.66) and 1000 grain weight (52.19-54.32 g) which were significantly higher than those (33.29, 2.74 and 45.81 g, respectively) of the lowest values of the Dec 30 sowing date (Table 4.4.7). Sowing 4th sowing Nov 20 sowing had the least tillers (2.74/plant) while the Dec 20 sowing had the higher tillers (over 3.6/plant). Nov 30 to Dec 20 sowing also had higher ground coverage on 74-75 days after sowing, while other sowing in about 67-71 days. Dec 20 had the maximum chlorophyll content (45 SPAD units) at heading while Nov 30 and Dec 10 had that (45 SPAD units) at anthesis (Table 4.1.7).

At the SAU site (in the fifth experiment) in the 2016-17 rabi season, the Nov 30 sowing showed the highest grain yield (3.02 t ha^{-1}) which was significantshowing over 55% higher grain yield as compared to that (1.940 t ha^{-1}) of the grain yield obtained in the latest sown plots (Dec 30). The higher grain yield of Nov 30 sowings of the fifth expt. may be attributed to the higher grains/spike (over 40). That is during this season at bit later sowing date (Nov 30) had higher grain yield than the earlier sowing dates of Nov 20.

In 2014-16 Nov10-20 sowing in three experiments at SAU had higher grain yields (over 4 tons ha^{-1}) than the Nov30 sowing dates (below 4 t ha^{-1}). But in the further trial in 2016-17 at this site Nov 30 sowing had higher grain yields (3.020 t ha^{-1}) than the earlier November sowing on Nov 20 (2.79 t ha^{-1}). That is over the two year's experiments at the SAU site it may be said that the sowing wheat in the month of November had better yield performance than sowing in the later sowing in December. But at Rajshahi during 2016-17 rabi season a later sowing as compared to the sowing dates at SAU, the Dec10 to 20 sowing showed higher grain yields (3.39-3.52 t ha^{-1}) which were significantly higher (up to 39%) than those of other earlier (November) or later (December) sowing dates treatments (2.44-3.24 t ha^{-1}, table.4.1.7).

These results from the first year's three trials showed evidences that the earliest sowing (at or before Nov 10) of wheat caused reductions in grain yield almost with all the three varieties. Probably in the early part of Nov rainfall did not cease which caused damage up to a certain extent to the germinated grain creating soil impudence along with reduced grain growth due to probable low temperature as compared to the later sowings and less availability of sunlight due to partial cloud coverage. However, in this study effect of rainfall was not analyzed. That is, in both the sites the grain yields increased when sown after Nov10 to December 20; and again decreased sowing after that showing reduced grain yields at Dec 30. Probably the incidence of rainfall, soil moisture, and temperature determined the sowing dates (Appendix II) which composes the suitable situation in favor of getting higher grain yields. The suitable sowing at SAU was in November as this earlier sowing (November) had lesser Maximum temperature in the reproductive phase (from anthesis to maturity) in the months of Feb-March (below 31.88-31.95 ^{0}C) than those of the December sowing treatments (32.05-32.91^{0}C)(appendix table of the average temperature.7.1.1). While there was no remarkable difference in the reproductive phase of the crops at Rajshahi where the earlier sowing had 29.44-29.55^{0}C(in Feb-March) of the November sown crops and 29.68-29.77^{0}C in the December 10-20 sown crops (Fig.

4.4.10-4.4.13.). That is, an elongated lower temperature prevailing in the reproductive phase at Rajshahi did not reduce the grain yields even sown later in the month of December.

Moreover, the yield performance of wheat also depends on the other environmental parameters such as rainfall, sunshine etc excepting the ambient temperature. The rainfall at the grain filling has both beneficial and detrimental effect on grain yield. It may contribute to the increase in grain weight providing moisture to the plant through soil moisture. On the contrary, it may damage either by lodging the crop plants or by over moistening the ripening grains. Probably the incidence of rainfall at the grain filling stage of the December sown crops in the months of February-March may have been helpful to increase the grain weight of the maturing crop making the December sown a good performer. Besides, the varieties grown at both the sites were of heat tolerant ones which might have been good performers even at the warmer temperature of the February March. The crops grown at SAU might have suffered from very high ambient temperature coupled with over rainfall at their maturity period (104 days).

The higher grain yield productions of the earlier sowing at SAU was supported by the previous report of Ram *et al*., (2013) and Kaur *et al.*, (2010) who obtained higher grain yield under November 15 sowing as compared to late sown conditions in Hisar (Haryana) of India. There is also some other publications reporting increased wheat yields with early sowing and a reduction in yield when grains sowing delayed after the optimum time (Bassu *et al*., 2009 and Bannayan *et al*., 2013).

Under Bangladesh condition the grain yield of wheat decreases if its grain filling stage coincides with the increasing environmental temperature (Fig. 4.4.12-4.4.17). So it is one of the principal ways to choose proper sowing time so that its grain filling escapes the increased ambient temperature. However, wheat is grown in rice based cropping system wherein after harvesting rice wheat is sown starting from the early part of November. The ambient temperature starts increasing after February which frequently imposes the wheat crop's grain filling stage in the period when the ambient temperature under increased situation (35^0C).

Wheat is a winter crop in Bangladesh whose sowing starts in October and where from the temperature rises. From this time the ranges of standard normal max temperature declines from November (28.8-29.9^{0}C) and again rises from February (27.4-30.2^{0}C) and reaches pick in the month of April (31.4-36.1^{0}C). (Data of BBS, 2016).

The sowing dates having remarkable effect on different yield parameters has also been reported by Alam *et al*. (2013), Mumtaz *et al*. (2015), Pyare *et al.* (2015), Sattar *et al*. (2015) and many other workers on different parameters such as number of tillers/m2, plant height, number of grains/spike, 1000 grains weight and grain yield.

The higher grain yield is also influenced by the yield contributing plant parameters. It was found that at SAU, the tallest plant was observed from S_2 (sowing on 20 November) which was statistically similar to S_3 (sowing on 30 November) and closely followed by S_1 (sowing on 10 November). Whereas the shortest plant was found from S_4 (sowing on 10 December). Such evidence was also noticed in other trial made by BARI (1984) who reported that the tallest plant height was found when wheat was shown on 20 November and shortest with 30 December sowing.Sial *et al*. (2005)reported that in case of delayed planting, the development of plant organs and transfers from source to sink were remarkably affected, which was influenced and also reflected by overall shortening of plant height. Zia-Ul-Hassan *et al*. (2014) earlier reported that sowing dates remained significant in terms of plant height of modern cultivated wheat. Sowing time has a remarkable effect on the plant height of wheat. In a trial with cultivar Balaka in Joydepur and Jessore, BARI (1984) reported that the tallest plant (76.83 cm) was obtained at Jessore when sowing was done on 20 November and shortest with 30 December sowing. Similar results have also been observed by Farid *et al.* (1993). Haider (2002) conducted an experiment on wheat and observed that plants of all cultivars of wheat sown in 15 November became taller than December 5 sown plants under each irrigation regimes. Twelve wheat genotypes were tested by Sial *et al*. (2005) for yield and quality parameters at two levels of sowing dates i.e., normal (18th November) and late sowing (11th December). They observed that with the delayed planting, the development of plant organs and transfer from source to sink was remarkably affected, which was reflected by overall shortening of plant heights. Such evidences regarding the effect of sowing time on plant height were also obtained and reported by BARI (1984), Farid *et al.* (1993), Moula (1999), Chowdhury (2002), Sial *et al*. (2005), Baloch *et al*. (2010) and many other workers.

A study was undertaken by Mohsen *et al*. (2013) to determine the effects of sowing dates on growth and yield components of different wheat cultivar in Iran. Five sowing dates i.e. October 31, November 15 and 30, December 15 and 30 were in main plots, whereas five wheat cultivars were in sub plots. Results showed that the effect of sowing date was significant on all parameters. Shafiq (2004) revealed that early sowing increased germination per unit area, plant height, spikelet per spike, grains per spike and 100-grain weight compared to late sowing. Hossain *et al*. (1990) observed that maximum grain yield was obtained when the wheat was sown November 20 due to higher number of grains spike-1 and the highest 1000-grain weight. Effect of sowing date on different yield parameters and was also reported by Eissa *et al*. (1994), Qasim *et al*. (2008), Haider (2002), Hakim *et al*. (2012), Suleiman *et. al*. (2014), Saunders (1988), Shafiq (2004) and many other researchers.

The wheat grain yield is also governed by harvest index. In this trial the November sowing at SAU while the December sowing at Rajshahi had the higher values of harvest index. Harvest index contribute to yield by transforming more assimilates towards the grain formation. Samuel *et al.* (2000) reported that late sowing condition (6 January 1997) reduce the harvest index (36.1%) from (41.5%) over optimum sowing condition (29 November 1996) in wheat. Such happened probably the higher ambient temperature provoked the rate of respiration to increase causing more loss of the assimilates stored in the grains. Aldesuquy *et al*. (2012a) also observed higher harvest index were obtained from interaction effect of sowing date and varieties. In this study the sowing dates also affected the grain number of spikes which was higher in either the November sown crops at SAU, while in the December sown crops at Rahshahi. Under both Bangladesh and Indian condition, it was observed that the late planted wheat plants face a period of high temperature stress during reproductive stage causing reduced grain number spike^{-1}which subsequently reduced the grain yield (Bhatta *et al*., 1994 and Islam *et al*., 1993).

Number of tillers per plant also affects the grain yield of wheat greatly that has also been experienced in the November sown crops at SAU and in the December sown crops at Rajshahi. BARI (1984) reported that 20 November sowing produced the highest number of tillers plant^{-1}. Aslam *et al*. (2013) reported that the 5th November sowing significantly produced maximum tillers (345 m^{-2}) followed by the 15th November sowing while, the

25th October sowing produced minimum tillers (237 m^{-2}) owing to the incidence of high temperature at the grain filling stage of the late sown crop. Ahmed *et al*. (2006) reported that number of tiller per plant enhanced significantly with early sowing (30 November) in all varieties in the consecutive two years as compared to the later sowings. Similar results were also obtained and reported by Sarker *et al*. (1999), Chowdhury (2002), Sial *et al*. (2005), Baloch *et al*. (2010), Mohsen *et al*. (2013) and also some others.

As the sowing time may impose the crop's grain ripening stage to a warmer environment, it may exert an effect on 1000 grain weight through ambient temperature increasing the rate of respiration. In this study the delayed (December) sowing at SAU while further delay (December 30) at Rajshahi caused 1000 grain weight of the crops of both the places to decrease when the ambient temperature was higher in the month of Feb-March (the grain filling period of the Dec sown crops). Abdullah *et al.* (2007) found that 1000-grain weight declined progressively with delayed sowing where the maximum value was obtained in the earlier planting dates from 15-30 November and minimum value in the later planted ones i.e. 10th January. Chowdhury (2002) reported that 1000-grain weight decreased with delay in sowing time from November 15 and the lowest 1000-grain weight were recorded in December 15 sown plants. Khosravi *et al*. (2010) also observed higher 1000-grain weight in optimum sowing window in Kerman (Iran). Singh *et al* (2013) in Jaipur (Rajasthan) also reported an increase in 1000-grain weight with increase of photosynthesis.

The spike length is one of the most important parameters of wheat plants which may determine the number of grains per spike. Chowdhury (2002) conducted an experiment with four sowing dates and reported that ear length decreased with delay in sowing date from November 15 where the lowest ear length was recorded in December 15 sown plants.

Sowing time may have indirect effect on the grain formations and weight through effecting the biological yield of any crops especially the grain crops where migration pattern of the assimilates from the vegetative part to the reproductive part may be modified by the surrounding environmental condition specially the temperature. In general more the amount of the biological yield more the mobilization of the assimilates to the grain from the vegetative organ in cereals. In this study the crops sown either in

November at SAU or in December (10-20) had both higher values of biological and grain yields. This is in fully agreed with the findings of Said *et al*. (2012) who reported significant differences in the biological yields of the crops from the different planting dates where the maximum biological yield (11.953 t ha^{-1}) were produced from 20 to 30 November sown crops.

4.5.2.7 Varietal performance

In the first experiment two varieties (BARI Gom 21 and BARI Gom 23) were tried at SAU site. Results showed that the variety BARI Gom 23 had the higher grain yield ha^{-1} (4.110 t ha^{-1}) than that of BARI Gom 21 which was significantly higher than that of the BARI Gom 21 (3.95 t ha^{-1}). BARI Gom 23 had significantly higher values in plant height (105.06 cm), number of tillers per plant (6.57), dry matter accumulation per plant (6.01 g), number of spikes per plant (5.32) and number of spikelet per spike (21.43) as compared to those of the BARI Gom 21. Al-Musa *et al*. (2012) reported that among the BARI varieties, BARI Gom 21 produced the taller plant (47.91 cm). Qasim *et al*. (2008) reported that plant height varied for different cultivars of wheat. Al-Musa *et al*. (2012) reported that among the BARI varieties, BARI Gom 21 produced the taller plant (47.91 cm).

BARI Gom 23 had higher number of filled grains per spike (34.62) and total grains per spike (37.44) as compared to those of BARI Gom 21. This variety also showed higher values in straw yield (5.970 t ha^{-1}), biological yield (9.72 t ha^{-1}) and harvest index (42.53%).

In the expt. 2 and in the expt.3 BARI Gom 26 and BARI Gom 25 yielded 4.18 and 4.33 t ha^{-1} respectively which was higher over those yielded in the expt. 1 with BARI Gom 21 and BARI Gom 23(3.95 - 4.13 t ha^{-1}).

The two varieties tested in the previous year were omitted because of their longer durations (up to 115 days). Moreover, these two varieties were taller ones (95-100 cm) while other heat tolerant varieties (BARI Gom 25to BARI Gom 30) are around 80 cm tall (BARI, 2014; Awal *et al*., 2017) and that’s why farmers do not usually like them to grow as those are lodging susceptible at the later stage of their lifespan due to the incidence of early storm at the end of February to the early March when the crops remain in their grain filling. Such situation cause the drastic yield reduction (Wheat Production Manual, BARI; Personal communication with Dr. Elias and Dr. Abu Zaman Sarker, Scientists, WRC, BARI). Moreover, the BARI Gom 21 and BARI Gom 23has longer duration (up to 112-115 days,) which mature taking at least 7 more days compared to other heat tolerant varieties (BARI, 2014; Akter, *et al*., 2018; Shabi, 2018). Due to the longer durations and low grain yields (3.95 - 4.13 t ha^{-1}) in the first experiment during 2014-15 rabi season in the expt 1 the BARI Gom 21 and BARI Gom 23 were not further continued to be tested in the consecutive year.

In the fourth experiment at Rajshahi in the second year (2015-16) six different heat tolerant varieties (BARI Gom 25, BARI Gom 26, BARI Gom 27, BARI Gom 28, BARI Gom 29 and BARI Gom30) were sown in different dates (Nov20, Nov 30, Dec 10, Dec 20 and Dec 30) based on the grain yield results of the previous year (2014-15) wherein the November 10 sowing yielded the worst.

Crops grown at the later part of Nov (Nov 30) or at the early part of December (Dec 10) took longer days for anthesis (over 66 days) as compared to others (below 59.4-64.6 d) that is theanthesis time was elongated due to the delayed sowing from Nov 20 to Dec 10; and thereafter shortened. The physiological maturity was the earliest tin latest sowing dates (Dec 30) in only 94.5 days while the Nov 30-Dec 10 sowing took the longer days to maturity. From the polygonal regression it was observed that the days to maturity were elongated with the increasing the ambient average temperature up to $22.5^{0}C$ and thereafter again shortened with the further increase in temperature.

In experiment 4 at Rajshahi the variety BARI Gom 28 and BARI Gom 30 had significantly identical but higher grain yields (3.72-3.81 t ha^{-1}) which were over 25% higher as compared to that of the lowest of all (2.97 t ha^{-1}) shown by the variety BARI Gom 26.

Out of five varieties, BARI Gom 26, BARI Gom 27 and BARI Gom 28 had significantly higher tillers (over 3.3 / plant) compared others (below 3/plant) and accordingly same happened in case of physiological maturity. All the varieties matured in 100-102 days while the variety BARI Gom 29 matured in 95.6 days. Out of six varieties tested the

BARI Gom 27 had the maximum chlorophyll content 47.52 %) at anthesis while others 43-45%.

In the experiment 5 at SAU, The variety BARI Gom 30 produced significantly the highest grain yield (3.22 t ha^{-1}) which was 30% highest than the lowest value of the variety BARI Gom 26 (2.47 t ha^{-1}). The highest value of grain yield was attributed to the highest values of this variety in number of spikes per m^2 (243.83), biological yield (10.83 t ha^{-1}) and harvest index (30.56%).

It was observed that in the both sites BARI Gom 26 performed the worse while BARI Gom 30 had the highest grain yield. This was attributed to the plant parameters of the variety BARI Gom 30 giving the highest values at Rajshahi of ground coverage (78%) at 60 days after sowing, gaining fresh weight (12.18 g) at 28 days after anthesis, spikelet per spike (15.97), grains per spike (46), 1000 grain weight (49.48 g), biological yield (11.33 t ha^{-1}) and harvest index (33.60%). This variety also attained the physiological maturity at the earliest in 98.60 days as compared to 100-102 days of the other varieties. Likewise the highest grain yield of BARI Gom 30 at SAU was attributed to the highest values in number of spikes per m^2 (243.83), biological yield (10.83 t ha^{-1}) and harvest index (30.56%).

However, the varieties did not differ so much in respect of chlorophyll and canopy temperature which were a bit inconsistent. At Rajshahi tiller production, plant height, also did not have effect on grain yield.

The differential in yield potentials due to varieties was manifested by many scientists in the previous researches. BARI (2005) revealed that mean yield of wheat varieties Kanchan, Prodip, Shatabdi, Sourab and Gourab were 3.59, 3.29, 3.12 and 2.81 t ha^{-1}, respectively. Arbinda *et al*. (2007) observed that the grain yield was significantly affected by different varieties in Bangladesh. The workers found that the late planted wheat plants face a period of high temperature stress during reproductive stages causing reduced grain number $spike^{-1}$ (Bhatta *et al*., 1994 and Islam *et al*., 1993) as well as the reduction of grain yield. The variety BARI Gom 30 and 28 produced higher grain yield that was attributed to more number of spikes m^{-2} and grains $spike^{-1}$ and thousand grain weight. Similar results of grain yield were reported by Ram *et al*., (2013).

