

Effect of High Temperature and Mulching on Growth and Yield of Wheat (*Triticum aestivum* L.)



*A Thesis Submitted for the Degree of Doctor of Philosophy in
Agronomy in the Department of Agronomy and Agricultural
Extension, University of Rajshahi, Rajshahi-6205*

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Dedicated
To My
Beloved Parents

DECLARATION

I hereby declare that the whole work reported in this thesis entitled **Effect of High Temperature and Mulching on Growth and Yield of Wheat (*Triticum aestivum* L.)** for the degree of Doctor of Philosophy of the University of Rajshahi, Bangladesh, is based on my original investigation. This work has not been submitted before of this University or any other institution to obtain a degree or any other academic certificate, honour or title.

Nesa
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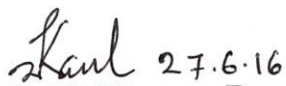
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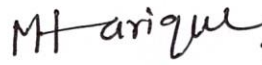
CERTIFICATE

We hereby certify that the research work entitled **Effect of High Temperature and Mulching on Growth and Yield of Wheat (*Triticum aestivum* L.)** now submitted for the degree of Doctor of Philosophy in the subject of Agronomy is a bonafide research work carried out by Mst. Nazmun Nesa under our supervision in the University of Rajshahi, Rajshahi-6205, Bangladesh. The results of the investigation, which embodied here are original and have not been submitted before in substance for any other degree of this or any other university.

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ACRONYMS

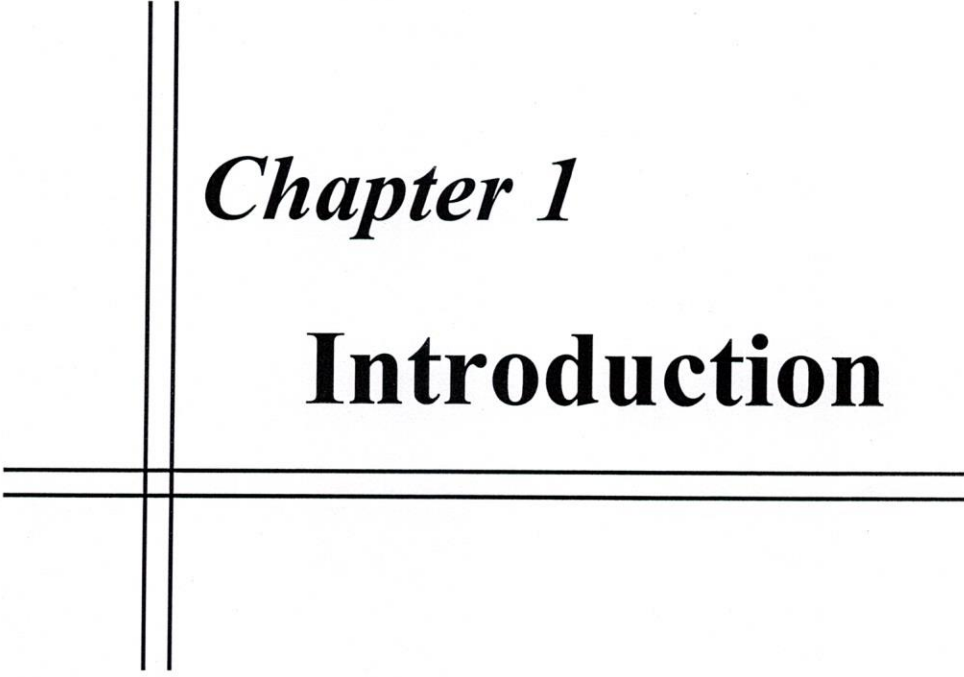
AEZ	=	Agro-ecological zone
BBS	=	Bangladesh Bureau of Statistics
BAU	=	Bangladesh Agricultural University
BARI	=	Bangladesh Agricultural Research Institute
cm	=	Centimeter
cv.	=	Cultivar
CGR	=	Crop Growth Rate
CRI	=	Crown Root Initiation
DAS	=	Days after sowing
DAE	=	Department of Agricultural Extension
DMRT	=	Duncan's Multiple Range Test
<i>et al.</i>	=	And others
FAO	=	Food and Agriculture Organization
g	=	Gram
ha ⁻¹	=	Per hectare
i.e.	=	that is
L.	=	Linneaus (Carolus Linneaus)
LAI	=	Leaf Area Index
LAR	=	Leaf Area Ratio
LS	=	Level of Significance
LWR	=	Leaf Weight Ratio
m	=	Meter
m ⁻²	=	Per square meter
mm	=	Millimeter
NAR	=	Net Assimilation Rate
NS	=	Not significant
pH	=	Negative logarithm of hydrogen ion (H ⁺) concentration

RGR	=	Relative Growth Rate
RLGR	=	Relative Leaf Growth Rate
SLA	=	Specific Leaf Area
t	=	Ton
TDM	=	Total Dry Matter
viz.	=	Namely
%	=	Percent
/	=	Per
°C	=	Degree Celsius

ABSTRACT

An experiment was conducted to study the effect of high temperature and mulching on growth and yield of wheat (*Triticum aestivum* L.) during two consecutive seasons (2008-09 and 2009-10). The experiment comprised of four sowing dates, viz., 17 November (S₁), 2 December (S₂), 17 December (S₃) and 1 January (S₄), two varieties namely, Bijoy (V₁) and Gourab (V₂) and four mulching treatments, no mulching (M₁), water hyacinth mulching (M₂), rice straw mulching (M₃) and black polythene mulching (M₄). The experiment was laid out in a split-split plot design assigning the sowing date to the main plot, variety to the sub-plots and mulching to the sub-sub plots. The treatments were replicated three times. The experimental results revealed that the highest total dry matter (TDM), leaf area index (LAI) and crop growth rate (CGR) were obtained from 17 November (S₁) sowing and the lowest were obtained from 1 January (S₄) sowing in both the years. With some exceptions, numerically the highest relative growth rate (RGR), relative leaf growth rate (RLGR) and leaf weight ratio (LWR) were obtained from S₁ sowing and the lowest were obtained from S₄ sowing in both the years at all the harvests. Numerically the highest leaf area ratio (LAR) values were observed at S₄ sowing at the early stages of growth and at the later stages S₁ sowing showed the highest value in 2008-09. In 2009-10 growing season, numerically the highest LAR values were observed at S₂ sowing at all the harvests. Other growth attributes such as net assimilation rate (NAR), specific leaf area (SLA) did not show any clear cut pattern among the sowing dates in both the years. Between the two varieties, Bijoy showed higher TDM, LAI and CGR values at all the harvests as compared to Gourab. No clear cut superiority was observed between the varieties for RGR, RLGR, NAR, SLA and LWR. The highest TDM, LAI and CGR were obtained from black polythene mulching (M₄) and the lowest were obtained from control treatment (M₁) in both the years at all the harvests. No clear cut pattern of mulching on RGR and RLGR was observed in both the years. With some exceptions, the highest NAR values were obtained from M₄ mulching and the lowest values were obtained from control in both the years. The number of days for attaining different phenological stages was higher for early sowing condition. 17 November sowing (S₁) required the maximum days for crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity. The S₄ (1 January sowing) plants required the lowest days to attain these stages in both the years. The highest heat units (GDD) were required in S₁ plants followed by S₂, S₃ and S₄ plants at all the phenological stages in both the years. It was also observed that the requirement of heat units for all the phenological stages decreased with delay in sowing. The S₁ plants had the highest HTU and S₃ plants had the lowest HTU at all the phenological stages in the first year. In the second year, the S₁ plants had the highest HTU at all the phenological stages except at

grain filling and maturity stages. Requirements of higher heat units, helio-thermal units (HTU) were observed in Bijoy (V_1) than Gourab (V_2) at all the phenological stages in both the growing seasons. It was found that the highest heat units were required in M_4 crops and was successively followed by M_3 , M_2 and M_1 . Moisture retention capacity (MRC) and relative leaf water content (RLWC) of the flag leaves were higher in the early-sown crops and lower in late-sown crops. The highest MRC and RLWC were observed in M_4 crops and the lowest were observed in M_1 (control) at each time of the day. The S_1 (17 November sowing) and M_4 plants (black polythene mulching) contained the highest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b) than the other sowings. The S_4 and M_1 (control) plants contained the lowest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b). All the yield and yield contributing characters i.e., plant height, number of total tillers plant^{-1} , number of effective tillers plant^{-1} , spike length, extrusion length, number of spikelets spike^{-1} , number of fertile spikelets spike^{-1} , 1000-grain weight, grain yield, straw yield, biological yield and harvest index were highest in 17 November sowing (S_1) and the lowest values were found in 1 January sowing (S_4) plants in both the years. Between the two varieties, Bijoy produced higher plant height, number of total tillers plant^{-1} , number of effective tillers plant^{-1} , spike length, extrusion length, number of spikelets spike^{-1} , number of fertile spikelets spike^{-1} , 1000-grain weight, grain yield, straw yield, biological yield and harvest index than Gourab. All the yield and yield contributing characters showed highest value in black polythene mulching (M_4) and the minimum values were observed in M_1 (control) in both the years.



Chapter 1

Introduction

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a self pollinated crop originated in South East Asia but now cultivated worldwide. About two-thirds of the world population live on wheat. Wheat is grown on more than 216,000,000 hectares, larger than for any other crop (FAO, 2013). In 2010, world production of wheat was 651 million tons, making it the third most produced cereal after maize (844 million tons) and rice (672 million tons). Wheat was the second most produced cereal in 2009, world production in that year was 682 million tons, after maize (817 million tons) and with rice (679 million tons) as a close third (FAO, 2010). World trade in wheat is greater than for all other crops combined. With rice, wheat is the world's most favored staple food. It is a major diet component because of the wheat plant's agronomic adaptability. In Bangladesh, wheat is the second most important cereal crop next to rice in terms of area and usefulness. In Bangladesh, wheat is grown over an area of 0.358 million hectare with annual production of 0.995 million tons where national average yield was 2.78 t ha^{-1} (DAE, 2013).

Wheat is highly nutritious and high energy food source. It is grown worldwide as the major sources of energy for human being. Among the consumers in the developing countries, wheat is the second most important source of calories (after rice) and is the largest source of protein. Wheat has high nutritious value in respect of protein 12%, fat 1.72%, carbohydrate 69.60% and minerals 27.2% (BARI, 1997) over rice. It provides 20% of the total food calories in Bangladesh. Its diverse use as food also signifies its elevated position in the cereal group of the food crops.

Wheat was a key factor enabling the emergence of city-based societies at the start of civilization because it was one of the first crops that could be easily cultivated on a large scale and had the additional advantage of yielding a harvest that provides long term storage of food. Wheat is grown under a wide range of climatic and soil conditions. In Bangladesh, it is a crop of rabi season, requires dry weather and bright sunlight. Farmers in Bangladesh grow wheat fitting the crop in their intensive rice-based cropping systems. About 2 million farmers have benefited from wheat cultivation. In absence of the wheat programme, the country would have to import on an average about 0.9 million metric tons more food grains annually (Gupta *et al.*, 2002).

Bangladesh is one of the densely populated countries in the world and its population density is increasing day by day. Total land area under crop production has been decreasing day by day to accommodate the rapidly increasing population. As a result the total production of cereal grain is decreasing and the country would suffering from food deficiency. At present the national consumption of wheat is about four fold higher than annual domestic production. Every year Bangladesh fails to feed her population with her own food production. Scarcity of food has become a chronic problem of this country. To mitigate the food shortage, measures should be taken to increase total food production. So, the cereal crop production like wheat should be increased to meet the demand of the escalating population, where an individual requires 454g cereal food (BARI, 2004). It is a future challenge for Bangladesh to better exploit the potential of the production of wheat crop to meet the country's grain food requirement without endangering the environment.

Though wheat is an important cereal crop in Bangladesh, its average yield is low (2.78 t ha^{-1}) compared to other wheat growing countries of the world (BBS, 2012). As the land shortage cannot be decreased in this over populated country, it is highly important to give attention to management practices of this crop for obtaining higher yield to meet the food deficit with the demand for food for increasing population.

There are several reasons which are responsible for lower productivity of wheat in the tropics and sub-tropics. Of the various reasons responsible for low yield, the main reason is late sowing due to late harvest of T. aman. Moreover, in view of the short winter period of Bangladesh, time of sowing is a major constraint to higher yield of wheat. The actual cause of low yield is due to effect of shorter growing period in the vegetative phase and steep rise in temperature at the grain filling stage. Time of sowing determines time of flowering and it has great influence on dry matter accumulation.

The climatic conditions and the cropping pattern of Bangladesh are such that seeding of wheat starts from the first week of November and continues till late December (Ahmed *et al.*, 1976). This sowing time depends on the weather condition, topography, soil and harvesting time of preceding crops. The majority of farmers in Bangladesh usually grow wheat in the same land after harvest of transplant aman rice that means sowing of wheat is often delayed result in lower yields. Thus large area of wheat is grown under above optimal temperature causing significant yield reduction. There is a potential yield decline @ 1.3% per day when sown beyond optimum time (Saunders, 1988). This problem will be further increased due to global warming. Because in Bangladesh also the annual

mean temperature of 25.75°C will be raised by about 2050 (Karmakar and Shrestha, 2000).

The growing period for wheat is about 90 to 105 days in this country. Generally, wheat like other cool season crop seeded early to take maximum period for growth and development toward maturity before the (possible) heat stress. The optimum temperature for wheat growth ranged from 15°C to 18°C (Choudhury and Wardlaw, 1978) but the temperature requirement of the crop during reproductive growth phases lies within 22°C for optimizing its grain yield (Campbell and Read, 1968). In case of late sowing, temperature becomes stressful above 26°C , when a premature ripening of wheat is taken place (Aborl *et al.*, 1991) and producing poorly develop grain in wheat (Hasan and Ahmed, 2005). Late sowing of wheat exposes the crop to high temperature ($>28^{\circ}\text{C}$) and affects growth, yield and quality. Temperature below or above normal alter plant functions and productivity. In late-sown wheat, low temperature prevailing during germination substantially affects the germination and seedling emergence. Late-sown wheat suffers more winter injury which produces fewer tillers and may ripen in lower grain weight and number of grains per plant.

Under high temperature, wheat crop completes its life cycle much faster than under normal temperature conditions (Fischer, 1985). All crop stages have a short duration, consequently, there are fewer days to accumulate assimilate during life cycle and production of biomass is reduced (Fischer and Maurer, 1974). It ultimately affects grain filling and lastly the yield of crop. Plant responses to high temperature vary with plant species, variety and phenological stages. Reproductive processes are markedly affected by high temperature which ultimately affects fertilization and post fertilization processes leading to reduced crop yield (Wahid *et al.*,

2007). The reproductive phase commences when the temperature starts rising in the later part of the season. The duration of growth and yield of wheat are determined by the thermal conditions experienced by the crop during its life cycle. So, it is essential to find out the optimum sowing date for wheat taking into consideration of climatic condition and cropping pattern of Bangladesh to obtain the maximum yield.

The genotypic response of wheat to planting dates varies for yield contributing characters due to different genetic potential. The decline becomes prominent in the cultivars requiring more days for heading under normal sowing. Increase in temperature causing shortening of heading period (Tashiro & Wardlaw, 1999). Similarly, cultivars matured earlier when planted late, indicating the forced maturity due to high temperature.

Mulching is one of the important agronomic practices in conserving the soil moisture and modifying the soil physical environment. It is considered a comprehensive approach to reduce water loss and water use from soil surface. Any material spread on the surface of the soil to protect it from raindrops, solar radiation and evaporation could serve the purpose of mulch. Mulches are used to cover surface of soil nearby crop plants to develop eco-friendly and favorable conditions for maintenance of growth. These materials significantly affect the soil electrical conductivity, organic matter, nitrogen, phosphorus, potassium content (Khurshid *et al.*, 2006 and Pakdel *et al.*, 2013), slower evaporation and reduce water requirement of crop plants (Chawla, 2006 and Liu *et al.*, 2009). The soil that is covered by mulch remains cooler as compared to non-mulched soil because of minimal temperature changes. The less evaporation and normal soil temperature develop more favorable conditions for the crop growth (Wood *et al.*, 2008). Mulching improves soil moisture status and structure of soil (Muhammad *et al.*, 2009), decreases salinity, control weeds and soil erosion (Bu *et al.*, 2002 and Kumar and Lal, 2012) and

increase the number of fertile tillers and biomass production of wheat crop (Ahmed *et al.*, 2009).

There are various materials which are being used for mulches; these include plastic sheets/films, sawdust, sugarcane trash, rice straw, water hyacinth, plant residues, poultry litter, paper pellets and city garbage, etc. Crop residues have been widely used as mulches. These mulching materials conserve water for greater crop production when present at adequate levels. These materials are cheap and often readily available and they permit water to enter the soil readily. The effect of mulch on soil temperature, moisture regime and root growth as well as crop yield depend on the climatic environment, mode of mulch application and quality and quantity of mulch material. When maintained at adequate levels, these mulching materials result in conserved water contents and reduced evaporation. The wheat grain yield is generally increased by increase in soil moisture content due to reduction of surface evaporation. Mulching resulted in 17% increase in grain yield and 19% in above ground biomass (Tolk *et al.*, 1999).

Objectives of the Study

1. To find out the optimum sowing date of wheat under changing climate, especially in the northern region of Bangladesh.
2. To investigate the effect of mulching under high temperature condition on the growth and yield of wheat.
3. To find out suitable variety(s) for growing under high temperature condition.
4. To investigate the combined effect of temperature and mulching on the growth and yield of wheat.

Chapter 2

Review of Literature

REVIEW OF LITERATURE

2.1 Effect of Sowing Date

2.1.1 Growth Attributes

Abdel-Raouf *et al.* (1983a) carried out an experiment to find out the associations between growth attributes of barley and grain yield under different seeding dates. They observed that plant height, dry weight, leaf area and leaf area index of 7-week plants decreased with delay in sowing date. Highest CGR, RGR of 7-14 week old plants were obtained by sowing on 5 December. After 15-17 weeks, the highest values were obtained by sowing on 15 November. Grain yield was positively correlated with plant height at all the growth stages. DM accumulation, leaf area and leaf area index at the latest growth stages were negatively correlated with RGR and NAR.

Mucci *et al.* (1985) reported that LAI of durum wheat was maximum 5.1 for early sowing and 4.8 for late sowing.

Kerr *et al.* (1992) found that delayed sowing of wheat caused a decrease in dry matter and kernel number.

Samanta *et al.* (1997) studied different growth parameters of four porsomillet cultivars as influenced by five sowing dates. They reported that LAI was maximum at 50% flowering in all the cultivars and decreased sharply at 15 days after flowering (DAF) and LAD had similar trend as the LAI. The rate of dry matter accumulation gradually increased up to 15 DAF and then declined due to leaf senescence in all the cultivars

and sowings. The cultivar Kumardhan produced the highest number of leaves, LAI, LAD, TDM and grain yield in 15 November sowing followed by 30 November sowing.

Ashraf and Bhatti (1998) reported that leaf area of wheat genotypes decreased with late sowing

Kumar and Sharma (1999) carried out a field experiment in Delhi, India during 1992-93 and 1993-94 and reported that delay in sowing of wheat resulted in the reduction of total dry matter, but their accumulation rate was faster in the late-sown crop.

Haque (2000) conducted a field experiment to study the physiological basis of growth and yield of eight wheat cultivars in relation to four sowing dates over two seasons. He observed that total dry matter (TDM), leaf area index (LAI) and leaf area duration (LAD) at most of the growth stages were highest for crops sown on 1 November (S_1) in the first year and on 15 November (S_2) in the second year. Among the cultivars, C 306 had the highest TDM, LAI and LAD and the lowest in BL 1183 in both years. Crop growth rate (CGR), leaf area ratio (LAR), relative leaf growth rate (RLGR) and specific leaf area (SLA) were highest in S_1 and S_2 of the first and second year respectively. But relative growth rate (RGR), net assimilation rate (NAR) and leaf weight ratio (LWR) were highest in S_4 (15 December) plants. The growth attributes such as RGR, LAR, RLGR, SLA and LWR declined throughout with the increasing time and plant weight. Only NAR showed increasing tendency towards the later stages of growth. Simple correlation coefficient between growth attributes and grain yield indicated that grain yield was positively correlated with LAI, TDM, CGR, LAR and in a few cases with SLA and LWR, whereas it

showed negative correlation with RGR and NAR at tillering, booting and anthesis stages.

Alam (2003) carried out a field experiment at research field of the Department of Botany, University of Rajshahi, Bangladesh in split plot design with three replications to study the sowing times on growth attributes of barley (*Hordeum vulgare* L.). The four sowing dates were 5 November, 17 November, 29 November and 11 December. Results indicated that growth attributes like RGR, NAR and RLGR of barley decreased when plants were sown after 17 November. But LAR increased at later sowings.

Alam et al. (2005) carried out a field experiment in the research field of the Department of Botany, University of Rajshahi in 2002-2003 with four barley cultivars in a split plot design with four sowing times, five N treatments in each sowing and cultivars with three replications to study the effect of sowing dates (November to December) and nitrogen fertilizers on nitrogen utilization and some related characters of barley cultivars (*Hordeum vulgare* L.). Their results indicated that sowing in the 1st and 2nd week of November resulted higher grain yield and total dry matter (TDM) compared to other sowing times. Delay in sowing, i.e., after 17 November decreased dry matter accumulation and nitrogen utilization.

A field experiment was conducted by **Paul and Sarker (2005)** during the 19995-96 to study the growth of two wheat cultivars (BL 1183 and Kanchan) under 4 dates of sowing- 1 November, 19 November, 1 December and 15 December. The highest total dry matter was produced in 1 November and then gradually reduced in the subsequent sowings.

LAI attained peak at 58-68 days after sowing and declined thereafter in both the cultivars in all the sowings. LAR declined with increase of time, but CGR increase to certain peak and then decreased gradually. NAR increased slowly at the early growth stages, but sharply at the later stages, except BL 1183 in which a decreasing tendency was noted towards the later stages of growth in 1 December sowing only. Simple correlation coefficient between growth attributes indicated that CGR positively correlated with total dry matter, LAI and NAR and negatively with LAR. The grain yield in all the sowings had no significant association with any of the growth attributes.

Alam *et al.* (2006) carried out an experiment at the experimental field of the Department of Botany, University of Rajshahi, Bangladesh to study the effect of sowing dates on growth attributes of two barley (*Hordeum vulgare* L.) cultivars. Two cultivars of barley (BB1 and Karan 351) were sown in four sowing dates viz., 5 November (S₁), 17 November (S₂), 29 November (S₃) and 11 December (S₄). Results indicated that growth attributes like, RGR, NAR and RLGR of both the cultivars decreased when plants were sown after 17 November, but LAR increased at the later sowing.

Hafiz (2007) conducted an experiment to investigate the growth and yield of barley in relation to different sowing times. Four sowing dates (viz., November 1, 15, 30 and December 15) were assigned in the experiment. Result revealed that TDM, LAI, LAD, CGR, RGR and NAR were significantly higher in early sowing (November 1) barley crops.

Bahadur (2008) carried out a field experiment to study the growth, development, phenological development, grain growth, heat unit use at

the different phenological stages, chlorophyll content, proline accumulation, correlation between growth attributes and grain yield and yield of barley in relation to different sowing time and irrigation level. Barley was sown in four sowing dates viz., November 1, November 16, December 1 and December 16. Result revealed that the highest total dry matter (TDM), leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR) and relative leaf growth rate (RLGR) was observed in November 16 sowing which was followed by December 1 sowing. The highest RGR was noted for S₄ (December 16 sown) plants. Late-sown crops had higher SLA than the early-sown crops.

Sikder (2008) carried out an experiment during 2005-06 to 2006-07 to study the physiological basis of heat tolerance in wheat. Results revealed that total dry matter (TDM), leaf area index (LAI), crop growth rate (CGR) and leaf area duration (LAD) showed higher value at normal growing condition (November 30 sowing) compared to late growing condition (December 30 sowing). Higher NAR was observed at normal growing condition upto 60-70 DAS compared to late growing condition. Growth attributes such as RGR, LAR, RLGR, SLA and LWR throughout the advancement of growth stages.

Mohiuddin (2010) conducted a field experiment at the research field of the Department of Botany, Rajshahi University, Rajshahi to study the effect of sowing date (November 15, November 30 and December 15) and soil moisture levels on the growth and yield of wheat varieties. Results revealed that early sowing increased total dry matter (TDM), leaf area (LA), leaf area index (LAI), crop growth rate (CGR), leaf area ratio (LAR) and relative leaf growth rate (RLGR).

Ahmed and Farooq (2013) studied the accumulated photothermal units, growth attributes and phenology of three wheat varieties (Chakwal-50, Wafaq-2001 and an advanced line NR-268) in four planting windows from 20th October-5th December at 15 days interval during 2008-2009. Results indicated that delayed sowing put adverse effects with respect to growth characteristics of tested varieties like crop growth rate (CGR), net assimilation rate (NAR) and leaf area index (LAI).

Radhika et al. (2014) carried out an experiment to study the physiological growth-yield relationships in wheat genotypes under sowing date mediated heat stress. They observed that all plant growth parameters (RGR, LAI, NAR) were adversely affected by temperature stress which finally reflected in yield reduction. The measurement of growth parameters LAI, RGR and NAR is important because they are positively correlated to biomass production. Final yield had strong positive association with the NAR and LAI.

2.1.2 Phenological Stages and Accumulated Heat Units

Pauli et al. (1964) carried out an experiment to determine the length of developmental phases in grain sorghum from planting to physiological maturity as influenced by variety, planting date and location. They sowed six varieties of sorghum on 1 May, 20 May, 10 June and 30 June. They found that earlier planting dates tended to lengthen the time from planting to the transition of the flowering point from the vegetative to the floral stage; to lengthen the time from floral transition to half bloom; to reduce the time from half bloom to physiological maturity of grain and to expand generally the total number from planting to physiological maturity of

grain. Regardless of its maturity characteristics, the number of days required by a variety to attain of its three developmental stages was almost identical. Average of 8 varieties showed that from planting, 30 days were required to floral transition, 31 additional days to reach half bloom and an additional 31 days to attain physiological maturity. Data on total time occupied by each developmental phase also indicated no significant differences.

Tomar and Mathur (1966) conducted an experiment on barley for the three consecutive years, 1961-62, 1962-63 and 1963-64 with three sowings dates viz., October 15, November 12, December 8; October 12, November 4, November 30 and October 10, November 5, December 4, respectively. On an average, the 1st and 2nd sowings maintained statistically superiority over the 3rd sowing. The lowest yield in case of 3rd sowing could be attributed to the fact that the crop had much reduced growth period while the 1st and 2nd sowings were favored by relatively longer growing period.

Ahmed *et al.* (1975) studied the performance of Mexican wheat under different sowing times in the northern part of Bangladesh. Five wheat varieties, namely Penjamo 62, Sonora 64, Mexipak 65, Inia 66 and Noreno 67 were sown on seven different dates at an interval of 10 days starting from October 20. The effect of different sowing dates on heading, maturity, height and yield was observed. Time taken from germination to 50% heading was reduced by the early sowing. It was also observed that late sowing reduced the duration from heading to 50% maturity but the early sowing lengthened the above period and took more than 23-40 days.

Bagga and Rawson (1977) conducted an experiment to study high temperature effect on wheat. They reported that higher temperatures during floral initiation resulted in reduced spike bearing tillers and produced lower grain number per main ear. The growth stages between double ridge and flag leaf emergence were significantly more sensitive than the other growth stages to any change in temperature.

Pirasteh and Welsh (1980) studied the effect of temperature on heading date of wheat cultivars under a lengthening photoperiod. They worked on five vernalized winter wheat and five spring wheat commonly grown under an increasing day-length by controlled environment in the growth chambers at 15°C (day) and 7.2°C (night) and 21°C (day) and 12.7°C (night). They reported that temperature, cultivar and temperature $\times$ cultivar interaction were all significant for both days and degree hours to heading. They also reported that all the cultivars headed more rapidly at the higher temperature. More degree-hours were used by all the cultivars at the warm temperature indicating that only part of the increased temperature was translated into the accelerated heading. They found that each cultivar had a specific set of phenological control mechanism, which affected the interaction with environment in the final yield expression.

Chakravarty *et al.* (1984) studied phenology, biomass accumulation and ambient temperature relationship in eight genotypes of barley. They expressed these relationships through phenothermal index and heat use efficiency. In four barley genotypes, heat use efficiency was computed and found to be in phase with crop growth rate.

Puri *et al.* (1985) studied grain yield of barley, wheat and triticale in relation to solar radiation and heat units for three years. They used four

planting dates (17 April to 7 May) and four seeding densities (100-400 seeds per sq meter) of seven cultivars of barley, wheat and triticale. They computed solar radiation and heat units for each of three growth periods e.g., early vegetative, early reproductive and late reproductive periods. They found that grain yields declined with delayed planting and stated that wheat and barley were more affected than triticale. There was a little effect of seeding densities on grain yields. They reported that barley required less solar radiation and heat units than wheat and triticale to produce maximum grain yield. Higher temperature and lower solar radiation during the early vegetative period to be beneficial for all the three crops.

Saini and Dadhwal (1986) stated that the time of panicle initiation, anthesis and maturity is dependent on the prevailing temperature during the growth period. They also reported that temperature affected the total growth period of wheat. They observed that 150 days life cycle of wheat in the northern India, progressively declined to 100-110 days in the central and 80-90 days in the southern and western India due to increasing warm weather during the growth period.

Saini et al. (1986) studied the influence of sowing dates on pre-anthesis phenology in wheat. They observed the dates of first spikelet initiation, terminal spikelet initiation and anthesis on HD 4502, a semi-dwarf medium duration variety of *Triticum durum* and three varieties of *T. aestivum* viz., Hindi 62, a tall late flowering variety, kalyansona a semi-dwarf medium duration variety and Sonalika, a semi-dwarf early flowering variety. They found that when sown early or late, the initiation of the first and the terminal spikelet was hastened and anthesis occurred

earlier. HD 4502 was less responsive to sowing earlier. When Hindi 62 was delayed in sowing, the duration from sowing to first and terminal spikelet initiation decreased but the period between the first and terminal spikelet initiation did not change much. And 8 day delay in sowing reduced the duration from sowing to first spikelet initiation by 1 day.

Hossain *et al.* (1987) observed that the late-sown crop took at least 15 to 20 days less time to mature because of forced maturity due to rise of temperature in March. Sowing date affected the duration of different phenophase, initiation of spike premordia, booting, heading, grain filling and maturity.

Rajput *et al.* (1987) studied that the influence of planting dates on phenology and heat unit relationships in wheat under late-sown conditions. They observed that the requirement of accumulated heat unites (AHU) decreased with delayed planting. They computed helio-thermal unit (HTU) as the product of degree days with the bright sunshine hours. They also introduced phenothermal index as the AHU per growth day. They also observed that HUE was also decreased with delay in planting. A phenothermal index was also introduced. It was nearly constant irrespective of planting dates and sites. A regression for predicting the maturity date for wheat crop using heat unites accumulated up to flowering initiation was developed.

Arabinda and Dolgodvorov (1994) studied the different stages of growth of two newly developed high yielding spring wheat varieties named Moskovskaya 35 and Mnovoskya spring. They divided the growth cycle into four major developmental phases viz., vegetative, panicle development, grain filling and ripening phases. They observed that the

vegetative phases started with the emergence of seedlings up to the point of panicle initiation and needed 36, 36 and 39 days after sowing in Moskovoskya 35 and 37, 36 and 38 days after sowing in Minovoskya spring in 1983, 1984 and 1985, respectively. The panicle developmental phase included the heading and flowering stages and required 56, 60, 67 days after sowing for Moskovoskya 35 and 58, 60 and 68 days after sowing for Minovoskya spring in the first, second and third year, respectively. The third growth phase began with the fertilization of florets in the panicle and continued up to the maturity of the plant and required 107, 108 and 112 days after sowing for Moskovoskya 35 and 108, 110 and 113 days after sowing for Minovoskya spring in 1983, 1984 and 1985, respectively.

Bishnoi *et al.* (1995) conducted an experiment to develop the relationship of phenological development with thermal units under different sowing dates in wheat. The crop was sown on 5 dates viz., 29 October, 13 November, 29 November, 13 December and 29 December. Phenological stages were root initiation, last tiller, flag leaf, last node, ear emergence, anthesis, grain filling, milking, hard dough and maturity. They found that the number of leaves emerged maximum in the early sowing (29 October followed by 13 November). Leaf number was higher in the main stem and decreased in the tillers. The emergence of leaves showed a linear response with the cumulative heat units. They also found that the requirements of heat units decreased with delay in sowing.

Saifuzzaman *et al.* (1996) studied the effect of sowing dates on growth stages of short and long duration wheat at Bangladesh Agricultural Research Institute, Joydevpur. They sowed short (Sonalika) and long

duration (Pavon 76) of wheat on four dates viz., 1 November, 15 November, 1 December and 15 December. They found three broad phases of growth namely vegetative, reproductive and grain filling stages. They observed that emergence was completed within 5-6 days after sowing in both the varieties and in all the dates of sowing. They also found slight difference in reaching crown root initiation stage. There were differences in reaching booting stage of 43-54 days after emergence (DAE). The variety Sonalika required 43, 46, 47 and 46 DAE whereas Pavon 76 required 59, 57, 56 and 58 DAE for heading in respect of seeding dates. The flowering was within 50-65 DAE in Sonalika and within 54-70 DAE in Pavon 76. The grain filling stage of both the varieties showed a trend of reduction in days with late sowing and hastened to high temperature which had pronounced effect on the duration of grain filling.

Bishnoi *et al.* (1996) studied micro-climatic condition under different environments in wheat crop. They measured the profiles of temperature, relative humidity, leaf temperature, leaf wetness and wind speed in the crop canopies of different sowing treatments. Higher air temperature and lower soil moisture were observed during reproductive phase under delayed sowings. Statistically higher grain yield was obtained from 31 October to 14 November under favourable micro-climate conditions at different phenological phases. Because maximum leaf area index and total dry matter accumulations were found under the above sowing times.

Shahid and Kabir (1997) reported that duration of post flowering phase dependent on the date of anthesis and maturity of wheat. Delayed flowering decreased the time between anthesis and maturity.

Samanta *et al.* (1997) studied the different growth stages and yield of porsomillet cultivars as influenced by sowing dates. They sowed four porsomillet cultivars viz., Kumardhan, BPM-24, BPM-40 and Tushar on five dates starting from November 15 at an interval of 15 days at BAU Farm, Mymensingh, Bangladesh. They observed that late sowing caused late germination and reduced the period (days) of panicle initiation, flowering and maturity due to low temperature at the seedling stage and high temperature at the grain filling stage. They also observed that sowing at November 15 took the highest number of days for attaining various growth stages and thereafter decreased with delayed sowing. Among the cultivars, Kumardhan took the highest number of days for attaining various stages of growth. They reported that LAI was the maximum at 50% flowering in all the cultivars and decreased sharply at 15 days after flowering (DAF) and LAD had similar trend as the LAI. The rate of dry matter accumulation gradually increased up to 15 DAF and then declined due to leaf senescence in all the cultivars and sowings. Grain yield was significantly higher on November 15 sowing, followed by November 30 than the other sowings due shorter growth period and higher ambient temperature during the grain filling stage.

Sandhu *et al.* (1999) studied the yield performance and heat unit requirement of wheat (*Triticum aestivum* L.), varieties as affected by sowing dates under rainfed conditions. They sowed the wheat varieties (PBW 175, PBW 299, PBW 320 and PBW 359) on four dates from October 25 to November 24 at an interval of 10 days. They observed the occurrence of different growth stages as well as the heat units to relate to different sowing dates. They reported that crop growth duration and heat unit decreased with delay in sowing. The number of days taken for

seedling emergence and jointing increased with a concomitant decrease in the duration reproductive phase, particularly flowering to maturity. Heat units did not differ so much during seedling emergence but increased during emergence to jointing and decreased during jointing to flowering when crops were sown on November 4. The heat units decreased during flowering to maturity with delay in sowing due to shortening of the ripening period.

Ghosh *et al.* (2000) observed that delay in sowing of wheat decreased the number of days taken to reach maturity.

Haque (2000) studied the phenological characters of eight wheat cultivars in relation to four sowing dates (1 November, 15 November, 1 December, 15 December) over two seasons. He found that higher values of all the phenological stages were obtained by early sowing (1 November) and optimum sowing (15 November). All the phenological stages showed their highest values in C 306 and lowest values in BL 1183. The requirements of heat units (GDD) at all the phenological stages were significantly higher in 1 November and 15 November. The cultivar C 306 accumulated the highest heat units (GDD) at all the phenological stages whereas the cultivar BL 1183 accumulated the lowest (GDD). Helio-thermal unit (HTU) at all the phenological stages was highest when the crops were sown within 15 November. The cultivars C 306 and BL 1183 obtained the highest and lowest HTU, respectively. Phenothermal indices (PTI) during the different phenological stages in order $S_1 > S_2 > S_3 > S_4$ in both years. At all the phenological stages, PTI values were highest in BL 1183 and lowest in C 306. 15 November sowing crops

used heats more efficiently (HUE) than other sowings. HUE was significantly higher in C 306 and lower in BL 1183.

Paul and Sarker (2000) conducted a field experiment to study the influence of sowing dates on phenology and heat unit relationships of wheat. Seeds of wheat cultivars BL 1183 and Kanchan were sown on four different dates from November to December (S_1 , S_2 , S_3 and S_4). The results indicated that the number of days required to attain different phenological stages decreased with delay in sowing. For all the phenological stages, S_1 needed higher heat units than that of the other sowings. The plants of S_1 used heat more efficiently than S_2 , S_3 and S_4 . At the earlier phenological stages, phenothermal index decreased with delay in sowing, but increased at later stages.

A field experiment was conducted by **Dogiwal and Pannu (2003)** in Hisar, Haryana, India during the 1997/98 rabi season on sandy loam soil. The main plot treatments consisted of three sowing dates (10 November, 10 December and 10 January) and wheat cultivars C 306, HINDI 62, HD 2285, HR 2329, LOK 1, PBW 373, RAJ 3765, SONAK, UP 2338 WH 291 and WH 533 were assigned to sub-plots. They observed that late sowing reduced the vegetative and the reproductive phases. The maximum heat unit consumption was observed with the crop sown on 10 January. Among the different cultivars, UP 2338 consumed the maximum heat units closely followed by WH 533 and HINDI 62. The thermal use efficiency was higher in PBW 343 and LOK 1 than the other cultivars

Haque et al. (2004) carried out a field experiment with eight wheat cultivars sown on four dates starting from 1 November at an interval of 15 days for two successive rabi seasons of 1995-1996 and 1997-1998 to

determine the effect of temperature on grain filling duration and grain weight. The regression lines were used to describe the relationship between temperature and grain filling duration and grain weight. The slopes of the regression equation indicated that 0.64 and 1.01 days were shortened by per $^{\circ}\text{C}$ increase in mean daily air temperature during the grain filling period for the 1st and 2nd year, respectively. Grain weight panicle⁻¹ was decreased by 24.0 and 64.0 mg for the 1st and 2nd year, respectively per $^{\circ}\text{C}$ increase in temperature during anthesis to maturity. A positive association between grain weight and grain filling duration indicated that grain weight panicle⁻¹ was increased by 50.0 and 58.0 mg for every 1 day increase in grain filling duration.

An experiment was conducted by **Bahadur *et al.* (2004)** at the Crop Botany Field Laboratory, Bangladesh Agricultural University, Mymensingh, to evaluate the effect of sowing date on phenology, morphology and yield of modern wheat varieties. Three wheat varieties (viz., Kanchan, Shatabdi and Sourav) and four sowing dates (viz., 1, 15, 30 November and 15 December) were included as experimental treatments. The results showed that occurrence and duration of different phenophases were significantly affected by wheat varieties different planting dates. The duration for anthesis, maturity and grain filling were curtailed due to delay in planting.

Sial *et al.* (2005) conducted an experiment with twelve wheat genotypes to assess the yield and quality parameters at normal (18 November) and late sowing (11 December) dates in Pakistan. The normal temperature persisted from December to February after which there was consistent rise in the temperature with heat shocks of 35°C in the end of March. With delayed planting, the development of plant organs and transfer from

source to sink were remarkably affected, which was reflected by overall shortening of plant height, reduction in number of internodes, days to heading, days to maturity and grain filling period and ultimately in the reduction of yield and yield components.

Rasal *et al.* (2006) carried out an experiment during the rabi season of 2004-05 in Niphad, Maharashtra, India to study the effects of heat stress on the heat susceptibility index and thermal requirements of 22 bread wheat cultivars grown under early (10 November) or late (20 December) sowing conditions. They observed that heat stress reduced the grain yield by 17.45%. NIAW 1500, NIAW 1498, NIAW 1501 and NIAW 1502 had low heat susceptibility indexes for grain yield and were found to be heat-tolerant. The duration and thermal requirements for physiological maturity decreased due to heat stress under late sowing conditions. The maturity duration of the crop sown on 20 December was reduced by approximately 15 days due to the prevalence of high temperature during the reproductive phase. NIAW 1423, NIAW 1461, NIAW 1422 and NIAW 1417 required the lowest number of heat units, whereas NIAW 1483, NIAW 1428 and NIAW 1429 required the highest number of heat units to attain physiological maturity.

A field study on 14 bread wheat (*Triticum aestivum* L.) genotypes was conducted by **Gavhane *et al.* (2007)** during rabi season of 2004-2005 to assess the response of wheat genotypes to their growth development with respect to anthesis and physiological maturity along with heat unit consumption and thermal use efficiency for grain yield. The wheat genotypes were exposed to high temperature stress conditions by undertaking sowing at two different dates i.e., 10th November and 20th December of 2004 under irrigated conditions. The results revealed that

the late sowing reduced the period required for anthesis and physiological maturity. The heat unit consumption i.e., thermal requirement of all the genotypes varied according to their growth phases and time of sowing. Thermal use efficiency for grain yield differed genotypically and it was found to be less with delayed sowing in all the genotypes.

Alam *et al.* (2007a) conducted an experiment to study the influence of sowing dates and nitrogen fertilizers on phenology and accumulated heat units of barley (*Hordeum vulgare* L.), seeds of four barley cultivars (BB 1, Karan 19, Karan 163 and Karan 351) were sown on four different dates from November to December with five nitrogen treatments. The results indicated that the number of days required for attaining different phenological stages decreased with delay in sowing. For all the phenological stages, S₁ needed higher heat units than S₂, S₃ and S₄. At all the phenological stages, phenothermal index decreased with delay in sowing.

Bahadur (2008) carried out a field experiment to study the growth, development, phenological development, grain growth, heat unit use at the different phenological stages, chlorophyll content, proline accumulation, correlation between growth attributes and grain yield and yield of barley in relation to different sowing time and irrigation level. Barley was sown in four sowing dates viz., November 1, November 16, December 1 and December 16. Result revealed that the number of days for attaining different phenological stages was higher for early sowing condition. November 1 sowing required the highest days for attaining crown root initiation, tillering, booting, heading, anthesis and maturity and December 16 sowing (S₄) plants required the lowest days for attaining these stages. The S₄ plants matured about 5 days earlier than the

S₁ plants. The highest heat units, growing degree day (GDD), helio-thermal unit (HTU) and pheno-thermal index (PTI) were required in S₁ followed by S₂ and the lowest was required in S₄ plants.

Zacharias *et al.* (2010) studied the impact of elevated temperature at different phenological stages on the growth and yield of wheat and rice. In this study they evaluated the response of two cultivars of wheat (PBW-343 and Kundan) and rice (PS-2 and P-44) to high temperature stress. The stress was given either throughout crop growth period or at one of the three growth phases viz., seedling to panicle initiation, panicle initiation to flowering and flowering to maturity. Results indicated that the warmer temperature hasten crop development, shortness the growth period and finally lowers the grain yield in both crops. The impact of high temperature on growth and yield is largely determined by the duration and coincidence of it with sensitive crop growth phase. Period from panicle initiation to flowering stage was found to be more sensitive to high temperature stress in both wheat and rice. Exposure to high temperature from seedling stage to panicle initiation stage affected yield predominantly due to associated tiller mortality and reduced number of spikes. Coincidence of high temperature stress with panicle initiation to flowering phase of crop affect grain yield by reducing dry matter accumulation, productive tillers, number of spikes, grain weight and increased floret sterility. When the crop was exposed to heat stress from flowering to maturity, then the reduction in yield is predominantly caused by floret sterility leading to reduced number of grains per spike and also due to reduced grain weight. Among the varieties, Kundan of wheat and PS-2 of rice were found to be more tolerant to heat stress.

Kaur and Behl (2010) conducted an experiment to investigate the effect of short periods of high temperature, drought and their combination at different growth stages of plant under controlled conditions. They observed that high temperature and drought applied at post-anthesis shortened duration of maturation, grain filling duration and reduced grain yield, mean grain weight, grain number and thousand-grain weight.

Ahmed and Farooq (2013) studied the accumulated photothermal units, growth attributes and phenology of three wheat varieties (Chakwal-50, Wafaq-2001 and an advanced line NR-268) in four planting windows from 20th October-5th December at 15 days interval during 2008-09. Results indicated that delayed sowing put adverse effects with respect to growing degree days and photothermal units but the intensity varied among the varieties.

Amrawat *et al.* (2013) carried out a field experiment during rabi season of 2011 to 2012 at Maharana Pratap University of Agriculture and Technology, Udaipur to study the phenology, accumulated growing degree days, photo thermal unit, helio-thermal unit, heat use efficiency and performance of wheat varieties grown under different sowing dates. They observed that the crop was sown on November 5 took maximum calendar days, growing degree days, photo thermal unit, helio-thermal unit to attend different phonological stages till maturity which reduced significantly with subsequent delay in sowing time. Among the varieties MP-1203 took highest calendar days growing degree days, photo thermal unit, helio-thermal unit to reach the maturity.

Alam *et al.* (2013) conducted an experiment in the field of Wheat Research Centre (WRC), Bangladesh Agricultural Research Institute

(BARI), Nashipur, Dinajpur, Bangladesh during 2012-13 to observe the effect of high air temperature on phenological traits of some advanced spring wheat genotypes and to screen heat tolerant genotypes at irrigated late sowing (ILS) conditions. The treatments were 4 dates of sowing viz., 30 November, 15 December, 30 December & 14 January and 4 genotypes viz., BARI Gom 26, BAW 1051, BAW 1120 & BAW 1141. Results indicated that in ILS conditions, the genotypes faced higher temperature i.e., 19.3 to 26.8⁰C mean temperature from 28 November, 2012 to 09 April, 2013 which reduced the duration of booting, heading, anthesis and physiological maturity stages.

2.1.3 Water Relations and Biochemical Characters

Relative Leaf Water Content (RLWC) and Moisture Retention Capacity (MRC)

Chaves (1991) stated that water potential can be of value to describe soil, plant and atmospheric water status. So, other parameters like RLWC may be more appropriate indicator of plant water status. The drought tolerant cultivars can be identified with greater certainty by a high RLWC following a period of drought.

Narayanasamy (1999) stated that the relative turgidity of cells can be measured as relative leaf water content (RLWC). Plant generally start wilting at RLWC of 75-85%.

Haque (2000) studied the relative leaf water content (RLWC) of eight wheat cultivars in relation to four sowing dates (1 November, 15 November, 1 December and 15 December) over two seasons. He found that higher values of RLWC were obtained by early (1 November) and

optimum sowing (15 November). For all sowings, it was higher towards morning, got reduced at noon and showed some recovery towards afternoon. Moisture retention capacity (MRC) of the flag leaves was also significantly higher for 1 and 15 November sown crops.

Haider (2002) in a study with different wheat cultivars grown under irrigated and non irrigated treatments in the early and late sowing conditions and observed that the RLWC values of the 4th and flag leaves were higher in the early sown wheat crops.

A field experiment was carried out by **Alam and Haider (2007)** to study the effects of sowing times and nitrogen fertilizers on accumulation of protein, chlorophyll and relative leaf water content in barley cultivars (*Hordeum vulgare* L.). Results indicated that sowing in the 1st and 2nd week of November were resulted higher RLWC compared to other sowing times.

Bahadur (2008) in a study with two barley cultivars grown under different sowing dates viz., November 1, November 16, December 1 and December 16 and observed that the moisture retention capacity (MRC) and relative leaf water content of the flag leaves were higher in the early sown crops than the late-sown crops.

Chlorophyll Content

Engelmann (1982) suggested that light energy absorbed by chlorophyll is utilized for photosynthesis. However, after publication of fundamental monographs on chlorophyll and photosynthesis it has become customary to consider chlorophyll as the photosynthetic pigment per excellence. The rate of photosynthesis is increased with the chlorophyll content.

Volcova and Koshkin (1984) reported that high temperature (41°C) caused a decrease in the potential photosynthetic rate in both heat resistant and susceptible varieties although the decrease was smaller and recovery ability higher in resistant variety.

Kuroyanagi and Paulsen (1985) observed that increasing temperature from $25/15$ to $35/25^{\circ}\text{C}$ day/night temperature after anthesis decreased growth, leaf viability, chlorophyll concentration in wheat.

Al-Khatib and Paulsen (1999) reported that evidences suggested that higher temperature stress at the grain filling stage accelerated senescence process and consequently caused pre-mature death and loss of chlorophyll. Photosynthetic rate also decreased when plants were exposed to high temperature. Leaf photosynthesis of wheat was recorded maximum at 22°C and then decreased as temperature increased.

Chowdhury (2002) conducted an experiment at the Crop Botany Field Laboratory, Bangladesh Agricultural University, Mymensingh to examine the effect of variety and sowing date on the morpho-physiological, yield and yield contributing characters of wheat. He found that date of sowing had a significant influence on chlorophyll content. November 1 sown crop showed the highest chlorophyll content which was followed by November 15 sown crop. The lowest chlorophyll content was observed in December 15 sown crop.

A field experiment was carried out by **Alam and Haider (2007)** to study the effects of sowing times and nitrogen fertilizers on accumulation of chlorophyll in barley cultivars (*Hordeum vulgare* L.) leaves. Results

indicated that sowing in the 1st and 2nd week of November resulted higher chlorophyll compared to other sowing times.

Bahadur (2008) conducted a field experiment to study the growth, development, phenological development, grain growth, heat unit use at the different phenological stages, chlorophyll content, proline accumulation, correlation between growth attributes and grain yield and yield of barley in relation to different sowing time and irrigation level. Barley was sown in four sowing dates viz., November 1, November 16, December 1 and December 16. Result revealed that the early sown crops contained the highest amount of chlorophyll than the late-sown crops.

Sikder (2008) carried out an experiment during 2005-06 to 2006-07 to study the physiological basis of heat tolerance in wheat. Results revealed that the number of days for attaining different phenological stages, the requirement of heat unit (GDD) and helio-thermal unit (HTU) were higher for normal growing condition (November 30 sowing) compared to late growing condition (December 30 sowing). At normal growing condition all the cultivars showed higher heat use efficiency than those of late growing condition.

GuiXia et al. (2010) carried out a field experiment in Jiangsu, China to study the effects of sowing date (September 29, October 7 and October 30) and density on grain yield, nutrition quality and physiological indexes of winter wheat cultivar (Zhongren 1). Determined in 0 to 28 days after flag leaf spreading, chlorophyll content of early sowing (September 29) and proper sowing (October 7) was higher than that of late sowing (October 30). However, chlorophyll content of late sowing was higher than that of early sowing and proper sowing during late growth stage.

Singh et al. (2014) conducted an experiment to study the effects of late sown condition on various biochemical and yield attributes at pre- and post anthesis stages, in two wheat genotypes i.e., HUW-468 (high temperature sensitive) and HUW-510 (high temperature resistant). The three dates of sowing were November 20, December 10 and December 30. Results indicated that late or very late sowing induced a significant decline in chlorophyll content in HUW-468 as compared to HUW-510, particularly at post anthesis under late-sown than normal sown condition.

2.1.4 Yield and Yield Components

Pal and Butany (1947) concluded that 1000-grain weight was reduced for late sowing because of high temperatures prevalent at the time of grain ripening.

Chinoy and Sharma (1957, 1958) found that external conditions such as temperature were mainly responsible for under developed or empty grain and not genetic factor as previously held.

Asana and Saini (1962) compared 1000-grain weight for two varieties of wheat, Pb.C. 281 and N.P. 720. They observed that 13.9% to 17.8% losses in grain weight for Pb.C. 281 and N.P. 720 respectively for a 5 °C rise in the mean temperature and assuming that yield attribute was determined solely by temperature.

Gupta et al. (1968) conducted a two-year trial with four wheat cultivars sown on five different dates and reported that the highest grain yield was obtained from sowing between 9 to 24 November.

Sharma and Singh (1972) studied the yielding abilities of dwarf wheat in different dates of sowing for three years. They sowed the wheat varieties on five dates (from the end of October to the beginning of January). They observed that November 1 and 15 for the first year, November 29 for the second year and November 9 for the third year, gave significantly higher yield than the other sowings. They reported that the optimum time of sowing was the beginning of November for long duration varieties like Kalyansona, the second half of November for short duration varieties like Sonalika and the middle of November for medium late varieties like Hira. They also found that Sonalika gave higher yield in the first year, Kalyansona in the second year and Hira in the third year. They stated that the interaction between sowing dates and varieties was significant both in the first and the second year.

Randhawa and Jolly (1974) reported that dwarf wheat cultivar Sonalika decreased grain yields from 4.57 to 3.74 and 2.18 t ha⁻¹ for successively delay in planting from 15 November to 15 January, respectively.

Ahmed *et al.* (1975) conducted an experiment to observe the effect of time of sowing date on the yield of Mexican wheat at northern part of Bangladesh and reported that the variety Mexipak-65 gave the highest yield at 1 November sowing. They conducted that the second week of November was the best seeding time under Bangladesh condition and yield decreased significantly after 15 November. Yield may be reduced by 50% if seeded in the third week of December.

Darwinkel *et al.* (1977) stated that delayed sowing decreased grain yield causing a smaller number of grains per ear and a lower grain weight. The grain yield ear⁻¹ depended on the age of the tiller. Early sowing emerged

earlier and produced more and heavier ears in both the autumn and winter. Whereas, late sown wheat produced many late formed tillers only in the spring that were mostly non-fertile. The number of grains per ear and the grain weight were related to the rate of development of the ear bearing shoot that confirmed by the early sown plants.

Rao *et al.* (1980) conducted a field experiment to find out the optimum date of sowing in wheat (*Triticum aestivum* L.) and the relationship between the date of sowing and the grain yield reduction. The dates of sowing were from November 5 to January 19 at fifteen days interval. They found that sowing on November 20 was the optimum time of sowing for the highest grain yield. They also found that sowing on December 20 did not occur much reduction in yield and further late sowing (January 4 and January 19) causing more reduction in yield due to high temperature at the grain filling stage.

Mudhplkar (1981) observed that higher temperature at the grain filling stage was one of the important reasons for lower grain yield in wheat crop.

Joshi and Shingh (1983) observed that normal planting of wheat (5 November) resulted in 10.2 and 19.9% increase in grain yields over early (5 October) and late (5 December) planting, respectively. Late planting adversely affected 1000-grain weight and favourably influenced the number of ears unit⁻¹ area.

Sufian *et al.* (1983) carried out a field experiment to determine the effect of sowing time on ten wheat genotypes. They sowed ten genotypes of wheat for early (October), medium (November) and late (December) with a view to finding the suitable genotypes. They reported that October and December

sowings reduced the average growing period for all the genotypes in comparison to November sowing. The genotypes Jupateco 73, BAW 6 and Bulbul sown in October; Bulbul, Nacozari 76, Kal Bb, BAW 6, Indian, RLx 4220 7c/yy 's', Chiroca 's', Pavon 's' sown in November and Bulbul, Nacozari 76, Chiroca 's', BAW 6 gave significantly higher yield in November sowing.

Photiodes and Hadjichristodoulou (1984) conducted a series of trials under dry land conditions in a Mediterranean type climate to study the main effect and interaction of sowing date, depth and rate and row spacing on wheat and barley. They observed that there was an optimum period of sowing date, which depended on rainfall pattern. For Cyprus this period was mid November to mid December. Yields were reduced by up to 70% with late sowing while tiller number and plant height also tended to decline.

An experiment was conducted by **Green and Ivins (1985)** to observe the effect of sowing times of winter wheat. They sowed three winter wheat cultivars on optimum and late seeding conditions under two growing seasons. They found that advancing the date of sowing for winter wheat cultivars increased the duration of the growing period and it increased the opportunity for the absorption of photons. As sowing being delayed, total dry matter accumulation decreased which ultimately influenced the yield of wheat. They reported that yield potential declined at a rate of 0.35% for every day when sowing was delayed after optimum sowing time.

Chaturvedi et al. (1985) studied the effects of sowing dates on the spike characters of mother shoot and various tillers of wheat (*Triticum aestivum* L.). They sowed the seeds of C 306, Kalyansona and Sonalika on seven

days at an interval of 15 days from October 1. They also studied the phenology and yield components of the main shoot. The duration of phenological phases and the ear differentiation were affected more in Kalyansona than C 306 by a change in photoperiod and temperature. In the early sown plants, the difference between main shoot and tillers were negligible for the number of spikelets, grains spike⁻¹ and grain weight spike⁻¹ except in Sonalika, where grain weight per spike was more in the main shoots. They found that all the attributes of ear of each variety were affected with delayed sowing. The grain weight spike⁻¹, number of grains spike⁻¹ and grain yield decreased significantly with the increase of temperature.

Sarker *et al.* (1986) conducted an experiment to investigate the effect of dates of planting on the growth and yield of some modern cultivars of wheat. They sowed four modern wheat varieties, e.g., Kanchan, Ananda, Akbar and Barkat on six different dates starting from November 15 at an interval of 10 days. They found no significant difference between cultivars in respect to yield. But they reported that Barkat produced significantly the highest straw yield in comparison to the other cultivars. They also reported that November 25 and December 5 sown plants produced significantly higher grain yield in respect to other dates of planting. They observed that the grain yield was severely reduced when planting was delayed beyond December 25 and January 4.

Hossain and Farid (1988) studied the influence of sowing date and seed rate on two wheat cultivars (Akbar and Barkat). They were sown on four dates starting from 5 November at an interval of 15 days under irrigated condition. The higher yield was obtained on November 20 followed by

December 5 due to higher number of spikes m^{-2} , number of grains spike $^{-1}$ and 100-grain weight for favourable atmospheric temperature prevailing from sowing to grain filling period. The early sowing (November 5) caused reduction (8.8%) in grain due to higher number of spikes m^{-2} , number of grains spike $^{-1}$ and 100-grain yield due to high temperature prevailing from sowing to seedling emergence and tiller initiation resulting in lower number of tillers per unit area. The late sowing (December 20) produced low yield due to shorter growing period at the vegetative phase and steep rise in atmospheric temperature at the grain filling period. It was observed that the early sowing produced taller plants than the late sowing. It was also observed that Akbar gave significantly higher grain yield than that of Barkat irrespective of date of sowing.

Tashiro and Wardlaw (1989) reported that 7-12 days after anthesis of grain development was sensitive to high temperature. Grain number per ear is limited by the number of spikelets ear $^{-1}$ and the number viable florets spikelet $^{-1}$. In general, the number of outer florets spikelet $^{-1}$ in wheat was reduced more by high temperature than the basal florets, irrespective of their growth stage. Number of grains spike $^{-1}$ is determined during GS₂ phase (double ridge to anthesis).

Wardlaw *et al.* (1989) observed the greatest reduction of individual grain weight in response to high temperature occurred at different times for different spikelet and floret positions. High temperature (upto 30/25 °C day/night) after anthesis reduced grain yield of wheat by reducing weight per grain, rather than grain number.

Ansari *et al.* (1989) carried out a field trial in 1986-87 at Tandojam with wheat cvs. M-141, M-154, M-5184 and Pavon sown on 10 or 20

November or 1, 10 or 20 December. Average grain yield plant⁻¹ declined from 6.84 g with sowing on 1 November to 4.51 g with sowing on 10 December as sowing was delayed. Average grain yield ranged from 1.94 t ha⁻¹ with sowing on 10 December to 3.74 t ha⁻¹ with sowing on 10 November. They found that the number of tillers plant⁻¹, grains spike⁻¹, and 1000-grain weight also tended to decline as sowing was delayed.

Islam *et al.* (1990) conducted a field experiment at Jamalpur during 1984-1985 and 1985-86 to evaluate the performance of existing and newly released wheat varieties sown on different dates. The varieties Ananda, Kanchan, Barkat, Aghrani and Sonalika were sown from November 1 to January 15 at 15 days interval. The highest yield over the two years was obtained from Aghrani (3.66 t ha⁻¹) and Akbar (3.56 t ha⁻¹) both sown on December 1. Delay in seeding after December 1 through January 15 reduced yield by 1.5% per day.

Kifayat *et al.* (1991) carried out a field experiment at Peshwar, Pakistan during 1984-86 winter season with wheat mutants WM-89-1, WM-56-1-2, WM 6-17, WM-81-2 and WM-120-3 and wheat cv. Pak-81 sown on 25 October and 10 day intervals until 24 December. The highest grain yield was obtained from sowing on 24 November but this was not significantly different from 4 or 14 November sowing dates. Thereafter, grain yield gradually decreased with later sowing dates. Sowing after 24 November reduced the number of days to heading of the mutants. The mutant WM-6-17 gave the highest grain yield of 3.72 t ha⁻¹ which was similar to that obtained from cv. Pak-81 (3.78 t).

Porwal *et al.* (1991) considered four sowing dates viz., October 31, November 15, December 15 and December 30. They concluded that grain

yield of barley was maximum when the crops were sown on November 15 followed by November 30. They assessed that sowing date also significantly influenced 1000-grain weight of barley.

Acevedo *et al.* (1991) observed detrimental effects of high temperature on grain number and the duration of spike development during GS₂ phase. High temperature accelerated organ production without any increase in net photosynthesis resulting in smaller organs. They also concluded that grain weight of wheat was reduced from 4% to 8% for each 1°C rise in daily temperature.

A field experiment was conducted at Joydebpur in 1991-92 to examine the effect of sowing date on wheat (**BARI, 1992**). Grain yield of wheat was significantly influenced by different dates of sowing. The highest grain yield (2.93 t ha⁻¹) obtained from timely sown wheat was probably due to higher number of effective tillers plant⁻¹, grains spike⁻¹ and 1000-grain weight. The optimum sowing time had also positive effect on higher straw yield. Grain yield declined as sowing time was delayed.

Sarker and Torofder (1992) conducted a field experiment in 1989-90 with Kanchan wheat. The grain yield as recorded in Jamalpur was 1.80 t ha⁻¹ when sown on 20 November and the yield was significantly lower with earlier or later sowing dates.

Singh *et al.* (1992) carried out a field experiment during the rabi (winter) season of 1985-87 at Hisar, Haryana. They observed that in wheat (cv. wheat 283) grain yield was decreased from delaying sowing after 28 November.

Jain et al. (1992) studied the effect of sowing time on wheat varieties. They worked with six varieties of bread wheat (*Triticum aestivum* L.) and one of the macaroni wheat (*T. durum*) under five dates of sowing starting from December 20 at the interval of 10 days. They found that late sowing significantly reduced the grain yield in all the varieties, i.e., by 4.17%, 22.30%, 30.71% and 56.62% with delay in sowing by 10, 20, 30 and 40 days compared with crop sown on December 20.

Islam et al. (1993) studied the effect of sowing dates on the yield of wheat varieties at Regional Agricultural Research Station (RARS), Ishurdi, under irrigated condition. They sowed the existing (Sonalika) and newly released wheat variety (Ananda, Kanchan, Barkat, Akbar and Aghrani) on six dates starting from November 1 to January 15 at fifteen days interval. They reported that the best time of sowing was November 15 for producing the higher grain yield due to higher number of spikes m^{-2} , number of grains spike⁻¹ and 1000-grain weight for favourable atmospheric condition during the growth period. Grain yield was decreased after December 15 sowing. The lower grain yield in the late sowing (January 15) was due to shorter growing period in vegetative phase and steep rise in temperature in the grain filling stages. Among the varieties, Kanchan produced the highest grain yield irrespective of sowing dates. The varieties followed the following order for the yield: Kanchan > Akbar > Barkat > Aghrani > Ananda > Sonalika. It was also observed that the yield due to different dates of sowing over the varieties followed the order: November 15 > December 1 > November 1 > December 15 > January 1 > January 15.

Dabre et al. (1993) conducted a field experiment in 1985-87 and 14 wheat cultivars were sown on the 1st and 15th of each month for 4

months beginning from October. The highest grain yields were obtained from sowing on 15 November.

Bhatta *et al.* (1994) evaluated the variation of ten spring wheat genotypes of similar maturity in grain yield, morpho-physiological characters and relationship between grain yield and plant traits over two planting periods. Most of the characters were altered when planting was delayed by one month from normal seeding date. Declines in grain yield, kernels per spikelet and 100-grain weight were relatively small in magnitude.

Moula *et al.* (1996) carried out an experiment at Regional Agricultural Research Station, Jamalpur, Bangladesh during the winter season 1993-94 to investigate the effect of sowing date and row direction on the yield and yield components of wheat (var. Kanchan). The experiment involved four sowing dates viz., i) November 20 ii) November 30 iii) December 10 and vi) December 30 and two row directions. Highest gross benefit, net return and benefit cost ratio were obtained from November 30 to December 10 sowing.

BARI (1997) reported from the study in Jamalpur, Bangladesh during the rabi season of 1997-98 on barley cv. Conquest that among the five sowing dates viz., November 5, November 20, December 5, December 20 and January 5, the grain yield was statistically different among those sowings. The crop sown on December 20 produced the lowest grain yield which was closely followed by that of January 5 sowing. A drastic reduction in grain yield was observed when the crop was sown on December 5 or later.

Karim *et al.* (1999) conducted a field trial in Gazipur, Bangladesh with wheat cultivars Kanchan and Akbar sown on 4 December 1995 or 4

January 1996. Kanchan outperformed Akbar in terms of number of spike bearing tillers m^{-2} , individual grain weight, grain growth rate and duration and grain yield at both sowing dates. They found that grain yield, grain growth rate and duration were reduced by delayed sowing.

Singh and Jain (2000) worked on the effect of sowing time, irrigation and nitrogen on grain yield and quality of durum wheat (*Triticum durum*). They reported that mid-November sowing crop gave significantly higher grain yield than the early and late sowing crops and extent of increase were 12.3% and 33.6%, because of number of effective tillers.

Lupu (2001) conducted an experiment during 1997-99. Winter wheat was studied in Moldavia in a monofactorial experiment at ten sowing times between 15 September and 20 November. The best conditions for their growth and development and the best yield results were obtained between 25 September and 15 October. Among the productivity parameters, the number of both grains and tillers per plant were most affected by climatic factors.

Haider (2002) conducted a two years study with different wheat cultivars grown under irrigated and non-irrigated treatments in early and late sowing conditions in Rajshahi University, Bangladesh. Irrigation and early sowing increased yield and almost all the yield components. Higher water use efficiency (WUE) was noticed in the early sown plants in both the years.

Paul and Sarker (2003) carried out an experiment in the experimental field Rajshahi University Campus, Bangladesh to study the effect of sowing time on grain yield of two wheat (*Triticum aestivum* L.) cultivars.

Two cultivars of wheat (Karan and BL 1183) were sown on four sowing dates, viz., 1 November (S_1), 19 November (S_2), 1 December (S_3) and 15 December (S_4). Results indicated that sowing up to 19 November had no adverse effect but sowing of 1 and 15 December affected the grain yield. Simple correlation analysis indicated that grain yield was positively correlated with number of tillers plant⁻¹, number of fertile tillers plant⁻¹, number of spikelets spike⁻¹ and total dry matter.

Patil et al. (2003) conducted an experiment during 1999-2000 in Akola, Maharashtra, India involving 6 early wheat cultivars, namely AKW-1071, AKW-381, AKW-3294, AKW-34, HI-977 and HD-2501 and 5 sowing dates, i.e. 15 November, 1 December, 15 December 1999 and 1 January and 15 January 2000 to observe the effect of temperature on yield and yield components of early wheat cultivars. They observed that the total biomass at maturity, grain number spike⁻¹, 1000-grain weight and yield m⁻² decreased significantly with delay in sowing. Among cultivars, AKW-381 was found suitable for late sowing, as it exhibited tolerance to high temperature during grain growth phase.

An experiment was conducted by **Bahadur et al. (2004)** at the crop Botany Field Laboratory, Bangladesh Agricultural University, Mymensingh, to evaluate the effect of sowing date on yield component and grain yield of modern wheat varieties. Three wheat varieties (viz., 1, 15, 30 November and 15 December) were included as experimental treatments. From the study it was observed that the difference in varieties and sowing dates significantly influenced plant height, spike length, tiller number plant⁻¹, effective tillers plant⁻¹, number of spikelets spike⁻¹, number of unfertile spikelets spike⁻¹, seeds spike⁻¹, 1000-grain weight, grain yield and straw yield. The varieties may be graded as Shatabdi (3.22

t ha⁻¹) > Sourav (2.90 t ha⁻¹) > Kanchan (2.80 t ha⁻¹) in respect to grain yield. The sowing dates may be graded as 15 November > 30 November > 1 December > 15 December in respect to grain yield.

Ram *et al.* (2004) carried out a field experiment in Hisar, Haryana, India, during the 2001/02 rabi season to determine the effect of sowing date (10 October, 20 October, 30 October, 10 November and 20 November) and row spacing (22.5, 30.0 and 37.5 cm) on the yield and yield components of wheat cv. C-306. They observed that wheat sown on 10 October gave the highest number of spikes plant⁻¹, number of grains spike⁻¹ and grain yield. The highest 1000-grain weight, straw yield and biological yield were obtained with 20 October sown wheat. The highest harvest index was obtained in 20 November sown wheat.

Zende *et al.* (2005) conducted an experiment during the 2002/03 rabi season in Akola, Maharashtra, India, to evaluate the effects of sowing time (15 November, 1 December and 15 December) on the growth and yield of durum wheat (*Triticum durum*) and concluded that the growth, yield and yield attributes, except for the spike length, showed significant increases when durum wheat crops were sown on 15 November compared with those sown on 1 December and 15 December.

Tahir *et al.* (2006) carried out an experiment with fifteen bread wheat genotypes in 2000/2001 and 18 genotypes in 2002/2003 to evaluate the performance of selected wheat genotypes under heat stress and to examine the effects of high temperatures during grain filling on grain yield and end-use quality parameters. Data collected included grain yield, grain weight and grain end-use quality including protein content, protein composition, SDS sedimentation values (SDSS) and gluten strength as

determined by mixograph analyses. High temperatures significantly decreased grain yield by decreasing grain weight.

Singha *et al.* (2006) conducted an experiment in West Bengal, India during 2002-03 on a set of 14 diverse genotypes and three different sowing dates (18 November, 29 November and 10 December), under different temperature regimes. Average minimum and maximum temperatures varied among the sowing dates. The dates of sowing showed significant differences on all the characters except number of spikelets panicle⁻¹. The genotypes and the interaction between date of sowing and genotypes, showed significant differences for all the characters. It was also found that with the increase in temperature (maximum and minimum) during grain filling period, all the yield components were reduced in mean values ranging from 4.77 to 10.05%. Consequently, maximum reduction in grain yield plant⁻¹, grain filling period and 1000-grain weight was observed in the third date of sowing as compared to the first date.

Bahadur (2008) carried out a field experiment to study the growth, development, phenological development, grain growth, heat unit use at the different phenological stages, chlorophyll content, proline accumulation, correlation between growth attributes and grain yield and yield of barley in relation to different sowing time and irrigation level. Barley was sown in four sowing dates viz., November 1, November 16, December 1 and December 16. Result revealed that the maximum grain yield was obtained in S₁ sowing followed by S₂ and S₃ sowing. Plant height, fertile tiller plant⁻¹, spike length, number of grains spike⁻¹, 1000-grain weight and total dry matter were reduced by delay in sowing.

Mohiuddin (2010) carried out a field experiment at the research field of the Department of Botany, Rajshahi University, Rajshahi to study the effect of three sowing date (November 15, November 30 and December 15) and two soil moisture levels on the growth and yield of wheat varieties. Results revealed that delayed sowing reduced plant height, number of fertile tiller plant⁻¹, spike length, number of grains spike⁻¹, weight of 1000-grain and finally grain yield. The maximum grain yield was obtained in S₁ sowing (November 15) followed by S₂ (November 30) and S₃ (December 15) sowing.

Khokhar *et al.* (2010) conducted a field experiment during 2000-01 and 2001-02 at Sakrand, Sindh to determine the effects of planting dates on growth and yield of different wheat genotypes. Four sowing dates i.e., November 1 and 15, December 1 and 15 were in main plots, whereas six wheat genotypes (V-7001, V-7002, V-7004, MPT-6, Abadgar-93, and Anmol-91) were in sub plots. They observed that because of better tillering, plant growth, growth period, number of grain per unit area and grain weight, November 15 planted wheat had maximum grain yield of 5904 kg ha⁻¹, followed by November 1 and December 1 which gave 5302 and 4948 kg ha⁻¹ respectively. Wheat planted on December 15 resulted in minimum grain yield of 4756 kg ha⁻¹. Results from the study revealed that maximum grain yield could be achieved with wheat planted in first fortnight of November and any delay in wheat planting might reduce wheat yield.