The variation in yield productivity of different varieties was attributed to plants physiological and biochemical attributes (Rahman *et al*., 2009). For example Rahman *et al*. in his study found that the genotype G11 (LOK-1) had significantly lower chlorophyll content and index than other varieties tested. They reported that at 60 days after sowing genotype G6 (AKAW-3931-2) recorded significantly higher chlorophyll content and harvest index. Rahman *et al*. (2009) reported that the mean chlorophyll content continued to increase up to 60 days after sowing and then declined towards maturity. Samuel *et al.* (2000) reported that heat tolerant and disease resistant varieties increase the harvest index (41.4%) from (45.5%) over normal varieties in wheat. Said *et al*. (2012) reported that maximum biological yield (13452 kg ha^{-1}) were produced from heat tolerant and disease resistant varieties. Data revealed that at 30, 45, 60 and 75 DAS, the maximum number of tillers $plant^{-1}$ was recorded from V_2.

In the 1st experiment at SAU it was observed that at 30, 45, 60, 75 DAS and harvest, the longest plant was found from V_2 (BARI Gom 23) which was statistically similar to V_1 (BARI Gom 21). Different genotypes produced different plant height on the basis of their varietal characters.

Qasim *et al*. (2008) reported that plant height varied for different cultivars of wheat. BARI Gom 29 at Rajshahi had the ground coverage at the latest in 78.70 days while others had it at earlier in about 70-74 days. Said *et al*. (2012) also reported that maximum biological yield (13452 kg ha^{-1}) were produced from heat tolerant and disease resistant varieties. At Rajshahi the late sowing with BARI Gom 30 variety took minimum days of heading. Early sown wheat took higher number of days to heading under sub-tropical conditions of Ludhiana, Punjab (Ram *et al.*, 2012). December 30 sown crop bear early ears, which was under high temperature. Earlier heading is advantageous in the retention of more green leaves at anthesis (Hossain *et al*., 2015).

WRC (2003) reported that the varieties Shatabdi produced maximum grain $spike^{-1}$.BARI (1993) revealed that mean yield of wheat varieties Kanchan, Akbar, Agrani and Sonalika were 3.59, 3.29, 3.12 and 2.81 t ha^{-1}, respectively. Arbinda *et al*. (1994) observed that the grain yield was significantly affected by different varieties in Bangladesh. The genotypes CB-15 produced higher grain yield (3.7 t ha^{-1}) that was attributed to more number of spikes m^{-2} and grains $spike^{-1}$.BARI (2005) revealed that mean yield of wheat varieties

Kanchan, Prodip, Shatabdi, Sourab and Gourab were 3.59, 3.29, 3.12 and 2.81 t ha^{-1}, respectively. Arbinda *et al*. (2007) observed that the grain yield was significantly affected by different varieties in Bangladesh. The variety BARI Gom 30 and 28 produced higher grain yield that was attributed to more number of spikes m^{-2} and grains $spike^{-1}$ and thousand grain weight. Similar results of grain yield were reported by Ram *et al*., (2013).Amrawat *et al*. (2013) in Udaipur (Rajasthan) also reported that varieties differ from each other with respect of biological yield. Samuel *et al.* (2000) also reported that heat tolerant and disease resistant varieties increase the harvest index (41.4% to 45.5%) over normal varieties in wheat.

4.5.2.8Canopy temperature

In the expt. 4 at Rajshahi, the canopy temperature at anthesis was minimum (21.13-21.51 degree within Nov sowing crops while remained higher (22.45^{0}C) in December sowing, but more higher in the later sowings (25.86-28.19^{0}C). *Basu et al., (2014) also reported higher canopy temperature of wheat under late sown conditions in West Bengal. Basu et al., (2014) also reported optimum canopy temperature was found from wheat varieties in West Bengal, India.* Ahamed *et al.* (2010) evaluated 5 existing wheat varieties of Bangladesh under two growing conditions (optimum and late) and showed that dry matter partitioning and production in all 5 varieties was affected at LS due to heat stress (30 to 32°C), resulting in reduced grain yield.

4.5.2.9 Sowing date-variety interaction

In the expt. 1 two varieties (BARI Gom 21 and BARI Gom 23 were sown four sowing dates (Nov 10, 20, 30 and Dec 10). In the experiment 1 at SAU two Interaction effects of wheat varieties and sowing dates showed significant differences on grain yield (Table 4.1.8). The highest grain yield was observed from V_2S_2, while the lowest grain yield was obtained from the treatment combination V_1S_4.

At 30, 45, 60, 75 DAS and harvest, the longest plant was observed from V_2S_2 (BARI Gom 23 and sowing on 20 November) and the shortest plant was obtained from the treatment combination V_1S_4 (BARI Gom 25 sowing and 10 December).

The interaction effect of variety and sowing dates has been found to be significant in wheat in the previous reports. Aldesuquy *et al*. (2012a) also observed higher harvest index were obtained from interaction effect of sowing date and varieties.

Ram *et al*., (2012) conducted a field experiment at Ludhiana (Punjab) using seven sowing dates (October 25, November 5, November 15, November 25, December 5, December 15 and December 25) with six varieties and reported that October 25 sowing recorded the highest grain yield which was statistically at par with November 5, whereas December 25 gave the lowest yield. Likewise, Aslam *et al*. (2013) conducted an experiment at Adaptive Research Farm, Rahim Yar Khan, Pakistan during winter seasons. Effect of four planting dates i.e. 25th October, 5th November, 15th November and 25th November was studied on yield and yield components of wheat. Average of two years data showed that 5th November sowing significantly increase in yield was associated with progressive increase in all growth components. The variant effect of sowing dates to different varieties of what was also demonstrated by many scientists including Haider (2007), Ram *et al*., (2012) and Aslam *et al*. (2013).

Suleiman *et al*. (2014) reported that sowing dates have significant effect yield components that decreased with delay in sowing date and the highest values were obtained when cultivars sown on 1st November and 15th November.

Grain development was monitored at Rajshahi taking data of grain fresh weight and dry weight after anthesis. It was found that the grain development was slower up to 14 days after anthesis (1.43-3.76 g/spike) which thereafter increased rapidly up to 28 days after anthesis (4.88-6.16 g). Varieties differed in gaining grain weight linearly from days after anthesis showing early gaining with higher values in grain weight (6.05-6.07 g) in BARI Gom 26 and BARI Gom 27 on 28 days after anthesis. However the significantly the highest grain weight was obtained in Nov30 sowing with BARI Gom 29 (7.6 G).

The effect of variety as well as sowing time had also exerted significant effect on the phenological parameters. It was observed that at Rahshahi, wheat sown at optimum time took maximum number of days to booting, as similar observations were also recorded by

Mumtaz *et al*., (2015) in Bahawalpur (Pakistan). November 30 sown crop took highest number of days to booting due to lower canopy temperature (Table 4.4.7-4.4.9 . BARI Gom 25 took more number of days to physiological maturity and BARI Gom 30 took lower number of days to physiological maturity. Varieties with ability to stay green for longer time take longer days to physiological maturity in Bangladesh (Hossain *et al*., 2011).According to Russell and Wilson (1994) and Chakrabarti *et al*., (2011) suitable temperature for anthesis was 18-24^{0}C. More the temperature early will be the onset of anthesis. Mumtaz *et al*., (2015) also observed that variety with ability to tolerate high temperature conditions took higher number of days to booting as compared to susceptible one in Bahawalpur (Pakistan).

Days taken by the variety to heading depend upon the thermal tolerance ability of wheat varieties in China (Tao *et al.,* 2012). More the thermal tolerance capacity of the variety more will be the days. Varieties with ability to stay green under high temperature conditions took more number of days to anthesis (Wahid *et al.,* 2007). Similar results were reported by Hossain *et al.*, (2015) in sandy loam to silty loam soils of Bangladesh.

In the expt. 1 two varieties (BARI Gom 21 and BARI Gom 23 were sown four sowing dates (Nov 10, 20, 30 and Dec10). Results showed that both the varieties had identical grain yields with the November sowing (4.14-4.27 t ha^{-1}). This higher grain yield was attributed to 1000 grain weight (over 44 g) and biological yield (over 9 t ha^{-1}).

In the expt. 4 BARI at Rajshahi six different varieties (BARI Gom 25 and BARI Gom 26, BARI Gom 27, BARI Gom 28, BARI Gom 29 and BARI Gom 30) were sown at five different sowing dates (Nov20, 30, Dec10, 20 and 30). BARI Gom 30 under November 30 sowing dates had identical but significantly higher grain yields (over 4 t ha^{-1}) than others.

In the expt. 5 at SAU six different varieties (BARI Gom 25 and BARI Gom 26, BARI Gom 27, BARI Gom 28, BARI Gom 29 and BARI Gom 30) were sown at five different sowing dates (Nov20, 30, Dec10, 20 and 30).BARI Gom 28 and BARI Gom 30 with November20-30 sowing gave significantly higher grain yields than other treatments. This was attributed to the harvest index values of these treatments (29-33 %).

In all the experiments varieties were tested under varying sowing dates. However in experiment 2 and 3 extra N was also tried along with the sowing times in two individual varieties BARI Gom 26 and BARI Gom 25. In experiment 1 out of two varieties (BARI Gom 21 and BARI Gom 23) both the varieties in all the sowing dates (Nov 10=Dec 10) showed similar but significantly higher than that at sown at the latest (Dec 10). In experiment 2 and 3 interaction could not be tested as the two varieties were grown individually under varying sowing dates. In experiment 4 at Rajshahi the variety BARI Gom 30 sown on Nov 30 to Dec 10 showed significantly the higher grain yields (4.10-4.28 t ha^{-1}) which was almost double (80-88%) when compared to that (2.28 t ha^{-1}) of variety BARI Gom 29 sown on Dec30. At SAU BARI Gom 30 and BARI Gom 28 produced significantly higher grain yields (3.2-3.44 t ha^{-1}) which was 71-84% higher than that of the lowest grain yield obtained in BARI Gom 29 sown on Dec 30.

Variation for tolerance to high temperature stress among genotypes has been reported in wheat (Wardlaw *et al*. 1989, Viswanathan and Khanna-Chopra 2001, Tahir and Nakata 2005). It has long been known (Stoy 1965, Spiertz 1974) that with high temperatures after anthesis, increasing leaf senescence is coupled to a significant development of the respiration rates in the grain.

4.5.2.10 Amount of irrigation water in conventional system and supplementary application at post anthesis stage

In experiment 2 and 3 at SAU different irrigation treatments were imposed. In expt 2, three irrigation levels 100 (control), 50 and 20% were tried. Results showed that the highest grain yield (3.95 t ha^{-1}) was obtained at irrigation keeping the soil at field capacity level which was 25% and 27% higher than those of 15 and 20% respectively. This was attributed to the significantly higher number of grain/spike (50.83) and 1000 grain weight (50.57 g) against the lowest grain number and 1000 grain weight (46.83 grains and 48.90 g 1000 grain weight. Write other higher/supporting values of the above good treatment

In experiment 3 at SAU another experiment was set imposing irrigation application at post heading stages (10,20 and 30 days after heading). Other irrigations were applied at the approved phenological stages. It was found that the treatment application of irrigation at 10 days after heading produced 3.9 t ha^{-1} grain yield which may be attributed the higher values of grains/spike (43.63) and 1000 grain weight (53.90 g). The lowest values were 42.91 grains/spike 50.26 g 1000 grain weight in 30 Dec sowing. The variety BARI Gom 25 and BARI Gom 29 were longer (85.33-86.63 cm) while other varieties were shorter (81.67 -83.68 cm).

Manipulation of irrigation through both amount and frequencies has been tried before this study my many workers. Mekkei and Haggan (2014) conducted two field experiments in the successive winter seasons using varying irrigation regime including irrigation as needed or escaping some at different growth stages. They showed that skipping irrigation at various growth stages had significant effect on days to heading, days to maturity and days from heading to maturity. It was also shown that skipping irrigation at various growth stages significantly decreased plant parameters including grain yield in both the seasons. Chaudhary and Dahatonde (2007) observed that Irrigation frequency affected grain yield insignificantly showing increased water consumption with the rise in irrigation frequency and quantity.

Wu *et al*. (2011) revealed the effect of compensation irrigation on the yield and water use efficiency of winter wheat and found that a combinative treatment of irrigation in the former stage and medium irrigation compensation in the later were better.

Wang *et. al.* (2012) reported that a significant irrigation effect was observed on grain yield, kernel numbers and straw yield. The highest levels were achieved with a high irrigation supply, although WUE generally decreased linearly with increasing seasonal irrigation rates.

4.5.2.11Sowing date – irrigation interactions

In the expt. 2 BARI Gom 26 was sown at four different sowing dates (Nov 10, 20, 30 and Dec10 along with the three different amount of irrigation water (field capacity, half of the field capacity and one fourth of the field capacity) and also with two levels of extra N application at the grain filling stage (zero and 20% of the basal). Nov20 sowing with irrigation at field capacity had significantly the highest grain yield (4.54 t ha^{-1}) than other interaction treatments. This higher grain yield was attributed to the biological yield as was shown by this interaction treatment (8.86 t ha^{-1}), 1000 grain weight (56.07 g) and number of spikelet per spike (18.52).

In the expt. 3 BARI Gom 25 was sown at four different sowing dates (Nov 10, 20, 30 and Dec10 along with the three different amount of post anthesis irrigation (10, 20 and 30 days after anthesis) and also with two levels of extra N application at the grain filling stage (zero and 20% of the basal). Like in expt 3, Nov20 sowing with irrigation at field capacity had significantly the highest grain yield (4.46 t ha^{-1}) than other interaction treatments. This higher grain yield was attributed to the biological yield as was shown by this interaction treatment (8.57 t ha^{-1}), 1000 grain weight (61.48 g) and spike length (16.05 cm) andgrains per spike (over 47). In the expt with BARI Gom 26 (expt 2), the highest value of grain yield (4.54 t ha^{-1}) was found in I_1S_2 and the lowest value (2.87 t ha^{-1}) of the same trait was obtained in I_3S_1.

4.5.2.12 Extra N application at post heading stage

In experiment 2 and 3 at SAU, an extra 20% N of the recommended dose was applied in the sub-sub plots. The study revealed that an extra 20% N of the recommended dose showed grain yield of 3.960 t ha^{-1} (in expt 2) and 3.93 t ha^{-1} (in expt 3) which were significantly higher than that of the N non-applied plots (3.14 t ha^{-1} a) at post heading stage in the varieties 26 and 25 respectively.

4.5.2.13 Sowing date – extra N interactions

In the expt 2 BARI Gom 26 was sown at four different sowing dates (Nov 10, 20, 30 and Dec 10 along with the three different amount of irrigation water (field capacity, half of the field capacity and one fourth of the field capacity) and also with two levels of extra N application at the grain filling stage (zero and 20% of the basal). Nov 20 sowing with extra N application had significantly the highest grain yield (4.45 t ha^{-1}) than other interaction treatments. This higher grain yield was attributed to the biological yield as was shown by this interaction treatment (8.48 t ha^{-1}), 1000 grain weight (54.37 g), grains per spike (52.07), and harvest index 48.04%. In the expt 3 BARI Gom 25 was sown at four different sowing dates (Nov 10, 20, 30 and Dec 10 along with the three different amount of post anthesis irrigation (10, 20 and 30 days after anthesis) and also with two levels of extra N application at the grain filling stage (zero and 20% of the basal). Like in expt 3, Nov20 sowing with irrigation at field capacity had significantly the highest grain yield (4.48 t ha^{-1}) than other interaction treatments. This higher grain yield was attributed to the biological yield as was shown by this interaction treatment (8.15 t ha^{-1}), 1000 grain weight (58.98 g) and spike length (15.68 cm) and grains per spike (over 46.61). In the expt with BARI Gom 26 (expt 2), the highest grain yield (4.22 t ha^{-1}) was found in I_1N_2 while the minimum grain yield (3.16 t ha^{-1}) was recorded in I_3N_1.

Nitrogen assimilation or redistribution during the grain filling period is a limiting factor for grainproduction in crops (Donnison *et al*., 2006) which may decline the photosynthetic activity (Sinclair and Horie, 1989; Angus and Fisher, 1992), shorten the duration of grain filling period, and finally limit the grain yield. Nitrogen is applied through ammonia-based fertilizers have the potential to volatilize. Urea fertilizers generally volatilize more than other N fertilizers. Most volatilization from urea typically occurs during a two- to three-week period after application. Warm temperatures increase the rate of urea hydrolysis and ammonium conversion to ammonia gas, and therefore volatilization. For example, an increase in temperature from 45°F to 60°F can double volatilization loss when moisture content is kept the same (Ernst, 1960; Fan *et al*. 2011). This situation happens at the grain filling period of wheat (during Feg-March) and this may cause increase in N volatilization. The present study dealt with this situation.

Kumari (2011) applying N at the grain filling stage of wheat showed that the rate of photosynthesis was high during grain fill which she attributed to increase in nitrogen content of leaves in terms of Ru BPCO protein contents. Some other experiments showed that high N regimes before floral initiation increased spikelet number, but generally did not affect the time of spike development (Whingwiri and Kemp 1980). Changing nitrogen supply levels at the end of floret initiation and at anthesis showed (Steer *et al*. 1984) that grain number was determined by nitrogen supply before floret initiation (Whingwiri and Stern 1982). Kumari (2011) described that nitrogen influx at post anthesis stage might help in the development of florets formed at or after terminal spikelet formation and contribute in increased grain number and grain N content. She concluded that during the reproductive stage, nitrogen is translocation to growing grains. KARA (2010) applied both in conventional and spray from of nitrogen, and showed that when applied in late-season foliar, grain yield significantly increased. Grain filling is the final stage of growth in cereals where fertilized ovaries develop into caryopses. Its duration and rate determine the final grain weight, a key component of the total yield. In today's crop production systems with their high yield outputs, improvement in grain filling has become more challenging than ever (Venkateswarlu & Visperas, 1987; Saini & Westgate, 2000; Zahedi & Jenner, 2003).

4.5.2.14 Interaction of sowing time-irrigation-extra N application at post heading interactions

In experiment 2 at SAU, the variety BARI Gom 26 was grown under varying sowing dates (Nov 10 to Dec 10) varying irrigation regime (Fc, 50% and 25% of Fc) and an extra N supply (0 and 20% of recommended dose) at post heading stage. Results showed that Nov 20 sowing along with irrigation for maintaining field capacity and supplying an extra N at post heading gave the maximum grain yield (4.81 t ha^{-1}) which was 10% higher than that (4.39 t ha^{-1}) Nov30 sowing under no extra N supply. This was attributed to biological yield (9.13 t ha^{-1}), harvest index (48.76%), spike length (37.79 cm), spikelet per spike (18.67), grains per spike (55.20) and 1000 grain weight (56.22 g).