Kumar *et al.* (2010) carried out a field experiment during the two consecutive rabi seasons of 2003-04 and 2004-05 on sandy loam soil to study the effect of sowing dates and variety on growth, yield attributing

characters and yield of wheat (*Triticum aestivum* L. emend Fiori & Paol). The tested varieties were HD 2285 (V₁), K 8804 (V₂) and K 9107 (V₃) under three sowing dates i.e., 20 November, 5 December and 20 December. At delayed sown, the growth and yield attributing characters were significantly reduced, resulting decline in grain yield by 20.6, 33.5 and 14.1, 22.5% during first and second year with 5 and 20 December sown, respectively compared to 20 November sown crop. The magnitude of loss in grain yield with variety at delayed sown was lowest in HD 2285 and highest in K 9107 during both the years.

Ahamed *et al.* (2010) conducted an experiment at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh from November, 2008 to April, 2009 to observe the effect of high temperature stress on the growth and development of five wheat varieties (Sourav, Prodig, Sufi, Shatabdi and Bijoy). There were two growing condition viz., normal sowing (November 30) and another was late sowing (30 December). The late sown wheat plants phased a significant heat stress especially at the reproductive period that influence their growth and development pattern. Plant height, tiller number, yield components and yield were compared of all varieties under two environmental conditions. All the varieties performed negatively for all parameters under heat stress condition. Due to high temperature stress plant height, no. of total tillers, fertile tillers, ear length, no. of spikelet main stem⁻¹, fertile floret main stem⁻¹, 1000 grain weight and yield decreased and no. of sterile tillers and no. of sterile floret main stem⁻¹ increased. The performance of Bijoy was the best in respect of yield as the yield reduction was the least (53.42%), whereas Sufi showed worst performance (73.01% yield reduction). Therefore, from this study it may be concluded that under

high temperature stress the performance of the variety Bijoy was the best especially regarding the yield components and yield.

Pahwa and Gill (2010) studied the influence sowing date on yield and its contributing characters of wheat. The study with two wheat cultivars (cvs. PBW-343 and WH-542) sown at three dates of sowing viz., 2 November, 1 December and 4 January resulted reduction in grain yield with delay in sowing. The results revealed that with delay in sowing there was significant decline in number of effective tillers m^{-2} , number of grains spike $^{-1}$, weight of grains spike $^{-1}$ and 1000- grain weight that ultimately affected the grain yield. Among the cultivars, cv. PBW-343 had higher values for yield (42.15 q ha^{-1}) and all yield contributing traits under all dates of sowing. Thus, the best results were obtained from cv. PBW-343 under 2 November sowing indicating that it possesses thermo tolerant characteristics.

Kaor *et al.* (2010) carried out an experiment to study the effect of various timings of N application and date of sowing on the performance of wheat. The results showed that maximum spike length, number of spikelets spike $^{-1}$ and number of grains spike $^{-1}$ and net returns were recorded in timely sown crop and minimum in very late-sown wheat. Delayed sowing resulted in significant decrease in test weight, number of effective and total tillers and consequently the grain yield.

Baloch *et al.* (2010) conducted an experiment at the Agricultural Research Institute, Dera Ismail Khan to study the effect of seeding density and planting time on the growth and yield attributes of wheat. Wheat variety Hashim-8 was sown on different sowing dates viz., October 25, November 10, November 25, December 10 and December

25 with seeding rates of 100, 125, 150, 175 and 200 kg ha⁻¹. Data indicated that sowing wheat on October 25 and November 10 produced the highest number of tillers, spike length, plant height, 1000-grain weight and the grain yield, which subsequently decreased with successive sowing dates. On the basis of results obtained, it is concluded that wheat variety Hashim-8 should be sown between October 25 to November 10 with seed rate of 150 kg ha⁻¹.

Biswas and Srivastava (2010) conducted an experiment on wheat varieties (Sonalika, HD 2329, K 9107, HUW 234) under different sowing dates at 15 days interval during rabi season. They found that optimum time of sowing for all the varieties is November 15 followed by October 30. The highest grain yield was obtained from November 15 sowing. Among five popular wheat varieties, HD 2329 recorded highest yield with 43.0, 41.78 and 39.71 q ha⁻¹ against lowest 39.0, 37.0 and 35.52 q ha⁻¹ in HUW 234 at November 15 sowing in all the three consecutive years.

Alam et al. (2010) carried out experiment in Kanpur, Uttar Pradesh, India to evaluate the effects of sowing dates (19 November and 19 December) on the yield of 10 bread wheat genotypes (K 9408, HP 1871, HD 2662, HUW 467, UP 2398, HUW 470, HUW 468, NW 1012, HUW 206 and HP 1761). They observed that earlier sowing resulted in better yield and seed quality in the different bread wheat cultivars.

GuiXia et al. (2010) studied the effects of sowing date (September 29, October 7 and October 30) and density on grain yield, nutrition quality and physiological indexes of winter wheat cultivar (Zhongren 1). Results revealed that sowing date had significant influence ($p < 0.05$) on grain

yield and yield contributing components. Grain yield of proper sowing were remarkably higher than those of early sowing and late sowing.

Kour *et al.* (2011) carried out two field experiments during two rabi seasons to study yield potential and simulation studies of wheat genotypes as influenced by sowing dates under temperate Kashmir. Effective tillers m^{-2} and 1000 seed weight were significantly higher under early-sown (1 October) wheat with the concomitant increase in grain yield during both the years. Cultivars HS 240 and SKW 191 not only proved superior in growth and yield attributes but also produced higher grain yield over HS 295, SKW 193, Shalimar wheat-1 and HS 365. For higher yield of wheat cultivars SKW 191 and HS 240 can be sown at 1 October (early).

Laghari *et al.* (2012) conducted a field experiment to observe the effect of high temperature stress on grain yield and yield components of wheat (*Triticum aestivum* L.). Results indicated that the late-sown (January) crop exposed to terminal heat stress during grain development period and therefore the grain yield (1425 kg ha^{-1}) and its associated traits were significantly decreased.

Gheith *et al.* (2013) conducted two field experiments in Egypt during 2011/2012 and 2012/2013 seasons at Experimental Research Center, Faculty of Agriculture, Cairo University, Egypt to determine the effect of different sowing dates and nitrogen levels on growth and grain yield and its components of some wheat genotypes. Wheat crop genotypes responded differently to the three factors for various characters (number of spikes m^{-2} , spike length, grain weight spike $^{-1}$, 1000-grain weight,

harvest index and grain yield fed^{-1}) produced the highest values at early sowing (25 November) as well as at $100 \text{ kg N fed}^{-1}$ in both seasons. Late sowing (December) and low nitrogen application significantly declined yielding capacity of wheat genotypes. Either L.R.-62 or Sids 1 produced highest grain yield performed better in term of grain yield as compared to other genotypes in both seasons, respectively. Moreover, all tested genotypes produced highest grain yield when planted early in 25 November and application of $100 \text{ kg N fed}^{-1}$.

Chakrabarti et al. (2013) carried out an experiment during 2007-2008 and 2008-2009 to study the growth and yield response of wheat and chickpea under high temperature. Results showed that high temperature reduced the crop growth duration. Days to 50% flowering reduced by 4-5 days in wheat with $1.8\text{-}2.9^{\circ}\text{C}$ increase in temperature. Photosynthesis rate, stomatal conductance and leaf area index reduced with the rise in temperature. High temperature inside the TGT caused reduction in both biomass and grain yield of wheat crop in both the years and the reductions in yield per degree temperature rise was 10.4-10.5% in wheat crop. Number of spikes plant^{-1} , number of grains spike^{-1} , 1000-seed weight was also affected with increased temperature.

Sokoto and Singh (2013) conducted field experiments during 2009/10 and 2010/2011 dry seasons at the Fadama Teaching and Research Farm of the Usmanu Danfodiyo University, Sokoto, in the Sudan Savanna ecological zone of Nigeria to study the effect of water stress, sowing date and cultivar on yield and yield components of wheat (*Triticum aestivum* L.). The treatments consisted of factorial combination of water stress at three critical growth stages, four sowing dates (21 November, 5

December, 19 December and 2 January) and two bread wheat cultivar. Result revealed that yield and yield components decreased with delay in sowing date and it was highest at 21 November and 5 December and lowest at 19 December and 2 January, therefore wheat should be sown in November or at least first week of December in this area and other area with similar climate.

Jat et al. (2013) conducted a field experiment during the winter (rabi) season 2010-11 at Agricultural Research Farm, BHU, Varanasi, Uttar Pradesh, to study the effect of sowing dates and fertilizer levels on growth and yield of wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]. Sowing dates and fertilizer levels significantly affected the number of tillers, plant height, dry-matter accumulation, ear weight, ear length, grains ear⁻¹, 1000-grain weight, grain and straw yield. Grain yield decreased with delay in the sowing dates. Maximum grain yield (3.66 t ha⁻¹) was recorded when the crop was sown on 20 November and the minimum (3.17 t ha⁻¹) when sown on 23 December.

Amrawat et al. (2013) carried out a field experiment during rabi season of 2011 to 2012 at Maharana Pratap University of Agriculture and Technology, Udaipur to study phenology growth and yield of wheat in relation to agrometeorological indices under different sowing dates. The grain yield recorded in 5 November was statistically at par with 20 November. The significant reduction in grain yield of timely sown varieties was recorded when sowing was delayed beyond 20 November. Among the varieties highest grain yield of 62.81 q ha⁻¹ was recorded in varieties Raj 4037, which was significantly superior over HI-1544 (58.75 q ha⁻¹) and MP-1203 (50.32 q ha⁻¹). The variety Raj 4037 recorded the

highest grain yield at 5 November sowing as compared to all other sowing dates.

Eslami *et al.* (2014) carried out an experiment during 2011-2012 to determine the effects of sowing dates and seeding density on growth and yield of wheat, variety N-85-5 in Iran. Three sowing dates i.e., December 21, December 30 and January 29 were in main plots, whereas two wheat seeding density (350 and 500 plant m⁻²) were in sub plots. Results indicated that sowing wheat on December 21 produced the highest number of spike, spike weight, 1000-grain weight and biological, grain yield, which subsequently decreased with successive sowing dates.

Ning *et al.* (2014) conducted an experiment from 2011 to 2013 in Inner Mongolia to investigate the influence of planting dates on yield and phenology of spring wheat and potential of improving resource (water and nitrogen) use efficiencies. Five sowing dates was designed from 26 April to 5 June with a 10-day interval. The results showed that the yields after 6 May were significantly ($p < 0.05$) decreased due to delayed sowing dates. Compared to early sowing date (26 April), the yield of the late sowing date was reduced by 63.3% to 72.3% due to the obvious reduction in daily temperature from the growth stages of heading to maturity. Harvest index (HI) and grain weight per 1000 seeds were also affected by sowing dates. The early sowing (26 April and 5 May) treatments had higher HI. But after 16 May, the HI decreased significantly ($p < 0.05$). The grain weight per 1000 seeds decreased from 44.65 to 20.73 g with the delaying of the seeding dates, which had a trend similar with HI. It indicated that low values of HI and grain weight contributed to yield decrease when sowing after 26 May.

Singh *et al.* (2014) carried out an experiment to study the effects of late-sown condition on various biochemical and yield attributes at pre- and post anthesis stages, in two wheat genotypes i.e., HUW-468 (high temperature sensitive) and HUW-510 (high temperature resistant). Seeds were sown on November 20, December 10 and December 30. Significant differences were observed among both the genotypes for the number of ears per 20 cm row length, spikelet ear⁻¹, number of grain ear⁻¹, test weight, yield plant⁻¹ and harvest index in all the dates of sowing. Normal sowing date showed higher grain yield as compared to other dates of sowing in both the genotypes.

Fergani *et al.* (2014) studied the response of some bread wheat cultivars to sowing dates. Each experiment included 15 treatments which were the combination between three wheat cultivars (Giza 168, Sakha 93 and Gemmiza 9) and five sowing dates (October 1, October 16, November 1, November 16 and December 1). The data revealed that sowing dates and cultivars both significantly affected wheat yield and its components. Sowing on November 1 exhibited significant maximum plant height, number of spike m⁻², main spike length and weight, grains number of main spike as well as grain, straw and biological yields as compared to early or late sowing in the season. Concerning wheat cultivars, Gemmiza 9 gave significantly highest yield and its components in comparison to Sakha 93 and Giza 168. The data revealed that sowing Gemmiza 9 wheat cultivar on November 1 was the most suitable environmental conditions for growing wheat in Kaluobia Governorate.

Puranik and Patel (2014) conducted an experiment during the rabi season of 2007-08 in Raipur, Chhattishgarh, India, involving four dates of

sowing i.e., 29 November, 8 December, 18 December and 28 December and six cultivars of wheat, namely Sujata, Kanchan and GW-273 to observe the effect of sowing dates on yield and yield components of wheat cultivars. Number of ear heads m^{-2} , length of ears, number of grains ear^{-1} , test weight, grain and straw yields were determined at harvest. The 29 November was the optimum time of sowing wheat. Kanchan is suitable for early sowing and Sujata shows better yield under late-sown condition, while GW-273 is suitable for all the sowing dates.

Ataur Rahman *et al.* (2015) carried out an experiment at the Hill Agricultural Research Station, BARI, Khagrachari for the two consecutive years (2009-10 and 2010-11) to find out the wheat variety suitable for hilly environment and investigate the interaction of sowing dates and varieties to recommend the promising varieties with proper sowing time. The experiment was laid out in a split plot design with three replications where three dates of sowing (November 20, November 30 and December 10) were assigned in the main plots and five modern wheat varieties (Shatabdi, Sufi, Sourav, Bijoy and Prodip) were in sub plots. Results revealed that the variety Bijoy gave maximum grain yield closely followed by Sourav in both the years. Shatabdi produced higher yield under early sowing (November 10) but yield was decreased due to late sowing (December 10). Initially the plant population and finally spikes m^{-2} were affected by late sowing that caused less yield in Shatabdi.

2.2 Effect of Mulching

Tarafder *et al.* (1996) conducted a field experiment to study the effect of tillage and mulching on wheat and maize seedling growth. Addition of mulch increased soil moisture content in the root zone and decreased soil

temperature significantly. This proved more stable environment for seedling establishment and growth than unmulched soil.

Feng-Min *et al.* (1999) carried out field experiments to observe the effects of clear plastic film mulch on yield of spring wheat involving three mulching treatments viz., for 20 d (M_1), 40 d (M_2) and 60 d (M_3) days after sowing (DAS), with a control (CK). Mulching increased temperature and moisture in the upper 5 cm of soil and shoots emerged 8 d earlier than in CK. Mulching also increased number of tillers, length of the growing period, spikelet and grain numbers spike⁻¹ and the duration from flowering to harvest. In the mulched treatments, photosynthesis rate and soluble sugar content were higher in the vegetative period, but soluble sugar content was lower in the grain filling period relative to CK. Grain yield following 20 d mulching was greatest (8207 kg ha⁻¹) and decreased gradually as the mulching period increased (7847 and 6702 kg ha⁻¹ for M_2 and M_3 , respectively). Plastic film removed after 20 d maximizes yield and minimizes soil pollution.

Maecka (2002) carried out a field experiment in the years 2001-02 at Research Station Brody of the Agricultural University of Poznan to determine the subsequent effects of cover crop mulches (straw, white mustard, oat-pea mixture, phacelia and no mulch control), two tillage methods (conventional, single ploughing) and two nitrogen rates (50 and 100 kg ha⁻¹) on winter triticale yield. Winter triticale yielded significantly higher when followed by cover crops compared to control - no mulch.

Niu *et al.* (2004) found that the mulched wheat had 23% greater number of seeds plant⁻¹, 5% higher seed weight and 28% higher grain yield than unmulched wheat. In semiarid northwestern China, the use of plastic

mulches promoted spring wheat root development, root biomass production and seed yield.

Feng-Min *et al.* (2004a) conducted field experiments using spring wheat (*Triticum aestivum* L. cv. Longchun 8139-2) to examine the effect of film-mulching with varying durations on crop yield and soil properties in 1999 and 2000 on Loess Orthic Entisols in the semiarid Loess Plateau of China. The three mulching treatments with varying durations were applied: (1) M₃₀: mulching for 30 days after sowing (DAS); (2) M₆₀: mulching for 60 DAS; (3) Mw: mulching for the whole growth period, as well as the control; M₀: without mulching. Highest yields were recorded from wheat treated with M₆₀. By contrast, no significant difference in yield was found among the three-mulched treatments in 1999. In 1999 the water use efficiency in all mulching treatments was significantly higher than in control, while in 2000 it was significantly higher in M₆₀ and Mw than in M₃₀ and control. These findings therefore suggest that mulching for 60 DAS increased grain yield by increasing the mineral nitrogen, soil water and the efficiency of water use and avoiding the over-decomposition of organic matter and over-mineralization of organic nitrogen.

FengMin *et al.* (2004b) studied the combination of pre-sowing irrigation and film mulch and its effect on spring wheat grain yield in semiarid Loess Plateau in China. Four treatments were employed: (1) C - control, without pre-sowing irrigation and without mulching (2) I - pre-sowing irrigation of 30 mm without mulching (3) M - plastic film mulching without pre-sowing irrigation and (4) IM - 30 mm pre-sowing irrigation plus mulching. It was observed that the grain yield was 29.4% greater in treatment IM in 1999 and 112.4% greater in 2000 compared with control.

The WUE was higher in the wet year of 1999 than in the dry year of 2000. The combination of pre-sowing irrigation with film mulching increased the soil temperature in the seedling stage, reduced the water deficit and achieved the highest shoot biomass, grain yield and water-use efficiency of the 2 years. It is, therefore, concluded that the combination of pre-sowing irrigation with plastic film mulching works well in increasing plant growth and yield of spring wheat and can be adopted for spring wheat production in the semiarid areas.

RiYao *et al.* (2004) conducted an experiment to investigate the comprehensive effects of different mulching: water-osmosis plastic film, straw and normal plastic film, on winter wheat production in Weibei highland, China. Results of the 3-year study revealed that all the mulching methods significantly increased yield and soil water content. Compared to normal plastic film and straw mulching, winter wheat yield with water-osmosis plastic film was increased by 43.1 and 40.4%, respectively.

Pawar *et al.* (2004) studied the effect of different mulches on soil moisture conservation and crop yield of groundnut (*Arachis hypogea*). Sugarcane trash mulch, wheat straw mulch, black plastic mulch and transparent plastic mulch were used in the study. They observed that percent increase in soil moisture conservation over control was maximum in sugarcane trash mulch (13.56%) followed by black plastic mulch (12.34%), transparent plastic mulch (10.74%) and wheat straw mulch (7.04%). The maximum crop yield was observed in transparent plastic mulch (24.87 q ha⁻¹) followed by black plastic mulch (22.73 q ha⁻¹), sugarcane trash mulch (21.42 q ha⁻¹), wheat straw mulch (18.92 q ha⁻¹)

and control (10.78 q ha^{-1}). As a result of better moisture conservation and higher crop yield the transparent plastic mulch gave the higher water use efficiency (WUE) of $37.03 \text{ kg ha}^{-1} \text{ cm}^{-1}$, which was 83.68% more than that of control.

Huang *et al.* (2005) studied the influence of straw mulch and irrigation on wheat yield and water-use efficiency for 2 years (1997–1998). They found that straw mulch increased wheat yields significantly during both dry (1997) and wet (1998) years. It increased biomass and grain yield by 37 and 52%, respectively, in 1997 and by 20 and 26%, respectively, in 1998. Straw mulch also significantly decreased evapotranspiration ($p < 0.05$), soil water depletion ($p < 0.01$), and increased water-use efficiency ($p < 0.001$).

Rahman *et al.* (2005) conducted a field experiment at the research farm of the Wheat Research Centre, Dinajpur, Bangladesh, for two consecutive years including three levels of mulching: no mulch (M_0), surface application of rice straw mulch at 4.0 Mg ha^{-1} that was withdrawn at 20 days after sowing (M_1), the same level of mulch as M_1 but allowed to be retained on the soil surface (M_2) and four nitrogen levels (control 80, 120 and 160 kg ha^{-1}). They reported that mulch treatment of M_1 and M_2 were equally effective at conserving soil moisture, suppressing growth of weed flora, promoting root development and thereby improved grain yield of no-till wheat.

Islam *et al.* (2005) carried out field experiments at the farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh during two consecutive rabi (winter) seasons of 2000/2001 and 2001/2002 to determine the tillage and mulch effects on

physical properties of shallow red brown terrace soils, using wheat as the test crop. They observed that grain yield increases over no mulch were 23, 18 and 11% with rice straw mulch, water hyacinth and polyethylene mulch, respectively.

YanJun *et al.* (2005) found that grain yields of wheat increased 38.5% in mulched treatments compared with non-mulched control plots.

ZhongKui *et al.* (2005) conducted field experiments to study the evapotranspiration (ET), evaporation (E), growth, yield and water use efficiency (WUE) of plastic-mulched spring wheat with hole planting in 1990 and 1991 under full and deficit irrigation at Zhangye Station of Water-saving Agriculture, Gansu Academy of Agricultural Science in northwest China. The study indicated that there were increases of 0.9-30.8% in ET and 4.0-110.3% in yield for all plastic-mulched treatment over non-mulch treatment.

YanMin *et al.* (2006) observed the effect of different mulch materials on winter wheat production during 2002-03 and 2003-04. Four treatments were set up: (1) no mulch (2) mulch with plastic film (3) mulch with maize straw and (4) mulch with concrete slab between the rows. The result indicated that concrete mulch and straw mulch was effective in conserving soil water compared to plastic film mulch, which increased soil temperature. Concrete mulch decreased surface soil salinity better compared to other mulches used. Straw mulch conserved more soil water but decreased wheat grain yield probably due to low temperature. Concrete mulch had similar effect with that of plastic film mulch on promoting winter wheat development and growth.

RiYao et al. (2006) carried out a field experiment in Weibei Highland, Shaanxi Province, China to analyse water use efficiency (WUE), water saving and yield increasing effect and the input and output of different mulching cultivation modes of winter wheat (*Triticum aestivum*). The mechanism of yield increase and water saving of different mulching cultivation modes were also determined. Results revealed that ridged mulched plastic film and furrow mulched straw cultivation were better than convention cultivation modes for winter wheat in Weibei Highland. These mulching cultivation modes increased WUE to 11.59 kg/mm per hm^{-2} and showed a water saving of unit grain produce of 37.21-39.85%, yield increase of unit water consumption 58.68-66.25% and output and input proportion of 1.34:11. Ridge mulched plastic film and furrow mulched straw cultivation modes are considered as one of the efficient methods for improving winter wheat yield and economic benefits.

Islam et al. (2006) conducted a field experiment at the farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur during two consecutive rabi seasons of 1999-2000 and 2000-2001 to study the tillage and mulching effects on the yield and yield attributes of wheat (*Triticum aestivum* L.). Four different tillage methods were used in the main plots and three different mulch materials, namely rice straw, dry water hyacinth and white polyethylene including no mulch were used in the sub-plots. Results indicated that rice straw mulch conserve more moisture than other mulch application. Straw mulch increased dry matter yield, crop growth rate, plant height, spike number m^{-2} , spike length, grains spike⁻¹ and straw and grain yield. Water hyacinth and polyethylene mulch also showed significant response against no mulch.

Mondal *et al.* (2007) conducted field experiments at Regional Agricultural Research Station of Bangladesh Agricultural Research Institute (BARI), Jessore during the rabi seasons of 1999-2000 and 2000-2001 to evaluate the effect of tillage and mulch practices on the conservation of residual soil moisture, yield attributes and yield of wheat (cv. Shatabdi). The experiment consisting of three levels of tillage and four levels of mulch viz., rice straw, water hyacinth, black polythene and no mulch. Black polythene mulch significantly increased grain yield by 29% over no mulch and also conserved more moisture in the soil.

Ahmed *et al.* (2007) carried out a field experiment at the University of Arid Agriculture, Rawalpindi during rabi 2001-2002 to evaluate the effect of planting geometry and mulching on soil moisture, weed control and growth parameters of wheat under rainfed conditions. The experiment consisting of three types of planting geometries and four levels of wheat straw mulch i.e., 1, 2, 3 and 4 t ha⁻¹ was compared against control. The results obtained indicated that mulching treatments had significantly increased soil moisture contents at tillering (6-21%), booting (4-16%) and grain formation (2-24%) stage when mulch rate increased from 1 to 4 t ha⁻¹ compared to control treatment. Similarly, the increase in mulch rate from 1 to 4 t ha⁻¹ wheat straw when compared with control, progressively increased the emergence count (24-42%), number of tillers (26-52%), plant height (10-37%) and reduced the weed biomass (3-17%). This indicated that emergence counts, plant height, number of tillers were directly proportional to the mulching material.

Chakraborty *et al.* (2008) conducted field experiments during winter seasons of 2004-2005 and 2005-2006 to evaluate the soil and plant water

status in wheat under synthetic (transparent and black polyethylene) and organic (rice husk) mulches with limited irrigation and compared with adequate irrigation with no mulch). Though all the mulch treatments improved the soil moisture status, rice husk was found to be superior in maintaining optimum soil moisture condition for crop use. The residual soil moisture was also minimum, indicating effective utilization of moisture by the crop under RH. The plant water status, as evaluated by relative water content and leaf water potential were favourable under RH. Specific leaf weight, root length density and dry biomass were also greater in this treatment. Therefore, it was concluded that under limited irrigation condition, RH mulching will be beneficial for wheat as it is able to maintain better soil and plant water status, leading to higher grain yield and enhanced water use efficiency.

Singh et al. (2011a) conducted two field experiments during 2006-2008 in the Punjab, India, to study the effects of rice straw mulch and irrigation scheduling on wheat growth, yield, water use and water productivity. Mulching increased soil water content and this led to significant improvement in crop growth and yield determining attributes where water was limiting, but this only resulted in significant grain yield increase in two instances.

A field experiment was conducted by **Singh et al. (2011b)** at Selakui, Dehradun during 2001-04 to study the effect of tillage (conventional and minimum) and mulching practices (no mulching and live mulching) under artificially created varying land slopes (0.5, 2.5, 4.5 and 9.5%) on soil-moisture conservation, productivity and nutrient uptake in maize-wheat cropping system. They observed that sunnhemp (*Crotalaria juncea*

L.) intercropped with maize gave 0.87-1.09 tonnes biomass (dry weight) and accumulated 24.8-31.4 kg N/ha at 30 days of growth when it was mulched. Intercropping of maize with sunnhemp and spreading the cut biomass as mulch at 30 days (live mulching) improved soil moisture conservation at maize harvest (+1.63 to 1.94%) and yield of maize (12.0%) as well as of following wheat (13.8%) compared with the no mulching.

Singh et al. (2012) carried out a field experiment to evaluate the sowing methods and mulching effect on yield and yield components of wheat (*Triticum aestivum* L.). Two sowing methods and two mulching materials with no mulching treatments were used. Line sowing produced significantly higher yield components and grain yield. The harvest index and straw yield was also higher for line sowing than broadcast sowing. Mulching practice increased the spike population, while grains per spike and grain weight remained unaffected. Higher grain and straw yields were obtained with mulching. Line sowing and mulching with 4 t ha⁻¹ of sorghum stover is recommended for optimum grain and straw yields of wheat.

Zamir et al. (2013) conducted a field experiment at the Agronomic Research Farm, University of Agriculture, Faisalabad during spring season, 2011 to evaluate the effect of different sowing techniques and mulches on the growth and yield attributes of maize. The experiment comprised of five sowing methods and three mulches (maize pith, wheat straw and rice straw). They observed that among the mulch treatments, wheat straw mulch perform better and gave higher grain yield (6.21 Mg ha⁻¹) as compared to the rice straw mulch and maize pith.

Farzadi and Masoum (2013) carried out an experiment during 2009-2010 cropping season at the Safiabad Agricultural Research Center, Dezful, Iran to study the effect of cover crops on weed dry matter and grain yield of wheat cv. Chamran. Cover crops included mung bean, clover and fallow that were grown and practiced and returned in soil before wheat was planted. Results showed that the effect of cover crops was significant ($p \leq 0.01$) on weeds dry matter at three stages of wheat; stem elongation, heading and physiological maturity. Cover crops also had significant ($p \leq 0.01$) effect on spikes m^{-2} , grains spike $^{-1}$ and grain yield of wheat cv. Chamran. Results also indicated that mung bean controlled weeds more effectively and increased spikes m^{-2} (by 148 spikes m^{-2}), grains spike $^{-1}$ (by 8 grains spike $^{-1}$) and grain yield (by 1.341 t ha^{-1}) as compared with fallow treatment.

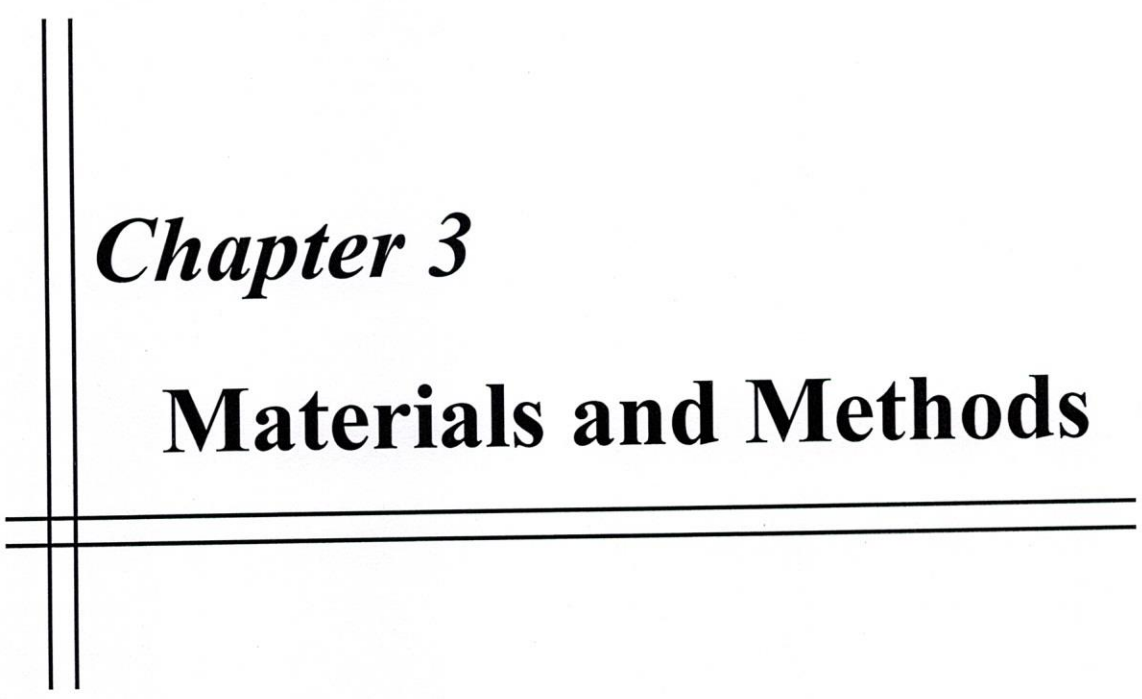
Khan et al. (2014) carried out an experiment during 2010-2011 at the research area of Soil and Water Conservation Research Institute, Chakwal, Pakistan to estimate the effects of different types of mulches on the growth, development and grain yield of wheat. Four different types of mulches (hoeing twice 30-40 & 60-70 DAE, straw mulch @ 2.0 ton ha^{-1} , litter mulch @ 1.5 ton ha^{-1} and gypsum @ 2.5 ton ha^{-1}) were compared with control (no mulch). The investigation revealed significant effects of different types of mulches on the germination count m^{-2} , plant height, no. of tillers m^{-2} , spike length, no. of spikelets spike $^{-1}$, biological yield and grain yield while there was non-significant difference among the treatments on 1000-grain weight. Hence, it was concluded that farmers could apply different mulches particularly gypsum @ 2.5 ton ha^{-1} to achieve highest grain yield ($kg ha^{-1}$) of wheat under rainfed conditions.

Stagnari *et al.* (2014) conducted out two field trials from 2010 to 2012 in a representative area of Southern Italy during the first two years of the transition to Conservation Agriculture (CA). Durum wheat was grown under three increasing levels of straw added as soil mulching: 5.0 t ha^{-1} (100 % mulch cover (100 % MC)), 2.5 t ha^{-1} (50 % MC) and 1.5 t ha^{-1} (30 % MC), plus a control. The influence of such additional straw on soil water and nutrient availability, physiological traits, growth and yield of durum wheat was assessed, as well as the necessary amount of additional straw was estimated. Both years of study indicated that root-zone moisture contents, monitored at 5 cm depth starting from the beginning of head emergence, were significantly improved by mulching, with the highest differences detected between 100% MC and control (36 and 41% higher in 2011 and 2012, respectively). Additional straw at higher rates improved crop physiology: leaf water content (LWC) was highest in 100 % MC (48.3%) and lowest in control (38.2%); chlorophyll content were respectively increased by 25% and 22% in 100 % MC and by 15% and 17% in 50 % MC, with respect to control.

Depar *et al.* (2014) carried out a field study at Nuclear Institute of Agriculture Experimental Farm, Tandojam, Pakistan to evaluate the effect of different mulches on soil moisture and yield of wheat. Five types of organic materials such as wheat straw, mungbean straw, rice husk, farm yard manure and poultry litter were used for mulching. Different mulches were applied at 10 tons ha^{-1} on 3rd day after 1st irrigation. A control without any mulch material was kept for comparison. Different mulches conserved the soil moisture content to 16-27% over control. Wheat straw retained maximum soil moisture of 27% followed by the farm yard manure (24.0%), rice husk (20.0%), mungbean straw (19%) and poultry litter (16.0%), respectively. A non-significant relationship was observed

between grain yield and irrigation regimes, but application of different mulches had significant effect on the grain yield. The highest wheat grain yield of 4.22 tons ha⁻¹ was observed in case of mulch with wheat straw, followed by poultry litter (3.92 tons ha⁻¹), farm yard manure (3.75 tons ha⁻¹), rice husk (3.61 tons ha⁻¹) and mungbean straw (3.38 tons ha⁻¹). These findings suggest that wheat straw could be used effectively for mulching to conserve soil moisture and increase crop productivity.

Peng et al. (2015) conducted an experiment in China to observe the effects of various straw mulch practices on soil water storage, grain yield and water use efficiency (WUE) of winter wheat (*Triticum aestivum*) with six different mulch combinations (two different mulch durations and three different mulch amounts): high (SM₁; 9000 kg ha⁻¹), medium (SM₂; 6000 kg ha⁻¹) and low (SM₃; 3000 kg ha⁻¹) straw mulch treatments for the whole period; and high (SM₄), medium (SM₅) and low (SM₆) straw mulch treatments during the growth period only, where the control was the whole period. Results revealed that the average soil water content in the 0–200 cm soil layer increased by 0.7–22.5% compared with CK, while the WUE increased significantly by 30.6%, 32.7% and 24.2% with SM₁, SM₂ and SM₃, respectively ($p < 0.05$). The yield increased by 13.3–23.0% when mulch was provided during the growth period, while the WUE increased by 15.2%, 17.2% and 18.0% with SM₄, SM₅, and SM₆, respectively, compared with CK.

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Chapter 3

Materials and Methods

MATERIALS AND METHODS

The present research work was carried out at Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi during the rabi season from November 2008 to April 2009 and November 2009 to April 2010 to study the effect of high temperature and mulching on growth and yield of wheat varieties. The details of the methods followed and materials used in the study are described below.

3.1 Description of the Experimental Site

3.1.1 Location

The experimental farm is located at the western side of Agronomy & Agricultural Extension Department, Rajshahi University, Rajshahi. Geographically the experimental field is located at $24^{\circ}22'36''$ N latitude and $88^{\circ}38'27''$ E longitude at an average altitude of 71 ft above the sea level belonging to Calcareous Dark Grey Flood Plain soils and Calcareous Brown Flood Plain soils under High Ganges River Floodplain (Agro-ecological Zone "AEZ-11").

3.1.2 Soil

The experimental plot of the Department Agronomy and Agricultural Extension of Rajshahi University, Rajshahi is of well drained soil with moderately slow permeability. The top soil is silty loam and slightly alkaline in reaction. The soil of the experimental field was analyzed for

physical and chemical characteristics before setting the experiment. The characteristics of the experimental soil have been presented in Appendix I.

3.1.3 Climate

The experimental site is characterized by moderately high temperature and heavy rainfall during the kharif season and scanty rainfall with moderately low temperature during the rabi season. The monthly maximum and minimum temperature, rainfall and sunshine hours during the growing period of study at the experimental site have been presented in Figures 1a, 1b and 2.

3.2 Description of the Variety

The crop taken in this study was bread wheat (*Triticum aestivum* L.) having semidwarf high yielding characteristics. Two wheat varieties i.e., Bijoy and Gourab were used as plant materials. They are tolerant to disease and pest and suitable for late sowing condition. Characteristics of the varieties used are as follows (BARI, 2006).

Gourab (BARI GAM-20)

Gourab was developed by Bangladesh Agricultural Research Institute (BARI) and released in 1998. It is a heat tolerant variety and suitable for late sowing condition. This variety attains a height of 90-102 cm. The leaves are deep green in colour. The flag leaves are erect, narrow and slightly twisted. The panicle is longer with narrow tip. It takes 100-108 days to complete life cycle and is resistant to leaf rust and leaf spot diseases. Number of tillers hill⁻¹ is 4-6. The grains are white. It takes 65-69 days to heading and the yield varies between 3.6-4.8 t ha⁻¹.

Bijoy (BARI GAM- 23)

Bijoy was developed by BARI and released in 2005. It is also a heat tolerant variety and suitable for late sowing condition. This variety attains a height of 95-105 cm. The leaves are wide and light green in colour. The panicle is longer. It takes 103-112 days to complete life cycle and is resistant to leaf rust and leaf spot disease. Number of tillers hill⁻¹ is 4-5. The grains are white in colour and small in size. It takes 60-65 days to heading and yield varies between 4.3-5.0 t ha⁻¹.

3.3 Experimental Treatments

The experiment consisted of the following three factors:

Factor A. Sowing Date (4)

- i. 17 November (S₁)
- ii. 2 December (S₂)
- iii. 17 December (S₃)
- iv. 1 January (S₄)

Factor B. Variety (2)

- i. Bijoy (V₁)
- ii. Gourab (V₂)

Factor C. Mulching (4)

- i. No mulching (M₁)
- ii. Water hyacinth mulching (M₂)
- iii. Rice straw mulching (M₃)
- iv. Black polythene mulching (M₄)

3.4 Experimental Design and Layout

The experiment was laid out in a split-split plot design assigning the sowing date on the main plot, variety to the sub-plots and mulching to the sub-sub plots. The treatments were replicated three times. Each block was divided into four main plots in which date of sowing were applied. Each main plot was further divided into two sub-plots and varieties were allocated to these plots. Then each sub plot was again divided into four sub-sub plots and mulching treatments were assigned in these plots at random. So, the total number of unit plots in the entire experimental plot was $4 \times 2 \times 4 \times 3 = 96$. The plot size was $2.5\text{m} \times 2\text{m}$. The plot to plot distance was 75 cm and the block to block distance was 1.0 m.

3.5 Land Preparation

Land preparation was done in several days. The experimental land was opened with a power tiller. Later on, the land was ploughed and cross ploughed three times by a power tiller followed by laddering to obtain the desirable tilth. The visible larger clods were broken into small pieces by wooden hammer. Weeds and stubble were removed from the field. The corners of the land were spaded. The land was prepared smoothly with spade before each sowing.

3.6 Fertilizer Application

Fertilizers were applied to the plots at the rate of 220, 180, 50, 120 kg ha⁻¹ urea, triple super phosphate (TSP), muriate of potash (MP) and gypsum, respectively in both the years during final land preparation. Urea was applied in two installments; two-third at the time of final land preparation and one-third at 20 days after sowing (DAS). All the applied fertilizers were thoroughly mixed to the soil.

3.7 Collection of Seeds

Seeds were collected from Regional Wheat Research Institute, Shyampur, Rajshahi. Germination test of seed was done in the laboratory before sowing and germination percentage was found to be 95.

3.8 Seed Treatment

Before sowing collected seeds were treated with Vitavax-200 @ 0.25% to prevent seeds from the attack of soil borne diseases.

3.9 Sowing of Seeds

The seeds were sown as per schedule on 17 November, 2 December, 17 December, 1 January during the first year (2008-2009) and 17 November, 2 December, 17 December and 1 January during the second year (2009-2010) at the rate of 120 kg ha⁻¹. The depth of sowing was 5 cm. The seeds were sown in 20 cm apart rows opened by specially made an iron hand tine. After sowing the seeds were covered with soil and slightly pressed by hands. Care was taken to protect the seedlings from birds. The experiment was conducted for the first time in 2008-2009 growing season and repeated the whole experiment in 2009-2010 growing season.

3.10 Weeding and Thinning

The crop was infested with some weeds such as *Chenopodium album*, *Cyperus rotundus*, *Anagallis arvensis*, *Vicia sativa*, *Vicia hirsuta*, *Fumaria parviflora* etc. which were controlled by hand hoe. One weeding was done to control weeds in the experimental field. Thinning was done followed by weeding for maintaining 5cm plant to plant distance.

3.11 Irrigation

The crop was irrigated three times during the cultivation. First irrigation was applied at crown root initiation stage (CRI stage), second irrigation at flowering stage (55 DAS) and third irrigation was applied at grain formation stage (70 DAS).

3.12 Application of Mulch Materials

Rice straw mulching: Rice straw was spread to cover the soil surface in between the plant rows at the rate of 2.5 tons ha⁻¹ after germination of seeds.

Water hyacinth mulching: The fresh water hyacinth plants were chopped into small pieces (5-7cm) and dried in the sun. The sun dried water hyacinth was spread to cover the soil surface in between the plant rows at the rate of 2.0 tons ha⁻¹ after germination of seeds.

Black polythene mulching: Polythene sheets were spread to cover the soil surface in between the plant rows after germination of seeds.

3.13 Diseases and Insect Control

The infestation of stem borer occurring at the maximum tillering stage was controlled by applying "Furadan" at the rate of 33 kg ha⁻¹.

3.14 Harvesting

The crop of both the varieties were harvested at full maturity on 18 March, 27 March, 5 April and 10 April of 2009 and on 20 March, 28 March, 5 April and 11 April of 2010 for the 1st, 2nd, 3rd and 4th sowing date respectively. The harvested crop was bundled separately, tagged properly and taken to the clean threshing floor.

3.15 Post Harvest Operations

After harvesting, crop of each plot was dried separately for four days. After that, threshing, cleaning and drying of grains were done plot-wise. Then the yields of grain and straw of each plot were recorded and the yields were then converted to hectare basis.

3.16 Data Collection

Data were collected and recorded according to the following heads as per experimental requirement.

3.16 .1 Phenological Parameters

The following stages were recorded in days when 50% plants of a variety of each replication reached a definite stage as the representative of that stage in both the growing seasons.

- i) Crown root initiation
- ii) Tillering
- iii) Booting
- iv) Heading
- v) Anthesis
- vi) Grain filling
- vii) Physiological maturity

The accumulated heat unit system which is based on the idea that plants have definite temperature requirements before they attain certain physiological stages, have significant relationship with temperature, plant growth and physiological development of a crop. The following parameters were calculated according to the formula of Rajput (1980).

- i) Growing degree day (GDD) = $\sum[(T_{\max} + T_{\min})/2 - T_b]$
- ii) Helio-thermal unit (HTU) = GDD $\times$ Duration of sunshine hours
- iii) Pheno-thermal index (PTI) = GDD $\div$ Growth days
- iv) Heat use efficiency (HUE) = Grain yield (kg ha^{-1}) $\div$ GDD

Here, $T_{\max}$ = Maximum temperature

$T_{\min}$ = Minimum temperature

T_b = Base temperature (10°C)

3.16.2 Biochemical Characters

Estimation of Chlorophyll

Chlorophyll content of the flag leaf was estimated according to Arnon (1949). Three discs, each of 0.503 cm^2 area, were taken from the different positions of the flag leaf. Chlorophyll was extracted with 80% aqueous acetone using a mortar and pestle to grind the tissues. The suspension was decanted into centrifuge tubes and centrifuged for 3 minutes. The clear green solution was then decanted from the colourless residue and made upto 10 ml with 80% acetone. The optical density (OD) of this solution was determined against 80% acetone as blank using a spectrophotometer at 645 and 663 nm. The chlorophyll a and b were determined according to the formulae used by Arnon (1949) as follows:

Chlorophyll a = $12.717 A_2 - 2.584 A_1$ = mg chlorophyll a per litre

Chlorophyll b = $22.869 A_1 - 4.670 A_2$ = mg chlorophyll b per litre

where A_1 and A_2 are OD at wavelengths of 645 and 663 nm, respectively.

Amount of chlorophyll per unit of area was calculated in the following ways:-

$$\frac{\text{mg chl a or b per litre} \times 10}{1000 \times \text{leaf area}} \text{mg/dm}^2$$

3.16.3 Water Relations

Relative Leaf Water Content (RLWC)

Relative leaf water content (RLWC) was determined from the flag leaves. For this purpose, the leaves were collected in tightly fastened polythene bags. Two leaves / treatment were collected at 8 am, 12 noon and 4 pm. Their fresh weight (FW) was taken immediately and was sink into water kept in test tubes for 4 hours. After 4 hours, they were taken off from water and after drying with blotting paper when the cells of the leaves became fully turgid, their turgid weight (TW) was determined. Then the leaves were dried in an oven at 85°C for 24 hours and their dry weight (DW) was taken with the help of an electric balance. The relative leaf water content was calculated from the following formula (Barrs and Weatherly, 1962).

$$\text{Relative leaf water content (RLWC\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Moisture Retention Capacity (MRC)

Moisture retention capacity (MRC) of the flag leaves was measured during the anthesis stage of the crop. For this purpose, the leaves were collected in tightly fastened polythene bags. Two leaves/treatment were collected at 8.30 am and their fresh weight (FW) was taken immediately. Then the leaves were arranged systematically in a tray. After arrangement of the leaves, their fresh weight was taken at 30 minutes intervals for 6 times and thereafter 4 times at 60 minutes intervals. Finally, the leaves were dried in an oven at 85°C for 24 hours and their dry weight (DW) was taken with the help of an electric balance. The moisture retention capacity of leaves was calculated from the following formula.

$$\text{Moisture retention capacity (MRC\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

3.16.4 Data Collection for Growth Analysis

Measurement of Dry Weight and Leaf Area

For the purpose of growth analysis, 8 harvests were taken at equal intervals at 10 days. The first harvest was taken at 20 days after sowing (DAS). At each harvest 3 plants were carefully uprooted from each treatment. At each harvest the tops were separated into leaves, stems and spikes (when appeared). Number of tillers plant⁻¹ and number of spikes plant⁻¹ (when appeared) were counted. The samples were packed separately in labeled brown paper bags and were oven dried for 72 hours at about 85 °C till they reached constant weights. Dry weights were then measured separately with an electrical balance.

For determining the leaf area, 3 segments each of 4cm long were taken and weighted after oven drying. Then the leaf area was calculated by using the following formula:

$$\text{Area of leaf} = \frac{\text{Area of segments} \times \text{Weight of leaves}}{\text{Weight of segments}}$$

Growth Attributes

From the dry weight of different plant parts and leaf area data, the following growth attributes were calculated between two successive harvests by following the classical technique of growth analysis (Radford, 1967).

$$1. \text{ Leaf area index (LAI)} = \frac{\text{Total leaf area}}{\text{Ground area}}$$

$$2. \text{ Crop growth rate (CGR)} = \frac{(W_2 - W_1)}{(t_2 - t_1)}$$

$$3. \text{ Relative growth rate (RGR)} = \frac{(\log_e W_2 - \log_e W_1)}{(t_2 - t_1)}$$

$$4. \text{ Net assimilation rate (NAR)} = \frac{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}{(LA_2 - LA_1)(t_2 - t_1)}$$

$$5. \text{ Leaf area ratio (LAR)} = \frac{(LA_2 - LA_1)(\log_e W_2 - \log_e W_1)}{(\log_e LA_2 - \log_e LA_1)(W_2 - W_1)}$$

$$6. \text{ Relative leaf growth rate (RLGR)} = \frac{\log_e LA_2 - \log_e LA_1}{t_2 - t_1}$$

$$7. \text{ Specific leaf area (SLA)} = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

$$8. \text{ Leaf weight ratio (LWR)} = \frac{\text{Leaf dry weight}}{\text{Total plant dry weight}}$$

Where W_2 and W_1 are the total dry weights, LA_2 and LA_1 are the leaf area per plant and t_2 and t_1 are the later and former harvest, respectively.

3.16.5 Data Collection on Yield and Yield Contributing Characters

At maturity data on plant characters and yield components were recorded from ten randomly selected plants in each plot. The following data on yield and yield contributing characters were recorded -

1. Plant height (cm)
2. Number of total tillers plant⁻¹
3. Number of effective tillers plant⁻¹
4. Spike length (cm)
5. Extrusion length (cm)
6. Number of spikelets spike⁻¹
7. Number of fertile spikelets spike⁻¹

8. 1000-grain weight (g)
9. Grain yield (t ha^{-1})
10. Straw yield (t ha^{-1})
11. Biological yield (t ha^{-1})
12. Harvest index (%)

Procedure of Data Collection

Plant height(cm): The plant height was taken from ten randomly selected plants of each plot. The height of the plant was measured from the base of the plant to the tip of the upper most spikelets of the spike.

Number of total tillers plant⁻¹: Tillers plant⁻¹ that had at least one leaf visible was counted. It included both effective and non-effective tillers.

Number of effective tillers plant⁻¹: The tillers bearing even a single spikelet were counted and considered as effective tillers.

Length of spike⁻¹(cm): Measurement was taken from basal node of the rachis to the apex of last grains of each spike.

Extrusion length (cm): The length from the flag leaf to the first of the spikelet was measured as cm

Number of spikelets spike⁻¹: Spikelets spike⁻¹ was recorded and mean was calculated later on.

Number of fertile spikelets spike⁻¹: Presence of any food material in the spikelet was considered as filled seeds and total number of filled seeds present on each spike was counted.

1000-grain weight (g): 1000 grains were randomly selected from sample plants of each treatment plot, dried in an oven, adjusted at 14% moisture content and weighed by using an electric balance.

Grain yield (t ha^{-1}): Grain yields were determined by harvesting crops grown one square meter area at the center of each plot. The harvested samples were then threshed, dried, weighed and the values were expressed in t ha^{-1} .

Straw yield (t ha^{-1}): Straw yields obtained from each unit plot including the straw of sample plants of respective unit plot were dried in sun and weighed to record the final straw yield plot^{-1} and the values were converted to t ha^{-1} .

Biological yield (t ha^{-1}): Grain yield and straw yield altogether regarded as biological yield. The biological yield was calculated with the following formula:

$$\text{Biological yield} = \text{Grain yield} + \text{Straw yield}$$

Harvest index (%): It denotes the ratio of grain yield (economic yield) to biological yield and was calculated with the following formula (Gardner *et al.*, 1985):

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

3.16.6 Collection of Soil Samples

Soil samples were collected before the ploughing of experimental field. Physio-chemical properties of soil viz., soil pH, organic matter, total nitrogen, phosphorous, potassium, sulphur and zinc were analyzed from Soil Resources Division, Shyampur, Rajshahi.

3.16.7 Collection of Meteorological Data

Meteorological data were collected from the Regional Meteorological Station, Shyampur, Rajshahi. The data like maximum and minimum temperature ($^{\circ}\text{C}$), sunshine hours and rainfall (mm) were collected during the study period.

3.17 Statistical Analysis of Data

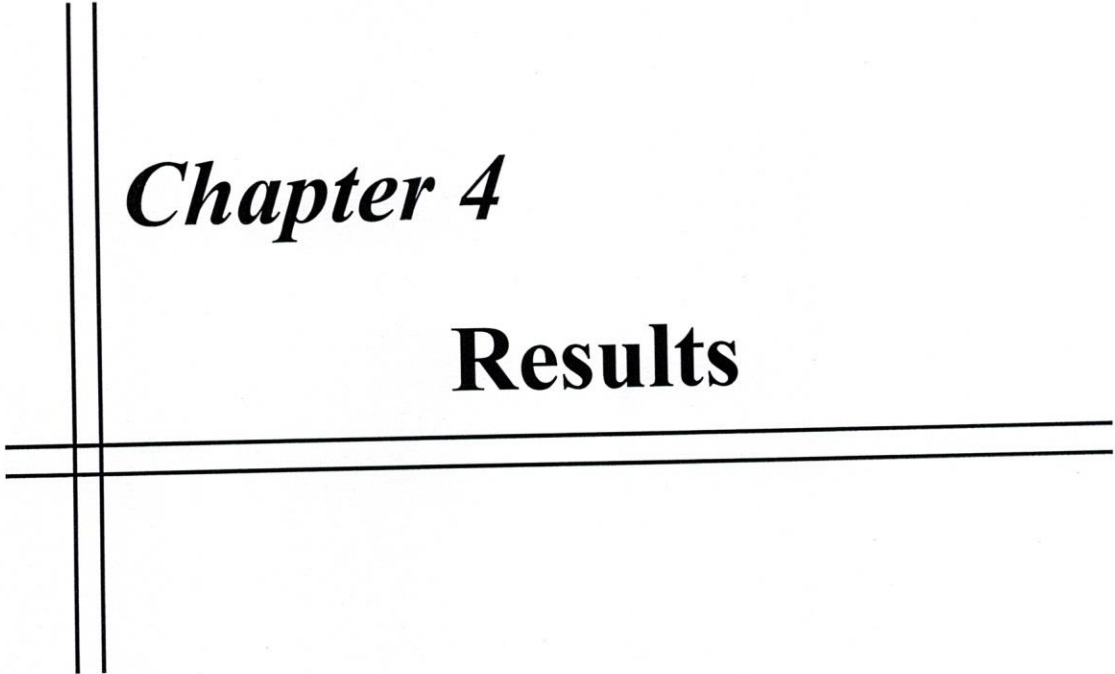
The data recorded were compiled and tabulated for statistical analysis. The data were analyzed statistically using the analysis of variance technique and the mean differences among the treatments were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984) with the help of MSTAT software.

Throughout the thesis, the following notations have been used to specify statistical significance.

NS= Non-significant

*=Significant at $p = 0.05$

**= Significant at $p = 0.01$



Chapter 4

Results

RESULTS

The results obtained in this experiment consisting of four sowing dates, two varieties and four mulching have been presented in this chapter in tabular and graphical forms. The experiment was performed to examine the effect of sowing date, variety and mulching on the growth and yield and yield contributing characters of wheat.

4.1 Meteorological Data

Air temperature (maximum and minimum), sunshine hours and monthly total rainfall are presented in Figures 1a, 1b and 2 for both the years. Early sowing period (S_1) had higher air temperature than the late sowing periods (S_2 , S_3 and S_4). Both the maximum and minimum temperatures declined gradually until mid or late January and then increased with fluctuations. The highest temperature was recorded in April and the lowest temperature was recorded in January. Lower sunshine hours were observed during early January to late February. Sunshine hours increased gradually at the later stages of growth. Higher sunshine hours were observed during the first year than the second year throughout the whole growth periods with fluctuations. In the first year, some rain occurred in February and March and a very little in January. In the second year, there was no rainfall up to late growth stage of wheat (up to March) and there was some rainfall in April.

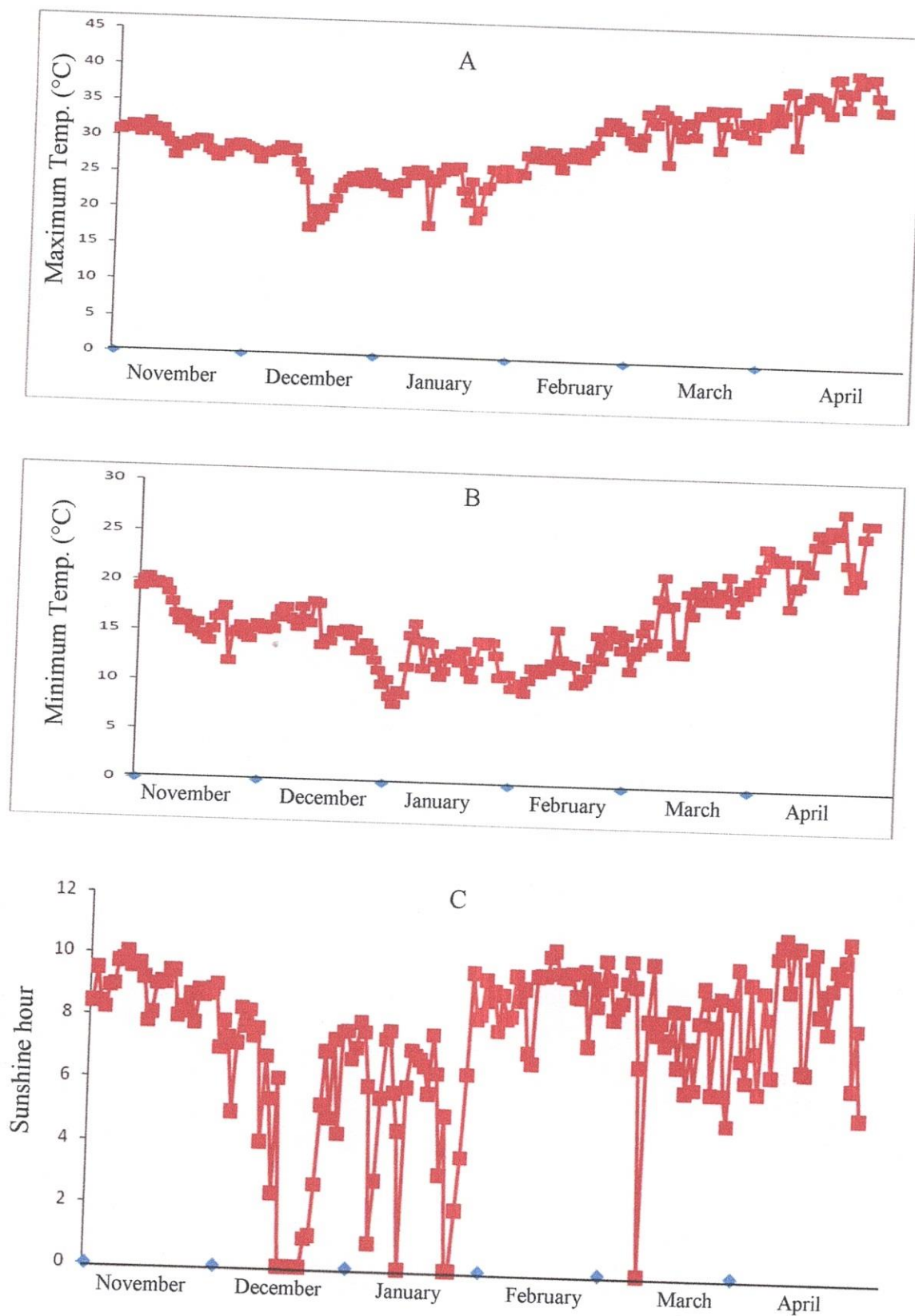


Figure 1a: Some meteorological parameters during the crop-growing season of 2008-2009. A maximum temperature, B minimum temperature and C sunshine hours

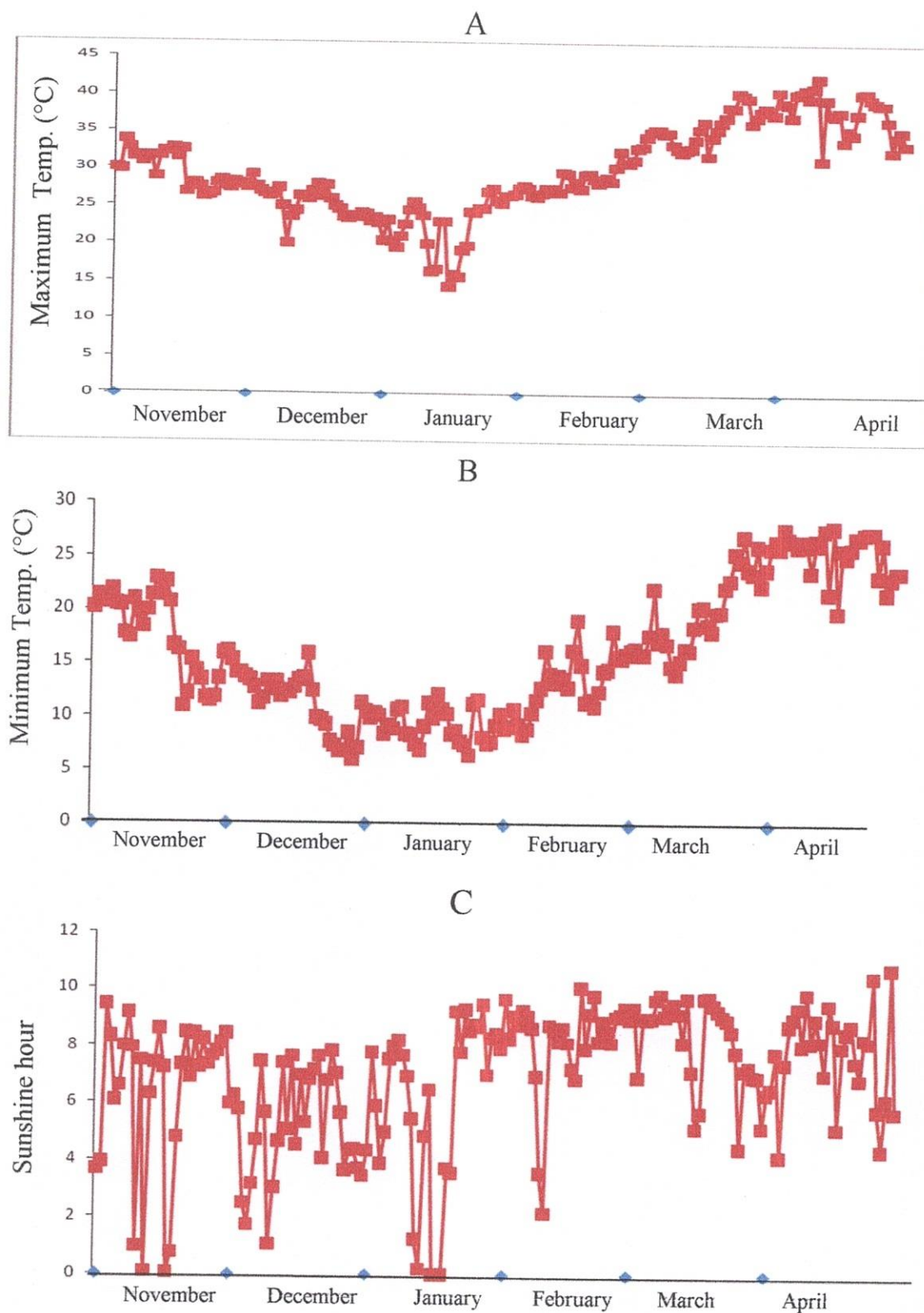


Figure 1b: Some meteorological parameters during the crop-growing season of 2009-2010. A maximum temperature, B minimum temperature and C sunshine hours

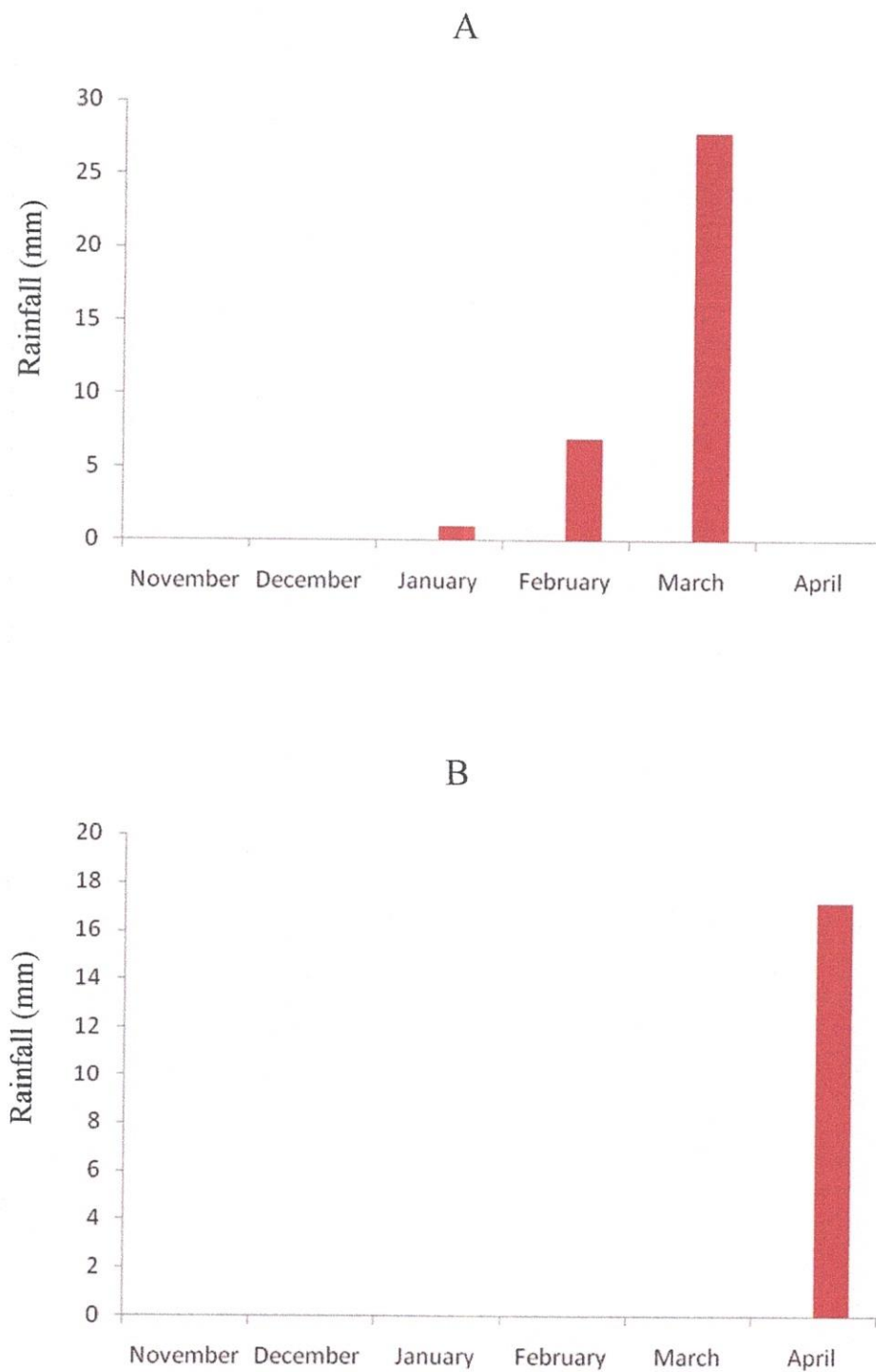


Figure 2: Monthly total rainfall during the growing season. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2 Growth Characters

4.2.1 Total Dry Matter (TDM)

The analysis of variance indicated that sowing date had significant effect on total dry matter at all the harvests (Appendices IIIa and IIIb). In both the years, the highest TDM was obtained from S_1 sowing and the lowest was obtained from S_4 sowing (Tables 1a and 1b). Effect of sowing date on TDM of two wheat varieties at different harvests are shown in Figure 3a. In all the sowings of both the varieties, TDM increased slowly up to 50 DAS and then increased sharply with the advancement of growth period.

Total dry matter varied significantly due to variety at all the harvests in both the years (Appendices IIIa and IIIb). From the Tables 1a and 1b, it was observed that between the two varieties, Bijoy showed higher TDM value at all the harvests as compared to Gourab.

Mulching had significant effect on TDM at all the harvests (Appendices IIIa and IIIb). The highest TDM was obtained from black polythene mulching (M_4) and the lowest was obtained from control (M_1) in both the years at all the harvests. M_2 was statistically identical with M_3 at 50, 70 and 90 DAS during 2008-2009 and at 20, 70, 80 and 90 DAS during 2009-2010 (Tables 1a and 1b). Effect of mulching on TDM of two wheat varieties at different harvests are shown in Figure 3b. In all the mulching treatments of both the varieties, TDM increased slowly up to 50 DAS and then increased sharply with the advancement of growth period.