In the other trial with BARI Gom 25was sown at varying dates (Nov 10 to Dec 10) (grown under normal irrigated condition but supplying extra irrigation at post heading (10, 20 and 30 days after heading) plus supplying 20% extra N at post heading. Results showed that Nov20 sowing with 20% extra N application at 10 to 20 days after heading gave significantly higher grain yield (4.48-4.6 t ha^{-1}) showing 35-39% extra grain yields as compared to that the lowest obtained with Nov 10 sowing having no extra N and irrigated at 30 days after heading (3.3 t ha^{-1}). These higher grain yields were attributed to biological yield (8.30-8.59 t ha^{-1}), harvest index (48.76%), spike length (15.89-16.27), spikelet per spike (19.35-19.85), grains per spike (47.44-48.57) and 1000 grain weight (60.09-61.78 g).

BARI Gom 25 and BARI Gom 29 with Dec 10 sowing had the longest plant height (over 91 cm). In this study extra N was top dressed at the grain filling period in experiment 2 and 3. N topdressing at grain filling stage need to be followed by a light irrigation (as during this stage no precipitation occurs in Bangladesh) so that the dressed N gets into the root zone and so was done in these trials. There are evidences that under this moisture supply, pre-anthesis assimilate reserves in the stems and sheaths of wheat (*Triticum aestivum*) contribute 10–40% of the final grain weight (Rawson & Evans, 1971; Gallagher *et al*., 1976; Bidinger *et al*., 1977; Schnyder, 1993; Gebbing & Schnyder, 1999). Moreover, remobilization of reserves to the grain is critical for grain yield if the plants are subjected to water stress (unfavorable to the point of being stressful (Yoshida, 1972; Nicolas *et al*., 1985a,b; Palta *et al*., 1994; Ehdaie & Waines, 1996; Asseng & van Herwaarden, 2003; Plaut *et al*., 2004). Again there is strong evidence for sink limitation in modern wheat cultivars under post anthesis drought stress, and it appears that post anthesis nitrogen supply increases grain yield by decreasing sink limitation, and not by increasing source strength (BRUCKNER; FROHBERG, 1991).

4.5.2.15 Correlation analysis

In experiment 2 and 3 at SAU correlation was made among the yield and yield attributes. It was observed that all the attributes were significantly correlated at 1% level of probability (Table 2.1.1, 2.1.2 and 3.1.1). (correlation coefficient, r=0.530-0.966). Higher correlation (r) coefficient was observed between grain yield ha^{-1} with number of spikelet/spike (r=0.8200.814), 1000 grain weight (0.806-0.819), biological yield (r=0.802-0.912) and harvest index (r=0.802-0.912). Samuel *et al.* (2000) reported that late sowing condition (6 January 1997) reduce the harvest index (36.1%) from (41.5%) over normal sowing condition (29 November 1996) in wheat.

4.5.2.16Regression analysis

In this study linear regression and polynomial regression line/curve were fitted to data keeping temperature (Appendix table III) on the X axis whereas, number of grain/spike, grain weight/plant (g) and grain yield per hectare on the Y axis. The relationship between the yield and yield parameters were examined with temperatures at two different growth stages – from sowing to anthesis (before anthesis) and from anthesis to physiological maturity (Table .4.4.8). At these two growth stages (before and after anthesis) the data on yield and yield parameters were examined at three levels of temperature; maximum temperature (Tmax), minimum temperature (Tmin) and average temperature (Tave). As such the Tmax was calculated for these two stages (from sowing to anthesis and from anthesis to maturity) by averaging the maximum temperature of the days along these two stages. Likewise the Tmin (minimum temperature) was also calculated for these two stages (before anthesis and after anthesis) by averaging the minimum temperature of the days from sowing to anthesis and again from anthesis to maturity. The average temperature of these two stages was calculated averaging the average temperature (average of daily maximum and daily minimum temperature) along these two stages, that is from sowing to anthesis and from anthesis to maturity.

4.5.2.17 Positive effect of temperature from sowing to anthesis

Although temperature had mostly a negative effect on yield and yield contributing parameters at Rajshahi, it (before anthesis) had also positive impact on these parameters. Temperature before anthesis the temperature had positive impacts on the yield and yield parameters. The grain weight/plant increased with increasing minimum temperature (slope +139.89, R^2=0.659 &0.883). The minimum temperature had also positive effect on the yield ha^{-1} (slope 5.542,R^2= 0.390 &0.0.957, Fig. 4.1.9). Likewise the average temperature (maximum and minimum) had positive effect on grain weight (slope 216.33,R^2=o.326 &0.335, Fig. 4.4.8) and grain yield ha^{-1} (slope 2086.048,R^2=0.096 &0.0.120, Fig.4.4.10). Maximum temperature always showed negative effect on yield ha^{-1} (slope -0.300, R^2 = 0.777, Fig. 4.5.2).

From the polygonal curve it was grain that the number of grain/spike was maximum at the minimum temperature of 12.95^{0}C (R^2 value 0.943, Fig.4.4.11). The grain weight/plant was maximum at the average of daily minimum temperatures 13^{0}C (R^2 value 0.883, Fig.5.1.1). The minimum temperature of 13^{0}C also increased the grain yield ha^{-1} (R^2=C 0.727). Results also revealed that maximum temperature not above 25.5^{0}C helped to increase the grain yield of wheat (R^2=C 0.727).

However, no positive effect of temperature from sowing to anthesis was observed on the yield and yield attributes at SAU site (Fig.4.4.13-4.4.18). The polygonal analysis of the temperature from sowing to anthesis showed that at this site the minimum temperature below 15.5^{0}C showed maximum number of grains/spike (R^2= 0.819, Fig. 4.4.1), while the average temperature below 21.5 had maximum grain yields(4.56 t ha^{-1}, R^2=0.789, Fig. 4.4.8). The maximum temperature below 27.5^{0}C helped to produce maximum grain yield per hectare (R^2=885, Fig. 4.4.12).That is, at Rajshahi keeping the maximum, minimum and average temperature before anthesis below 27.5, 15.5 and 21.5^{0}C respectively were found to be not harmful for producing maximum grain number per spike and yield ha^{-1} (Fig. 4.4.12-4.4.14).

4.5.2.18 Positive effect of temp from anthesis to maturity

Positive effect of temperature at Rajshahi from anthesis to maturity up to a certain level was also having beneficial effect on the yield and yield attributes of wheat (Fig. 4.5.9-4.5.17). Linear regression showed that the number of grain/spike increased due to maximum daily temperature (slope 15.969,R^2=o.0.383 &0.0.832, Fig. 4.5.9), minimum temperature (slope 10.193,R^2=0.436 &0.0.907, Fig. 210) and average temperature (slope 12.494,R^2=0.417 &0.0.881, Fig. 4.5.11). No other yield and yield attributes did not increase due the ambient temperature.

The cause of increasing number of grain/spike with the increasing temperature both at vegetative (from sowing to anthesis) and reproductive stage (from anthesis to maturity) may be that the increasing all levels of temperature up to a certain level was favorable for the formation of grains at the vegetative stage. At the reproductive stage, the grains formed survived at the ambient temperature even that of the daily maximum.

This statement may be demonstrated by explaining the polygonal curves drawn with these yield and yield attribute parameter. Grain /spike increased with increasing the temperature not above the maximum, minimum and average respectively of 29.75, 15.75

and 22.7^{0}C (R^2= 0.832-0.907, Fig. 4.5.9-4.5.11). Likewise at the reproductive stage increasing the minimum and average temperature up to and not above 15.5 and 22.5^{0}C increased the grain yield ha^{-1} (R^2=0.922-0.992, Fig. 4.5.15-4.5.17).

Such situation also happened at SAU farm where not all the yield parameters, only the number of grain/spike increased with increasing the maximum, minimum and average temperature (slope 4.277-4.637,R^2=0.167-0.330 at linear & 0.474 to 0.905 at polygonal (Fig. 4.4.9). Again like in Rajshahi the polygonal regression at SAU showed that this grain/spike increased when the maximum, minimum and average temperature were maintained below 32.5, 18.5 and 25.5^{0}C at SAU site (Fig. 109-111).

4.5.2.19Negative effect of the ambient temperature from sowing to anthesis

At Rajshahi, the most of the yield and yield attributes responded negatively to the ambient temperature. Before anthesis, the most significant (based on the R^2 value) but negative effect was seen with the number grains/spike and the average temperature (slope -187.95, R^2=-0.753, Fig. 4.5.2), the grain weight/plant and all the temperature (maximum, minimum and average) with slope -5.305 to 316.33, R^2=0.304-0.883, fig. 203-205. and; yield ha^{-1} and maximum temperature (Tmax) with slope -0.300, R^2 = 0.777.

The polygonal regression shows that the number of grains per spike was maximum when the minimum temperature was around 12.97^{0}C before anthesis (Fig. 4.5.1). Likewise, the grain yield ha^{-1} decreased when the ambient max temperature increased above 25.5^{0}C before anthesis (Fig. 4.5.5).

At SAU, the relationship of the grain/spike and yield had also negative with the ambient maximum temperature. The grain per spike had a slope of -4.487 and R^2=-0819 with the polygonal regression. Likewise, yield per hectare had a slope -0.250 and R^2=0.885, (Fig. 4.4.6). That is, these two parameters decreased even with the increase of the maximum temperature enjoyed from sowing to anthesis.

At SAU, the polygonal regression shows that the number of grains/spike decreased when the ambient minimum temperature was above 15.3^{0}C. Likewise, the yield ha^{-1} decreased when the maximum temperature before anthesis was above 27.5^{0}C.

4.5.2.20 Negative effect of the temperature from anthesis to maturity

After anthesis at Rajshahi, all the ambient temperature (maximum, minimum and average) had a negative relation with the total grain weight/plant decreased (slope -24.505 to -41.14, R^2=0.933-0.972, Fig. 4.5.13) and yield ha^{-1} (slope -0.9736 to -1.755, R^2=0.922-0.992, Fig. 4.5.16).

The polygonal regression shows that grain weight decreased as the maximum temperature increased after anthesis (Fig. 4.5.9-4.5.11). The most pronounce effect was observed with the yield ha^{-1} which decreased the ambient maximum, minimum and average temperature during grain filling period (after anthesis) respectively were 29.5,15.5 and 22.5^{0}C (Fig. 4.5.15-4.5.17). Similar situation was also observed at SAU showing that the grain number per spike and yield ha^{-1} decreased with the increase of the ambient temperature (maximum, minimum and average) showing respectively slope -13.198 to -18.206, R^2=0.888-0.993; and slope -0.691 to -0.973, R^2=0.492-0.989 Fig. 4.4.2-4.4.4&4.4.8- 4.4.10).

Effect of the ambient temperature has been found to be a determinant factor on the plant parameters. Temperature may act as a modifying factor in all stages of wheat development including tillering, booting, ear emergence, anthesis and maturity since it can influence the rate of water supply and other substrates necessary for growth, but varies with plant species, variety and phenological stages (Wahid *et al*., 2007). Under high temperature, the crop completes its life cycle much faster than under normal temperature conditions (Fischer, 1985; Hakim *et al*., 2012; Hossain *et al*., 2009, 2011, 2012a, 2012b, 2012c; Nahar *et al.,* 2010; Rahman *et al*., 2009). Delayed planting in a sub-tropical region such as Pakistan, India, Bangladesh, etc. reduced plant height, days to heading, days to maturity and the duration of grain filling and ultimately reduced yield and yield components (Din and Singh, 2005; Mahboob *et al*., 2005).Wheat sown at optimum time took maximum number of days to booting, as similar observations were also recorded by Mumtaz *et al*., (2015) in Bahawalpur (Pakistan).

CHAPTER 5

SUMMARY AND CONCLUSION

SUMMARY

A series of experiments were conducted to identify climate change resilient heat tolerant varieties, suitable sowing dates, irrigation regimes and application of supplemented N to wheat during two rabi seasons at two different locations of Bangladesh. The specific objectives of these trial were to detect appropriate sowing time preferable for the heat tolerant wheat varieties so as to set climate resilient management and to identify short duration heat tolerant late variety(ies) of wheat in Bangladesh. To increase wheat productivity under the ever increasing temperature at the reproductive stage and to evaluate the amount and timing of irrigation to cope with the soil moisture depletion under increased ambient temperature especially at the reproductive stage of wheat. To investigate the effect of supplemented nitrogen application at post anthesis stage of the late varieties of wheat and to find relationship between ambient temperature with the growth, phenology and yield attributes.

Five experiments were conducted in this study: first three at SAU during rabi 2014-15, 4th at Rajshahi and 5th at SAU during rabi 2016-17. The title and treatments of the experiments were; Experiment 1. Performance of wheat varieties as influenced by different sowing dates with two factors; Factor A (Variety: BARI Gom 21, BARI Gom 23; Factor B sowing at 10 November, 20 November 30 November and 10 December; Experiment 2. Effects of irrigation, sowing date and post anthesis supplemented nitrogen application on the performance of wheat (variety BARI Gom 26) with three factors; Factor A: Irrigation at field capacity, Irrigation at 50% of field capacity, Irrigation at 25% of field capacity, Factor B: sowing at 10 November, 20 November, 30 November and 10 December; Factor

C: 20% supplemental nitrogen of recommended dose as top dressing at the reproductive stage and no nitrogen; Experiment 3. Effect of sowing dates, supplemental irrigation and nitrogen application on the performance of wheat (variety BARI Gom 25) with three factors; Factor A: Irrigation at heading stage, Irrigation after 10 days of heading and irrigation after 20 days of heading, Factor B: sowing at 10 November, 20 November, 30 November and 10 December; and Factor C: 20% nitrogen as top dressing at the reproductive stage ad no nitrogen application at the reproductive stage of the recommended dose of N; Experiment 4. Phenology, chlorophyll, canopy temperature, growth and yield of wheat varieties as influenced by sowing dates in northern Bangladesh with two factors; Factor A:Sowing Nov 20, Nov 30, Dec 10, Dec 20, Dec 30, Factor B: 6 wheat varieties BARI Gom 25, BARI Gom 26,
BARI Gom 27, BARI Gom 28, BARI Gom 29 and BARI Gom 30; Experiment 5. Growth, yield attributes and yield of wheat as influenced by sowing dates and varieties in Dhaka at SAU with same factor and same treatments.

Data on yield attributes and yield were recorded and analyzed. This chapter represents the summary and conclusion for the series of experiments. The results have been summarized below.

Effect of sowing dates on ambient temperature

In this study the ambient temperature has been studied at two growth stages of the crops; from sowing to anthesis (vegetative) and anthesis to maturity (reproductive). In each stage the averages of the daily maximum, minimum and average temperature were calculated.

Results showed that irrespective of the growth stages, the SAU site had higher maximum temperature (29.44-32.91^{0}C) than Rajshahi (24.85-29.91^{0}C) and across the sites the maximum temperature was higher at the reproductive stage of plants (24.85-29.91^{0}C) as compared to the anthesis to maturity (29.44-32.91^{0}C).

Across the sites the average of the daily average temperature was higher at the reproductive stage of plants (22.34-25.96^{0}C) than at the vegetative (19.86-23.12). Again at the reproductive stage the SAU site had higher average temperature (23.12-25.96^{0}C with Dec 30 sowing) than at Rajshahi 19.92-22.96^{0}C).

Sowing to anthesis, both at Rajshahi and SAU had the higher average of the daily average maximum (26.96-30.21^{0}C) with De 30, but the higher minimum was with Nov 20 (above 13^{0}C-16.21^{0}C). Again at SAU the Dec 20 sowing had the higher average temperature 23.12^{0}C). But at anthesis to maturity, the Dec 30 sowing at SAU site had always higher maximum temperature (32.91) than at Rajshahi (29.91^{0}C).

Again, the differences of maximum, minimum and average between the vegetative and reproductive stages were wider at Rajshahi (respectively 2.94, 3.0 and 3.04^{0}C) than at SAU (respectively 1.7, 2.81 and 2.84^{0}C). Moreover the difference was wider at the vegetative than at the reproductive.

In this study sowing date started on November 10 of 2014-15 in SAU farm using four different wheat varieties (BARI GOM-21, BARI GOM-23, BARI GOM-25 and BARI Gom 26). BARI Gom 21 and BARI Gom 23 were accommodated in a single experiment, while other two varieties were tested in two individual experiment as such these four varieties were accommodated in three experiments. All the varieties were sown in four different dates (Nov10, 20, 30 and Dec 10). Results showed that most of the varieties performed better while sown on Nov 20.

Effect of sowing dates on canopy temperature

In the expt. 4 at Rajshahi, the canopy temperature at anthesis was minimum (21.13-21.51^{0}C) with in Nov sowing crops while it remained higher (22.45^{0}C) in December sowing, but more higher in the later sowings (25.86-28.19^{0}C). BARI Gom 29 at Rajshahi had the higher ground coverage at the latest in 78.7 days while others had it at earlier in about 70-74 days.

Effect of sowing dates on ground coverage

Statistically significant variation was recorded on the effect of sowing dates on percent ground coverage at different growth stage (Fig.4.4.2). The maximum ground coverage percentage (75.28%) was found from S_3 that mean December 10 sowing at 60 DAS followed by (74.72%) was found from S_2 at 60 DAS and statistically significant from (74.17%) from S_4 whereas the minimum ground coverage percentage (67.17%) at 60 DAS was recorded from the treatment S_1 that mean early sowing. Regression analysis showed that the ground coverage data was best fitted to the polynomial regression although it was negative (slope-4682 in linear, with R^2=0.964 in polynomial, Fig.4.4.2-4.4.3).

Effect of sowing dates on chlorophyll content

Different sowing dates significantly influenced the chlorophyll content (%) at all crop growth stages. Chlorophyll content percentage was increased to increasing at anthesis stage and decreases at maturity stage. The maximum chlorophyll content (50.90%) was found from V_3S_3 at anthesis stage. The chlorophyll content (at anthesis) decreased with the increase of the ambient maximum temperature. The relationship was linearly but negative both in linear regression (slope -0.629) and the R^2=0.86).