Table 1a: Effect of sowing date, variety and mulching on TDM (g m^{-2}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	14.54a	45.57a	95.40a	179.21a	316.45a	585.31a	749.95a	871.97a
S ₂	13.64b	42.72b	89.41b	166.41b	294.37b	547.35b	701.89b	816.19b
S ₃	12.05c	37.63c	78.74c	146.18c	258.88c	476.51c	614.59c	709.87c
S ₄	7.43d	23.06d	48.56d	88.43d	159.65d	294.61d	375.52d	424.89d
LS	**	**	**	**	**	**	**	**
b) Variety								
V ₁	13.45a	41.70a	87.34a	162.91a	289.66a	532.32a	688.76a	797.67a
V ₂	10.38b	32.79b	68.72b	127.20b	225.02b	419.57b	532.22b	613.80b
LS	**	**	**	**	**	**	**	**
c) Mulching								
M ₁	11.31b	29.94d	62.46d	114.48c	202.53d	379.13c	490.60d	568.26c
M ₂	11.92a	37.49c	78.66c	146.52b	260.19c	481.71b	616.20c	718.16b
M ₃	12.07a	39.18b	82.18b	153.10b	171.37b	499.00b	644.10b	741.40b
M ₄	12.35a	42.38a	88.81a	166.11a	295.25a	543.94a	691.06a	795.11a
LS	*	**	**	**	**	**	**	**
CV%	5.11	5.40	5.37	6.60	4.47	5.43	4.37	4.38

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 1b: Effect of sowing date, variety and mulching on TDM (g m^{-2}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	15.59a	51.60a	110.27a	203.60a	351.57a	706.68a	842.26a	936.32a
S ₂	14.46b	47.67b	101.88b	186.98b	323.55b	655.35b	770.89b	867.98b
S ₃	12.80c	42.20c	90.06c	165.16c	286.58c	577.66c	688.55c	757.22c
S ₄	7.93d	25.99d	55.52d	99.63d	177.20d	349.93d	412.59d	449.57d
LS	**	**	**	**	**	**	**	**
b) Variety								
V ₁	14.32a	46.83a	99.55a	183.42a	322.50a	643.21a	763.15a	842.54a
V ₂	11.07b	36.90b	79.31b	144.26b	246.95b	501.60b	593.99b	663.00b
LS	**	**	**	**	**	**	**	**
c) Mulching								
M ₁	12.03c	33.61d	71.23d	127.55d	225.63d	457.53c	548.76c	620.11c
M ₂	12.70b	42.19c	89.67c	165.99c	289.85c	580.06b	687.74b	782.01b
M ₃	12.84ab	43.94b	93.71b	175.44b	302.31b	603.06b	713.44b	790.90b
M ₄	13.21a	47.72a	103.11a	186.39a	321.11a	648.97a	764.35a	818.07a
LS	*	**	**	**	**	**	**	**
CV%	4.73	4.39	4.81	5.55	5.06	5.73	5.94	3.44

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation LS=Level of significance

S₁=17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂= Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

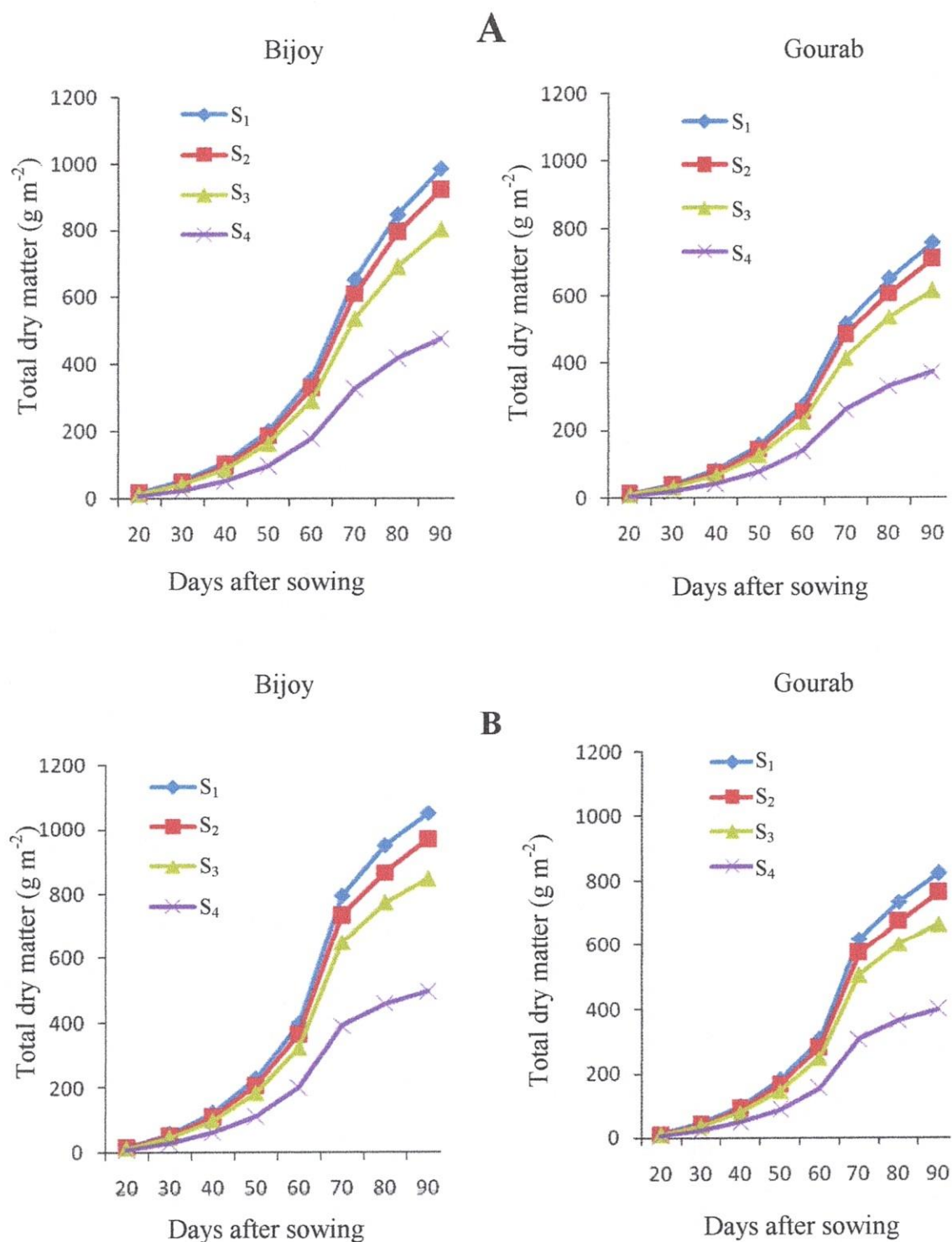


Figure 3a: Effect of sowing date on total dry matter (TDM) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

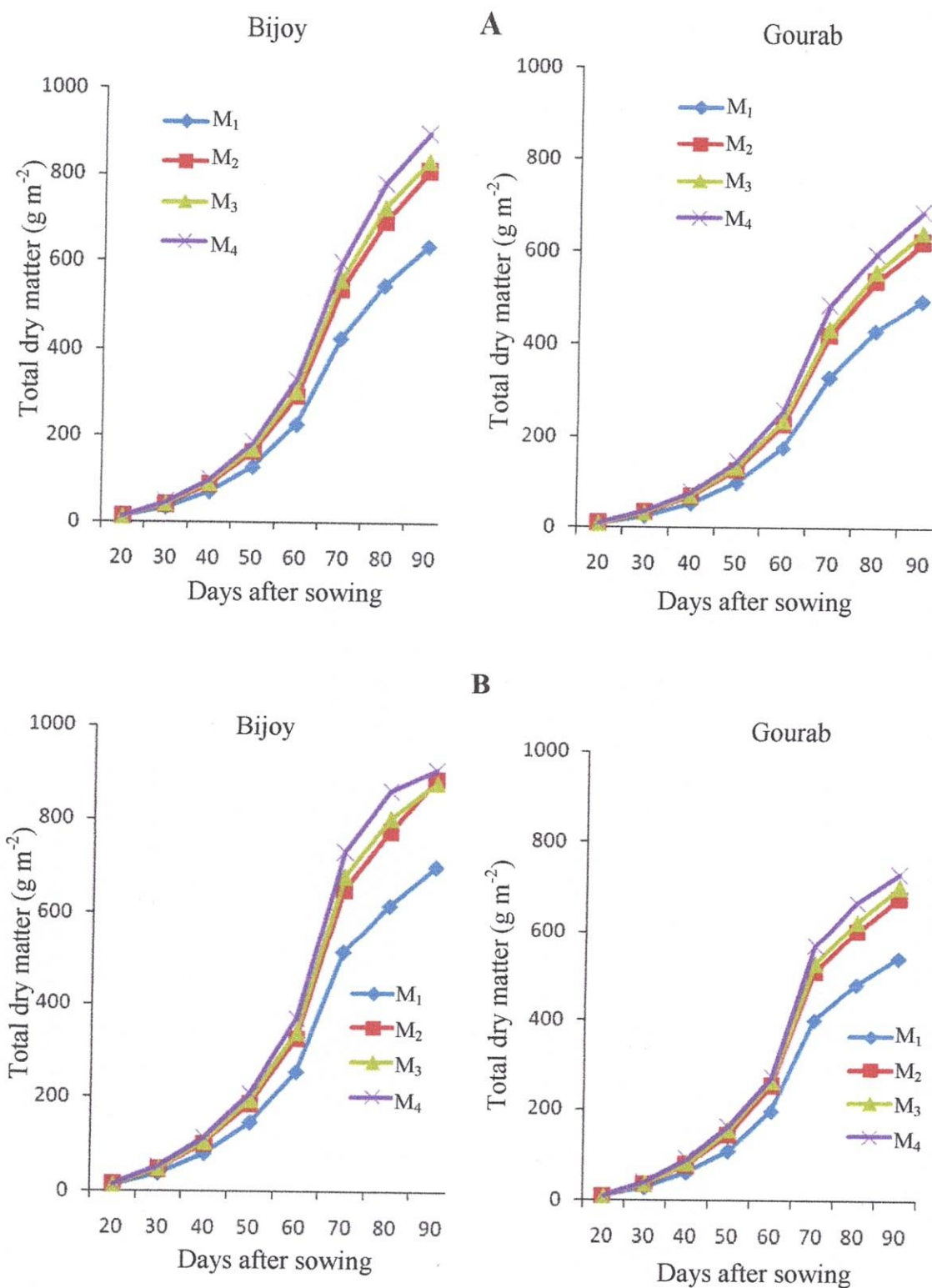


Figure 3b: Effect of mulching on total dry matter (TDM) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

Analysis of variance for TDM showed significant sowing date $\times$ variety effects at all the harvests except 60 DAS in 2008-2009 and at all the harvests in 2009-2010. Significant variety $\times$ mulching effects on TDM were observed at 20, 60, 80 and 90 DAS in 2008-2009 and at 20, 30, 60 and 90 DAS in 2009-2010 growing season (Appendices IIIa and IIIb).

4.2.2 Leaf Area Index (LAI)

The analysis of variance indicated that sowing date had significant effect on leaf area index (LAI) at all the harvests in both the years (Appendices IVa and IVb). The highest LAI was obtained from S_1 sowing and the lowest was obtained from S_4 sowing at all the harvests. S_2 sowing was statistically identical with S_1 at 20, 40 and 50 DAS during 2008-2009 and at 20, 30 and 40 DAS during 2009-2010 growing season (Tables 2a and 2b). Effect of sowing date on LAI of two wheat varieties at different harvests of both the years are shown in Figure 4a. LAI of both the varieties for all the sowings started from a lower value and reached their peak at a certain stage of growth and declined thereafter with positive values. LAI showed the highest value at 60 DAS in all the sowings and both the years.

LAI varied significantly due to variety at all the harvests in both the years (Appendices IVa and IVb). From the Tables 2a and 2b, it was observed that between the two varieties, Bijoy showed higher LAI value than that of Gourab at all the harvests.

Table 2a: Effect of sowing date, variety and mulching on LAI of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	0.243a	0.554a	1.015a	1.875a	3.047a	2.919a	2.348a	1.062a
S ₂	0.227a	0.519b	0.953a	1.739a	2.828b	2.731b	2.182b	0.981b
S ₃	0.200b	0.457c	0.847b	1.527b	2.477c	2.329c	1.915c	0.862c
S ₄	0.125c	0.280d	0.525c	0.923c	1.490d	1.466d	1.149d	0.514d
LS	**	**	**	**	**	**	**	**
b) Variety								
V ₁	0.227a	0.513a	0.928a	1.702a	2.772a	2.662a	2.139a	0.960a
V ₂	0.170b	0.392b	0.742b	1.330b	2.149b	2.061b	1.657b	0.749b
LS	**	**	**	**	**	**	**	**
c) Mulching								
M ₁	0.199	0.392c	0.718c	1.305c	2.119c	2.037c	1.622c	0.755c
M ₂	0.203	0.452b	0.832b	1.509b	2.442b	2.396b	1.921b	0.871ab
M ₃	0.205	0.471ab	0.868ab	1.576ab	2.563ab	2.456ab	1.968ab	0.859b
M ₄	0.188	0.496a	0.922a	1.675a	2.717a	2.556a	2.083a	0.933a
LS	NS	**	**	**	**	**	**	**
CV%	12.32	8.78	9.75	11.77	9.05	7.65	10.05	9.67

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 2b: Effect of sowing date, variety and mulching on LAI of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	0.263a	0.638a	1.158a	2.012a	3.055a	3.323a	2.684a	1.177a
S ₂	0.247a	0.597a	1.085a	1.876b	2.838b	3.083b	2.496b	1.088b
S ₃	0.218b	0.525b	0.955b	1.645c	2.491c	2.707c	2.187c	0.958c
S ₄	0.133c	0.323c	0.590c	0.996d	1.493d	1.622d	1.315d	0.571d
LS	**	**	**	**	**	**	**	**
b) Variety								
V ₁	0.249a	0.596a	1.029a	1.798a	2.780a	2.966a	2.452a	1.064a
V ₂	0.182b	0.446b	0.865b	1.467b	2.159b	2.401b	1.889b	0.833b
LS	**	**	**	**	**	**	**	**
c) Mulching								
M ₁	0.202b	0.443b	0.825b	1.386b	2.128c	2.289d	1.867c	0.841c
M ₂	0.214a	0.541a	0.983a	1.663a	2.452b	2.590c	2.183b	0.942b
M ₃	0.227a	0.533a	0.959a	1.734a	2.573ab	2.773b	2.230ab	0.981ab
M ₄	0.219a	0.565a	1.020a	1.747a	2.724a	3.083a	2.401a	1.030a
LS	*	**	**	**	**	**	**	**
CV%	10.30	11.07	10.73	10.61	10.14	8.41	10.67	8.44

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁= 17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂= Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

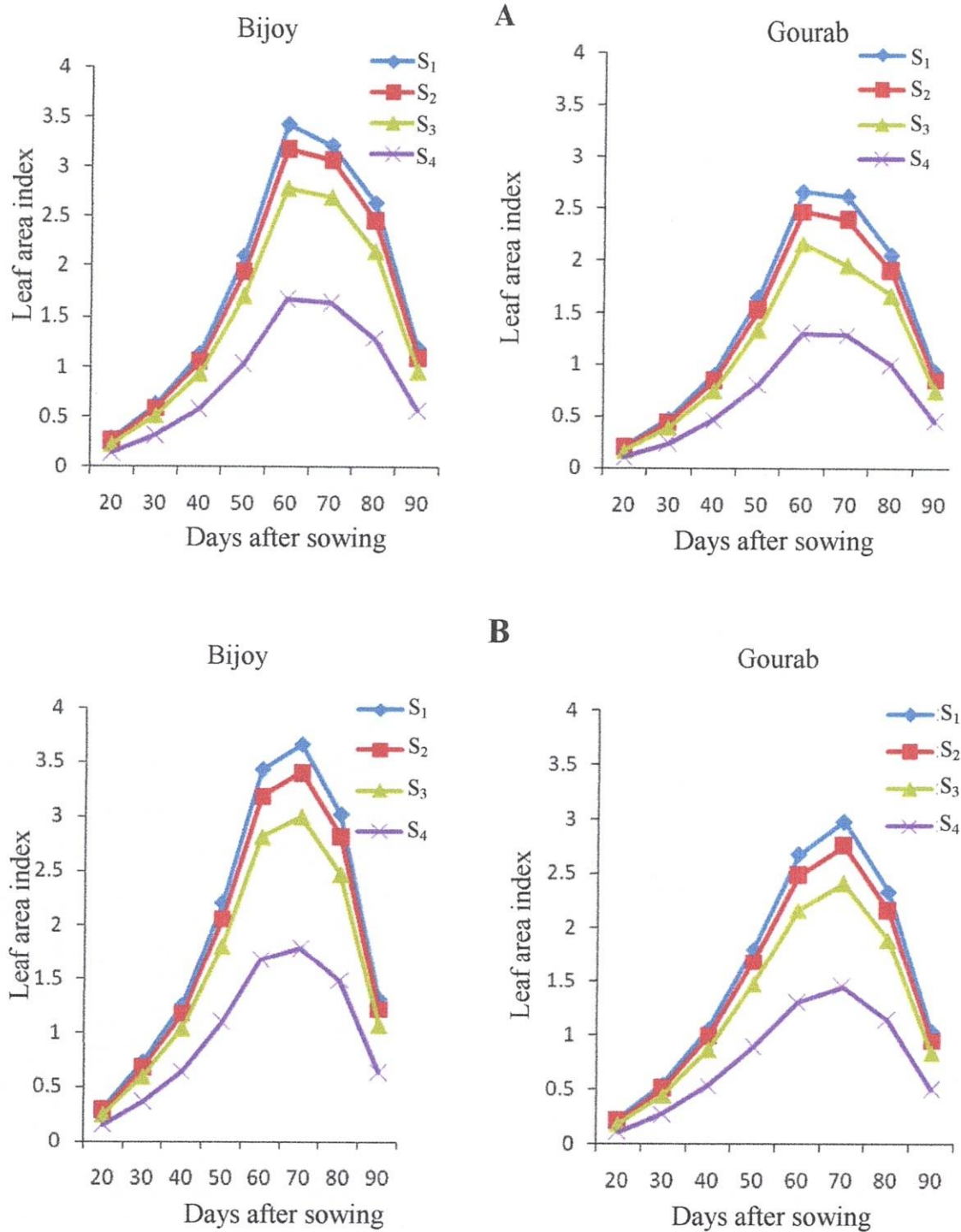


Figure 4a: Effect of sowing date on leaf area index (LAI) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

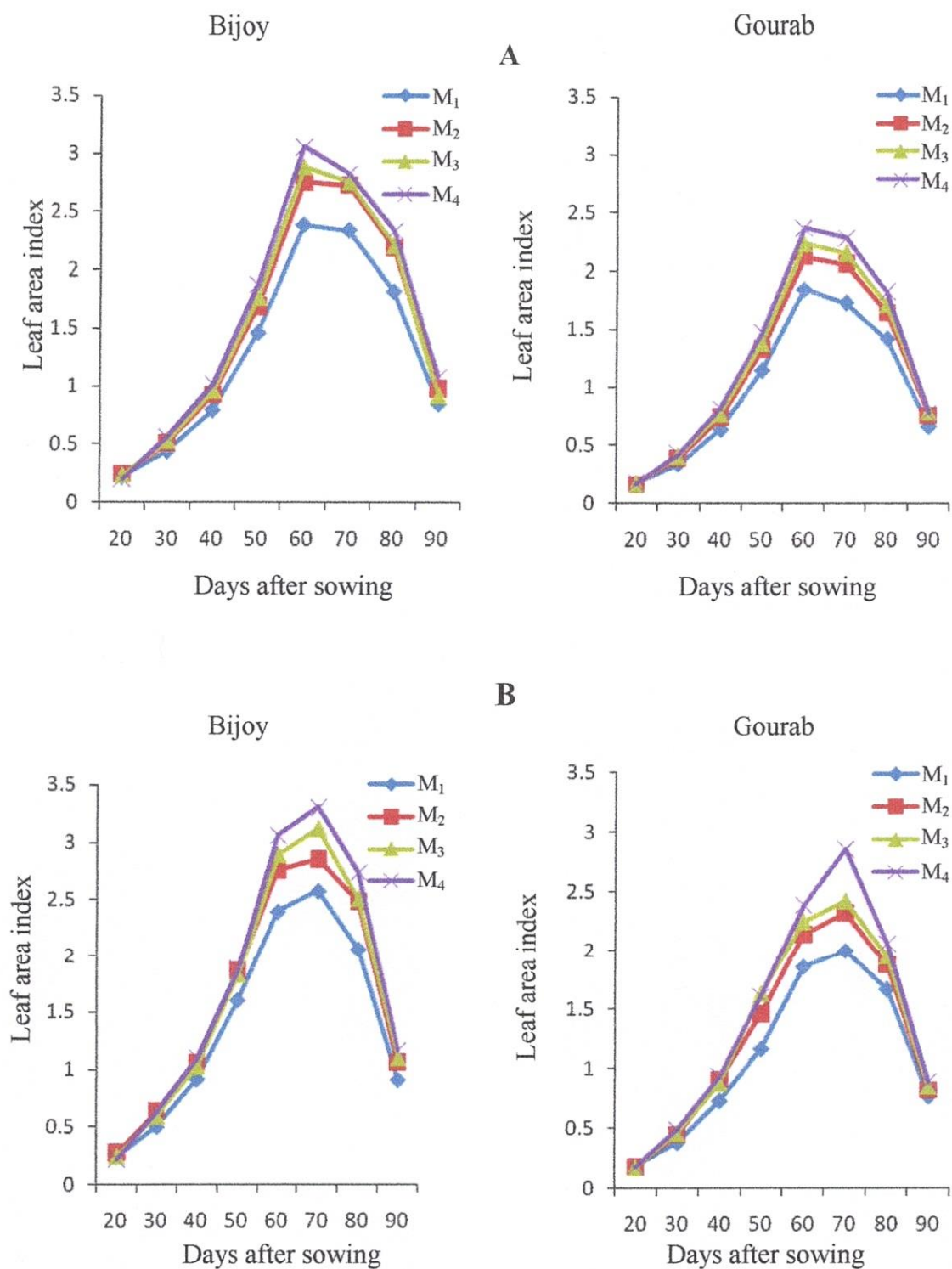


Figure 4b: Effect of mulching on leaf area index (LAI) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

Mulching had significant effect on LAI at all the harvests except 20 DAS during 2008-2009 and at all the harvests during 2009-2010 (Appendices IVa and IVb). Tables 2a and 2b showed that M_4 plants (black polythene mulching) produced the highest LAI value and M_1 plants (control) produced the lowest LAI value at all the harvests except 20 DAS in both the years. Effect of mulching on LAI of two wheat varieties at different harvests are shown in Figure 4b. LAI of both the varieties for all the mulching treatments started from a lower value at the early stages of growth, reached their highest value at 60 DAS and then declined with positive values.

Analysis of variance for LAI also showed significant sowing date $\times$ variety effects at 60, 80 and 90 DAS during 2008-2009 and at 60 and 90 DAS during 2009-2010. Variety $\times$ mulching effects were non-significant for LAI at all the harvests during 2008-2009 and at all the harvests except 20 and 90 DAS during 2009-2010 growing season (Appendices IVa and IVb).

4.2.3 Crop Growth Rate (CGR)

From the analysis of variance it was revealed that sowing date had significant effect on crop growth rate at all the harvests in both the years (Appendices Va and Vb). The highest CGR values were obtained from S_1 (17 November) sowing and the lowest values were obtained from S_4 (1 January) sowing. S_2 is statistically identical with S_1 at 50-60, 60-70 and 80-90 in 2008-2009 and at 50-60, 60-70, 70-80 and 80-90 in 2009-2010 growing season (Tables 3a and 3b). Effect of sowing date on CGR of two wheat varieties at different harvests of both the years are shown in Figure 5a. In all the sowing dates, starting from a lower value, CGR of both

Bijoy and Gourab reached a certain peak and thereafter declined with lower positive values. The highest CGR value was observed at 60-70 DAS in all the sowings in both the varieties and both the years.

Crop growth rate was significantly influenced by the variety at all the harvests in 2008-2009 and at all the harvests except 80-90 DAS in 2009-2010 growing season (Appendices Va and Vb). Between the two varieties, Bijoy showed higher crop growth rate than Gourab at all the harvests in both the years (Tables 3a and 3b).

Mulching had significant effect on CGR at all the harvests except 80-90 DAS in the first year and at all the harvest except 70-80 DAS in the second year (Appendices Va and Vb). The highest CGR values were obtained from M₄ (black polythene mulching) which was statistically identical with M₃ (rice straw mulching) at 70-80 DAS in the first year and with M₂ (water hyacinth mulching) and M₃ (rice straw mulching) at 40-50 and 50-60 DAS in the second year (Tables 3a and 3b). The effect of mulching on CGR of two wheat varieties at different harvests of both the years are shown in Figure 5b. Starting from a lower value, CGR of both the varieties reached a certain peak and thereafter declined with lower positive values for all the mulching treatments. The highest CGR value was observed at 60-70 DAS in both the varieties and both the years.

Analysis of variance for crop growth rate revealed that significant sowing date $\times$ variety effects were observed at 70-80 DAS in 2008-2009 and at 30-40 DAS in 2009-2010 growing seasons. Significant variety $\times$ mulching effects were observed at 70-80 DAS in 2008-2009 and at 50-60 DAS in 2009-2010 growing seasons (Appendices Va and Vb).

Table 3a: Effect of sowing date, variety and mulching on CGR ($\text{g m}^{-2} \text{ day}^{-1}$) of wheat in 2008-2009

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	3.103a	4.983a	8.379a	13.725a	26.888a	16.465a	12.202a
S ₂	2.908b	4.669b	7.698b	12.796a	25.299a	15.455ab	11.431a
S ₃	2.557c	4.112c	6.745c	11.269b	21.763b	13.808b	9.527a
S ₄	1.562d	2.550d	3.987d	7.121c	13.495c	8.092c	4.937b
LS	**	**	**	**	**	**	**
b) Variety							
V ₁	2.825a	4.564a	7.557a	12.674a	24.266a	15.645a	10.891a
V ₂	2.240b	3.593b	5.848b	9.781b	19.456b	11.265b	8.158b
LS	*	**	**	**	**	**	*
c) Mulching							
M ₁	1.861c	3.253c	5.201c	8.805c	17.661c	11.148b	7.766
M ₂	2.557b	4.118b	6.786b	11.366b	22.151b	13.449ab	10.195
M ₃	2.710b	4.300b	7.092b	11.827ab	22.764ab	14.510a	9.730
M ₄	3.002a	4.643a	7.730a	12.913a	24.869a	14.712a	10.405
LS	**	**	**	**	**	**	NS
CV%	8.21	9.11	10.81	13.70	14.02	18.68	20.58

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 3b: Effect of sowing date, variety and mulching on CGR ($\text{g m}^{-2} \text{ day}^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	3.601a	5.868a	9.332a	14.797a	35.512a	13.559a	9.407a
S ₂	3.321b	5.420b	8.510b	13.657a	33.180a	11.554a	9.709a
S ₃	2.940c	4.786c	7.509c	12.143b	29.108b	11.089a	6.868ab
S ₄	1.807d	2.953d	4.411d	7.756c	17.274c	6.266b	3.698b
LS	**	**	**	**	**	**	**
b) Variety							
V ₁	3.251a	5.272a	8.387a	13.907a	32.072a	11.995a	7.939
V ₂	2.583b	4.242b	6.495b	10.269b	25.465b	9.239b	6.901
LS	**	**	**	**	**	**	NS
c) Mulching							
M ₁	2.158d	3.763c	5.630b	9.808b	23.191c	9.123	7.135ab
M ₂	2.950c	4.748b	7.633a	12.385a	29.021b	10.768	9.427a
M ₃	3.110b	4.977b	8.172a	12.688a	30.075ab	11.038	7.747ab
M ₄	3.452a	5.540a	8.328a	13.472a	32.787a	11.538	5.373b
LS	**	**	**	**	**	NS	*
CV%	5.96	9.82	13.37	13.25	13.23	20.21	22.48

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation LS=Level of significance

S₁=17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂= Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

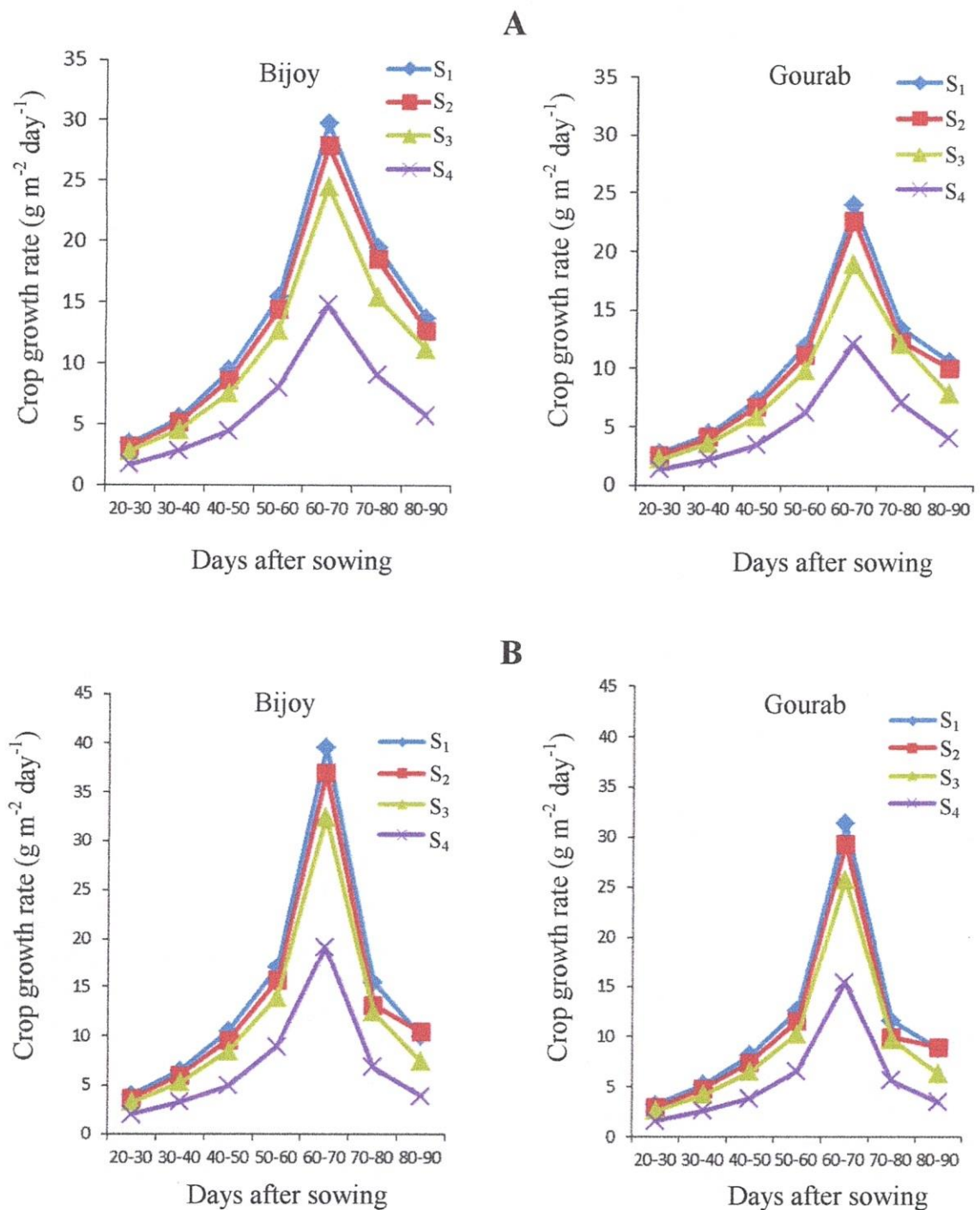


Figure 5a: Effect of sowing date on crop growth rate (CGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

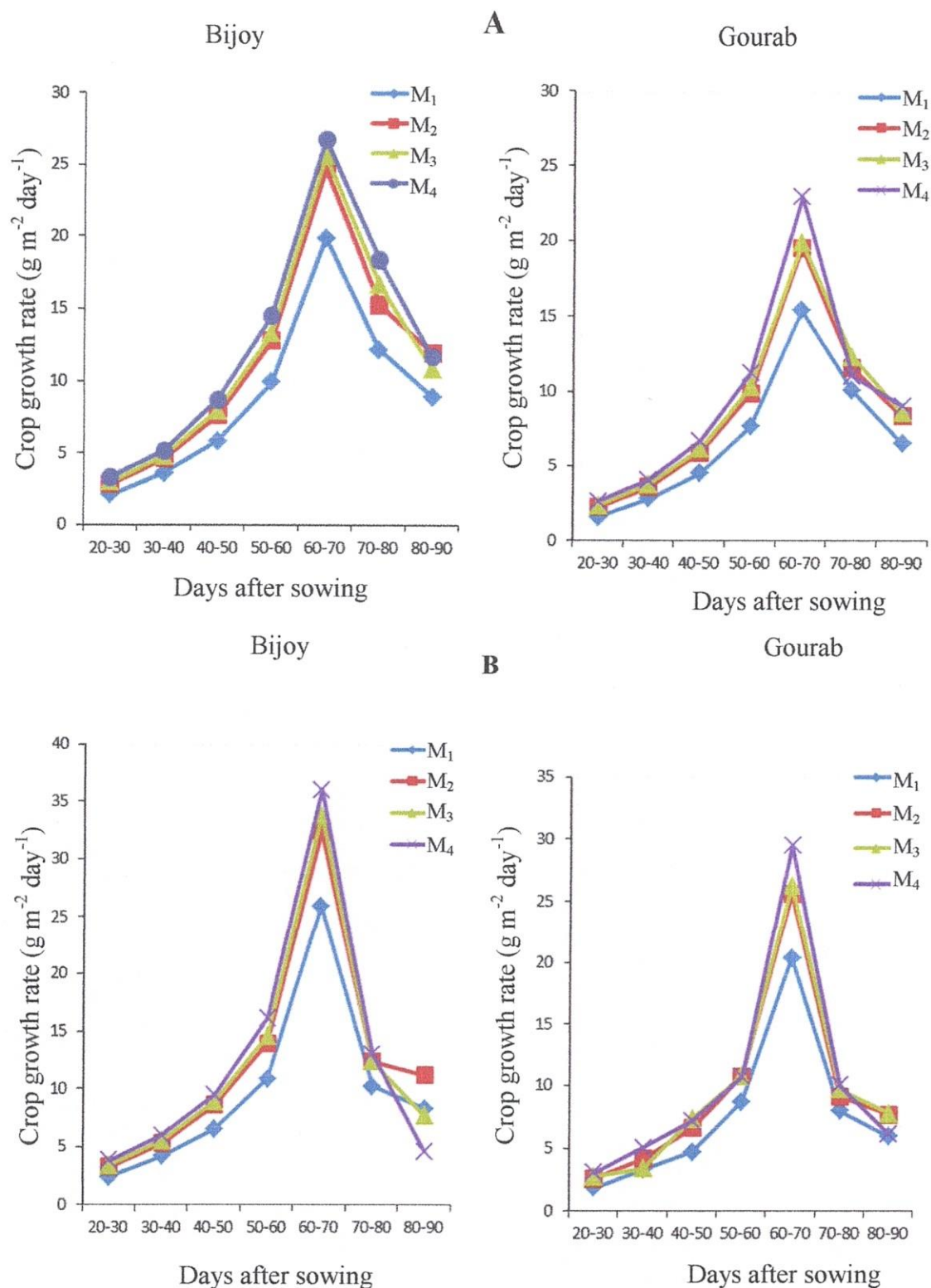


Figure 5b: Effect of mulching on crop growth rate (CGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.4 Relative Growth Rate (RGR)

The mean squares from the analysis of variance for RGR indicated that sowing date differences were non-significant at all the harvests in both the years (Appendices VIa and VIb). With some exceptions, numerically the highest RGR was obtained from S_1 sowing and the lowest was obtained from S_4 sowing in both the years at all the harvests (Tables 4a and 4b). Effect of sowing date on RGR of two wheat varieties at different harvests of both the years are shown in Figure 6a. From the Figure 6a it was observed that RGR showed a downward trend with moderate fluctuation and this decreasing trend continued till maturity.

Relative growth rate was not significantly influenced due to variety at all the harvests during 2008-2009 and at all the harvests except 30-40 DAS during 2009-2010 (Appendices VIa and VIb). No clear cut superiority was observed between the varieties for RGR (Tables 4a and 4b).

Mulching had no significant effect on RGR at all the harvests except 20-30 DAS during 2008-2009 and at all the harvests except 20-30 and 80-90 DAS during 2009-2010 growing seasons (Appendices VIa and VIb). No clear cut pattern of mulching on RGR was observed in both the years (Tables 4a and 4b). Effect of mulching on RGR of two wheat varieties at different harvests of both the years are shown in Figure 6b. RGR of both the varieties for all the mulching treatments showed a downward trend with moderate fluctuation and this decreasing trend continued till maturity. RGR values were found to be maximum at 20-30 DAS and then

Table 4a: Effect of sowing date, variety and mulching on RGR ($\text{g g}^{-1} \text{ day}^{-1}$) of wheat in 2008-2009

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	0.114	0.074	0.063	0.057	0.062	0.025	0.015
S ₂	0.114	0.074	0.062	0.057	0.062	0.025	0.015
S ₃	0.113	0.074	0.062	0.057	0.061	0.026	0.014
S ₄	0.113	0.074	0.060	0.059	0.062	0.024	0.012
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	0.112	0.074	0.062	0.058	0.061	0.026	0.015
V ₂	0.114	0.074	0.061	0.057	0.062	0.024	0.014
LS	NS	NS	NS	NS	NS	NS	NS
c) Mulching							
M ₁	0.097c	0.074	0.060	0.057	0.063	0.026	0.014
M ₂	0.115b	0.074	0.062	0.058	0.062	0.025	0.015
M ₃	0.118ab	0.074	0.062	0.057	0.061	0.025	0.014
M ₄	0.123a	0.074	0.062	0.058	0.061	0.023	0.014
LS	*	NS	NS	NS	NS	NS	NS
CV%	6.19	7.63	7.15	12.44	11.71	20.16	22.32

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 4b: Effect of sowing date, variety and mulching on RGR ($\text{g g}^{-1} \text{ day}^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	0.119	0.076	0.061	0.055	0.070	0.018	0.011
S ₂	0.119	0.076	0.061	0.055	0.071	0.016	0.012
S ₃	0.119	0.076	0.060	0.055	0.070	0.018	0.010
S ₄	0.118	0.076	0.058	0.058	0.068	0.017	0.009
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	0.118	0.075b	0.061	0.057	0.069	0.017	0.010
V ₂	0.120	0.076a	0.059	0.054	0.071	0.017	0.011
LS	NS	*	NS	NS	NS	NS	NS
c) Mulching							
M ₁	0.102b	0.075	0.058	0.057	0.071	0.018	0.012a
M ₂	0.120a	0.075	0.061	0.056	0.069	0.017	0.013a
M ₃	0.123a	0.076	0.063	0.055	0.069	0.017	0.010a
M ₄	0.129a	0.077	0.059	0.054	0.070	0.016	0.007b
LS	*	NS	NS	NS	NS	NS	**
CV%	4.77	8.86	11.89	11.81	10.72	19.80	22.00

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂=Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

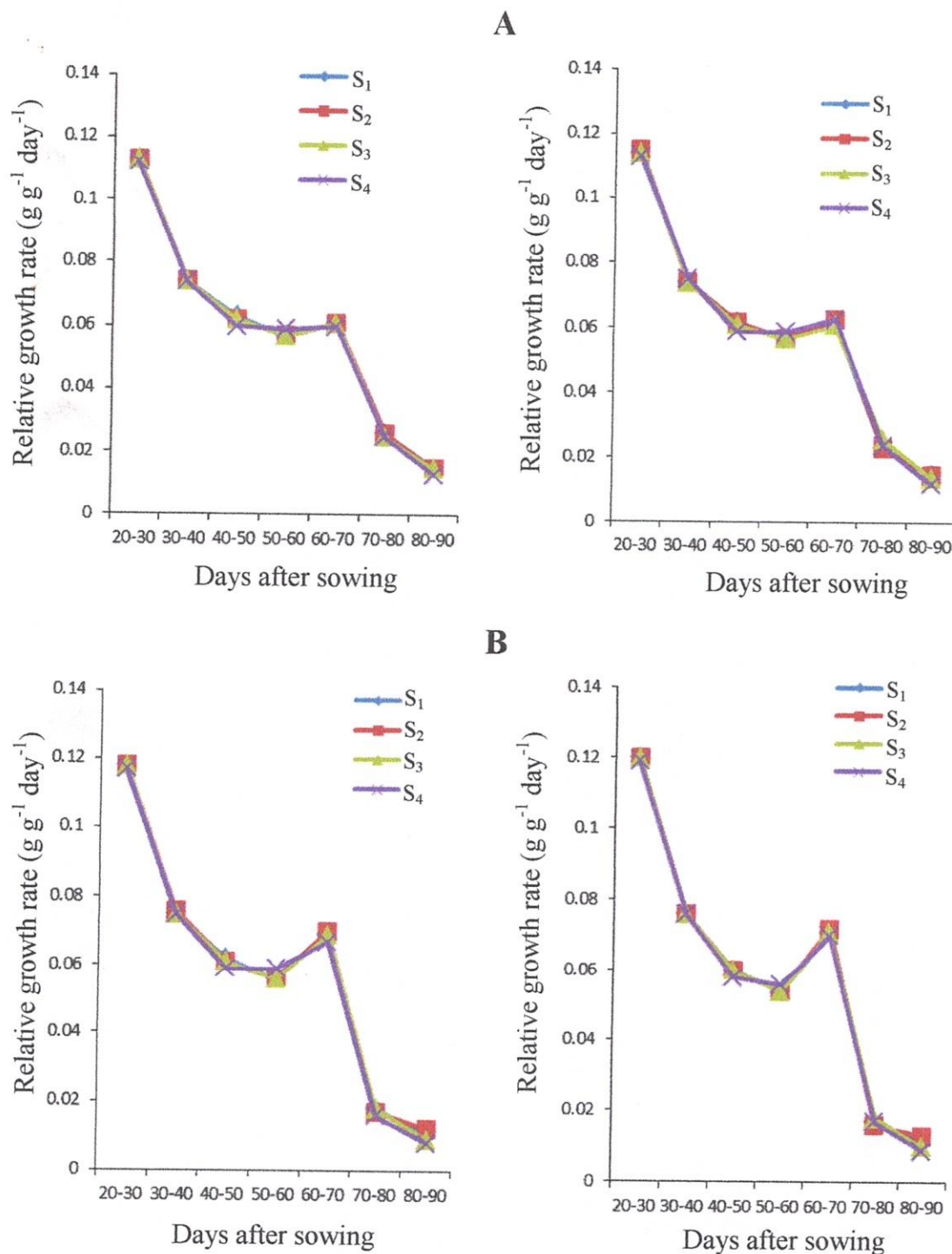


Figure 6a: Effect of sowing date on relative growth rate (RGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

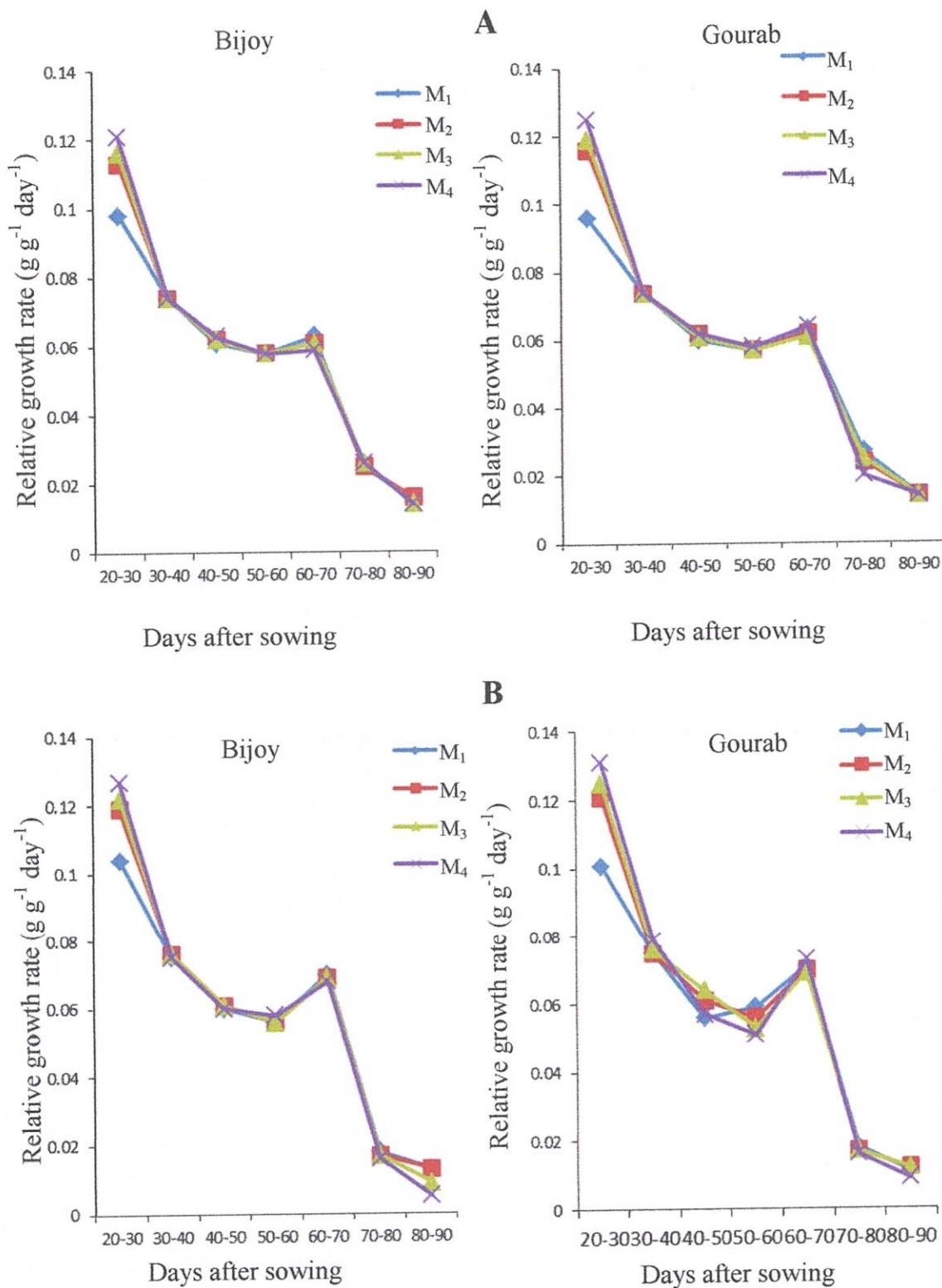


Figure 6b: Effect of mulching on relative growth rate (RGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

it gradually declined throughout the whole growth period with moderate fluctuation.