Effect of sowing dates on phenological stages

Sowing dates had also significant effect on the phenological stages of wheat. Significantly higher number of days was taken by November 30 sown crop to booting than November 20, December 10, December 20 and December 30 sowing. November sown crop took 3-5 days more than November 20 and

December 10-30 sown crop. Date of sowing significantly influenced the days taken to heading. November 30 sown crop took maximum calendar days to heading 60 which was significantly higher than November 20 and December 10-30 sown crop. At Rajshahi the Nov 30 sowing took more days to booting, heading (60 days) and maturity. The maturity became delayed at the average temperature below 22.5^0C and beyond which it was shortened. November 20 sown crop took maximum calendar days to anthesis, which was statistically at par with November 20 but significantly higher than December 10-30 sowing. Early onset of anthesis in December 10 was due high temperature conditions prevailed at the time of anthesis. November 30 sowing took maximum number of days to physiological maturity, which was significantly higher than November 20 and December 10-30 sowing. Crop sown on November 30 took 5.4 and 12.8% higher days to physiological maturity as compared to November 20 and December 5-30 sowing, respectively.

Effect of sowing dates on yield and yield attributes

In the first experiment Nov 20 sowing produced grain yields from 4 to 4.06 t/ha over the varieties which were significantly higher and much higher than that sown on Nov 30 3.59 t ha^{-1} showing a difference of over 14%. Likewise in the second experiment with BARI Gom 26, Nov 20 sowing produced the highest seed yield (4.180 tha^{-1}) which was significantly higher than the values of other sowing especially showing over 33% higher seed yields as compared to that of Nov 10 sowing (3.14 t ha^{-1}). In the third experiment with BARI Gom 25, again the Nov 20 sowing out yielded the other sowing dates showing seed yield of 4.33 t/ha which was also significantly higher than the grain yields of other sowing showing over 27% higher seed yield than that (3.4) produced by Nov10 sowing.

In the fourth experiment at Rajshahi in the second year (2015-16) six different varieties (BARI Gom 25, BARI Gom 26, BARI Gom 27, BARI Gom 28, BARI

Gom 29 and BARI Gom 30) were sown in different dates (Nov 20, Nov 30,Dec10, Dec 20 and Dec 30) based on the seed yield results of the previous year (2014-15) wherein the November10 sowing yielded the worst. Same varieties were also sown in SAU farm so as to make a comparison for identifying the impact of the surrounding temperature as prevailed in these two distinct region. Dec 10 to 20 showed significantly higher seed yields (3.39-3.52 t ha^{-1}) which were significantly higher (up to 39%) than those other treatments (2.44-3.24 t ha^{-1}). The Variety BARI Gom 25 and BARI Gom 29 were longer (85.33-86.63 cm) while other varieties were shorter (81.67 -83.68 cm).

While in the SAU farm (fifth experiment) in the same year the Nov 30 sowing showed the highest grain yield (3.02 t ha^{-1}) which was significant over others showing over 55% higher grain yield as compared to that (1.94 t ha^{-1}) of the grain yield obtained in the latest sown plots (Dec 30).

Effect of varieties

In experiment 1-3 four varieties were tested, BARI Gom 21 and BARI Gom 23 were tried in Expt 1 while in the expt 2 and 3 BARI Gom 26 and BARI Gom 25 were used to identify proper irrigation, extra N and sowing time for having good yields. In the expt 1 BARI Gom 23 performed better showing 4.11 tha^{-1} which was significantly higher than that of the BARI Gom 21 (3.95 t ha^{-1}). In the expt 2 and 3 BARI GOM-26 and BARI Gom 25 yielded 4.18 and 4.33 t ha^{-1}respectively by BARI Gom 26 and BARI Gom 25. In expt 3 (at Rajshahi) and 4 (at SAU) six different heat tolerant wheat varieties (BARI Gom 25, BARI Gom 26, BARI Gom 27, BARI Gom 28, BARI Gom 29 and BARI Gom 30) were tested.

In experiment 4 at Rajshahi the variety BARI Gom 28 and BARI Gom 30 had significantly identical but higher grain yields (3.72=3.81 t ha^{-1}) which were over 25% higher as compared to that of the lowest of all (2.97 t ha^{-1}) shown by the variety BARI Gom 26.

In the experiment 5 at SAU, The varieity BARI Gom 30 produced significantly the highest seed yield (3.22 t ha^{-1}) which was 30% highest than the lowest value of the variety BARI Gom 26 (2.47 t ha^{-1}).

Evaluating the results of SAU and Rajshahi it may be summerized that in the both sites BARI Gom 26 performed the worse while BARI Gom 28 and BARI Gom 30 had the highest grain yield. This was attributed to the plant parameters of the variety BARI Gom 30 giving the highest values at Rajshahi of ground coverage (78%) at 60 days after sowing, gaining fresh weight (12.18 g) at 28 days after anthesis, spikelets per spike (15.97), grains per spike (46), 1000 grain weight (49.48 g), biological yield (11.33 t/ha) and harvest index (33.60%). This variety also attained the physiological maturity at the earliest in 98.60 days as compared to 100-102 days of the other varieties. Likewise the highest seed yield of BARI Gom 30 at SAU was attributed to the highest values in number of spikes per m^2 (243.83), biological yield (10.83t ha^{-1}) and harvest index (30.56%). That is in the both sites BARI Gom 26 performed the worse while BARI Gom 30 had the highest grain yield.

Interaction effect of variety and sowing time

The interaction of sowing date-variety showed that in experiment 1 out of two varieties (BARI Gom 21 and BARI Gom 23) both the varieties in all the sowing dates (Nov 10=Dec 10) showed similar but significantly higher than that at sown at the latest (Dec 10). In experiment 4 at Rajshahi the variety BARI Gom 30 sown on Nov 30 to Dec10 showed significantly the higher seed yields (4.10-4.28 t/ha) which was almost double (80-88%) when compared to that (2.28 t ha^{-1}) of variety BARI Gom 29 sown on Dec 30. This was attributed to the plant parameters of the variety BARI Gom 30 giving the highest values at Rajshahi of ground coverage (78%) at 60 days after sowing, gaining fresh weight (12.18 g) at 28 days after anthesis, spikelets per spike (15.97), grains per spike (46), 1000 seed weight

(49.48 g), biological yield (11.33 t ha^{-1}) and harvest index (33.60%). This variety also attained the physiological maturity at the earliest in 98.60 days as compared to 100-102 days of the other varieties. Likewise the highest seed yield of BARI Gom 30 at SAU was attributed to the highest values in number of spikes per m^2 (243.83), biological yield (10.83 t ha^{-1}) and harvest index (30.56%).

In all the experiments varieties were tested under varying sowing dates. However, in experiment 2 and 3 extra N was also tried along with the sowing times in two individual varieties BARI Gom 26 and BARI Gom 25. In experiment 1 out of two varieties (BARI Gom 21 and BARI Gom 23) both the varieties in all the sowing dates (Nov 10 to Dec 10) showed similar but significantly higher than that at sown at the latest (Dec 10). In experiment 2 and 3 interactions could not be tested as the two varieties were grown individually under varying sowing dates.

Effect of irrigation

In experiment 2 at SAU different irrigation treatments were imposed. In expt. 2, three irrigation levels were tried. Results showed that the highest grain yield (3.95 t ha^{-1}) was obtained at irrigation keeping the soil at field capacity level which was higher than those of other two levels. In experiment 3 at SAU another experiment was set imposing irrigation application at post heading stages, (at heading, 10 and 20 days after heading). Other irrigations were applied at the approved phenological stages. It was found that the treatment application of irrigation at heading produced 3.9 t ha^{-1} grain yield which was significantly higher than those of the irrigation treatment at 10 and 20 days after heading, respectively.

Effect of extra N application at post heading stage

In experiment 2 and 3 at SAU, and supplemental 20% N of the recommended dose was applied in the sub-sub plots. The study revealed that an supplemented

20% N of the recommended dose showed grain yield of 3.96 t ha^{-1} (in expt 2) and 3.93 t ha^{-1} (in expt 3) which were higher than that of the N non-applied plots (3.14 t ha^{-1}) at post heading stage in the varieties 26 and 25 respectively.

An supplemental 20% N application over the recommended dose at the post heading stage in experiment 2 and 3 at SAU showed higher grain yields of 3.960 t ha^{-1} (in expt 2) and 3.93 t ha^{-1} (in expt 3) which were significantly higher than that in the plots where no N was applied (around 3 t ha^{-1}).

In experiment 2 at SAU irrigation keeping the soil at field capacity level showed the highest grain yield (3.95 t ha^{-1}) was obtained at which was 25% and 27% higher than those of 15% and 20% respectively. This was attributed to the significantly higher number of grain/spike (50.83) and 1000 grain weight (50.57 g) against the lowest seed number and 1000 grain weight (46.83 grains and 48.90 g 1000 grain weight. While in experiment 3 at SAU irrigation application at heading produced 3.9 t ha^{-1} grain yield which may be attributed the higher values of grains/spike (43.63) and 1000 grain weight (53.90 g). The lowest values were 42.91 grains/spike 50.26 g 1000 grain weight in 10 Dec treatment.

Interaction effect of sowing dates and irrigation

In respect of the interactions of sowing date and irrigation showed that In the expt. 2 and 3, Nov 20 with irrigation individually at field capacity and at heading in addition to the recommended irrigation had significantly the highest grain yield (4.46-4.54 t ha^{-1}) which were higher compared to other interaction treatments.

Interaction effect of sowing date and extra N applied at the post heading stage in the expt 2 and 3 showed that the Nov 20 sowing with extra N application had significantly the highest grain yield (4.45 -4.48 t ha^{-1}) than other interaction treatments.

Interaction of sowing time-irrigation-supplemented N application at post heading showed that in experiment 2 at SAU showed that the Nov 20 sowing gave the higher seed yields (4.65 t ha^{-1}) when grown individually maintaining the soil moisture at field capacity, giving an extra irrigation at heading and supplying an extra 20% N at post heading stage (4.6-4.81 t ha^{-1}) which was significantly higher than the lowest grain yield of Nov10 sowing (3.3 t $ha^{-1)}$ under the above conditions.

Interaction of sowing time, irrigation and supplemented N application at post heading

In experiment 2 at SAU, the variety BARI Gom 26 was grown under varying irrigation regime (Fc, 50% and 25% of Fc) and an extra N supply (0 and 20% of recommended dose) at post heading. Results showed that Nov 20 sowing along with irrigation for maintaining field capacity and supplying an extra N at post heading gave the maximum seed yield (4.81 t ha^{-1}) which was 10% higher than that (4.39 t ha^{-1}) Nov 30 sowing under no extra N supply.

In the other trials with BARI Gom 25 sown at varying dates (grown under normal irrigated condition but supplying extra irrigation at heading, 10 days, 20 days after heading and supplying 20% supplemented N at post heading showed that Nov 20 sowing with 20% supplemented N application than at 10 to 20 days after heading gave significantly higher grain yield (4.48-4.6 t/ha) showing 35-39% extra grain yields as compared to that the lowest obtained with Nov10 sowing having no extra N and irrigated at 20 days after heading (3.3 t ha^{-1}).

Correlation analysis

The correlation analysis using the data of yield and yield attributes of the experiment 2 and 3 at SAU showed higher correlation were found the number of spikelet $spike^{-1}$ (r=0.814-0.820), 1000 seed weight (0.806-0.819), biological yield (r=0.802-0.912) and harvest index (r=0.802-0.912).

Regression analysis

It was observed that at Rajshahi the grains spike^{-1}, grain weight per spike and yield per hectare did not have good fitness when set them either to linear regression analysis nor to even polynomial regression showing lower coefficient of determination (R^2) values in the range of 0.201-0.727 when fitted with maximum temperature. That is these two parameters did not depend much on the ambient temperature although the values decreased after reaching maximum at a certain temperature increase. When fitted with the minimum temperature, these parameters fitted as week as with maximum temperature showing R^2 values in the range of 0.390-0.659. But when fitted using polynomial regression the R^2 value were much higher showing the range of 0.883-0.943 proving that under a certain range of minimum temperature of the day, the values of these three parameters increased increasing the ambient temperature up to a certain level and thereafter decreased under further increase. Change in the trend of such polynomial regression line suggest that for the proper development of the yield parameters an optimum temperature needs to be available surrounding the plants microclimate.

The linear as well as polynomial regression showed that the higher temperature at the vegetative stage had positive impact on grain weight/plant and grain yield per hectare (slope +6 to 2086, R^2=0.120 to 0.957). While at the anthesis to maturity except the number of grain/spike, no other yield and yield attributes increased due the increase in

ambient temperature. The grain yield was at the highest at the minimum and average temperature not above 15.5 and 22.5^{0}C, respectively (R^2=0.922-0.992).

At both the vegetative and reproductive stage at both the places, a negative relationship was seen of the number grains/spike, grain weight per plant and yield per hectare with (slope minus 3 to minus 188; R^2= 0.753 to 0.972. The polygonal regression shows that maximum temperature for obtaining the maximum yield/ha should not be above 25.5^{0}C before anthesis while the maximum, minimum and average after anthesis should not be over 29.5, 15.5 and 22.5^{0}C respectively.

The polynomial regression showed that higher ground coverage (maximum of 60 DAS) was seen at the minimum temperature of 15.5^{0}C. The higher ground coverage was seen at the average temperature of 21^{0}C and with further increase the ground coverage decreased. The regression analysis showed that the biological yield decreased with the increase of canopy temperature, however the slope was not so high (-0.497) and it increased when the canopy temperature increased from 20^{0}C having the maximum value at about 21.5^{0}C. The chlorophyll content (at anthesis) decreased with the increase of the ambient maximum, minimum and average temperature (slope - 0.629 to -1.222) and the R^2=0.625-0.882). Such relationships were also observed while fitting the data of number of grains per spike, grain weight per spike and yield per hectare at SAU site.

Fitting the yield and yield parameter revealed that the minimum temperature were more congenial for increasing the values of the yield and yield attributes although the values of these parameters reached pick at a certain level of maximum, minimum and average temperature and thereafter decreased under further increase in temperature.

CONCLUSION

During 1st year three experiments were conducted and included the sowing at 10 November, 20 November, 30 November and 10 December either with a single or multiple varieties like BARI Gom 21 and 23, Expt 2: BARI Gom 26 and Expt 3: BARI Gom 25 and two of them (Expt 2 and 3) had irrigation treatments; (in expt 2: Irrigation at field capacity, 50% of the field capacity and 25% of the field capacity and application stages (in expt. 3: Irrigation at heading stage, 10 days after heading and 20 days after heading along with the application of 20% supplemental Nitrogen (in expt. 2 and 3). While in the second year six different heat tolerant varieties were tested in two different agro-climatic zones (Dhaka and Rajshahi) under five different sowing dates at Nov 20, Nov 30, Dec 10, Dec 20 and Dec 30). Data were taken on the ambient temperatureof both Rajshahi and SAU) in the second year only), crop phenology, growth and yield of wheat varieties only.

The ambient temperature had been studied at two growth stages of the crops; from sowing to anthesis (vegetative) and anthesis to maturity (reproductive). In each stage the averages of the daily maximum, minimum and average temperature were calculated.

Irrespective of the growth stages, the SAU site had higher maximum temperature (29.44-32.91^{0}C) than Rajshahi (24.85-29.91^{0}C) and across the sites the maximum temperature was higher at the reproductive stage of plants (24.85-29.91) as compared to that of the anthesis to maturity (29.44-32.91^{0}C).

Across the sites the average of the daily average temperature was higher at the reproductive stage of plants (22.34-25.96) than at the vegetative (19.86-23.12^{0}C). Again at the reproductive stage the SAU site had higher average temperature (23.12-25.96^{0}C with Dec 30 sowing) than at Rajshahi 19.92-22.96^{0}C).

Sowing to anthesis, both at Rajshahi and SAU had the higher average of the daily average maximum (26.96-30.21^{0}C) with Dec 30, but the higher minimum was with Nov20 (above 13^0C-16.21^0C). Again at SAU the Dec 20 sowing had the higher average temperature 23.12 ^0C). But at anthesis to maturity, the Dec 30 sowing at SAU site had always higher maximum temperature (32.91^0C) than at Rajshahi (29.91^0C).

Again, the differences of maximum, minimum and average between the vegetative and reproductive stages were wider at Rajshahi (respectively 2.94, 3.00 and 3.04^0C) than at SAU (respectively 1.7, 2.81 and 2.84^0C). Moreover the difference was wider at the vegetative than at the reproductive.

Sowing dates had also had effect on the phenological stages of wheat. At Rajshahi the Nov 30 sowing took more days to booting, heading (60 days) and maturity.The maturity became delayed at the average temperature below 22.50^0C and beyond which it was shortened.

The polynomial regression showed that higher ground coverage (maximum of 60 DAS) was seen at the minimum temperature of 15.5^0C. The higher ground coverage was seen at the average temperature of 21^0C and with further increase the ground coverage decreased. The regression analysis showed that the biological yield decreased with the increase of canopy temperature, however the slope was not so high (-0.497) and it increased when the canopy temperature increased from 20^0C having the maximum value at about 21.5^0C. The chlorophyll content (at anthesis) decreased with the increase of the ambient maximum, minimum and average temperature (slope - 0.629 to -1.222) and the R^2=0.625-0.882).

In 2014-16 Nov 10-20 sowing in three experiments at SAU had higher seed yields (over 4 t/ha) than the Nov 30 sowing dates (below 4 t/ha). But in the further trial in 2016-17 at this site Nov 30 sowing had higher seed yields (3.02 t/ha) than the earlier November sowing on Nov 20 (2.79 t/ha). But at Rajshahi during 2016-17 rabi season, the Dec 10 to 20 sowing showed higher seed yields (3.390-3.520 t/ha) It was observed that in the both sites BARI Gom 26 performed the worse while BARI Gom 28 and BARI Gom 30 had the highest seed yield. This was attributed to the plant parameters of the variety BARI Gom30 giving the highest values at Rajshahi of ground coverage (78%) at 60 days after sowing, gaining fresh weight (12.18 g) at 28 days after anthesis, spikelets per spike (15.97), grains per spike (46), 1000 grain weight (49.48 g), biological yield (11.33 t/ha) and harvest index (33.60%). This variety also attained the physiological maturity at the earliest in 98.60 days as compared to 100-102 days of the other varieties. Likewise the highest seed yield of BARI Gom 30 at SAU was attributed to the highest values in number of spikes per m^2 (243.83), biological yield (10.83 t/ha) and harvest index (30.56%).

In the expt. 4 at Rajshahi, the canopy temperature at anthesis was minimum (21.13-21.51^{0}C) with in Nov sowing crops while it remained higher (22.45^{0}C) in December sowing, but higher in the later sowings (25.86-28.19^{0}C).

BARI Gom 29 at Rajshahi had the ground coverage at the latest in 78.70 days while others had it at earlier in about 70-74 days.

The interaction of sowing date-variety showed that in experiment 1 out of two varieties (BARI Gom 21 and BARI Gom 23) both the varieties in all the sowing dates (Nov 10=Dec 10) showed similar but significantly higher than that at sown at the latest (Dec 10). In experiment 4 at Rajshahi the variety BARI Gom 30 sown on Nov 30 to Dec 10 showed significantly the higher grain yields (4.10-4.28 t/ha) which was almost double (80-88%) when compared to that (2.28 t/ha) of variety BARI Gom 29 sown on Dec 30. At SAU BARI Gom 30 and BARI Gom 28 produced significantly higher grain yields (3.2-3.44 t/ha) which was 71-84% higher than that of the lowest seed yield obtained in BARI Gom 29 sown on Dec 30.

In experiment 2 at SAU irrigation keeping the soil at field capacity level showed the highest seed yield (3.95 t ha^{-1}) was obtained at which was 25 and 27% higher than those of 15 and 20% respectively. This was attributed to the significantly higher number of grain $spike^{-1}$ (50.83) and 1000 grain weight (50.57 g) against the lowest seed number and 1000 seed weight (46.83 grains and 48.90 g 1000 seed weight. While in experiment 3 at SAU irrigation application at 10 days after heading produced 3.9 t ha^{-1} grain yield which may be attributed the higher values of grains $spike^{-1}$ (43.63) and 1000 grain weight (53.90 g). The lowest values were 42.91 grains $spike^{-1}$ and 50.26 g 1000 grain weight in 30 Dec treatment.

The Variety BARI Gom 25 and BARI Gom 29 were longer (85.33-86.63 cm) while other varieties were shorter (81.67 -83.68 cm). In respect of the interactions of sowing date and irrigation showed that In the expt. 2 and 3, Nov 20 with irrigation individually at field capacity and at 10 days after heading in addition to the recommended irrigation had significantly the highest grain yield (4.46-4.54 t ha^{-1}) which were higher compared to other interaction treatments. An extra 20% N application over the recommended dose at the post heading stage in experiment 2 and 3 at SAU showed higher seed yields of 3.960 t/ha (in expt. 2) and 3.93 t ha^{-1} (in expt 3) which were significantly higher than that in the plots where no N was applied (around 3 t ha^{-1}).

Interaction effect of sowing date and extra N applied at the post heading stage in the expt 2 and 3 showed that the Nov 20 sowing with extra N application had significantly the highest seed yield (4.45-4. t ha^{-1}) than other interaction treatments.

Interaction of sowing time-irrigation-supplemental N application at post heading showed that in experiment 2 and 3 at SAU showed that the Nov 20 sowing gave the higher grain yields (4.65 t ha^{-1}) when grown individually maintaining the soil moisture at field capacity, providing an supplemental irrigation 10 days after heading and supplying an supplemental 20% N at post heading stage (4.6-4.81 tha^{-1}) which was significantly higher than the lowest grain yield of Nov 10 sowing (3.3 t ha^{-1}) under the above conditions.

The correlation analysis using the data of yield and yield attributes of the experiment 2 and 3 at SAU showed higher correlation were found the number of spikelet $spike^{-1}$ (r=0.8200.814), 1000 grain weight (0.806-0.819), biological yield (r=0.802-0.912) and harvest index (r=0.802-0.912).

The linear as well as polynomial regression showed the higher temperature at the vegetative stage had positive impact on grain weight $plant^{-1}$ and grain yield per hectare (slope +6 to 2086, R^2=0.120to 0.957). While at the anthesis to maturity except the number of grain $spike^{-1}$, no other yield and yield attributes increased due the increase in ambient temperature. The grain yield was highest at the minimum and average temperature not above 15.5 and 22.5^0C, respectively (R^2=0.922-0.992).

At both the vegetative and reproductive stage at both the places, a negative relationship was seen of the number grains $spike^{-1}$, grain weight per plant and yield per hectare with (slope minus 3 to minus 188; R^2= 0.753 to 0.972. The polygonal regression shows that maximum temperature for obtaining the maximum yield ha^{-1} should not be above 25.5^0C before anthesis while the maximum, minimum and average after anthesis should not be over 29.5, 15.5 and 22.5^0C respectively.

RECOMMENDATION

In experiment 1 at Sher-e-Bangla Agricultural University (SAU), BARI Gom 23 sown on November 20-30 showed higher grain yield. In experiment 2 and 3 at SAU wheat sown on November 20-30 had higher grain yields. At Rajshahi, Variety BARI Gom 28 and BARI Gom 30 sown on November 30 to December 10 showed significantly higher grain yields whereas, at SAU BARI Gom 28 and BARI Gom 30 produced significantly higher grain yields when sown on November 30. Application of 20% supplemental N and irrigation at reproductive stage did not produce grain yield significantly. However the interaction with sowing dates, varieties affected significantly.

Temperature at SAU in Dhaka city was 3 to 4^{0}C higher than that of periphery of Dhaka district. Again at Rajshahi the trial was made at on-farm in the village of Shahapur and for that the result may not fit to other villages of Rajshahi region.

So, for the precise recommendation the current study needs to be repeated to all the agro-ecological regions of Bangladesh so that a general recommendation could be made for farmers regarding the selection of climate resilient variety (ies) of wheat.

CHAPTER 6

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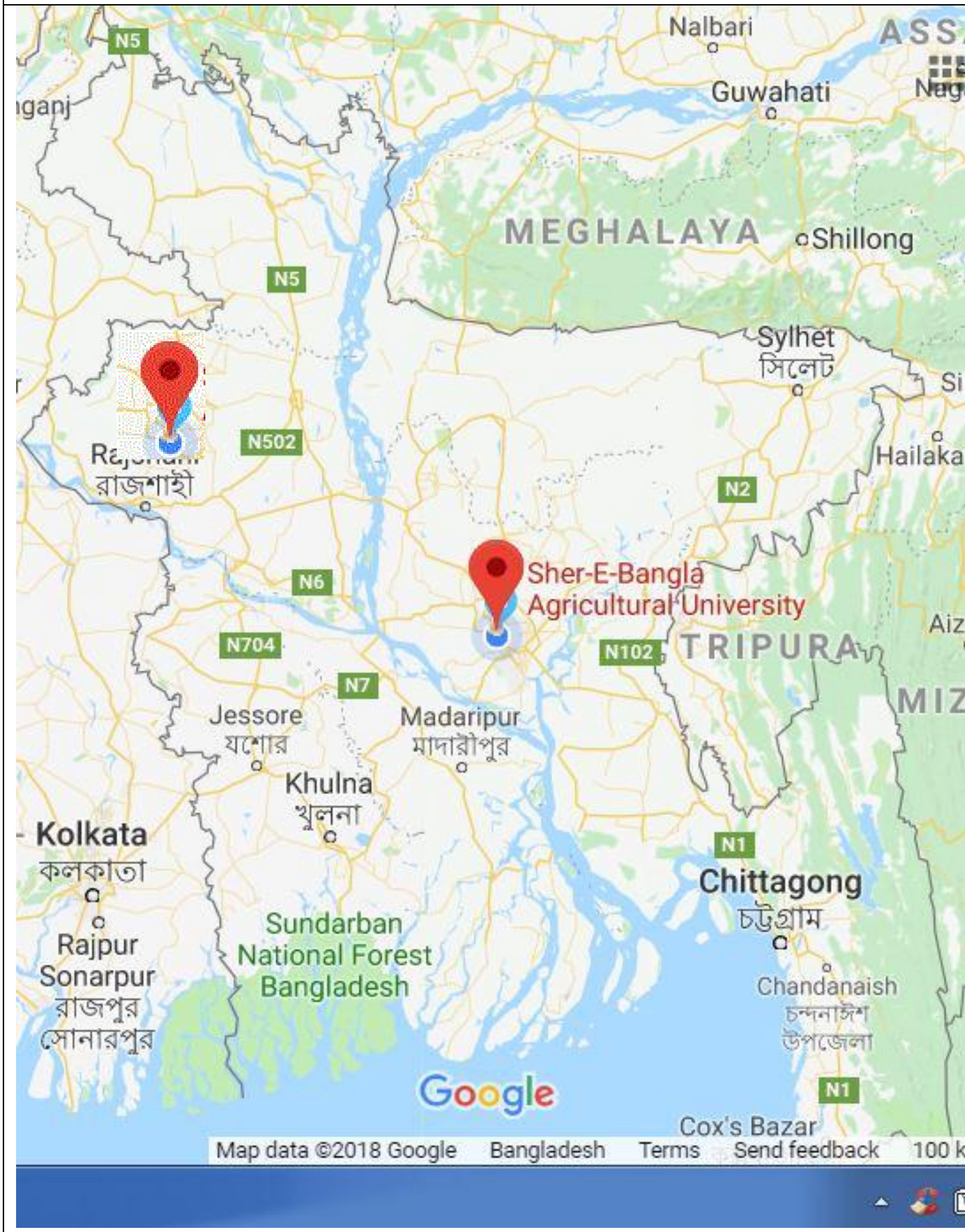
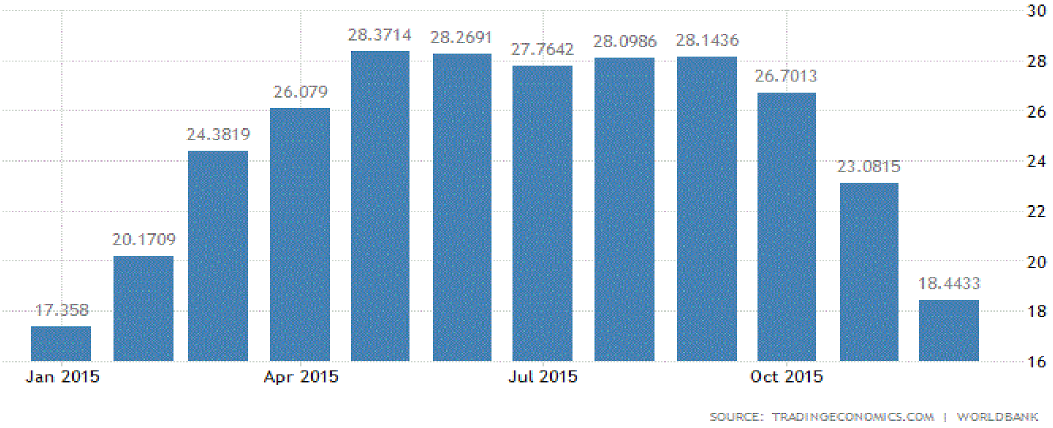
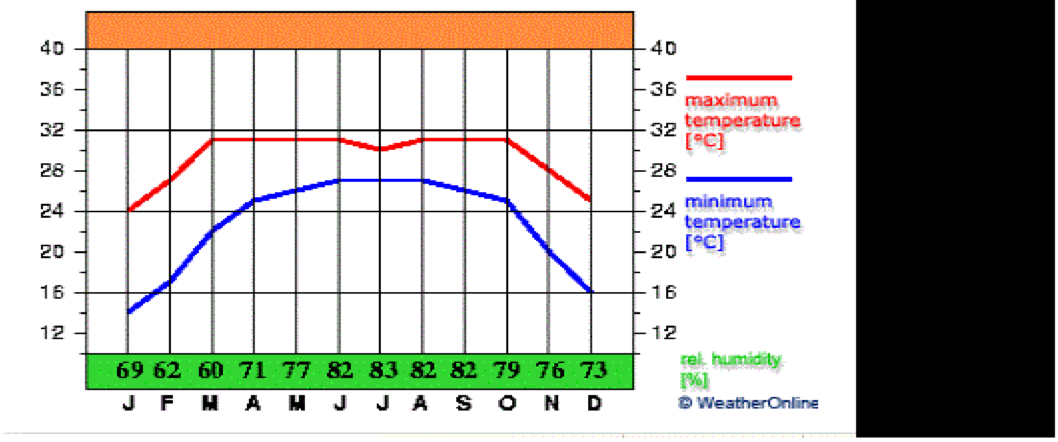
APPENDICES



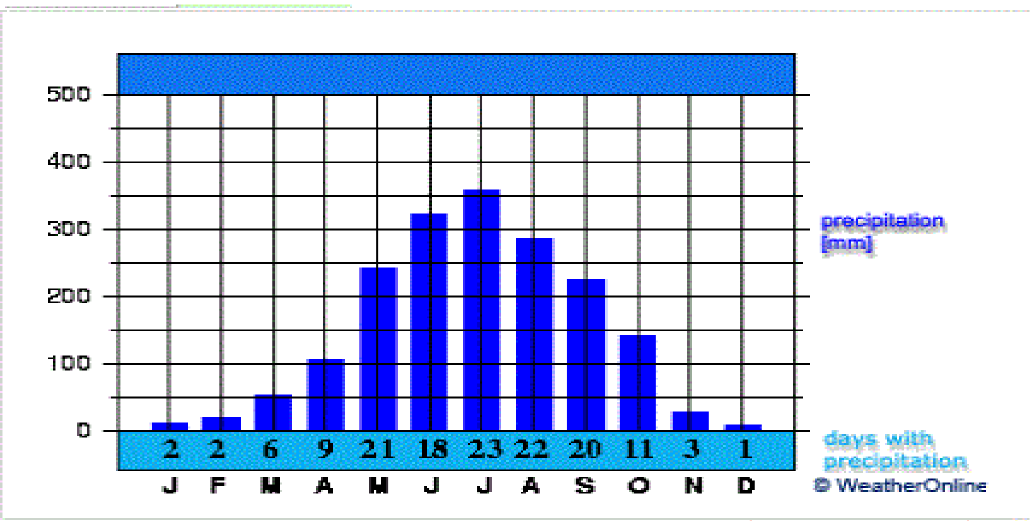
Appendix I. (a). Experimental site at Sher-e-Bangla Agricultural University, Dhaka-1207



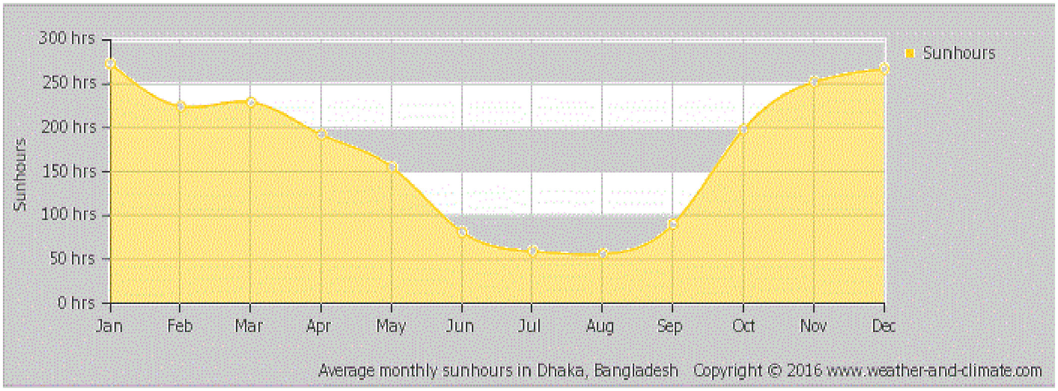
Maximum and minimum temperature



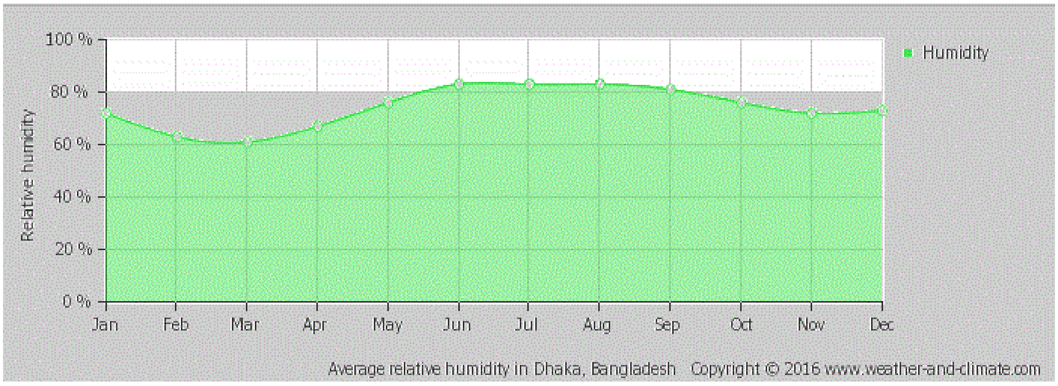
Appendix 1. (b). Average, maximum and temperature (degree C) in Bangladesh during 2015.