Analysis of variance for RGR also showed that the effects of sowing date $\times$ variety and variety $\times$ mulching were non-significant at all the harvests in both the years (Appendices VIa and VIb).

4.2.5 Net Assimilation Rate (NAR)

The mean squares from the analysis of variance revealed that sowing date differences were non-significant at all the harvests in 2008-2009 and at all the harvests except 80-90 DAS in 2009-2010 growing seasons (Appendices VIIa and VIIb). No clear cut pattern of sowing date effects on NAR was observed in both the years (Tables 5a and 5b). Effect of sowing date on NAR of two wheat varieties at different harvests of both the years are shown in Figure 7a. From the Figure 7a it was observed that NAR values fluctuated heavily throughout the growing period.

Net assimilation rate was not significantly influenced due to variety at all the harvests in 2008-2009 and at all the harvests except 20-30 and 50-60 DAS in 2009-2010 growing season (Appendices VIIa and VIIb). Bijoy showed higher NAR values at 40-50, 50-60, 70-80 and 80-90 DAS in the first year and at 40-50, 50-60 and 70-80 DAS in the second year (Tables 5a and 5b).

Mulching showed significant effects on NAR at 20-30, 30-40, 40-50 and 50-60 during 2008-2009 and at 20-30, 30-40, 40-50 and 80-90 DAS during 2009-2010 growing season (Appendices VIIa and VIIb).

Table 5a: Effect of sowing date, variety and mulching on NAR ($\text{g cm}^{-2} \text{ day}^{-1}$) of wheat in 2008-2009

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	0.825	0.655	0.595	0.571	0.903	0.626	0.757
S ₂	0.827	0.654	0.588	0.573	0.915	0.625	0.765
S ₃	0.824	0.652	0.583	0.577	0.906	0.661	0.716
S ₄	0.817	0.654	0.562	0.603	0.921	0.627	0.620
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	0.805	0.653	0.589	0.582	0.896	0.650	0.727
V ₂	0.841	0.654	0.576	0.580	0.926	0.619	0.702
LS	NS	NS	NS	NS	NS	NS	NS
c) Mulching							
M ₁	0.656c	0.606b	0.527b	0.532b	0.857	0.623	0.670
M ₂	0.831b	0.664a	0.594a	0.594a	0.922	0.632	0.747
M ₃	0.856b	0.664a	0.596a	0.589a	0.912	0.654	0.717
M ₄	0.949a	0.680a	0.612a	0.608a	0.954	0.629	0.727
LS	**	**	**	*	NS	NS	NS
CV%	10.71	9.58	8.17	14.61	15.84	21.19	23.28

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 5b: Effect of sowing date, variety and mulching on NAR ($\text{g cm}^{-2} \text{ day}^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	0.858	0.673	0.601	0.590	1.117	0.451	0.532a
S ₂	0.843	0.664	0.585	0.587	1.121	0.420	0.583a
S ₃	0.848	0.667	0.590	0.596	1.125	0.454	0.479a
S ₄	0.849	0.667	0.570	0.631	1.114	0.433	0.425a
LS	NS	NS	NS	NS	NS	NS	*
b) Variety							
V ₁	0.823b	0.667	0.608	0.621a	1.119	0.443	0.482
V ₂	0.876a	0.669	0.565	0.581b	1.120	0.436	0.528
LS	*	NS	NS	**	NS	NS	NS
c) Mulching							
M ₁	0.691d	0.614c	0.519b	0.574	1.057	0.444	0.547a
M ₂	0.831c	0.644bc	0.589a	0.616	1.155	0.454	0.624ab
M ₃	0.892b	0.689ab	0.624a	0.601	1.131	0.444	0.514ab
M ₄	0.985a	0.724a	0.614a	0.613	1.134	0.418	0.335b
LS	**	**	**	NS	NS	NS	**
CV%	9.37	10.80	15.48	14.35	14.35	21.21	23.22

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation LS=Level of significance

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

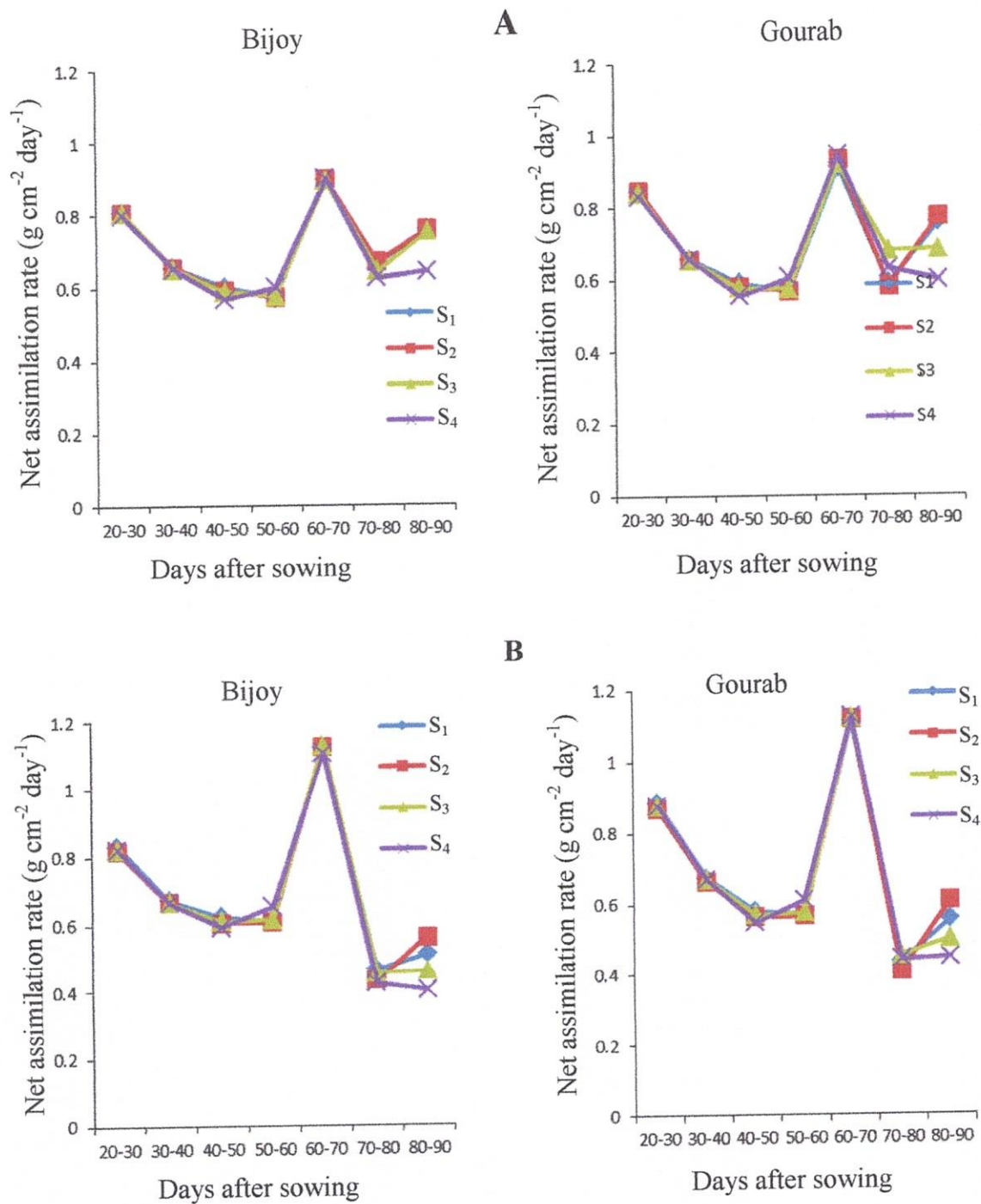


Figure 7a: Effect of sowing date on net assimilation rate (NAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

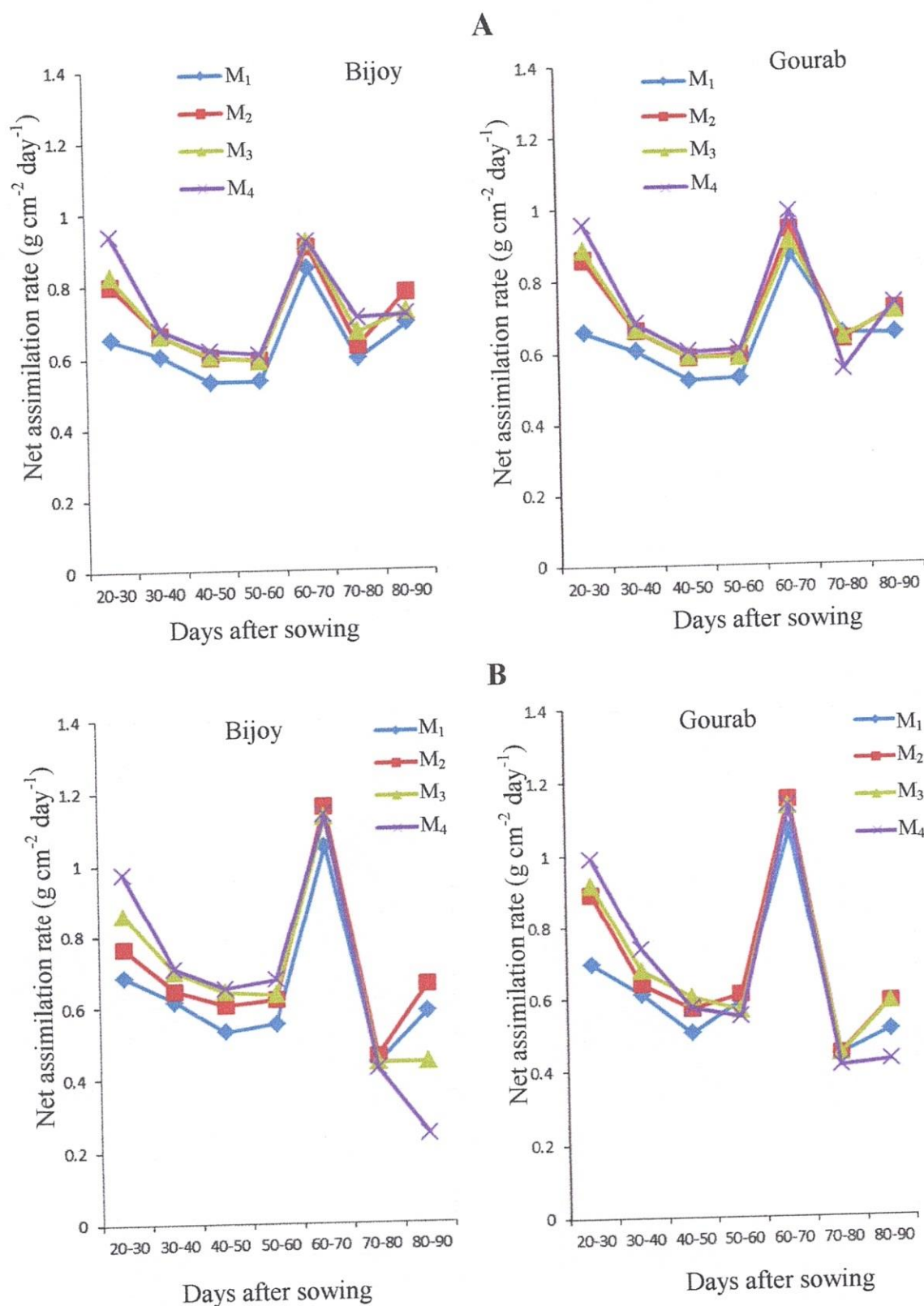


Figure 7b: Effect of mulching on net assimilation rate (NAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

With some exceptions, the highest NAR values were obtained from M₄ (black polythene mulching) and the lowest values were obtained from M₁ (control) treatment in both the years (Tables 5a and 5b). Effect of mulching on NAR of two wheat varieties at different harvests of both the years are shown in Figure 7b. NAR values for all the mulching treatments fluctuated heavily throughout the growing period.

Analysis of variance for NAR also showed that sowing date $\times$ variety effects were non-significant at all the harvests in both the years and variety $\times$ mulching effects were non-significant at all the harvests in 2008-2009 and at all the harvests except 20-30 and 50-60 DAS in 2009-2010 growing season (Appendices VIIa and VIIb).

4.2.6 Leaf Area Ratio (LAR)

Analysis of variance indicated that sowing date differences were non-significant for leaf area ratio at all the harvests in both the years (Appendices VIIIa and VIIIb). Numerically the highest LAR values were observed at S₄ sowing at the early stages of growth and at the later stages S₁ sowing showed the highest value in 2008-2009. In 2009-2010 growing season, numerically the highest LAR values were observed at S₂ sowing at all the harvests (Tables 6a and 6b). Effect of sowing date on LAR of two wheat varieties at different harvests are shown in Figure 8a. LAR of both the varieties for all the sowing dates showed a downward trend with moderate fluctuation and this decreasing trend continued till maturity.

Leaf area ratio was not significantly influenced due to variety at all the harvests except 20-30 DAS in both the years (Appendices VIIIA and VIIIB). No clear cut superiority was observed between the varieties in both the years (Tables 6a and 6b).

Mulching had significant effect on LAR at all the harvests in both the years (Appendices VIIIA and VIIIB). The highest LAR values were obtained from control treatment (M_1) at all the harvests. Statistically similar LAR was observed in M_2 , M_3 and M_4 mulching at most of the harvests (Tables 6a and 6b). Effect of mulching on LAR of two wheat varieties at different harvests are shown in Figure 8b. LAR of both the varieties for all the mulching treatments also showed a downward trend with moderate fluctuation and this decreasing trend continued till maturity.

Analysis of variance for LAR also showed that the effects of sowing date $\times$ variety were non-significant at all the harvests in both the years and variety $\times$ mulching effects were non-significant at all the harvests in 2008-2009 and at all the harvests except 20-30 and 80-90 DAS in 2009-2010 growing season (Appendices VIIIA and VIIIB).

Table 6a: Effect of sowing date, variety and mulching on LAR ($\text{cm}^2 \text{g}^{-1}$) of wheat in 2008-2009

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	138.95	113.37	106.07	100.64	68.61	39.74	20.15
S ₂	139.01	113.43	105.88	100.36	68.51	39.60	19.95
S ₃	138.80	113.92	106.33	100.20	67.61	39.08	20.063
S ₄	139.27	114.39	106.71	98.79	67.52	39.15	19.79
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	141.13a	113.93	105.794	99.97	68.49	39.63	19.94
V ₂	136.89b	113.63	106.71	100.03	67.64	39.15	20.03
LS	*	NS	NS	NS	NS	NS	NS
c) Mulching							
M ₁	148.44a	121.89a	114.46a	108.61a	73.53a	41.95a	21.35a
M ₂	138.98b	112.06b	104.30b	97.74b	67.07b	39.23b	19.90b
M ₃	138.33b	111.78b	104.08b	97.98b	67.13b	38.82b	19.40b
M ₄	130.28c	109.37b	102.15b	95.66b	64.53b	37.56b	19.30b
LS	**	**	**	**	**	**	**
CV%	7.25	5.64	6.95	6.18	6.20	6.50	7.29

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 6b: Effect of sowing date, variety and mulching on LAR ($\text{cm}^2 \text{g}^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	140.53	113.44	102.53	92.87	63.03	38.95	20.63
S ₂	142.21	115.02	103.93	93.93	63.30	39.27	20.81
S ₃	141.46	114.56	103.47	93.30	62.98	38.80	20.69
S ₄	141.00	114.40	103.78	91.89	61.73	38.62	20.73
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	145.10a	114.03	101.29	92.06	62.12	38.68	20.78
V ₂	137.50b	114.68	105.56	93.93	63.40	39.13	20.65
LS	**	NS	NS	NS	NS	NS	NS
c) Mulching							
M ₁	149.22a	122.51a	111.66a	100.29a	67.10a	41.20a	22.08a
M ₂	146.00ab	117.33a	104.65b	91.37b	60.19b	37.68b	20.09b
M ₃	138.88bc	110.51b	101.00bc	91.24b	61.29b	37.95b	20.24b
M ₄	131.11c	107.07b	96.40c	82.08b	62.46b	38.80ab	20.45b
LS	**	**	**	**	**	**	**
CV%	7.78	6.91	6.82	7.16	6.61	8.43	6.35

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

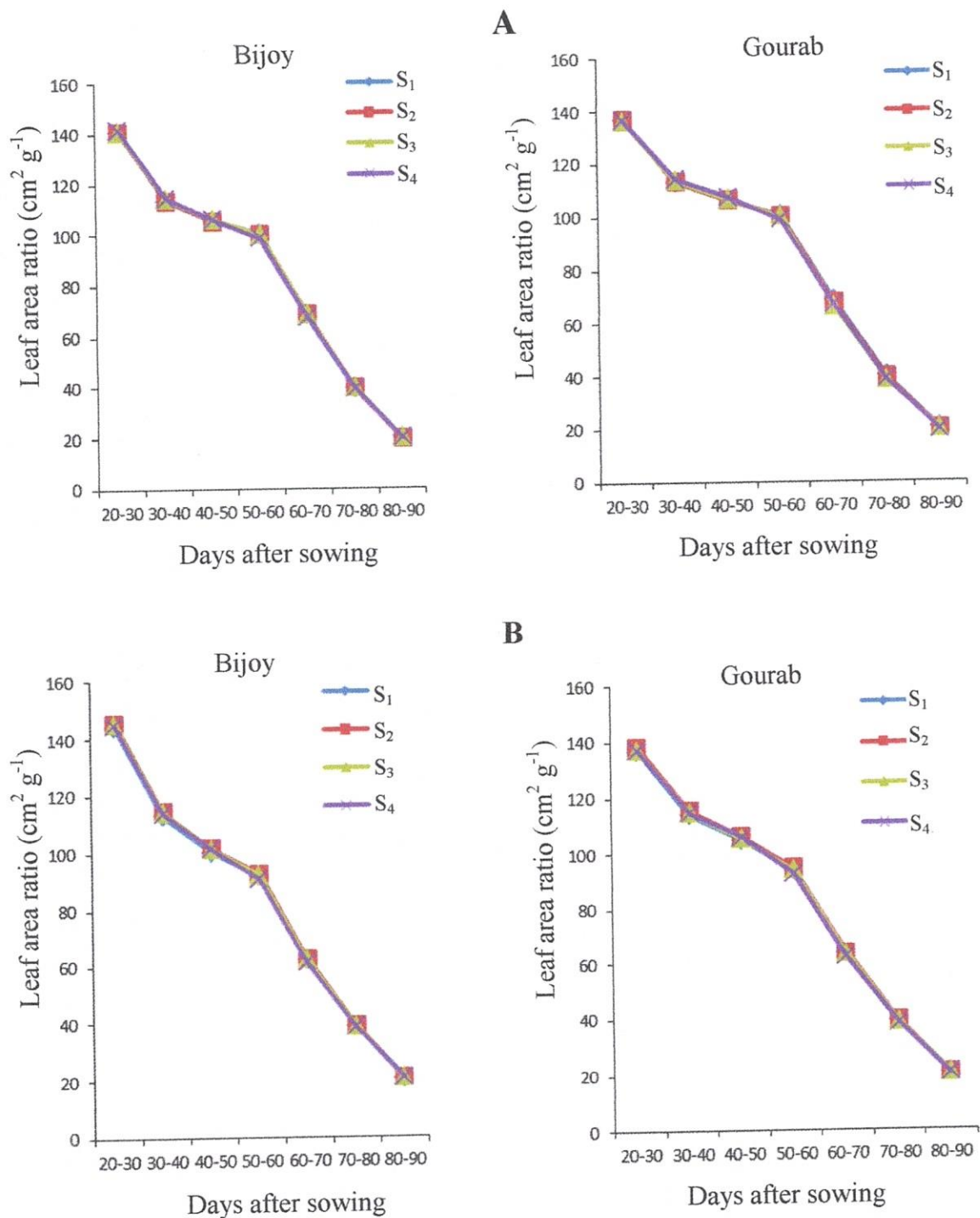


Figure 8a: Effect of sowing date on leaf area ratio (LAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

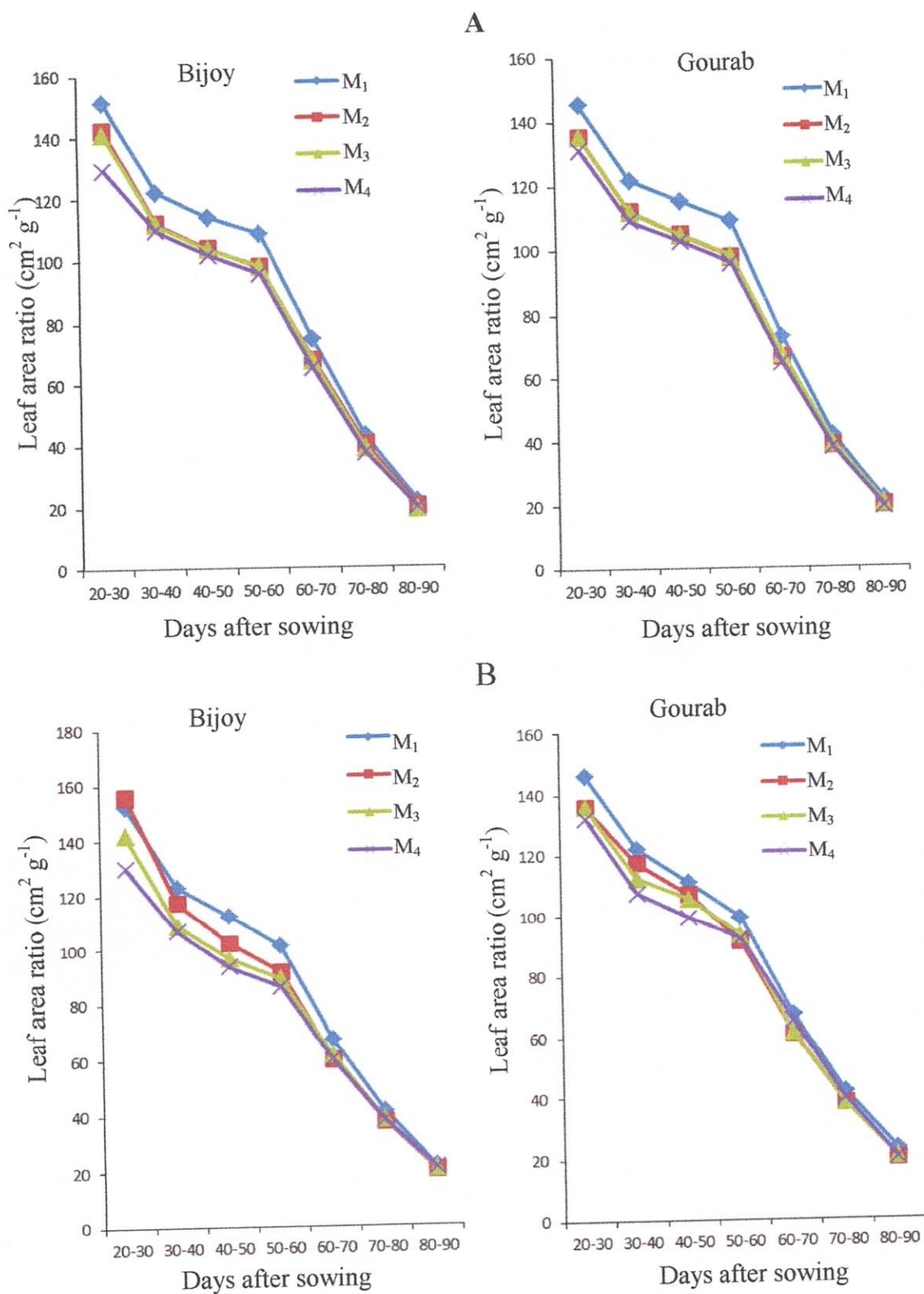


Figure 8b. Effect of mulching on leaf area ratio (LAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.7 Relative Leaf Growth Rate (RLGR)

The mean squares from the analysis of variance indicated that sowing date differences for RLGR were non-significant at all the harvests in both the years (Appendices IXa and IXb). With some exceptions, numerically the highest RLGR was obtained from S₁ sowing and the lowest was obtained from S₄ sowing in both the years at all the harvests (Tables 7a and 7b). Effect of sowing date on RLGR of two wheat varieties at different harvests are shown in Figure 9a. RLGR of both the varieties for all the sowing dates started from higher positive values at the early stages of growth and declined with fluctuations and ended in a negative value at the later stages of growth in both the years.

Relative leaf growth rate was not significantly influenced by the variety at all the harvests in 2008-2009. In 2009-2010, RLGR was significantly influenced by the variety at 30-40, 50-60, 60-70 and 70-80 DAS (Appendices IXa and IXb). No clear cut superiority was observed between the varieties for RLGR (Tables 7a and 7b).

Mulching had no significant effect on RLGR at all the harvests except 20-30 DAS in both the years (Appendices IXa and IXb). No clear cut pattern of mulching affected on RLGR was observed in both the years (Tables 7a and 7b). Effect of mulching on RLGR of two wheat varieties at different harvests are shown in Figure 9b. RLGR of both the varieties for all the mulching treatments started from higher positive values at the early

Table 7a: Effect of sowing date, variety and mulching on RLGR ($\text{cm}^2 \text{cm}^{-2} \text{day}^{-1}$) of wheat in 2008-2009

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	0.083	0.061	0.061	0.049	-0.004	-0.022	-0.079
S ₂	0.083	0.061	0.060	0.049	-0.003	-0.023	-0.080
S ₃	0.083	0.061	0.059	0.048	-0.006	-0.019	-0.080
S ₄	0.081	0.063	0.056	0.048	-0.001	-0.025	-0.080
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	0.081	0.059	0.060	0.049	-0.003	-0.022	-0.080
V ₂	0.083	0.064	0.058	0.048	-0.004	-0.022	-0.079
LS	NS	NS	NS	NS	NS	NS	NS
c) Mulching							
M ₁	0.067c	0.061	0.059	0.049	-0.004	-0.023	-0.077
M ₂	0.081bc	0.061	0.059	0.048	-0.002	-0.022	-0.079
M ₃	0.084b	0.061	0.059	0.049	-0.004	-0.023	-0.083
M ₄	0.097a	0.062	0.059	0.048	-0.006	-0.021	-0.081
LS	**	NS	NS	NS	NS	NS	NS
CV%	14.66	20.84	19.25	23.83	24.69	23.62	18.26

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 7b: Effect of sowing date, variety and mulching on RLGR ($\text{cm}^2 \text{cm}^{-2} \text{day}^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
a) Sowing Date							
S ₁	0.088	0.061	0.055	0.041	0.008	-0.021	-0.082
S ₂	0.088	0.061	0.054	0.041	0.008	-0.021	-0.082
S ₃	0.088	0.061	0.054	0.041	0.008	-0.021	-0.082
S ₄	0.088	0.061	0.052	0.041	0.008	-0.022	-0.083
LS	NS	NS	NS	NS	NS	NS	NS
b) Variety							
V ₁	0.087	0.055b	0.056	0.043a	0.006b	-0.019a	-0.083
V ₂	0.089	0.067a	0.052	0.039b	0.010a	-0.024b	-0.082
LS	NS	**	NS	*	*	*	NS
c) Mulching							
M ₁	0.073c	0.062	0.051	0.043	0.007	-0.020	-0.079
M ₂	0.087bc	0.061	0.052	0.039	0.006	-0.018	-0.083
M ₃	0.090b	0.060	0.059	0.039	0.008	-0.022	-0.082
M ₄	0.102a	0.060	0.054	0.044	0.010	-0.026	-0.085
LS	**	NS	NS	NS	NS	NS	NS
CV%	15.58	24.73	25.72	23.87	25.35	22.69	16.47

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

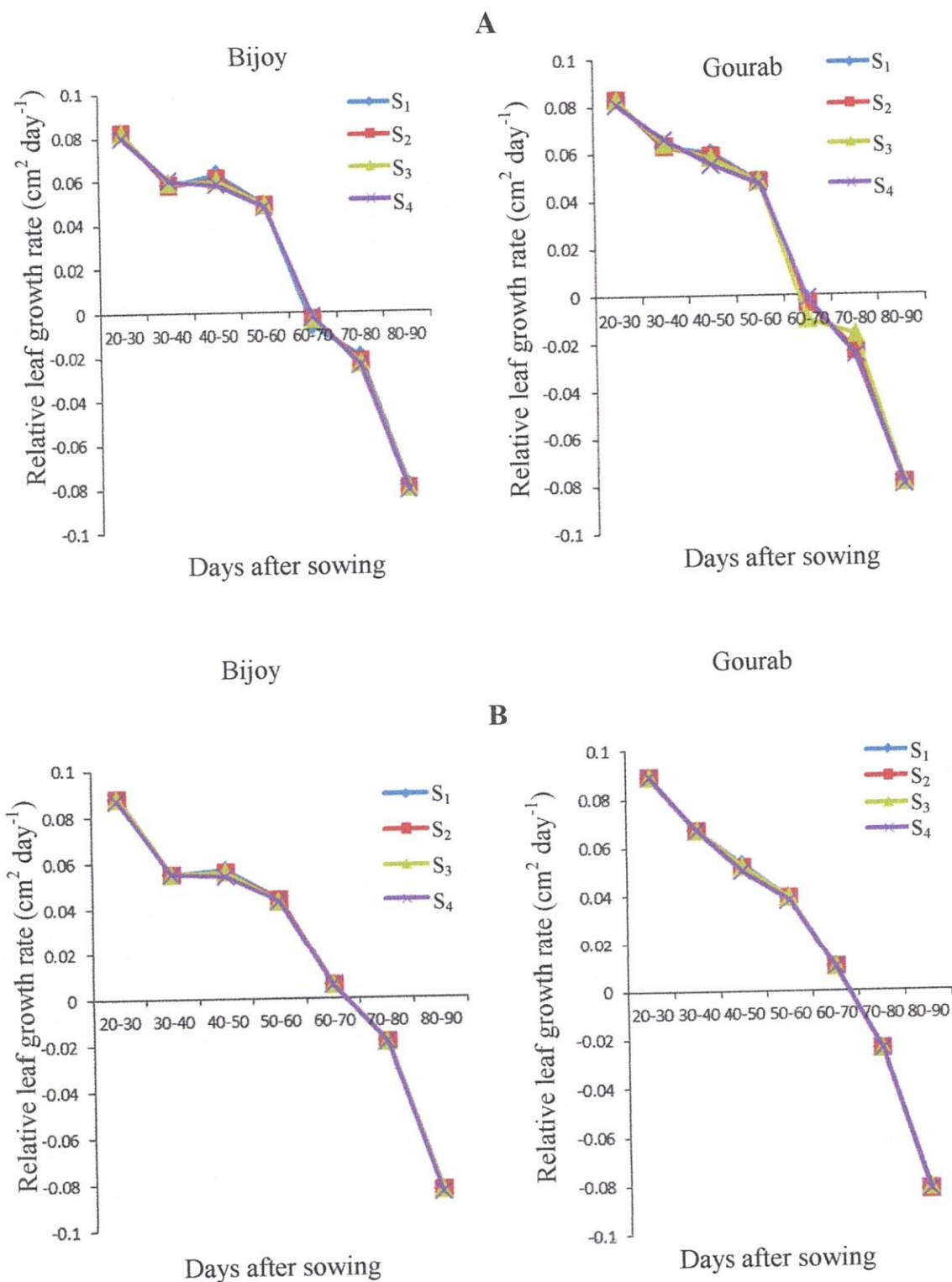


Figure 9a: Effect of sowing date on relative leaf growth rate (RLGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

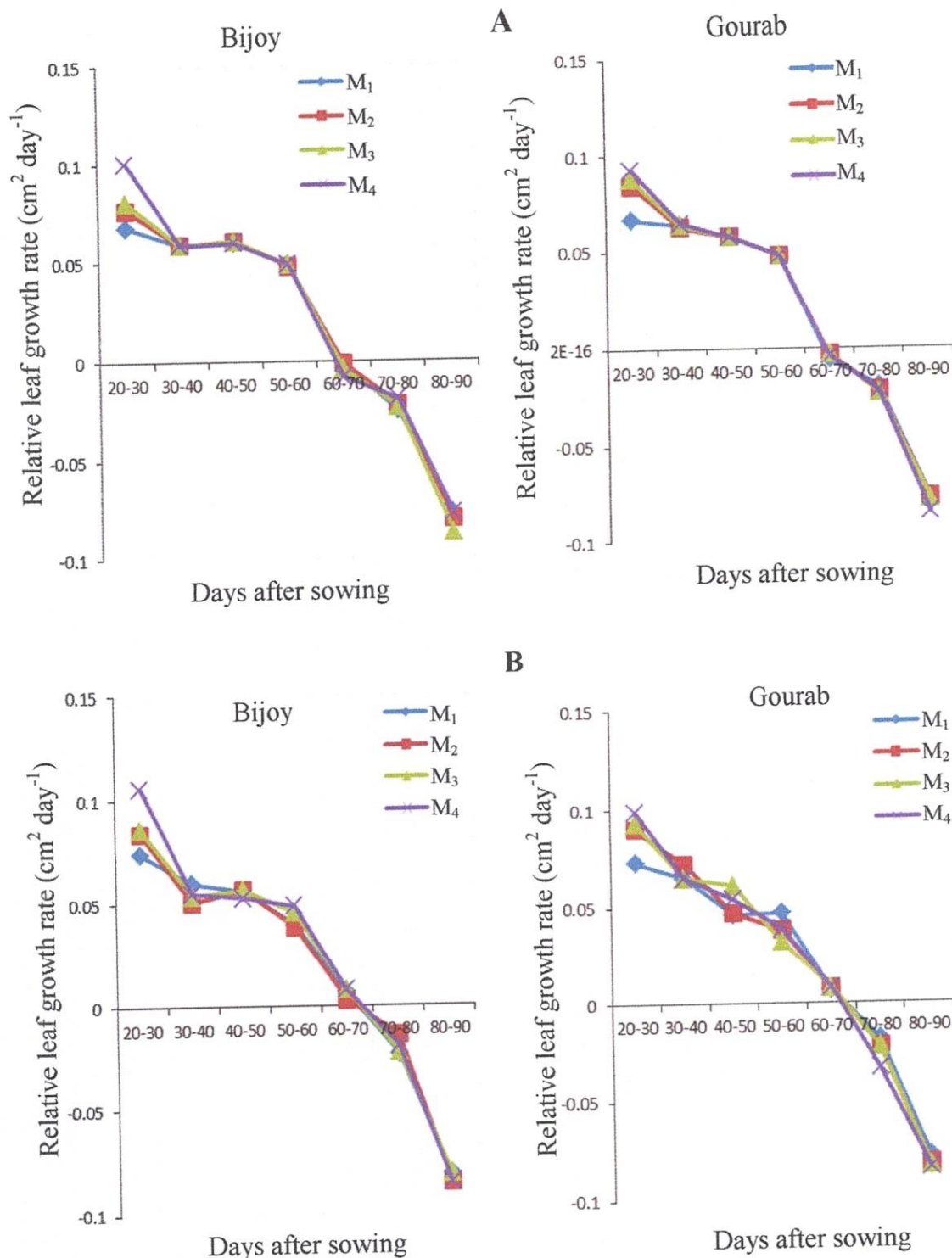


Figure 9b: Effect of mulching on relative leaf growth rate (RLGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

stages of growth and declined with fluctuations and ended in a negative value at the later stages of growth.