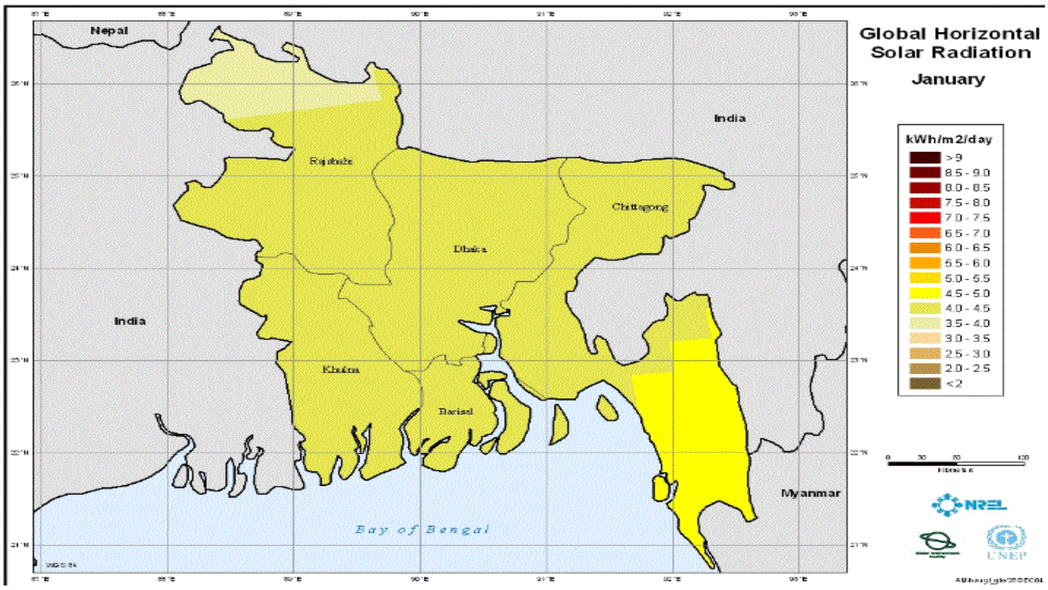
Appendix 1. (c). Average rainfall (cm) in Bangladesh



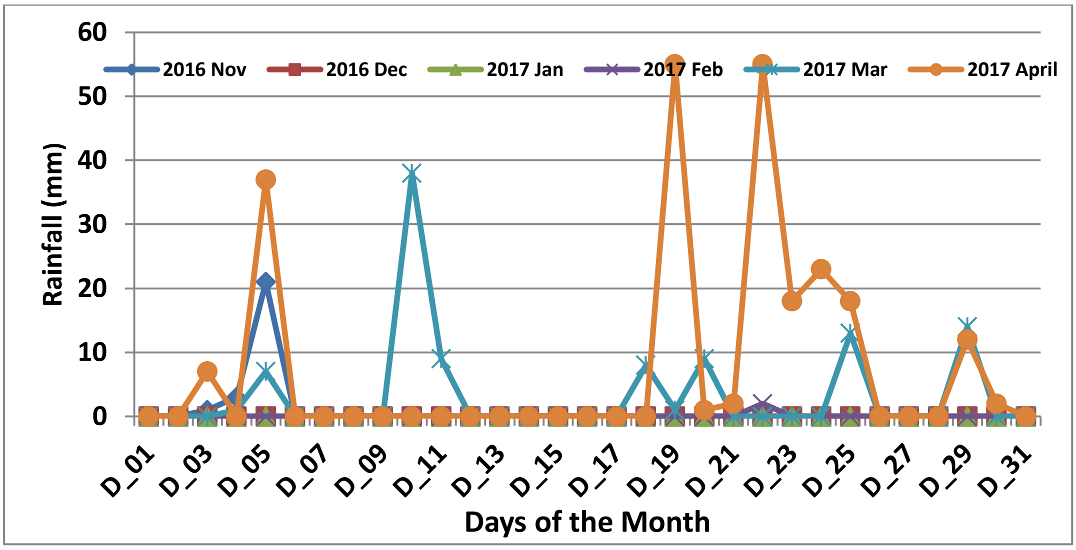
Appendix 1. (d) . Average sunshine monthly hours on Bangladesh



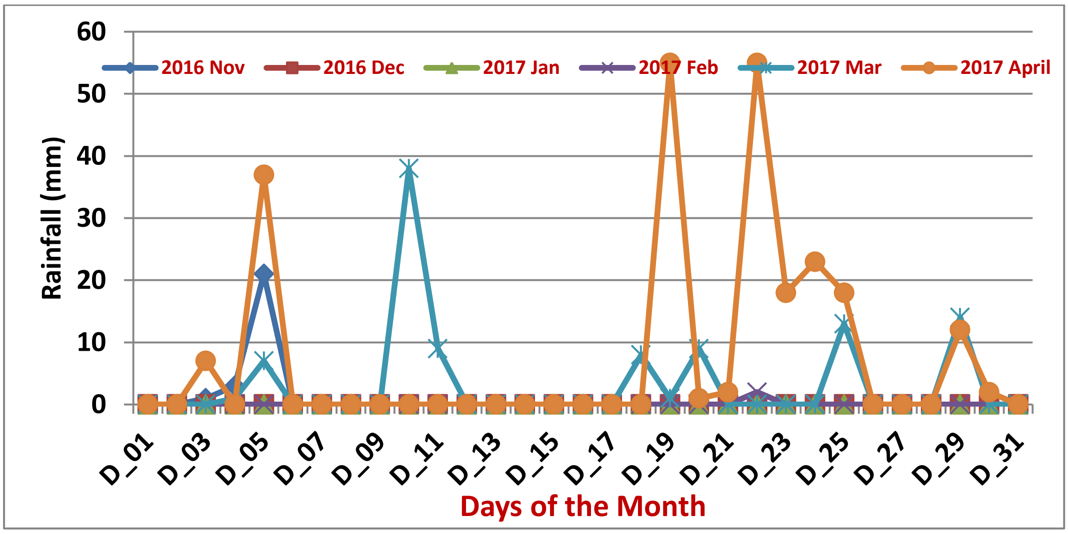
Appendix 1. (e). Average humidity in Bangladesh



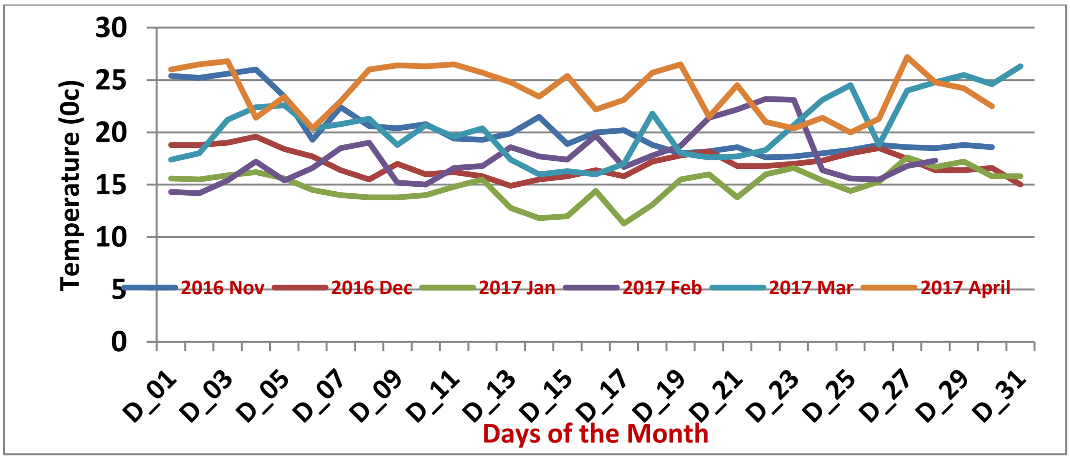
Appendix 1. (f). Solar radiation energy in the month of January in Bangladesh



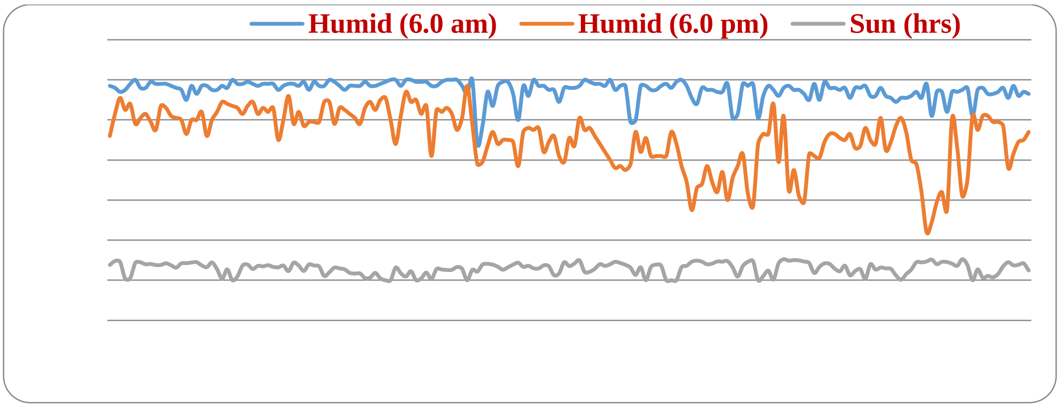
Appendix 1. (g). Rainfall of SAU, Dhaka during Nov 2016 to April 2017 at day basis



Appendix 1. (h). Rainfall of SAU, Dhaka during Nov 2016 to April 2017 at day basis

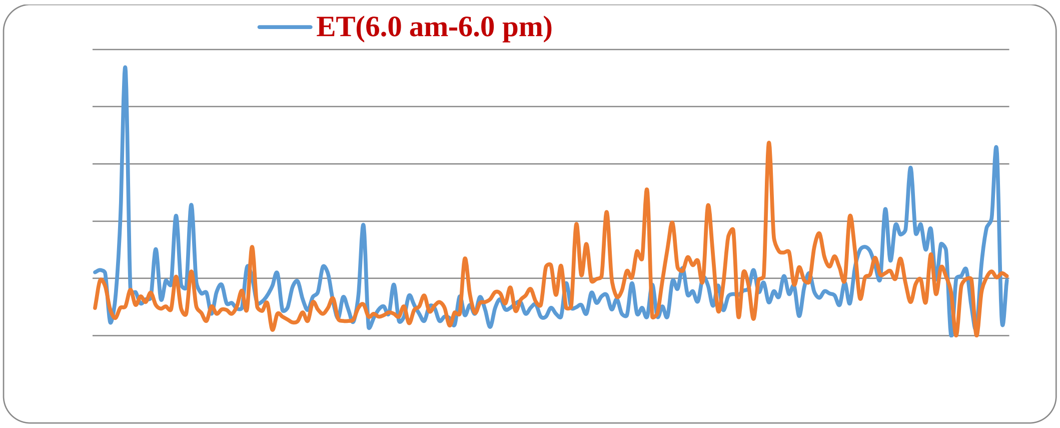


Appendix 1. (i). Temperature of SAU, Dhaka during Nov 2016 to April 2017 at day basis



Appendix 1.(j) . Rainfall of SAU, Dhaka during Nov 2016 to April 2017 at day basis

Appendix 1. (k). Humidity and sunshine hour's data from Nov/2016 to April/2017 in Rajshahi



Appendix 1. (L). Evapo-transpiration data from Nov/2016 to April/2017 in Rajshahi

Appendix II: Maximummminium and average temperature at Rajshahi during rabi 2016-17

Appendix II: Maximum, minimum and

Date	Tmax	Tmin	Average Temp	Date	Tmax	Tmin	Average Temp
01-Nov	32.6	23.6	28.1	13	22.3	10.8	16.55
2	32.7	23	27.85	14	23.5	11.2	17.35
3	32.7	23.2	27.95	15	25.4	10.8	18.1
4	29.5	23.7	26.6	16	25.8	10	17.9
5	27.2	22.4	24.8	17	26.8	13.6	20.2
6	29.2	20	24.6	18	26.5	12.8	19.65
7	30.2	19	24.6	19	27	12.8	19.9
8	30.4	17.7	24.05	20	27.2	13.1	20.15
9	30.6	17.3	23.95	21	24.8	11.3	18.05
10	30.7	18.1	24.4	22	25.8	12.8	19.3
11	31	18.6	24.8	23	27.2	15.2	21.2
12	31.4	17.8	24.6	24	27.6	14.5	21.05
13	31.2	18.7	24.95	25	27.4	15.5	21.45
14	30.4	17.6	24	26	27.5	15.1	21.3
15	30.2	15.8	23	27	26.3	13.1	19.7
16	30	14.4	22.2	28	23.8	15	19.4
17	29.8	13.4	21.6	29	21.5	13.4	17.45
18	29.6	14.5	22.05	30	25.8	13.2	19.5
19	29.5	14	21.75	31	23	13.8	18.4
20	29.6	15	22.3	01-Jan	25.2	13.2	19.2
21	29.3	16.3	22.8	2	26.6	12.4	19.5
22	29	14.8	21.9	3	25.5	12.1	18.8
23	28.1	15.2	21.65	4	24.4	12	18.2
24	29	15.2	22.1	5	23.6	12	17.8
25	28.6	15.8	22.2	6	23.3	11.7	17.5
26	28.1	16.3	22.2	7	24	12.1	18.05
27	29.8	15.5	22.65	8	25.6	9.7	17.65
28	29.6	15.6	22.6	9	26	11.2	18.6
29	29.9	16.4	23.15	10	17.2	13.2	15.2
30	29.9	16.7	23.3	11	25.2	10	17.6
01-Dec	29.4	16.4	22.9	12	22.6	11.8	17.2
2	29.6	16.6	23.1	13	22.4	9.2	15.8
3	28.8	16.5	22.65	14	22	5.1	13.55
4	26.9	18.2	22.55	15	24.2	7.8	16
5	27.3	16	21.65	16	24.4	7.6	16
6	26	14.8	20.4	17	24.7	8	16.35
7	29.6	15.3	22.45	18	25.5	8.9	17.2
8	27	14.8	20.9	19	26.7	11.7	19.2
9	23.8	13.8	18.8	20	27	10.6	18.8
10	25.6	12.1	18.85	21	25.9	9	17.45
11	26	10.8	18.4	22	26.5	10.8	18.65
12	25.3	9.8	17.55	23	26.8	9.8	18.3

Appendix II : (contd.)

Date	Tmax	Tmin	Average Temp	Date	Tmax	Tmin	Average Temp
24	26.2	12.2	19.2	7	31.2	14.3	22.75
25	29	12.9	20.95	8	27.4	17.4	22.4
26	29.4	12.6	21	9	28.6	17.5	23.05
27	28.5	16.2	22.35	10	31.5	18.6	25.05
28	26.4	15.7	21.05	11	26.5	19.4	22.95
29	25.3	10.6	17.95	12	28.5	17.5	23
30	25.4	11	18.2	13	29	13.8	21.4
31	25	10.4	17.7	14	29.4	12.8	21.1
01-Feb	23.8	11.4	17.6	15	29.6	12.8	21.2
2	23.6	12	17.8	16	30.6	13	21.8
3	24.4	11	17.7	17	33.4	14.4	23.9
4	27.3	13.8	20.55	18	32.7	18.6	25.65
5	29.8	14.3	22.05	19	28.7	17.2	22.95
6	30	12.3	21.15	20	29	18.8	23.9
7	29.1	13.4	21.25	21	28.8	15.3	22.05
8	27.5	11.3	19.4	22	32.3	18.3	25.3
9	28.4	10.6	19.5	23	33.1	20.5	26.8
10	28.5	12.4	20.45	24	32.6	22.4	27.5
11	26.5	15.2	20.85	25	33.5	20.2	26.85
12	27.2	14.6	20.9	26	31.7	21.6	26.65
13	29.2	16	22.6	27	33.4	23	28.2
14	28.8	15.5	22.15	28	33	24.6	28.8
15	29.3	13.4	21.35	29	32.7	25.2	28.95
16	29.1	12.5	20.8	30	37.8	25.4	31.6
17	29	13.6	21.3	31	35	26.5	30.75
18	29	12.2	20.6	01-Apr	37.4	25.5	31.45
19	29.4	16	22.7	2	37.4	25.7	31.55
20	30.5	18.5	24.5	3	37.9	26	31.95
21	33.5	18	25.75	4	30.4	21.5	25.95
22	33.2	13	23.1	5	30.3	22	26.15
23	30.3	16.2	23.25	6	34.2	23.4	28.8
24	28.6	11.3	19.95	7	36.6	26	31.3
25	28.4	11.2	19.8	8	37.4	25.1	31.25
26	28.8	11.8	20.3	9	37.4	23	30.2
27	30.4	14	22.2	10	37.6	25	31.3
28	31	12.6	21.8	11	36.6	18.2	27.4
01-Mar	31.3	13.4	22.35	12	37.1	18.8	27.95
2	34	15.3	24.65	13	37	22.7	29.85
3	33.5	18.8	26.15	14	37.3	22.1	29.7
4	28.6	20.5	24.55	15	36.2	23	29.6
5	31.5	19.7	25.6	16	33	21.7	27.35
6	31.2	17.2	24.2	17	35.2	21.5	28.35

Appendix II : (contd.)

Date	Tmax	Tmin	Average Temp
19	31.3	24.2	27.75
20	31.6	21.4	26.5
21	34.8	24.3	29.55
22	27.5	21	24.25
23	30.5	22	26.25
24	32.2	21.4	26.8
25	37.2	22	29.6
26	38.4	26.5	32.45
27	37.7	26.5	32.1
28	37.9	24	30.95
29	36.9	26.8	31.85
30	30.2	22.6	26.4

Appendix table III: Maximum, minimum and average temperature at SAU during rabi season 2016-17

Maximum temp

Month	D_01	D_02	D_03	D_04	D_05	D_06	D_07	D_08	D_09	D_10	D_11	D_12	D_13	D_14	D_15
November 2016	34.0	34.1	34.5	28.5	25.0	24.2	27.4	30.2	31.2	30.7	29.5	30.1	30.8	30.6	29.8
December 2016	29.6	29.6	29.5	30.4	29.6	29.6	30.7	31.0	28.4	28.8	28.2	27.9	25.8	25.7	26.3
January 2017	26.8	27.5	27.2	26.6	23.9	23.6	26.0	27.0	27.3	25.6	25.0	25.0	23.2	23.4	25.6
February 2017	27.4	26.4	25.2	29.2	32.0	31.0	30.2	29.0	28.2	29.0	29.0	30.1	29.7	29.5	29.8
March 2017	31.5	33.2	33.5	30.4	30.4	30.2	31.0	30.5	27.8	32.0	26.8	29.0	29.5	29.5	29.8
April 2017	33.8	33.0	33.4	32.2	30.5	30.4	34.0	34.0	33.7	35.5	35.7	35.1	36.2	36.5	34.5

nth	D_16		D_17	D_18	D_19	D_20	D_21	D_22	D_23
November 2016	30.4		30.6	30.0	29.8	29.0	28.5	28.5	28.5
December 2016	26.8		26.7	26.8	26.0	26.8	25.8	27.5	28.5
January 2017	25.0		25.4	26.3	28.0	26.2	27.2	27.8	26.7
February 2017	29.5		30.2	31.3	30.0	28.4	31.2	30.7	30.5
March 2017	30.0		31.6	29.6	31.2	23.6	29.0	31.2	31.9
April 2017	31.5		34.0	34.6	33.4	29.6	28.3	24.8	28.8

nth		D_24	D_25	D_26	D_27	D_28	D_29	D_30	D_31
November 2016		29.5	29.2	28.4	28.5	28.8	28.5	29.2	
December 2016		28.0	28.2	27.5	26.5	25.8	25.8	26.5	26.2
January 2017		28.2	29.4	30.2	27.7	27.8	25.8	25.7	26.3
February 2017		29.8	29.0	29.8	30.8	31.0			
March 2017		32.4	27.5	31.6	32.8	30.6	30.1	33.2	33.6
April 2017		25.2	34.0	34.0	33.8	34.4	34.5	34.2	

Minimum temperature

Month	D_01	D_02	D_03	D_04	D_05	D_06	D_07	D_08	D_09	D_10	D_11	D_12	D_13	D_14	D_15
November 2016	25.4	25.2	25.6	26.0	23.4	19.3	22.4	20.6	20.4	20.8	19.4	19.3	19.9	21.5	18.9
December 2016	18.8	18.8	19.0	19.6	18.4	17.7	16.4	15.5	17.0	16.0	16.2	15.8	14.9	15.5	15.8
January 2017	15.6	15.5	15.9	16.2	15.6	14.5	14.0	13.8	13.8	14.0	14.8	15.5	12.8	11.8	12.0
February 2017	14.3	14.2	15.4	17.2	15.4	16.6	18.5	19.0	15.2	15.0	16.6	16.8	18.6	17.7	17.4
March 2017	17.4	18.0	21.2	22.4	22.6	20.4	20.8	21.3	18.8	20.7	19.6	20.4	17.4	16.0	16.3
April 2017	26.0	26.5	26.8	21.4	23.4	20.4	23.0	26.0	26.4	26.3	26.5	25.7	24.8	23.4	25.4