Analysis of variance for RLGR revealed that the effects of sowing date $\times$ variety and variety $\times$ mulching were non-significant at all the harvests in both the years (Appendices IXa and IXb).

4.2.8 Specific Leaf Area (SLA)

The mean squares from the analysis of variance it is revealed that sowing date differences were non-significant at all the harvests in both the years (Appendices Xa and Xb). No clear cut pattern of sowing date effects on SLA was observed in both the years (Tables 8a and 8b). Effect of sowing date on SLA of two wheat varieties at different harvests are shown in Figure 10a. From the Figure 10a it was observed that SLA values fluctuated moderately throughout the growing period.

Specific leaf area was not significantly influenced by the variety at all the harvests in 2008-2009 and at all the harvests except 40 DAS in 2009-2010 growing season (Appendices Xa and Xb). No clear cut pattern of varietal effects on SLA was found in both the years (Tables 8a and 8b).

Mulching showed significant effects on specific leaf area SLA at all the harvests (Appendices Xa and Xb). With some exceptions, the highest SLA values were obtained from M_1 (control) and the lowest values were obtained from M_4 (black polythene mulching) in both the years (Tables 8a and 8b). With some exceptions, M_2 , M_3 and M_4 showed statistically similar SLA value in both the years.

Table 8a: Effect of sowing date, variety and mulching on SLA ($\text{cm}^2 \text{g}^{-1}$) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	232.17	231.32	235.75	239.32	228.04	230.57	226.09	162.78
S ₂	231.94	231.90	235.87	239.30	227.80	230.60	226.21	162.67
S ₃	232.16	231.35	237.54	239.23	227.62	230.37	226.18	162.78
S ₄	234.26	232.39	240.25	239.17	228.11	230.54	226.15	162.53
LS	NS	NS	NS	NS	NS	NS	NS	NS
b) Variety								
V ₁	236.45	232.87	234.90	239.02	227.93	230.77	224.89	164.07
V ₂	228.82	230.62	239.80	239.49	227.85	230.27	227.42	161.30
LS	NS	NS	NS	NS	NS	NS	NS	NS
c) Mulching								
M ₁	245.08a	248.98a	254.12a	259.39a	248.63a	249.32a	244.28a	177.70a
M ₂	236.71a	228.25b	233.48b	234.58b	222.20b	226.17b	222.32b	160.97b
M ₃	235.17a	227.95b	233.16b	234.21b	223.99b	226.03b	221.79b	160.59b
M ₄	213.59b	221.79b	228.64b	228.85b	216.75b	220.57b	216.24b	151.49c
LS	**	**	**	**	**	**	**	**
CV%	8.36	7.34	6.99	6.95	6.49	6.48	6.18	6.38

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 8b: Effect of sowing date, variety and mulching on SLA ($\text{cm}^2 \text{g}^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	234.36	234.37	234.60	228.79	204.03	234.17	228.58	162.16
S ₂	237.14	237.73	238.26	231.59	206.49	235.69	234.29	164.62
S ₃	236.14	236.50	237.00	230.74	204.82	233.77	230.41	163.89
S ₄	235.04	236.28	237.03	231.41	204.00	236.60	235.09	164.59
LS	NS	NS	NS	NS	NS	NS	NS	NS
b) Variety								
V ₁	242.02	240.44	229.07b	227.35	205.18	230.48	231.15	163.50
V ₂	229.31	232.00	244.38a	233.91	204.49	238.64	233.04	164.14
LS	NS	NS	**	NS	NS	NS	NS	NS
c) Mulching								
M ₁	245.82a	250.42a	254.46a	253.55a	223.47a	251.51a	253.18a	184.44a
M ₂	247.62a	241.15ab	242.71a	229.16b	199.90b	222.62c	225.98b	159.96b
M ₃	234.34a	229.60b	227.10b	222.57b	201.26b	228.37bc	225.41b	159.92b
M ₄	213.90b	223.70b	222.63b	217.24b	194.71b	235.74b	223.80b	150.94c
LS	**	**	**	**	**	**	**	**
CV%	9.20	9.94	8.10	9.12	7.76	5.30	8.25	7.18

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁= 17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂= Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

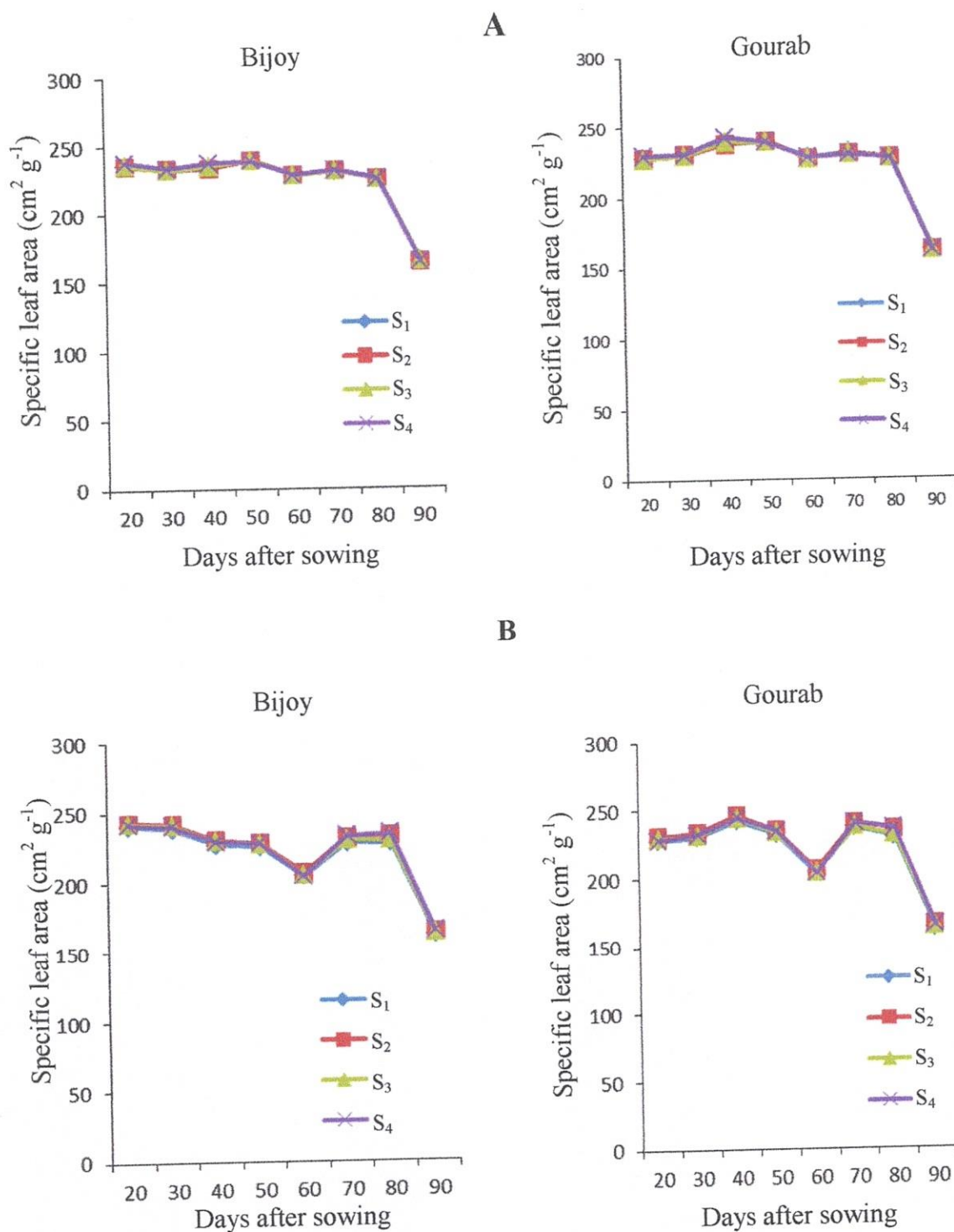


Figure 10a: Effect of sowing date on specific leaf area (SLA) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

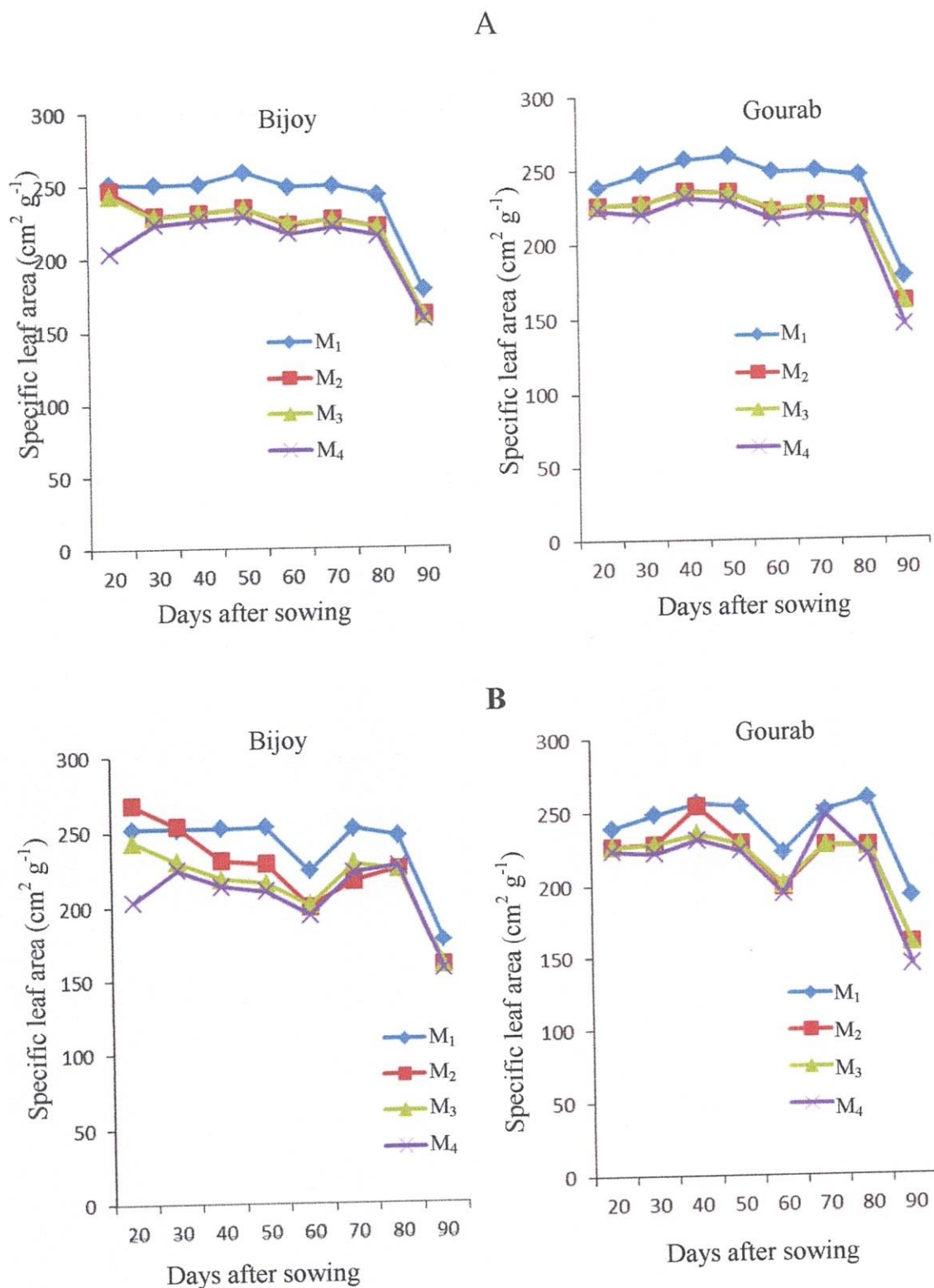


Figure 10b: Effect of mulching on specific leaf area (SLA) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

Effect of mulching on SLA of two wheat varieties at different harvests of both the years are shown in Figure 10b. SLA values for mulching also fluctuated moderately throughout the growing period.

Analysis of variance for SLA showed non-significant sowing date $\times$ variety effects at all the harvests in both the years. Variety $\times$ mulching effects on SLA were non-significant at all the harvests in 2008-2009 and at all the harvests except 20, 70 and 90 DAS in 2009-2010 growing season (Appendices Xa and Xb).

4.2.9 Leaf Weight Ratio (LWR)

From the analysis of variance it is revealed that sowing date differences for LWR were non-significant at all the harvests except 60 DAS in both the years (Appendices XIa and XIb). With some exceptions, numerically the highest LWR was obtained from S_1 sowing and the lowest was obtained from S_4 sowing at all the harvests (Tables 9a and 9b). Effect of sowing date on LWR of two wheat varieties at different harvests of both the years are shown in Figure 11a. In all the sowing dates of both the varieties and years LWR showed the highest values at the beginning and gradually declined with the plant age.

Leaf weight ratio was not significantly influenced due to variety at all the harvests except 30 DAS in both the years (Appendices XIa and XIb). No clear cut superiority was observed on LWR between the varieties (Tables 9a and 9b).

Table 9a: Effect of sowing date, variety and mulching on LWR (g g^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	0.718	0.527	0.455	0.440	0.426a	0.218	0.139	0.076
S ₂	0.718	0.527	0.455	0.440	0.425a	0.218	0.139	0.075
S ₃	0.716	0.527	0.455	0.440	0.423a	0.213	0.138	0.075
S ₄	0.715	0.524	0.455	0.440	0.412b	0.217	0.136	0.075
LS	NS	NS	NS	NS	*	NS	NS	NS
b) Variety								
V ₁	0.716	0.532a	0.455	0.440	0.421	0.219	0.139	0.074
V ₂	0.717	0.521b	0.455	0.440	0.421	0.215	0.137	0.076
LS	NS	*	NS	NS	NS	NS	NS	NS
c) Mulching								
M ₁	0.717	0.525	0.455	0.440	0.420	0.215	0.135	0.074
M ₂	0.716	0.528	0.455	0.440	0.421	0.220	0.140	0.076
M ₃	0.718	0.527	0.454	0.440	0.420	0.219	0.138	0.073
M ₄	0.716	0.526	0.455	0.440	0.423	0.213	0.140	0.077
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	2.80	4.44	4.10	4.72	5.09	6.62	8.30	7.44

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 9b: Effect of sowing date, variety and mulching on LWR (g g^{-1}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20	30	40	50	60	70	80	90
a) Sowing Date								
S ₁	0.718	0.527	0.454	0.436	0.430a	0.204	0.140	0.078
S ₂	0.719	0.527	0.454	0.436	0.428a	0.202	0.139	0.077
S ₃	0.718	0.527	0.454	0.436	0.426a	0.202	0.137	0.079
S ₄	0.718	0.527	0.454	0.436	0.415b	0.198	0.135	0.078
LS	NS	NS	NS	NS	*	NS	NS	NS
b) Variety								
V ₁	0.718	0.532a	0.456	0.435	0.421	0.202	0.139	0.078
V ₂	0.719	0.522b	0.452	0.437	0.428	0.200	0.137	0.078
LS	NS	*	NS	NS	NS	NS	NS	NS
c) Mulching								
M ₁	0.718	0.525	0.457	0.427	0.420	0.199	0.134	0.074
M ₂	0.718	0.527	0.457	0.437	0.422	0.201	0.139	0.077
M ₃	0.719	0.528	0.456	0.447	0.421	0.203	0.138	0.078
M ₄	0.719	0.528	0.457	0.433	0.436	0.202	0.140	0.084
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	2.25	5.09	5.83	6.26	6.16	8.17	6.43	7.08

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

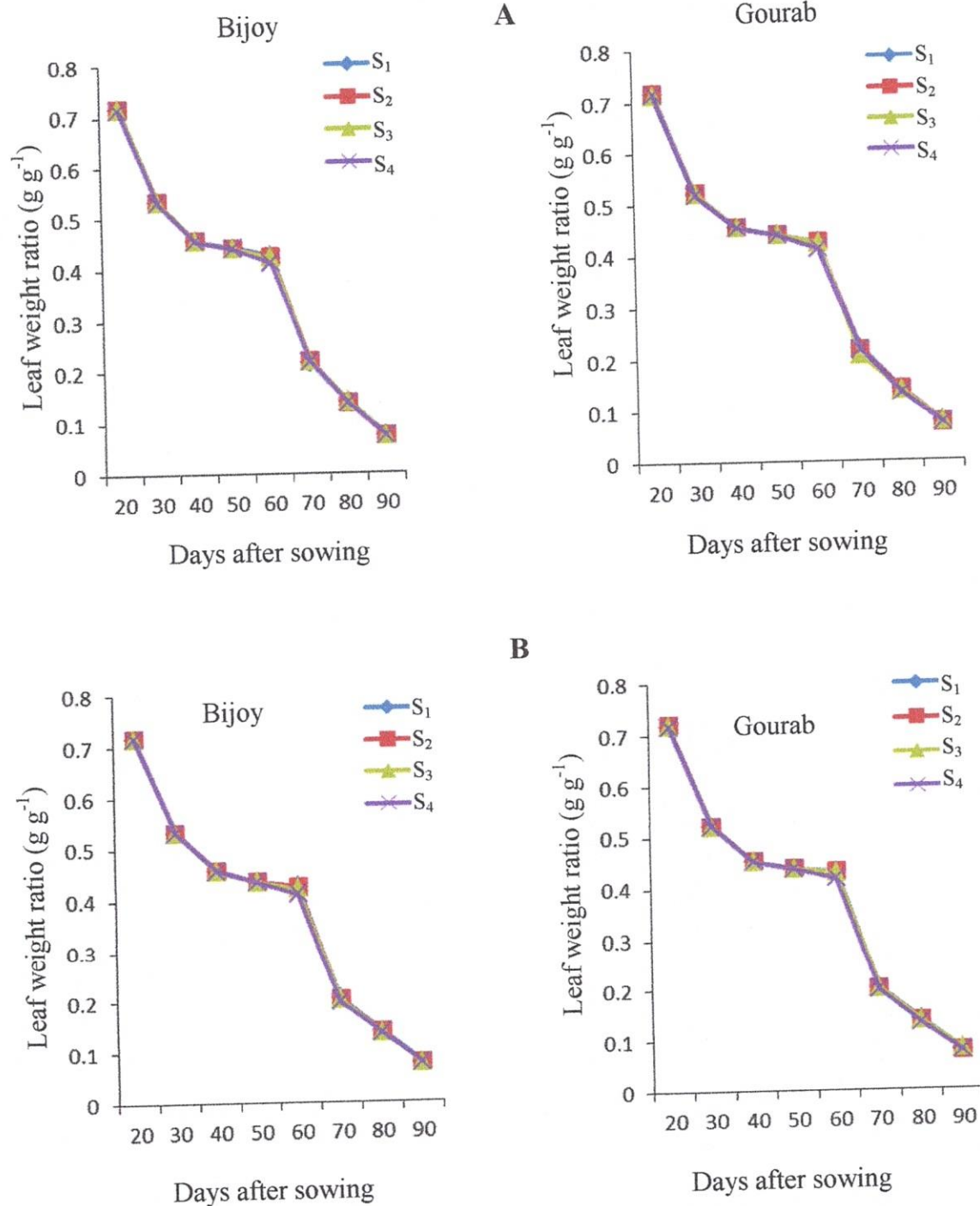


Figure 11a. Effect of sowing date on leaf weight ratio (LWR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

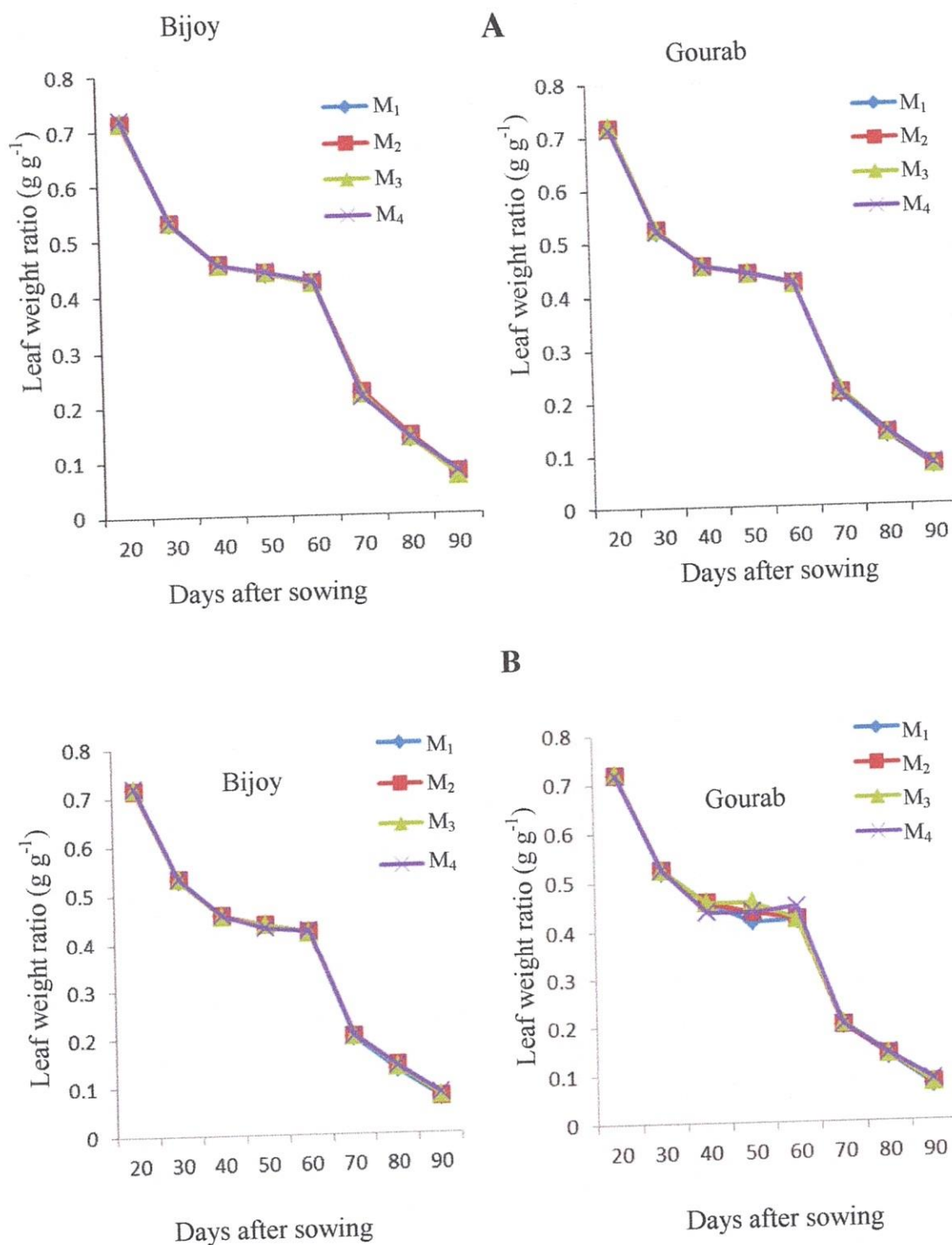


Figure 11b. Effect of mulching on leaf weight ratio (LWR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

Mulching had no significant effect on LWR at all the harvests in both the years (Appendices XIa and XIb). Tables 9a and 9b showed that with few exceptions the highest LWR was obtained from M₄ mulching in both the years (Tables 9a and 9b). Effect of mulching on LWR of two wheat varieties at different harvests are shown in Figure 11b. In all the mulching treatments of both the varieties and years, LWR showed the highest values at the beginning and gradually declined with the plant age.

Analysis of variance for LWR also showed that the effects of sowing date $\times$ variety and variety $\times$ mulching were non-significant at all the harvests in both the years (Appendices XIa and XIb).

4.3 Phenological Stages

Sowing date had significant effect on the days to crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity stages in both the years (Appendices XIIa and XIIb). Days to crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity decreased with delay in sowing. November 17 sowing (S₁) required the maximum days for crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity. It was observed that delayed sowing required comparatively lesser days to attain different phenological stages. The S₄ (1 January sowing) plants required the lowest days to attain crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity in both the years (Tables 10a and 10b).

Days to attain different phenological stages varied significantly due to variety in both the growing season (Appendices XIIa and XIIb). Variety Gourab attained its crown root initiation, tillering, booting, heading,

anthesis, grain filling and maturity stages earlier than Bijoy (Tables 10a and 10b).

Mulching had significant effect on the days to crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity stage in both the years (Appendices XIIa and XIIb). The plants grown in M_4 condition (black polythene mulching) required the highest days to attain crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity stages and M_1 (control) plants required the lowest days for attaining these stages in both the years (Tables 10a and 10b).

From the analysis of variance it was observed that sowing date $\times$ variety interaction effects were found to be significant for heading and maturity stage in both the years and variety $\times$ mulching effects were found to be significant for crown root initiation in 2008-2009 and tillering in 2009-2010 growing season. Sowing date $\times$ mulching effects were non-significant for all the phenological stages (Appendices XIIa and XIIb). The maximum days required to attain crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity stages for the crops sown in 17 November (S_1) with black polythene mulching (M_4) and the minimum days required in 1 January sowing (S_4) with control (M_1) in both the years (Tables 11a and 11b).

Table 10a: Time (days after sowing) taken for different phenological stages of wheat as influenced by sowing date, variety and mulching in 2008-2009

Treatment	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
a) Sowing Date							
S ₁	20.62a	26.73a	58.55a	65.86a	71.92a	104.90a	117.10a
S ₂	19.15b	24.35b	57.11a	61.88b	68.71b	100.37b	112.64b
S ₃	16.86c	21.35c	53.42b	57.24c	63.71c	92.87c	101.94c
S ₄	12.93d	16.78d	44.27c	50.61d	56.66d	77.82d	90.24d
LS	**	**	**	**	**	**	**
b) Variety							
V ₁	18.46a	24.18a	56.33a	62.22a	68.27a	98.24a	109.44a
V ₂	16.32b	20.43b	50.35b	55.58b	62.23b	89.74b	101.52b
LS	**	**	**	**	**	**	**
c) Mulching							
M ₁	15.18c	19.64c	50.24c	55.56c	62.40c	91.00b	102.30c
M ₂	17.41b	22.30b	53.44b	58.96b	65.27b	94.14a	105.64b
M ₃	17.98b	22.96b	54.12ab	59.65b	65.92ab	94.75a	106.32ab
M ₄	18.99a	24.32a	55.57a	61.42a	67.42a	96.07a	107.35a
LS	*	**	**	**	**	**	**
CV%	5.22	6.17	3.70	3.77	3.14	2.75	2.21

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 10b: Time (days after sowing) taken for different phenological stages of wheat as influenced by sowing date, variety and mulching in 2009-2010

Treatment	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
a) Sowing Date							
S ₁	21.03a	27.00a	59.56a	67.85a	76.18a	106.98a	119.01a
S ₂	19.89b	24.58b	57.56b	63.88b	72.53b	102.37b	114.54b
S ₃	17.15c	20.69c	54.13c	59.33c	68.12c	94.98c	103.55c
S ₄	14.99d	17.93d	45.19d	53.56d	58.93d	79.93d	91.54d
LS	**	**	**	**	**	**	**
b) Variety							
V ₁	19.33a	24.75a	57.27a	65.18a	73.04a	100.50a	111.64a
V ₂	17.20b	20.35b	50.90b	57.13b	64.84b	91.64b	102.69b
LS	**	**	**	**	**	**	**
c) Mulching							
M ₁	15.32c	19.97c	51.14c	57.87c	65.43c	92.74b	104.02c
M ₂	18.42b	22.50b	54.12b	61.20b	69.13b	96.09a	107.02b
M ₃	19.10b	23.18b	54.70ab	61.81b	69.59b	96.64a	107.72b
M ₄	20.22a	24.54a	56.39a	63.74a	71.61a	98.79a	109.89a
LS	**	**	**	**	**	**	**
CV%	5.06	5.18	4.09	3.45	3.13	3.77	2.36

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁= 17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂=Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

Table 11a: Time (days after sowing) taken for different phenological stages of wheat as influenced by interaction effect of sowing date and mulching in 2008-2009

Interactions	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
S ₁ M ₁	18.14	24.22	55.76	62.49	69.01	101.93	113.97
S ₁ M ₂	20.16	26.75	58.58	65.43	71.82	105.06	117.33
S ₁ M ₃	20.93	27.42	59.23	66.36	72.48	105.64	118.00
S ₁ M ₄	23.25	28.54	60.62	69.18	74.37	106.95	119.10
S ₂ M ₁	17.13	21.70	53.75	58.96	65.53	97.41	109.80
S ₂ M ₂	19.25	24.39	57.30	61.92	68.88	100.58	112.67
S ₂ M ₃	19.75	25.06	57.98	62.57	69.51	101.18	113.50
S ₂ M ₄	20.47	26.27	59.43	64.09	70.92	102.33	114.59
S ₃ M ₁	14.52	18.67	50.24	53.83	61.07	89.87	98.78
S ₃ M ₂	17.13	21.41	53.45	57.44	63.71	92.94	102.06
S ₃ M ₃	17.64	22.08	54.17	58.14	64.36	93.60	102.78
S ₃ M ₄	18.10	23.28	55.83	59.53	65.72	95.07	104.15
S ₄ M ₁	10.92	13.96	41.20	46.97	53.98	74.81	86.67
S ₄ M ₂	13.10	16.65	44.43	51.04	56.67	77.98	90.51
S ₄ M ₃	13.61	17.33	45.08	51.54	57.32	78.57	91.00
S ₄ M ₄	14.11	19.18	46.39	52.90	58.67	79.92	92.77
LS	NS	NS	NS	NS	NS	NS	NS
CV%	5.22	6.17	3.70	3.77	3.14	2.75	2.21

CV = Co-efficient of variation

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

LS=Level of significance

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

Table 11b: Time (days after sowing) taken for different phenological stages of wheat as influenced by interaction effect of sowing date and mulching in 2009-2010

Interactions	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
S ₁ M ₁	18.09	24.47	56.60	64.27	72.67	103.81	115.94
S ₁ M ₂	21.05	26.97	59.58	68.01	76.40	107.10	118.95
S ₁ M ₃	21.92	27.47	60.11	68.51	76.68	107.43	119.53
S ₁ M ₄	23.08	29.08	61.57	70.61	78.97	109.59	121.65
S ₂ M ₁	17.08	21.97	54.61	60.75	69.17	99.27	111.42
S ₂ M ₂	20.05	24.56	57.59	63.83	72.51	102.27	114.43
S ₂ M ₃	20.74	25.30	58.14	64.60	73.04	102.77	115.13
S ₂ M ₄	21.69	26.48	59.91	66.32	75.40	105.18	117.19
S ₃ M ₁	14.07	17.98	51.14	56.23	64.49	91.55	100.38
S ₃ M ₂	17.42	20.69	54.23	59.33	68.35	94.87	103.39
S ₃ M ₃	17.92	21.47	54.80	59.92	68.98	95.75	104.04
S ₃ M ₄	19.21	22.63	56.35	61.85	70.67	97.76	106.38
S ₄ M ₁	12.06	15.48	42.20	50.21	55.41	76.32	88.33
S ₄ M ₂	15.18	17.80	45.09	53.64	59.26	80.12	91.29
S ₄ M ₃	15.84	18.48	45.75	54.23	59.64	80.63	92.18
S ₄ M ₄	16.88	19.97	47.72	56.16	61.42	82.64	94.35
LS	NS	NS	NS	NS	NS	NS	NS
CV%	5.06	5.18	4.09	3.45	3.13	3.77	2.36

CV = Co-efficient of variation
 S₁=17 November sowing
 S₂= 2 December sowing
 S₃= 17 December sowing
 S₄= 1 January sowing

LS=Level of significance
 M₁= No mulching
 M₂= Water hyacinth mulching
 M₃= Rice straw mulching
 M₄= Black polythene mulching

4.4 Accumulated Heat Units

4.4.1 Growing Degree Days (GDD)

Growing degree days (GDD) from sowing to different phenological stages varied significantly owing to variation in sowing dates in both the growing seasons (Appendices XIIIa and XIIIb). It was observed from the tables 12a and 12b that with some exceptions, the highest heat units (GDD) were required in S_1 plants followed by S_2 , S_3 and S_4 plants at all the phenological stages in both the years. On an average, the S_1 plants required 246.15 heat units (GDD) for crown root initiation, 320.37 for tillering, 587.51 for booting, 649.94 for heading, 700.33 for anthesis, 1062.36 for grain filling and 1245.16 for maturity in the first year and in the second year the corresponding values were 224.59, 277.93, 488.28, 535.73, 598.68, 958.00 and 1151.39. In the second year S_2 plants required the highest heat units (1190.23) to attain maturity. It was also observed that the requirement of heat units for all the phenological stages decreased with delay in sowing (Tables 12a and 12b).

Heat units for all the phenological stages were significantly influenced by the variety (Appendices XIIIa and XIIIb). Requirements of higher heat units were observed in Bijoy (V_1) than Gourab (V_2) at all the phenological stages in both the growing seasons (Tables 12a and 12b).