Month	D_16	D_17	D_18	D_19	D_20	D_21	D_22	D_23	D_24	D_25	D_26	D_27	D_28	D_29	D_30	D_31
November 2016	20.0	20.2	18.8	18.0	18.2	18.6	17.6	17.7	18.0	18.3	18.8	18.6	18.5	18.8	18.6	
December 2016	16.4	15.8	17.2	17.8	18.2	16.8	16.8	17.0	17.3	18.0	18.5	17.5	16.4	16.4	16.6	15.0
January 2017	14.4	11.3	13.1	15.5	16.0	13.8	16.0	16.6	15.4	14.4	15.3	17.6	16.7	17.2	15.8	15.8
February 2017	19.7	16.7	17.8	18.7	21.4	22.2	23.2	23.1	16.4	15.6	15.5	16.8	17.3			
March 2017	16.0	17.0	21.8	18.0	17.6	17.7	18.3	20.7	23.1	24.5	18.8	24.0	24.8	25.5	24.6	26.3
April 2017	22.2	23.1	25.7	26.5	21.5	24.5	21.0	20.4	21.4	20.0	21.3	27.2	24.8	24.2	22.5	

Average temperature

Month	D_01	D_02	D_03	D_04	D_05	D_06	D_07	D_08
Nov-16	29.7	29.65	30.1	27.3	24.2	21.8	24.9	25.4
Dec-16	24.2	24.2	24.3	25	24	23.7	23.6	23.3
Jan-17	21.2	21.5	21.6	21.4	19.8	19.1	20	20.4
Feb-17	20.85	20.3	20.3	23.2	23.7	23.8	24.4	24
Mar-17	24.45	25.6	27.4	26.4	26.5	25.3	25.9	25.9
Apr-17	29.9	29.75	30.1	26.8	27	25.4	28.5	30

Month	D_09	D_10	D_11	D_12	D_13	D_14	D_15
Nov-16	25.8	25.8	24.5	24.7	25.4	26.1	24.4
Dec-16	22.7	22.4	22.2	21.9	20.4	20.6	21.1
Jan-17	20.6	19.8	19.9	20.3	18	17.6	18.8
Feb-17	21.7	22	22.8	23.5	24.2	23.6	23.6
Mar-17	23.3	26.4	23.2	24.7	23.5	22.8	23.1
Apr-17	30.1	30.9	31.1	30.4	30.5	30	30

Month	D_16	D_17	D_18	D_19	D_20	D_21	D_22	D_23
Nov-16	25.2	25.4	24.4	23.9	23.6	23.6	23.1	23.1
Dec-16	21.6	21.3	22	21.9	22.5	21.3	22.2	22.8
Jan-17	19.7	18.4	19.7	21.8	21.1	20.5	21.9	21.7
Feb-17	24.6	23.5	24.6	24.4	24.9	26.7	27	26.8
Mar-17	23	24.3	25.7	24.6	20.6	23.4	24.8	26.3
Apr-17	26.9	28.6	30.2	30	25.6	26.4	22.9	24.6
D_24	D_25	D_26	D_27	D_28	D_29	D_30	D_31	
23.8	23.8	23.6	23.6	23.7	23.7	23.9	####	
22.7	23.1	23	22	21.1	21.1	21.6	20.6	
21.8	21.9	22.8	22.7	22.3	21.5	20.8	21.1	
23.1	22.3	22.7	23.8	24.2	####	####	####	
27.8	26	25.2	28.4	27.7	27.8	28.9	30	
23.3	27	27.7	30.5	29.6	29.4	28.4	####	

Appendix. IV. Physical properties of the soil in Rajshahi site

Properties	Soil depth (0-15 cm)
Sand	80.42
Silt	10.69
Clay	8.89
Texture class	Sandy loam

Appendix. V. Chemical properties of the soil of the experimental field at Rajshahi

Soil properties	Soil depth (0-15 cm)	Status
pH	7.4	Alkaline
EC (d/Sm)	0.17	Normal
OC (%)	0.626	Low
OM	0.94	Low
Total N (%)	0.07	Very low
Avail. P (mg/g soil)	0.18	Low
Exch. K (ml eq/100 g soil)	0.26	Low
Avail. S (mg/g soil)	11.86	Medium
Avail. Zn (mg/g soil)	24.0	Medium
Avail. Mn (mg/g soil)	2.6	Medium
Avail. B (mg/g soil)	17	Low

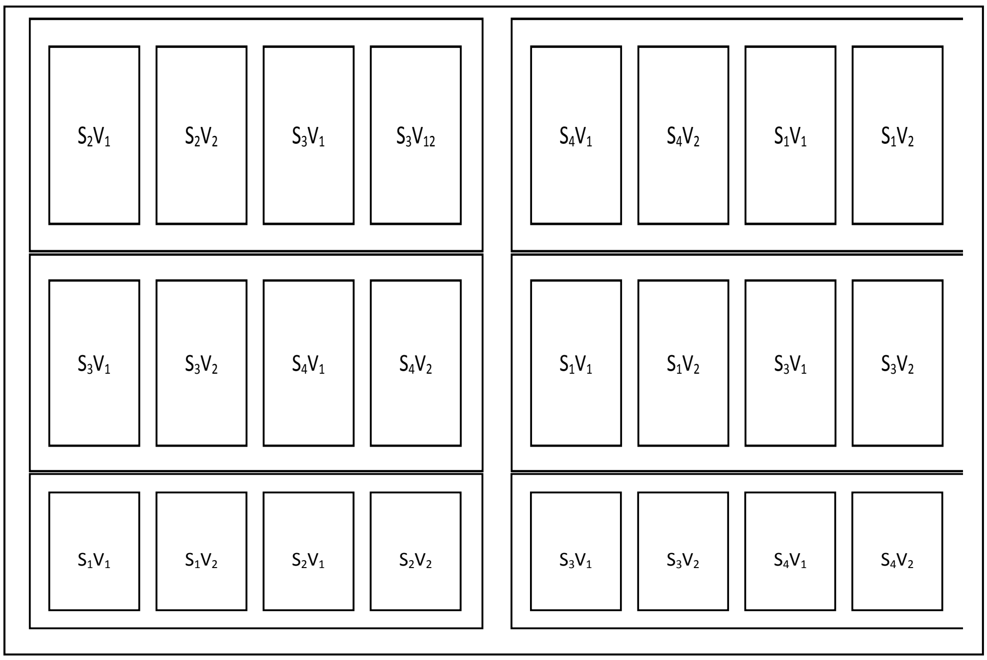
Source: SRDI, Rajshahi

Appendix. VI.Physical properties of the soil before experimentationin SAU, Dhaka

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	silty-clay

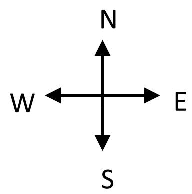
Appendix. VII. Layouts of the experimental plots

Experiment 1: Performance of varieties as influence by different sowing dates



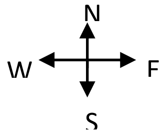
Sowing time: 4(main plot)

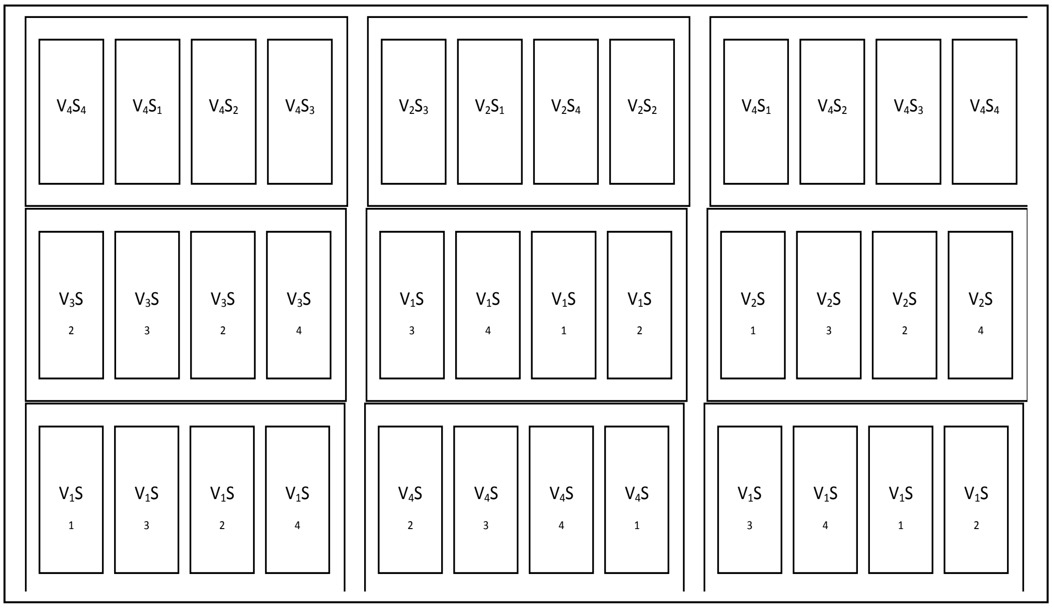
- ❖ Nov 10, S_1
- ❖ Nov 20, S_2
- ❖ Nov 30, S_3
- ❖ Dec 10, S_4



Variety 2 (sub plot)
V_1 = BARI Gom 21
V_2= BARI Gom 30

Experiment 2. Irrigation water, sowing dates and post anthesis extra nitrogen application effect on the performance of wheat



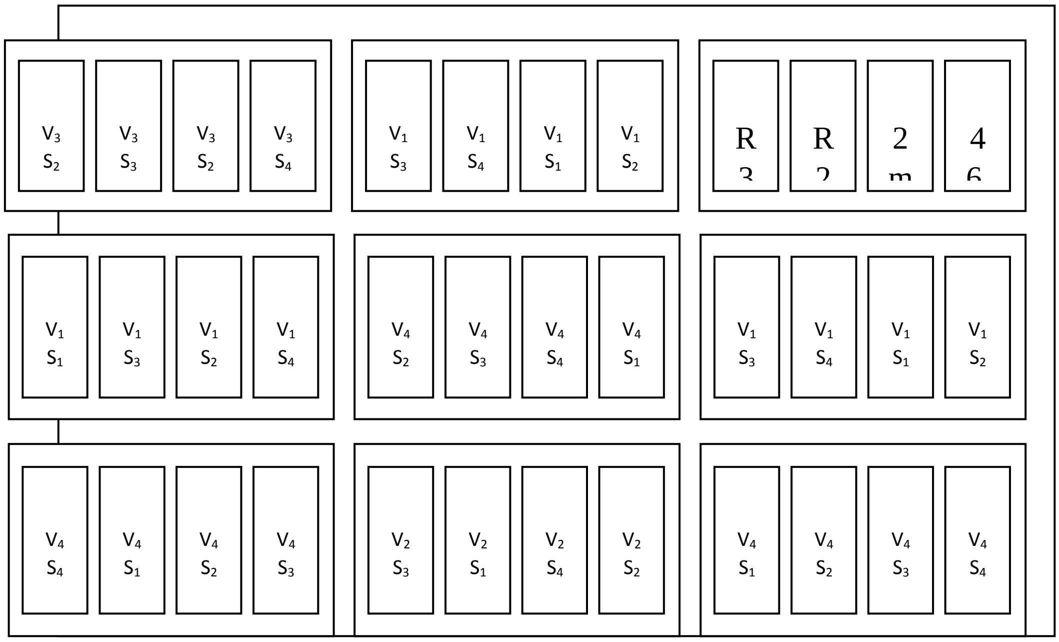


A. S**owing dates:** 4 (Main plot)
S_1= 1st sowing at 10 November
S_2= 2nd sowing at 20 November
S_3= 3rd sowing at 30 November
S_4= 4rd sowing at 10 December

B. Irrigation: 3 (sub plot)
- Irrigation at field capacity, coded as I_1
- Irrigation at 1/2 of the field capacity , coded as I_2
- Irrigation at 1/4th of the field capacity , coded as I_3

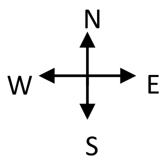
C. Nitrogen top dressing at the reproductive stage 2 (sub-sub plot)
N_1 = no nitrogen at the reproductive stage
N_2 = top dressing 20% of the recommended dose of N

Experiment 3. Effect of sowing dates, extra irrigation water and nitrogen on the performance of wheat



A. Main plot (Irrigation at reproductive stage – 3)

1. I_1=Irrigation at heading stage
2. I_2=Irrigation after 10 days of I_1
3. I_3=Irrigation after 10 days of I_2



B. Sub-plot (sowing time -7):

1. S_1= 1^{st} sowing at 10 November
2. S_2= 2^{nd} sowing at 20 November
3. S_3= 3^{rd} sowing at 30 November
4. S_4= 4^{th} sowing at 10 December

C: Sub-sub plot (Nitrogen top dressing at the reproductive stage – 2)

1. N_1 = no nitrogen application at the reproductive stage
2. N_2 = 20% N top dressing of the recommended dose of N

Experiment 4. Phenology, chlorophyll, canopy temperature, growth and yield of wheat varieties as influenced by sowing dates in northern Bangladesh

S1	S4	S3	S2	S5
V1	V4	V3	V5	V2
V3	V6	V4	V2	V1
V2	V3	V2	V6	V5
V4	V5	V6	V4	V3
V6	V1	V5	V1	V6
V5	V2	V1	V3	V4

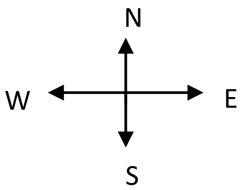
S3	S5	S1	S4	S2
V2	V6	V3	V1	V5
V5	V4	V1	V6	V6
V3	V2	V5	V2	V3
V4	V1	V2	V4	V1
V6	V5	V4	V3	V4
V1	V3	V6	V5	V2

S4	S2	S5	S3	S1
V4	V6	V5	V3	V1
V3	V1	V6	V5	V2
V2	V5	V4	V4	V3
V1	V2	V3	V2	V4
V5	V3	V1	V6	V5
V6	V4	V2	V1	V6

Factor A. (main plot):5 Sowing times

1. 20 Nov. (S1)
2. 30 Nov. (S2)
3. 10 Dec. (S3)
4. 20 Dec. (S4)

5.30 Dec. (S_5)



Factor B (sub plot): 6 Varieties

1. BARI Gom 25 (V1)
2. BARI Gom 26 (V2)
3. BARI Gom27 (V3)
4. BARI Gom28 (V4)
5. BARI Gom29 (V5)
6. BARI Gom30 (V6)

Experiment 5. Growth, yield attributes and yield of wheat as influenced by sowing dates and varieties I Central Bangladesh

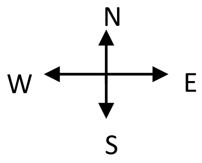
S1	S4	S3	S2	S5
V1	V4	V3	V5	V2
V3	V6	V4	V2	V1
V2	V3	V2	V6	V5
V4	V5	V6	V4	V3
V6	V1	V5	V1	V6
V5	V2	V1	V3	V4

S3	S5	S1	S4	S2
V2	V6	V3	V1	V5
V5	V4	V1	V6	V6
V3	V2	V5	V2	V3
V4	V1	V2	V4	V1
V6	V5	V4	V3	V4
V1	V3	V6	V5	V2

S4	S2	S5	S3	S1
V4	V6	V5	V3	V1
V3	V1	V6	V5	V2
V2	V5	V4	V4	V3
V1	V2	V3	V2	V4
V5	V3	V1	V6	V5
V6	V4	V2	V1	V6

Factor A (main plot): 5 Sowing times

1. 20 Nov. (S1)
2. 30 Nov. (S2)
3. 10 Dec. (S3)
4. 20 Dec. (S4)
5. 30 Dec. (S_5)

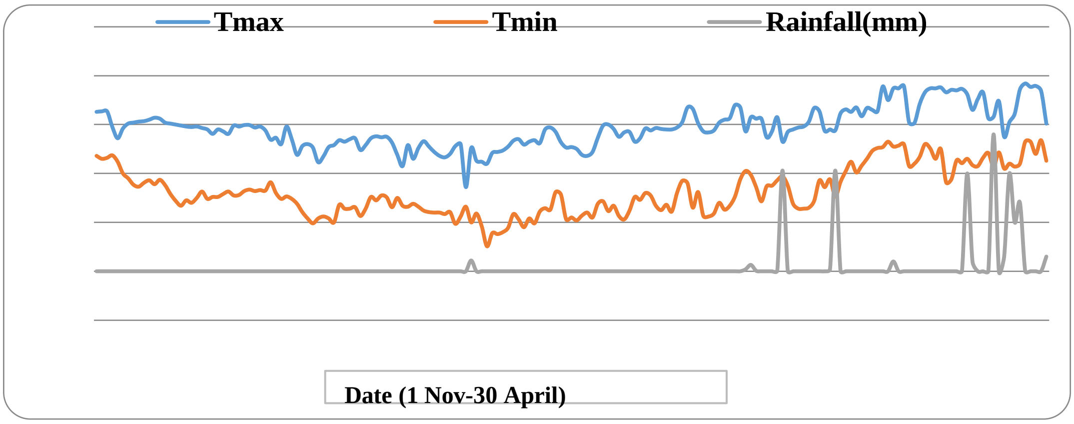


Factor B (sub plot): 6 Varieties

1. BARI Gom 25 (V_1)
2. BARI Gom 26 (V_2)
3. BARI Gom 27 (V_3)
4. BARI Gom 28 (V_4)
5. BARI Gom 29 (V_5)
6. BARI Gom30 (V_6)

Appendix VIII. Averages of daily maximum, minimum and averages temperature 0[C] from sowing to anthesis and from anthesis to maturity at Rajshahi during rabi 2016-17

		Tmax	Tmin	Tave
	Sowing date to anthesis			
s1	Nov 20-Jan24	26.78	13.05	19.92
s2	Nov30-Feb08	25.86	13.01	19.89
s3	Dec10-Fe16	24.85	12.96	19.86
s4	Dec20-Feb24	26.48	12.96	19.87
s5	Deec30 – March02	26.97	12.93	19.87
	Anthesis to maturity			
s1	Jan 24-March28	29.44	15.26	22.35
s2	Feb08-March15	29.55	15.46	22.50
s3	Feb17- March22:	29.68	15.66	22.67
s4	Feb 25:-Mar29	29.77	15.88	22.82
s5	March03-May04	29.91	16.02	22.96



Appendix IX: Averages of daily maximum, minimum and averages temperature 0^C from sowing to anthesis and from anthesis to maturity at SAU during rabi 2016-17

SAU		Tmax	Tmin	T average
	Sowing to anthesis	Antheis		
S_1	Nov 20-Jan 21	29.32	16.21	22.77
S_2	Nov 30-Feb 05	27.98	15.68	21.83
S_3	Dec 10- Feb 12	26.77	14.75	20.76
S_4	Dec 20-Feb 21	28.38	15.86	22.12
S_5	Dec 30: March 01	30.21	16.03	23.12
	Anthesis to maturity			
S_1	Nov 20: Jan 21-March 2	31.88	17.47	24.67
S_2	Nov 30: Feb 05-march 11	31.95	17.88	24.91
S_3	Dec 10: Feb12-March15 :	32.05	18.02	25.03
S_4	Dec 20:Feb 21:-Machr 26	32.58	18.44	25.51
S_5	Dec 30: March01: May 02	32.91	19.02	25.96

Appendix X: ANOVA TABLE

Expt 1: Summary of ANOVA analysis data for different characters (var: 21 & 23)

Variety	Grand mean	Standard deviation	Standard Error	C of V	Rep	Sowing date	Rep*SD	Variety	SD*Var
Grain yield	3.878	0.40793	0.17517E-03	7.87	0.000	0.000	1. 000	0.000	0.000
Straw yield	5.3896	0.67447	0.00000	6.58	1.000	1.000	1.000	1.000	1.000
Biomass	8.9333	0.97612	0.44730E-03	8.57	0.000	0.000	1.000	0.000	0.000
Harvest Index	41.647	1.3557	0.66409E-03	10.54	0.000	0.000	1.000	0.000	0.000
Spike length (cm	17.458	1.5497	0.25095E-03	8.75	0.000	0.000	1.000	0.000	0.000
Filled grains spike^{-1}	32.866	2.2079	0.00000	9.75	1.000	1.000	1.000	1.000	1.000
Unfilled grains spike^{-1}	3.6315	0.55701	0.19211E-03	8.75	0.000	0.000	1.000	0.000	0.000
Total grains spike^{-1}	36.165	1.7848	0.99078E-03	10.54	0.000	0.000	1.000	0.000	0.000
Days to spike initiation	64.333	3.4096	0.00000	11.85	1.000	1.000	1.000	1.000	1.000
Days to maturity	108.81	3.0057	0.11629E-02	12.65	0.000	0.000	1.000	0.000	0.000
Number of spikes plant^{-1}	4.9458	0.51427	0.33784E-04	5.65	0.000	0.000	1.000	0.000	0.000
Number of spikelet spike^{-1}	20.746	0.98737	0.00000	6.87	1.000	1.000	1.000	1.000	1.000
Dry matter content/plant									
DMC 30 DAS	1.0358	0.25403	0.00000	5.45	1.000	1.000	1.000	1.000	1.000
DMC 45 DAS	2.1652	0.34167	0.86639E-04	4.65	0.000	0.000	1.000	0.000	0.000
DMC 60 DAS	3.5896	0.44055	0.19690E-03	5.68	0.000	0.000	1.000	0.000	0.000
DMC 75 DAS	5.6183	0.62230	0.24419E-03	5.64	0.000	0.000	1.000	0.000	0.000
Tiller/plant									
Tiller 30 DAS	3.1352	0.34128	0.14484E-03	6.54	0.000	0.000	1.000	0.000	0.000
Tiller 45 DAS	3.9683	0.30278	0.00000	5.65	1.000	1.000	1.000	1.000	1.000
Tiller 60 DAs	5.6308	0.41589	0.13307E-03	6.54	0.000	0.000	1.000	0.000	0.000
Tiller 75 DAS	5.9996	0.61563	0.00000	4.56	1.000	1.000	1.000	1.000	1.000
Plant height (cm)									
Pl ht 30 DAS	27.353	2.1354	0.12190E-02	5.65	0.000	0.000	1.000	0.000	0.000
Pl ht 45 DAS	59.348	2.9871	0.00000	4.65	1.000	1.000	1.000	1.000	1.000
Pl ht 60 DAS	84.950	3.3378	0.12568E-02	11.35	0.000	0.000	1.000	0.000	0.000
Pl ht 75 DAS	94.086	4.5404	0.22815E-02	12.54	0.000	0.000	1.000	0.000	0.000
Pl ht Harvest	99.373	6.2660	0.30442E-02	12.54	0.000	0.000	1.000	0.000	0.000
TGW	43.756	2.2918	0.00000	10.54	1.0000	1.0000	1.0000	1.0000	1.0000

Expt.2. Summary of ANOVA analysis data for different characters

Variables	Grand mean	Standard deviation	Standard Error	% CV	Rep	Sowing Date	Rep*SD	Variety	SD *Var
Tiller/plant									
Tillering stage	1.8467	0.533	0.47155	25.5	0.7648	0.0452	0.023	0.136	0.3005
Booting stage	2.7578	0.819	0.63859	23.2	0.1207	0.000	0.054	0.523	0.2239
Heading stage	2.9644	0.851	0.67768	22.9	0.0531	0.000	0.287	0.577	0.3936
Anthesis stage	3.0589	0.930	0.72619	23.7	0.0299	0.000	0.159	0.5708	0.3853
PM Stage	2.8389	0.914	0.64980	22.9	0.1208	0.000	0.191	0.8526	0.079
Yield and yield contributing characters									
Height (cm)	83.784	6.162	3.3221	4.0	0.9832	0.000	0.537	0.0013	0.0444
Spike/m^2	233.28	34.055	22.546	9.7	0.6640	0.000	0.076	0.000	0.5939
Spikelet/spike	15.896	2.018	0.96276	6.1	0.0228	0.000	0.008	0.000	0.0114
Grains/spike	41.069	7.361	4.5349	11.0	0.0106	0.000	0.106	0.000	0.1029
TGW (g)	44.628	8.0489	4.1809	9.4	0.5885	0.000	0.5493	0.000	0.2967
GY (t/ha)	3.1768	0.675	0.48420	15.2	0.5266	0.000	0.0015	0.0929	0.2179
Biomass (t/ha)	11.154	2.394	1.4803	13.3	0.6364	0.000	0.0362	0.6088	0.3896
Canopy temp ^{0}C									
Booting	20.257	1.810	1.0639	5.3	0.4866	0.000	0.8162	0.2846	0.4794
Heading	21.510	1.537	0.95833	4.5	0.0047	0.000	0.0645	0.1916	0.7396
Anthesis stage.	22.668	3.194	0.87144	3.8	0.5905	0.000	0.1118	0.0251	0.000
Phenological parameters									
Booting days	52.833	3.419	0.85505	1.6	0.6710	0.000	0.000	0.000	0.000
Heading days	59.811	3.505	0.94868	1.6	0.1694	0.000	0.0003	0.000	0.000
Anthesis days	66.144	2.885	0.64118	1.0	0.0340	0.000	0.000	0.000	0.000
Phy Mat days	100.70	2.675	0.93690	0.9	0.7711	0.000	0.005	0.000	0.000
Ground coverage									
15 days	13.694	2.939	1.6192	11.8	0.0833	0.000	0.308	0.2825	0.4117
30 days	37.678	10.936	3.9771	10.6	0.2993	0.000	0.016	0.0125	0.1465
45days	60.068	9.447	4.9890	8.3	0.0885	0.000	0.489	0.0238	0.5711
60days	71.611	4.422	2.5232	3.5	0.4555	0.000	0.011	0.000	0.178
75days	63.628	4.368	3.4646	5.4	0.7265	0.000	0.177	0.0177	0.6642
90days	44.200	7.890	4.0051	9.1	0.1264	0.000	0.787	0.0027	0.1417
Chlorophyll contents									
Booting	40.832	3.526	2.2863	5.6	0.0328	0.0004	0.122	0.000	0.0137
Heading	43.867	3.212	2.2725	5.2	0.0003	0.0083	0.216	0.000	0.5533
Anthesis	44.284	2.974	2.0766	4.7	0.0691	0.0173	0.083	0.000	0.1089
Grain growth parameters									
Fresh weight	6.0956	1.134	0.95128	15.6	0.7601	0.0013	0.147	0.0009	0.6436
Dry weight	1.8022	0.402	0.30518	16.9	0.9294	0.000	0.247	0.0001	0.3637
Fresh weight	7.9589	1.425	1.1660	14.6	0.1525	0.0218	0.105	0.0002	0.416
Dry weight	2.7889	0.641	0.49989	17.9	0.4009	0.001	0.004	0.0002	0.6816
Fresh weight	9.6622	1.475	1.1607	12.0	0.0059	0.0001	0.065	0.0188	0.3504
Dry weight	4.2300	1.331	0.61417	14.5	0.0055	0.000	0.005	0.0002	0.589
Fresh weight	10.226	1.858	1.5551	15.2	0.0809	0.0007	0.067	0.1576	0.8323
Dry weight	5.3361	1.262	0.93134	17.5	0.3196	0.000	0.052	0.6485	0.9892
Fresh weight	10.739	2.035	1.6554	15.4	0.1203	0.0033	0.542	0.1552	0.6082
Dry weight	6.075	1.216	0.93512	15.4	0.182	0.0002	0.681	0.612	0.721

Expt. 4.Summary table of ANOVA data analysis for different characters at SAU

Variables	Grand mean	Standard deviation	Standard Error	% CV	Rep	Sowing Date	Rep*SD	Variety	SD *Var
Tiller/plant									
Tillering stage	1.8467	0.533	0.47155	25.5	0.7648	0.0452	0.023	0.136	0.3005
Booting stage	2.7578	0.819	0.63859	23.2	0.1207	0	0.054	0.523	0.2239
Heading stage	2.9644	0.851	0.67768	22.9	0.0531	0	0.287	0.577	0.3936
Anthesis stage	3.0589	0.93	0.72619	23.7	0.0299	0	0.159	0.5708	0.3853
PM Stage	2.8389	0.914	0.6498	22.9	0.1208	0	0.191	0.8526	0.079
Yield and yield contributing characters									
Height (cm)	83.784	6.162	3.3221	4	0.9832	0	0.537	0.0013	0.0444
Spike/m^2	233.28	34.055	22.546	9.7	0.664	0	0.076	0	0.5939
Spikelet/spike	15.896	2.018	0.96276	6.1	0.0228	0	0.008	0	0.0114
Grains/spike	41.069	7.361	4.5349	11	0.0106	0	0.106	0	0.1029
TGW (g)	44.628	8.0489	4.1809	9.4	0.5885	0	0.5493	0	0.2967
GY (t/ha)	3.1768	0.675	0.4842	15.2	0.5266	0	0.0015	0.0929	0.2179
Biomass (t/ha)	11.154	2.394	1.4803	13.3	0.6364	0	0.0362	0.6088	0.3896
Canopy temp ^{0}C									
Booting	20.257	1.81	1.0639	5.3	0.4866	0	0.8162	0.2846	0.4794
Heading	21.51	1.537	0.95833	4.5	0.0047	0	0.0645	0.1916	0.7396
Anthesis stage.	22.668	3.194	0.87144	3.8	0.5905	0	0.1118	0.0251	0
Phenological parameters									
Booting days	52.833	3.419	0.85505	1.6	0.671	0	0	0	0
Heading days	59.811	3.505	0.94868	1.6	0.1694	0	0.0003	0	0
Anthesis days	66.144	2.885	0.64118	1	0.034	0	0	0	0
Phy Mat days	100.7	2.675	0.9369	0.9	0.7711	0	0.005	0	0
Ground coverage									
15 days	13.694	2.939	1.6192	11.8	0.0833	0	0.308	0.2825	0.4117
30 days	37.678	10.936	3.9771	10.6	0.2993	0	0.016	0.0125	0.1465
45days	60.068	9.447	4.989	8.3	0.0885	0	0.489	0.0238	0.5711
60days	71.611	4.422	2.5232	3.5	0.4555	0	0.011	0	0.178
75days	63.628	4.368	3.4646	5.4	0.7265	0	0.177	0.0177	0.6642
90days	44.2	7.89	4.0051	9.1	0.1264	0	0.787	0.0027	0.1417

Chlorophyll contents									
Booting	40.832	3.526	2.2863	5.6	0.0328	0.0004	0.122	0	0.0137
Heading	43.867	3.212	2.2725	5.2	0.0003	0.0083	0.216	0	0.5533
Anthesis	44.284	2.974	2.0766	4.7	0.0691	0.0173	0.083	0	0.1089
Grain growth parameters									
Fresh weight	6.0956	1.134	0.95128	15.6	0.7601	0.0013	0.147	0.0009	0.6436
Dry weight	1.8022	0.402	0.30518	16.9	0.9294	0	0.247	0.0001	0.3637
Fresh weight	7.9589	1.425	1.166	14.6	0.1525	0.0218	0.105	0.0002	0.416
Dry weight	2.7889	0.641	0.49989	17.9	0.4009	0.001	0.004	0.0002	0.6816
Fresh weight	9.6622	1.475	1.1607	12	0.0059	0.0001	0.065	0.0188	0.3504
Dry weight	4.23	1.331	0.61417	14.5	0.0055	0	0.005	0.0002	0.589
Fresh weight	10.226	1.858	1.5551	15.2	0.0809	0.0007	0.067	0.1576	0.8323
Dry weight	5.3361	1.262	0.93134	17.5	0.3196	0	0.052	0.6485	0.9892
Fresh weight	10.739	2.035	1.6554	15.4	0.1203	0.0033	0.542	0.1552	0.6082
Dry weight	6.075	1.216	0.93512	15.4	0.182	0.0002	0.681	0.612	0.721

Expt.5. Summary ANOVA data analysis table for different characters at SAU, Dhaka

Variables	Grand mean	Standard deviation	Standard Error	% CV	Rep	Sowing Date	Rep*SD	Variety	SD *Var
Tiller/plant									
Tillering stage	1.8467	0.533	0.47155	25.5	0.7648	0.0452	0.023	0.136	0.3005
Booting stage	2.7578	0.819	0.63859	23.2	0.1207	0.000	0.054	0.523	0.2239
Heading stage	2.9644	0.851	0.67768	22.9	0.0531	0.000	0.287	0.577	0.3936
Anthesis stage	3.0589	0.930	0.72619	23.7	0.0299	0.000	0.159	0.5708	0.3853
PM Stage	2.8389	0.914	0.64980	22.9	0.1208	0.000	0.191	0.8526	0.079
Yield and yield contributing characters									
Height (cm)	83.784	6.162	3.3221	4.0	0.9832	0.000	0.537	0.0013	0.0444
Spike/m^2	233.28	34.055	22.546	9.7	0.6640	0.000	0.076	0.000	0.5939
Spikelet/spike	15.896	2.018	0.96276	6.1	0.0228	0.000	0.008	0.000	0.0114
Grains/spike	41.069	7.361	4.5349	11.0	0.0106	0.000	0.106	0.000	0.1029
TGW (g)	44.628	8.0489	4.1809	9.4	0.5885	0.000	0.5493	0.000	0.2967
GY (t/ha)	3.1768	0.675	0.48420	15.2	0.5266	0.000	0.0015	0.0929	0.2179
Biomass (t/ha)	11.154	2.394	1.4803	13.3	0.6364	0.000	0.0362	0.6088	0.3896
Canopy temp ^{0}C									
Booting	20.257	1.810	1.0639	5.3	0.4866	0.000	0.8162	0.2846	0.4794
Heading	21.510	1.537	0.95833	4.5	0.0047	0.000	0.0645	0.1916	0.7396
Anthesis stage.	22.668	3.194	0.87144	3.8	0.5905	0.000	0.1118	0.0251	0.000
Phenological parameters									
Booting days	52.833	3.419	0.85505	1.6	0.6710	0.000	0.000	0.000	0.000
Heading days	59.811	3.505	0.94868	1.6	0.1694	0.000	0.0003	0.000	0.000
Anthesis days	66.144	2.885	0.64118	1.0	0.0340	0.000	0.000	0.000	0.000
Phy Mat days	100.70	2.675	0.93690	0.9	0.7711	0.000	0.005	0.000	0.000
Ground coverage									
15 days	13.694	2.939	1.6192	11.8	0.0833	0.000	0.308	0.2825	0.4117
30 days	37.678	10.936	3.9771	10.6	0.2993	0.000	0.016	0.0125	0.1465
45days	60.068	9.447	4.9890	8.3	0.0885	0.000	0.489	0.0238	0.5711
60days	71.611	4.422	2.5232	3.5	0.4555	0.000	0.011	0.000	0.178
75days	63.628	4.368	3.4646	5.4	0.7265	0.000	0.177	0.0177	0.6642
90days	44.200	7.890	4.0051	9.1	0.1264	0.000	0.787	0.0027	0.1417
Chlorophyll contents									
Booting	40.832	3.526	2.2863	5.6	0.0328	0.0004	0.122	0.000	0.0137
Heading	43.867	3.212	2.2725	5.2	0.0003	0.0083	0.216	0.000	0.5533
Anthesis	44.284	2.974	2.0766	4.7	0.0691	0.0173	0.083	0.000	0.1089
Grain growth parameters									
Fresh weight	6.0956	1.134	0.95128	15.6	0.7601	0.0013	0.147	0.0009	0.6436
Dry weight	1.8022	0.402	0.30518	16.9	0.9294	0.000	0.247	0.0001	0.3637
Fresh weight	7.9589	1.425	1.1660	14.6	0.1525	0.0218	0.105	0.0002	0.416
Dry weight	2.7889	0.641	0.49989	17.9	0.4009	0.001	0.004	0.0002	0.6816
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Dry weight	4.2300	1.331	0.61417	14.5	0.0055	0.000	0.005	0.0002	0.589
Fresh weight	10.226	1.858	1.5551	15.2	0.0809	0.0007	0.067	0.1576	0.8323
Dry weight	5.3361	1.262	0.93134	17.5	0.3196	0.000	0.052	0.6485	0.9892
Fresh weight	10.739	2.035	1.6554	15.4	0.1203	0.0033	0.542	0.1552	0.6082
Dry weight	6.075	1.216	0.93512	15.4	0.182	0.0002	0.681	0.612	0.721