Mulching significantly influenced the heat unit requirement of all the phenological stages in both the years (Appendices XIIIa and XIIIb). It was found that the highest heat units were required in M_4 crops and was successively followed by M_3 , M_2 and M_1 . On an average, the M_4 plants required 188.34 heat units for crown root initiation, 239.27 for tillering, 511.28 for booting, 569.34 for heading, 633.27 for anthesis, 1018.10 for grain filling and 1214.23 for maturity in the first year and in the second

Table 12a: Effect of sowing date, variety and mulching on the growing degree day (GDD) of wheat at different phenological stages in 2008-2009

Treatment	Growing degree day (GDD)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
a) Sowing Date							
S ₁	246.15a	320.37a	587.51a	649.94a	700.33a	1062.36a	1245.16a
S ₂	201.67b	249.15b	524.16b	565.43b	630.17b	1036.20a	1236.85a
S ₃	136.55c	173.63c	457.04c	495.94c	567.44c	985.34b	1140.96b
S ₄	107.69d	139.70d	391.93d	464.09d	542.33d	860.88c	1074.97c
LS	**	**	**	**	**	**	**
b) Variety							
V ₁	182.60a	238.35a	518.91a	576.19a	643.40a	1053.32a	1241.96a
V ₂	163.42b	203.08b	461.42b	511.51b	576.74b	919.07b	1107.02b
LS	**	**	**	**	**	**	**
c) Mulching							
M ₁	153.81c	195.86c	460.95c	511.12c	580.15c	940.74b	1118.94c
M ₂	172.25b	220.56b	491.05b	544.21b	609.66b	988.17a	1176.63b
M ₃	177.64b	227.16b	497.37ab	550.73b	617.20b	997.77a	1188.14ab
M ₄	188.34a	239.27a	511.28a	569.34a	633.27a	1018.10a	1214.23a
LS	**	**	**	**	**	**	**
CV%	6.01	5.68	3.74	4.05	3.29	4.08	3.26

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 12b: Effect of sowing date, variety and mulching on the growing degree day (GDD) of wheat at different phenological stages in 2009-2010

Treatment	Growing degree day (GDD)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
a) Sowing Date							
S ₁	224.59a	277.93a	488.28a	535.73a	598.68a	958.06a	1151.39ab
S ₂	184.17b	212.98b	403.68b	455.76b	542.07b	957.29a	1190.23a
S ₃	115.02c	137.28c	363.12c	419.43c	524.57b	954.21a	1134.17bc
S ₄	79.92d	93.10d	324.80d	424.20d	500.66c	853.28b	1098.56c
LS	**	**	**	**	**	**	*
b) Variety							
V ₁	157.57a	194.50a	422.40a	497.99a	591.09a	1011.33a	1238.55a
V ₂	144.28b	166.14b	367.58b	419.57b	491.90b	901.18b	1048.63b
LS	**	**	**	**	**	**	**
c) Mulching							
M ₁	131.41c	163.59c	370.16c	427.90c	501.06c	872.14b	1078.34c
M ₂	152.41b	180.23b	395.18b	458.53b	543.03b	931.12a	1140.43b
M ₃	156.50b	184.25b	399.89b	464.61b	549.19b	940.38a	1154.45b
M ₄	163.38a	193.22a	414.73a	484.09a	572.70a	979.19a	1201.13a
LS	**	**	**	**	**	**	**
CV%	4.11	4.41	4.77	4.88	4.87	7.06	4.40

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂= Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

year the corresponding values were 163.38, 193.22, 414.73, 484.09, 572.70, 979.19 and 1201.13. With some exceptions, M_2 was statistically identical with M_3 in both the years (Tables 12a and 12b).

From the analysis of variance it was observed that sowing date $\times$ variety interaction effects on the growing degree day (GDD) were significant at booting stage and maturity stage in the first year and booting stage, heading stage, anthesis stage and maturity stage in the second year. Growing degree day (GDD) from sowing to different phenological stages except crown root initiation stage were not significantly influenced by the variety $\times$ mulching interaction effects in 2008-2009 and all the stages in 2009-2010 growing season. Sowing date $\times$ mulching effects were not significant for all the phenological stages except crown root initiation stage in both the years (Appendices XIIIa and XIIIb). Early sown crops (S_1) with black polythene mulching (M_4) required the highest heat units at all of the phenological stages while delayed sowing (S_4) with no mulching (M_1) required the lowest heat units in both the years (Tables 13a and 13b).

Table 13a: Interaction effect of sowing date and mulching on the growing degree day (GDD) of wheat at different phenological stages in 2008-2009

Interactions	Growing degree day (GDD)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
S ₁ M ₁	216.48c	293.22	563.07	619.51	676.53	1019.64	1193.55
S ₁ M ₂	239.57b	321.54	587.98	647.01	698.76	1065.87	1245.18
S ₁ M ₃	250.08b	328.43	593.85	654.06	704.69	1072.72	1255.98
S ₁ M ₄	278.48a	338.28	605.14	679.19	721.35	1091.23	1285.93
S ₂ M ₁	186.04d	224.68	495.83	538.39	598.58	990.23	1188.73
S ₂ M ₂	202.12cd	249.98	525.52	564.93	631.51	1038.77	1236.73
S ₂ M ₃	206.17c	255.93	531.37	570.97	638.40	1048.87	1250.96
S ₂ M ₄	212.33c	266.01	543.93	587.42	652.18	1066.94	1271.00
S ₃ M ₁	121.14f	151.23	424.72	462.44	538.20	939.97	1083.10
S ₃ M ₂	138.50e	172.69	457.68	497.21	566.73	985.04	1144.30
S ₃ M ₃	141.56e	180.28	464.13	503.91	574.43	995.73	1155.93
S ₃ M ₄	144.98e	190.33	481.65	520.20	590.38	1020.63	1180.52
S ₄ M ₁	91.58g	114.31	360.18	424.13	507.27	813.13	1010.40
S ₄ M ₂	108.83f	138.03	393.01	467.69	541.63	863.00	1080.31
S ₄ M ₃	112.77f	143.99	400.14	473.99	551.28	873.75	1089.71
S ₄ M ₄	117.57f	162.46	414.38	490.56	569.14	893.63	1119.45
LS	**	NS	NS	NS	NS	NS	NS
CV%	6.01	5.68	3.74	4.05	3.29	4.08	3.26

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

Table 13b: Interaction effect of sowing date and mulching on the growing degree day (GDD) of wheat at different phenological stages in 2009-2010

Interactions	Growing degree day (GDD)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
S ₁ M ₁	197.34c	254.25	474.56	513.45	570.48	910.06	1098.28
S ₁ M ₂	225.74b	277.84	489.32	536.13	600.12	959.26	1150.90
S ₁ M ₃	232.78b	282.39	491.39	539.19	602.92	963.96	1159.10
S ₁ M ₄	242.48a	297.22	497.84	554.15	621.19	998.97	1197.26
S ₂ M ₁	161.90e	197.88	381.55	427.91	505.66	903.14	1124.51
S ₂ M ₂	186.60d	213.01	403.58	454.78	541.77	957.93	1186.79
S ₂ M ₃	190.95cd	216.89	407.25	462.32	547.55	964.91	1200.96
S ₂ M ₄	197.23c	224.16	422.36	478.05	573.32	1003.18	1248.66
S ₃ M ₁	98.22h	120.73	333.03	387.07	477.58	889.75	1063.73
S ₃ M ₂	116.46g	137.78	364.42	417.86	525.91	951.08	1129.83
S ₃ M ₃	119.16fg	142.10	369.60	424.82	536.27	967.37	1145.36
S ₃ M ₄	126.26f	148.53	385.72	447.98	558.53	1008.63	1197.62
S ₄ M ₁	68.18j	81.50	291.48	383.17	450.53	785.62	1026.83
S ₄ M ₂	80.83i	92.29	323.41	425.33	504.31	856.23	1094.03
S ₄ M ₃	83.10i	95.61	331.31	432.12	510.03	865.29	1112.39
S ₄ M ₄	87.56i	102.98	353.02	456.17	537.78	905.97	1161.00
LS	**	NS	NS	NS	NS	NS	NS
CV%	4.11	4.41	4.77	4.88	4.87	7.06	4.40

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

4.4.2 Helio-thermal Unit (HTU)

The helio-thermal unit (HTU) from sowing to different phenological stages was significantly influenced by sowing dates in both the growing seasons (Appendices XIVa and XIVb). The S_1 plants had the highest HTU at all the phenological stages and S_3 plants had the lowest HTU at most of the phenological stages in the first year. In the second year, the S_1 plants had the highest HTU at all the phenological stages except at grain filling and maturity stage. In the second year, at heading stage the highest HTU was recorded in both S_1 and S_4 plants, at anthesis stage S_1 , S_3 and S_4 plants and at grain filling stage in S_3 plants and at maturity stage in S_4 plants (Tables 14a and 14b). On an average, the S_1 plants required 2000.67 HTU for crown root initiation, 2425.76 for tillering, 3433.42 for booting, 3758.50 for heading, 3996.01 for anthesis, 7066.95 for grain filling and 8466.76 for maturity in the first year and in the second year the corresponding values were 1370.84, 1621.39, 2745.72, 3010.48, 3529.26, 6300.77 and 7824.96.

The helio-thermal unit (HTU) from sowing to different phenological stages was significantly influenced by the variety in both the growing seasons (Appendices XIVa and XIVb). Higher HTU was observed in Bijoy (V_1) at all the phenological stages than Gourab (V_2) in both the years (Tables 14a and 14b).

Mulching had significant effect on helio-thermal units (HTU) from sowing to different phenological stages in both the growing seasons (Appendices XIVa and XIVb). The M_4 plants had the highest HTU at all the phenological stages in both the years. The M_4 plants required 1096.56 HTU for crown root initiation, 1345.61 for tillering, 2920.75 for booting, 3354.67 for heading, 3864.14 for anthesis, 6948.46 for grain filling and 8397.83 for maturity in the first year and in the second year the corresponding values were 904.45, 1068.81, 2478.17, 2997.60, 3691.90, 6866.23 and 8528.31. The lowest HTU was observed at M_1 plants in both the years (Tables 14a and 14b).

Table 14a: Effect of sowing date, variety and mulching on the helio-thermal unit (HTU) of wheat at different phenological stages in 2008-2009

Treatment	Helio-thermal unit (HTU)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
a) Sowing Date							
S ₁	2000.67a	2425.76a	3433.42a	3758.50a	3996.01a	7066.95a	8466.76a
S ₂	895.53b	1064.62b	2613.01b	2910.61c	3448.66c	6759.40b	8208.67b
S ₃	558.64c	750.81c	2483.12c	2797.69c	3419.14c	6664.03b	7798.94c
S ₄	583.79c	785.13c	2540.25bc	3177.82b	3849.16b	6333.62c	7939.54c
LS	**	**	**	**	**	**	**
b) Variety							
V ₁	1060.56a	1344.22a	2982.97a	3409.00a	3949.21a	7209.84a	8602.81a
V ₂	958.75b	1168.94b	2551.93b	2913.31b	3407.27b	6202.16b	7604.14b
LS	**	**	**	**	**	**	**
c) Mulching							
M ₁	906.93c	1132.71c	2555.56c	2910.43c	3444.83c	6358.26b	7693.44c
M ₂	1001.04b	1255.81b	2774.50b	316.66b	3671.75b	6719.97a	8118.18b
M ₃	1034.10b	1292.18b	2818.98ab	3212.85b	3732.26b	6797.31a	8204.47ab
M ₄	1096.56a	1345.61a	2920.75a	3354.67a	3864.14a	6948.46a	8397.83a
LS	**	**	**	**	**	**	**
CV%	6.59	5.41	5.12	5.45	4.48	4.53	3.52

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 14b: Effect of sowing date, variety and mulching on the helio-thermal unit (HTU) of wheat at different phenological stages in 2009-2010

Treatment	Helio-thermal unit (HTU)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
a) Sowing Date							
S ₁	1370.84a	1621.39a	2745.72a	3010.48a	3529.26a	6300.77b	7824.96
S ₂	952.05c	1123.74b	2205.40b	2614.72b	3245.91b	6459.71b	8185.96
S ₃	644.09	791.59c	2254.55b	2665.92b	3465.85a	6845.72a	8165.18
S ₄	412.96	452.99d	2154.85b	2937.22a	3555.83a	6386.23b	8221.56
LS	**	**	**	**	**	*	*
b) Variety							
V ₁	873.75a	1076.43a	2521.70a	3108.73a	3837.46a	7122.38a	8784.35a
V ₂	816.22b	918.42b	2158.56b	2505.43b	3060.96b	5873.83b	7414.49b
LS	**	**	**	**	**	**	**
c) Mulching							
M ₁	751.41c	909.64c	2168.22c	2579.02c	3131.88c	6048.94c	7614.74c
M ₂	853.04b	994.45b	2341.11b	2801.50b	3463.52b	6502.69b	8074.33b
M ₃	871.03b	1016.80b	2373.02ab	2850.22b	3509.55b	6574.56b	8180.28b
M ₄	904.45a	1068.81a	2478.17a	2997.60a	3691.90a	6866.23a	8528.31a
LS	**	**	**	**	**	**	**
CV%	3.87	5.00	5.89	6.19	6.02	7.66	4.62

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂=Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

Table 15a: Interaction effect of sowing date and mulching on the helio-thermal unit (HTU) of wheat at different phenological stages in 2008-2009

Interactions	Helio-thermal unit (HTU)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
S ₁ M ₁	1778.42c	2318.05	3297.96	3605.66	3874.20	6712.57	8091.42
S ₁ M ₂	1959.86b	2442.64	3439.74	3742.24	3971.16	7085.40	8474.60
S ₁ M ₃	2043.80b	2473.07	3466.70	3769.03	4010.05	7155.24	8544.16
S ₁ M ₄	2220.59a	2469.29	3529.29	3917.05	4128.63	7314.61	8756.87
S ₂ M ₁	904.85d	963.23	2441.85	2705.76	3185.36	6417.86	7862.31
S ₂ M ₂	887.05d	1053.55	2618.98	2906.27	3457.20	6776.64	8206.00
S ₂ M ₃	882.93d	1087.90	2654.57	2948.46	3516.83	6863.10	8307.81
S ₂ M ₄	907.30d	1153.81	2736.63	3081.94	3635.27	6980.00	8458.56
S ₃ M ₁	440.68g	621.45	2219.30	2511.22	3170.16	6328.91	7374.08
S ₃ M ₂	573.99ef	752.89	2488.27	2804.35	3413.23	6666.38	7820.27
S ₃ M ₃	601.61ef	796.01	2541.91	2864.91	3477.46	6738.05	7908.48
S ₃ M ₄	618.27e	832.88	2683.01	3010.30	3615.70	6922.77	8092.94
S ₄ M ₁	503.76fg	628.13	2263.11	2819.09	3549.59	5973.72	7445.94
S ₄ M ₂	583.26ef	774.15	2551.06	3213.80	3845.40	6351.46	7971.85
S ₄ M ₃	608.06e	811.76	2612.75	3269.02	3924.69	6432.86	8057.43
S ₄ M ₄	640.07e	926.48	2734.09	3409.39	4076.96	6576.45	8282.93
LS	**	NS	NS	NS	NS	NS	NS
CV%	6.59	5.41	5.12	5.45	4.48	4.53	3.52

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

LS=Level of significance

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

Table 15b: Interaction effect of sowing date and mulching on the helio-thermal unit (HTU) of wheat at different phenological stages in 2009-2010

Interactions	Helio-thermal unit (HTU)						
	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
S ₁ M ₁	1257.53c	1504.06	2708.78	2866.01	3292.29	5923.38	7414.42
S ₁ M ₂	1375.73b	1609.50	2752.66	2998.93	3547.55	6309.24	7815.67
S ₁ M ₃	1403.66ab	1639.90	2753.73	3026.62	3569.91	6346.90	7884.64
S ₁ M ₄	1446.42a	1732.10	2767.72	3150.35	3707.31	6623.57	8185.12
S ₂ M ₁	801.10f	1037.96	2018.49	2407.77	2984.07	6041.50	7710.28
S ₂ M ₂	965.02e	1125.99	2205.73	2609.46	3247.94	6461.50	8169.15
S ₂ M ₃	1000.54de	1146.30	2236.26	2669.29	3283.53	6524.38	8262.54
S ₂ M ₄	1041.53d	1184.70	2361.12	2772.33	3468.09	6811.45	8601.87
S ₃ M ₁	552.30i	684.52	2034.49	2438.69	3100.46	6355.04	7649.38
S ₃ M ₂	650.87h	797.18	2268.09	2651.60	3474.84	6828.50	8131.53
S ₃ M ₃	665.93gh	822.09	2302.87	2703.42	3554.50	6948.16	8250.17
S ₃ M ₄	707.25g	862.56	2412.76	2869.98	3733.59	7251.18	8629.65
S ₄ M ₁	394.70j	412.04	1911.14	2603.59	3150.70	5875.85	7684.87
S ₄ M ₂	420.54j	445.14	2137.96	2946.01	3583.76	6411.53	8180.98
S ₄ M ₃	413.98j	458.91	2199.22	3001.55	3630.25	6478.81	8323.78
S ₄ M ₄	422.62j	495.87	2371.09	3197.72	3858.60	6778.74	8696.61
LS	**	NS	NS	NS	NS	NS	NS
CV%	3.87	5.00	5.89	6.19	6.02	7.66	4.62

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

LS=Level of significance

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourb

From the analysis of variance it was revealed that sowing date $\times$ variety interaction effects on the HTU was significant at all the phenological stages except tillering and grain filling stage. Variety $\times$ mulching interaction effects on the HTU was non-significant at all the phenological stages and sowing date $\times$ mulching interaction effects on the HTU was non-significant at all the phenological stages except crown root initiation stage in both the years (Appendices XIVa and XIVb). Numerically early sown crops (S_1) with black polythene mulching (M_4) had the highest HTU at most of the phenological stages while delayed sowing (S_3) with no mulching (M_1) had the lowest HTU in both the years (Tables 15a and 15b).

4.4.3 Pheno-thermal Index (PTI)

Pheno-thermal index from sowing to different phenological stages varied significantly owing to variation in sowing dates in both the growing seasons (Appendices XVa and XVb). It was observed from the tables that, the S_1 plants had the highest PTI at all the phenological stages except anthesis to grain filling and grain filling to maturity stage in 2008-2009 and heading to anthesis, anthesis to grain filling and grain filling to maturity stage in 2009-2010. In 2008-2009, the S_4 plants had the highest PTI at anthesis to grain filling and grain filling to maturity stage and in 2009-2010, the S_4 plants had the highest PTI at heading to anthesis, anthesis to grain filling and grain filling to maturity stage (Tables 16a and 16b).

Pheno-thermal index for all the phenological stages in both the years were significantly influenced by the variety except crown root initiation to tillering stage in 2008-2009 growing season (Appendices XVa and XVb). With some exceptions, variety Bijoy had higher PTI than Gourab (Tables 16a and 16b).

Table 16a: Effect of sowing date, variety and mulching on the pheno-thermal index (PTI) and heat use efficiency (HUE) of wheat at different phenological stages in 2008-2009

Treatment	Pheno-thermal index (PTI)							Heat use efficiency (HUE)
	Sowing to crown root initiation stage	Crown root initiation to tillering stage	Tillering to booting stage	Booting to heading stage	Heading to anthesis stage	Anthesis to grain filling stage	Grain filling to maturity stage	
a) Sowing Date								
S ₁	11.93a	12.00a	10.04a	9.88a	9.74a	10.13d	10.64d	3.69a
S ₂	10.55b	10.25b	9.18b	9.14b	9.17c	10.31c	10.97c	3.42b
S ₃	8.12c	8.12c	8.55c	8.65c	8.90d	10.59b	11.17b	3.09c
S ₄	8.33d	8.31d	8.84d	9.16b	9.55b	11.03a	11.89a	1.82d
LS	**	**	**	**	**	**	**	**
b) Variety								
V ₁	9.67a	9.67	9.19a	9.25a	9.43a	10.76a	11.40a	2.24a
V ₂	9.79b	9.67	9.12b	9.17b	9.25b	10.27b	10.94b	2.77b
LS	**	NS	**	**	**	**	**	**
c) Mulching								
M ₁	9.89a	9.69	9.13	9.16	9.28c	10.35b	10.98c	2.50c
M ₂	9.70b	9.66	9.15	9.20	9.33b	10.52a	11.17b	3.08b
M ₃	9.68b	9.67	9.16	9.21	9.36ab	10.55a	11.21ab	3.16ab
M ₄	9.67b	9.66	9.17	9.25	9.39a	10.62a	11.31a	3.28a
LS	**	NS	NS	NS	**	**	**	**
CV%	1.50	1.39	0.72	1.31	0.69	1.37	1.34	8.28
Values with same letter are not significantly different at 5% level by DMRT								

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 16b: Effect of sowing date, variety and mulching on the pheno-thermal index (PTI) and heat use efficiency (HUE) of wheat at different phenological stages in 2009-2010

phenological stages in 2009-2010								Heat use efficiency (HUE)
Treatment	Pheno-thermal index (PTI)							
	Sowing to crown root initiation stage	Crown root initiation to tillering stage	Tillering to booting stage	Booting to heading stage	Heading to anthesis stage	Anthesis to grain filling stage	Grain filling to maturity stage	
a) Sowing Date								
S ₁	10.70a	10.31a	8.23a	7.90a	7.86b	8.94d	9.66d	4.15a
S ₂	9.28b	8.72b	7.01bc	7.12b	7.46b	9.33c	10.37c	3.67b
S ₃	6.73c	6.65c	6.69c	7.03b	7.67b	10.01b	10.92b	3.27c
S ₄	5.36d	5.20d	7.15b	7.90a	8.45a	10.62a	11.96a	1.87d
LS	**	**	**	**	**	**	**	**
b) Variety								
V ₁	7.92a	7.60a	7.37a	7.65a	8.12a	10.13a	11.17a	3.42a
V ₂	8.11b	7.85b	7.17b	7.33b	7.60b	9.32b	10.28b	3.06b
LS	**	**	**	**	**	**	**	**
c) Mulching								
M ₁	8.26a	7.88a	7.19a	7.38c	7.65a	9.44b	10.42c	2.71c
M ₂	8.02b	7.72b	7.27a	7.48b	7.86a	9.73a	10.72b	3.32b
M ₃	7.94bc	7.68bc	7.28a	7.51ab	7.90a	9.77a	10.78b	3.46a
M ₄	7.85c	7.61c	7.34a	7.59a	8.01a	9.96a	10.99a	3.47a
LS	**	**	**	**	**	**	**	**
CV%	1.52	1.79	1.84	1.76	2.08	3.19	2.04	7.71
Values with different letters are not significantly different at 5% level by DMRT								

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

Mulching had significant effect on PTI at sowing to crown root initiation, heading to anthesis, anthesis to grain filling and grain filling to maturity stage in 2008-2009 and at all the phenological stages in 2009-2010 growing season (Appendices XVa and XVb). With some exceptions the highest PTI was observed in M_4 and the lowest was observed in control (M_1) at all the phenological stages in both the years (Tables 16a and 16b).

Analysis of variance revealed that sowing date $\times$ variety interaction effects on PTI was significant at all the phenological stages in 2008-2009 and at all the phenological stages except sowing to crown root initiation stage in 2009-2010 growing season. Variety $\times$ mulching interaction effects on PTI was non-significant at all the phenological stages except sowing to crown root initiation stage in 2008-2009 and crown root initiation to tillering in 2009-2010 growing season. Sowing date $\times$ mulching effects on PTI were significant at sowing to crown root initiation, crown root initiation to tillering, tillering to booting and heading to anthesis stage in 2008-2009 and at crown root initiation to tillering, tillering to booting, booting to heading and heading to anthesis stage in 2009-2010 (Appendices XVa and XVb).

4.4.4 Heat Use Efficiency (HUE)

Heat use efficiency was significantly influenced by sowing date in both the years (Appendices XVa and XVb). The S_1 plants used heat more efficiently than the other sowings and the lowest HUE was observed in S_4 plants in both the years (Tables 16a and 16b).

Table 17a: Interaction effect of sowing date and mulching on the pheno-thermal index (PTI) and heat use efficiency (HUE) of wheat at different phenological stages in 2008-2009

Interactions	Pheno-thermal index (PTI)							Heat use efficiency (HUE)
	Sowing to crown root initiation stage	Crown root initiation to tillering stage	Tillering to booting stage	Booting to heading stage	Heading to anthesis stage	Anthesis to grain filling stage	Grain filling to maturity stage	
S ₁ M ₁	11.94a	12.11a	10.10a	9.92	9.81a	9.99	10.53	3.05
S ₁ M ₂	11.88a	12.04ab	10.04ab	9.90	9.73ab	10.14	10.61	3.74
S ₁ M ₃	11.95a	12.00ab	10.03ab	9.86	9.72ab	10.15	10.64	3.91
S ₁ M ₄	11.97a	11.87b	9.99b	9.83	9.70b	10.20	10.80	4.04
S ₂ M ₁	10.88b	10.37c	9.23c	9.13	9.13f	10.16	10.82	2.85
S ₂ M ₂	10.51c	10.26cd	9.17c	9.13	9.16f	10.32	10.97	3.50
S ₂ M ₃	10.44c	10.23cd	9.17c	9.13	9.18f	10.36	11.02	3.57
S ₂ M ₄	10.38c	10.15d	9.16c	9.17	9.19f	10.42	11.08	3.75
S ₃ M ₁	8.35d	8.10fg	8.45g	8.58	8.81h	10.44	10.95	2.56
S ₃ M ₂	8.10ef	8.05g	8.56f	8.65	8.89gh	10.58	11.20	3.19
S ₃ M ₃	8.03f	8.16fg	8.56f	8.66	8.92g	10.62	11.23	3.25
S ₃ M ₄	8.00f	8.16fg	8.62f	8.73	8.98g	10.72	11.32	3.36
S ₄ M ₁	8.39d	8.18fg	8.74e	9.02	9.38e	10.84	11.64	1.53
S ₄ M ₂	8.31de	8.28ef	8.83d	9.15	9.54d	11.04	11.92	1.87
S ₄ M ₃	8.29de	8.30ef	8.86d	9.19	9.60cd	11.09	11.95	1.92
S ₄ M ₄	8.33d	8.47e	8.93d	9.26	9.69bc	11.16	12.05	1.96
LS	**	**	**	NS	**	NS	NS	NS
CV%	1.50	1.39	0.72	1.31	0.69	1.37	1.34	8.28

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

Table 17b: Interaction effect of sowing date and mulching on the pheno-thermal index (PTI) and heat use efficiency (HUE) of wheat at different phenological stages in 2009-2010

Interactions	Pheno-thermal index (PTI)							Heat use efficiency (HUE)
	Sowing to crown root initiation stage	Crown root initiation to tillering stage	Tillering to booting stage	Booting to heading stage	Heading to anthesis stage	Anthesis to grain filling stage	Grain filling to maturity stage	
S ₁ M ₁	10.91	10.42a	8.40a	8.00ab	7.85bcd	8.75	9.46	3.44
S ₁ M ₂	10.73	10.31ab	8.23a	7.89b	7.86bcd	8.94	9.67	4.24
S ₁ M ₃	10.63	10.29ab	8.19a	7.87b	7.86bcd	8.96	9.69	4.44
S ₁ M ₄	10.52	10.22b	8.10a	7.85b	7.87bcd	9.10	9.83	4.49
S ₂ M ₁	9.47	9.07c	6.99bcd	7.04de	7.30d	9.08	10.07	3.08
S ₂ M ₂	9.32	8.72d	7.00bcd	7.12d	7.46d	9.34	10.35	3.76
S ₂ M ₃	9.22	8.62de	7.00bcd	7.15d	7.48d	9.37	10.41	3.91
S ₂ M ₄	9.10	8.49e	7.05bcd	7.20d	7.59d	9.52	10.64	3.94
S ₃ M ₁	6.99	6.74f	6.49d	6.85e	7.38d	9.68	10.57	2.76
S ₃ M ₂	6.70	6.66fg	6.70cd	7.01de	7.67cd	10.00	10.90	3.36
S ₃ M ₃	6.66	6.62fg	6.73bcd	7.06d	7.75bcd	10.07	10.98	3.48
S ₃ M ₄	6.58	6.57g	6.83bcd	7.21d	7.87bcd	10.29	11.23	3.48
S ₄ M ₁	5.66	5.29h	6.87bcd	7.62c	8.09abcd	10.23	11.59	1.58
S ₄ M ₂	5.33	5.19h	7.14bcd	7.92ab	8.47abc	10.63	11.95	1.92
S ₄ M ₃	5.26	5.18h	7.22bc	7.95ab	8.508ab	10.69	12.03	1.98
S ₄ M ₄	5.20	5.15h	7.38b	8.11a	8.718a	10.91	12.27	1.99
LS	NS	*	**	**	**	NS	NS	NS
CV%	1.52	1.79	1.84	1.76	2.08	3.19	2.04	7.71

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

Heat use efficiency varied significantly due to variety in both the years (Appendices XVa and XVb). Significantly higher HUE was observed in variety Bijoy than Gourab (Tables 16a and 16b).

HUE was significantly influenced by mulching in both the years (Appendices XVa and XVb). The M_4 plants had the highest HUE and the lowest HUE was observed in M_1 plants (Tables 16a and 16b).

From the analysis of variance it was revealed that sowing date $\times$ variety effects on HUE was significant in both the years. Variety $\times$ mulching and sowing date $\times$ mulching effects on HUE were non-significant in both the years (Appendices XVa and XVb). The S_1 sowing with M_4 mulching showed higher HUE. The lowest HUE was observed in $S_4 \times M_1$ (Tables 17a and 17b).

4.5 Water Relation

4.5.1 Moisture Retention Capacity (MRC)

Moisture retention capacity (MRC) of flag leaves at different times of the day was significantly influenced by sowing dates in both the years (Appendices XVIa and XVIb). At every occasion, the highest MRC was observed in S_1 plants which were at par with S_2 and the lowest was observed in S_4 plants in both the years (Tables 18a and 18b). Effect of sowing date on MRC of two wheat varieties at different times of the day are shown in Figures 12a and 12b. In all the sowing dates of both the varieties and years, higher MRC values were found at the initial stages or early hours of the day and MRC decreased gradually at the later part of the day (Figures 12a and 12b).

Table 18a: Effect of sowing date, variety and mulching on moisture retention capacity (%) of flag leaf of wheat in 2008-2009

Treatments	Time of the Day									
	8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm
a) Sowing date										
S ₁	78.72a	78.12a	75.94a	75.75a	72.75a	71.26a	69.46a	66.35a	63.77a	61.93a
S ₂	76.90a	76.20a	73.90a	73.82a	70.81a	69.35a	67.52a	64.47a	62.41ab	60.59ab
S ₃	72.19b	71.28b	69.12b	69.08b	66.21b	64.64b	62.70b	60.31b	59.07bc	57.08bc
S ₄	69.95b	69.67b	67.98b	67.54b	64.68b	63.05b	61.28b	58.84b	57.42c	55.67c
LS	**	**	**	**	**	**	**	**	**	**
b) Variety										
V ₁	76.45	76.07a	74.16a	73.64a	70.99a	69.72a	68.13a	65.52a	63.52a	61.87a
V ₂	72.42	71.56b	69.31b	69.46b	66.23b	64.43b	62.37b	59.46b	57.81b	55.76b
LS	NS	**	**	**	**	**	**	**	**	**
c) Mulching										
M ₁	70.19b	69.45b	67.45b	67.07b	63.85b	61.74b	59.59b	56.52b	54.70b	52.63b
M ₂	75.01a	74.49a	72.19a	71.97a	69.16a	67.90a	66.16a	63.44a	61.39a	59.58a
M ₃	75.76a	75.13a	73.07a	72.90a	70.07a	68.65a	66.88a	64.27a	62.57a	60.72a
M ₄	76.80a	76.19a	74.22a	74.26a	71.37a	70.01a	68.33a	65.74a	64.01a	62.33a
LS	**	**	**	**	**	**	**	**	**	**
CV%	6.23	7.85	5.31	7.28	6.77	5.07	6.45	6.71	7.43	8.02

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁= 17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

Table 18b: Effect of sowing date, variety and mulching on moisture retention capacity (%) of flag leaf of wheat in 2009-2010

Treatments	Time of the Day									
	8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm
a) Sowing date										
S ₁	83.38a	80.83a	79.96a	79.37a	77.40a	75.55a	74.73a	73.29a	71.23a	68.68a
S ₂	81.83a	79.20a	78.26a	79.86ab	75.87a	73.87ab	73.00a	71.73ab	70.08a	67.67ab
S ₃	77.84b	75.07b	74.18b	73.97bc	72.07b	70.09bc	69.12b	68.30ab	67.26ab	64.76bc
S ₄	76.16b	74.04b	73.15b	72.38c	70.55b	68.72c	67.79b	66.67b	65.44b	63.80c
LS	**	**	**	**	**	**	**	*	**	**
b) Variety										
V ₁	81.42a	79.08a	78.41a	77.61a	75.93a	74.25a	73.53a	72.49a	70.90a	68.70a
V ₂	78.19b	75.49b	74.36b	74.18b	72.02b	69.87b	68.79b	67.51b	66.11b	63.58b
LS	**	**	**	**	**	**	**	**	**	**
c) Mulching										
M ₁	76.55b	73.83b	72.81b	72.23b	70.05b	67.68b	66.57b	65.12b	63.53b	61.25b
M ₂	80.19a	77.79a	76.75a	76.26ab	74.44a	72.70a	71.94a	70.76a	69.09a	66.84a
M ₃	80.82a	78.31a	77.52a	77.02a	75.19a	73.31a	72.52a	71.44a	70.09a	67.78a
M ₄	81.65a	79.21a	78.47a	78.07a	76.20a	74.54a	73.61a	72.66a	71.30a	69.05a
LS	**	**	**	**	**	**	**	**	**	**
CV%	4.50	6.57	4.97	7.56	6.51	8.61	5.43	9.38	7.79	5.87

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation LS=Level of significance

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourab

Table 19a: Interaction effect of sowing date and mulching on moisture retention capacity (%) of flag leaf of wheat in 2008-2009

Interactions	Time of the day									
	8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm
S ₁ M ₁	75.34	74.39	72.08	71.64	68.36	66.56	64.22	60.89	58.22	56.15
S ₁ M ₂	79.17	78.71	76.38	76.11	73.22	72.00	70.29	67.25	64.46	62.57
S ₁ M ₃	79.78	79.24	77.15	76.91	74.01	72.65	70.92	67.98	65.53	63.62
S ₁ M ₄	80.59	80.13	78.12	78.34	75.40	73.84	72.42	69.30	66.86	65.36
S ₂ M ₁	73.23	72.16	69.72	69.50	66.20	64.33	62.00	58.69	56.65	54.71
S ₂ M ₂	77.39	76.83	74.40	74.30	71.41	70.13	68.44	65.41	63.13	61.35
S ₂ M ₃	78.06	77.41	75.22	75.15	72.25	70.83	69.11	66.19	64.25	62.43
S ₂ M ₄	78.93	78.38	76.27	76.33	73.38	72.09	70.52	67.58	65.62	63.89
S ₃ M ₁	68.67	67.39	65.17	64.92	61.78	59.79	57.36	54.72	53.41	51.25
S ₃ M ₂	72.46	71.71	69.36	69.33	66.59	65.22	63.49	61.06	59.63	57.70
S ₃ M ₃	73.28	72.41	70.34	70.34	67.58	66.03	64.26	61.93	60.86	58.89
S ₃ M ₄	74.35	73.59	71.60	71.73	68.90	67.50	65.70	63.50	62.37	60.49
S ₄ M ₁	63.52	63.85	62.84	62.23	59.08	56.29	54.76	51.78	50.51	48.43
S ₄ M ₂	71.04	70.72	68.59	68.13	65.41	64.24	62.43	60.06	58.35	56.72
S ₄ M ₃	71.90	71.45	69.59	69.18	66.43	65.08	63.22	60.96	59.63	57.94
S ₄ M ₄	73.33	72.67	70.89	70.63	67.80	66.59	64.70	62.57	61.28	59.58
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	6.23	7.85	5.31	7.28	6.77	5.07	6.45	6.71	7.43	8.02

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowingM₁= No mulchingS₂= 2 December sowingM₂= Water hyacinth mulchingS₃= 17 December sowingM₃= Rice straw mulchingS₄= 1 January sowingM₄= Black polythene mulching

Table 19b: Interaction effect of sowing date and mulching on moisture retention capacity (%) of flag leaf of wheat in 2009-2010

Interactions	Time of the day										
	8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm	
S ₁ M ₁	80.51	77.79	76.77	76.07	73.84	71.59	70.54	68.78	66.55	63.95	
S ₁ M ₂	83.76	81.31	80.34	79.74	77.86	76.03	75.47	74.03	71.81	69.28	
S ₁ M ₃	84.28	81.74	80.97	80.39	78.51	76.56	75.98	74.63	72.72	70.15	
S ₁ M ₄	84.97	82.50	81.77	81.28	79.38	78.03	76.93	75.72	73.83	71.33	
S ₂ M ₁	78.71	75.89	74.80	74.32	72.07	69.77	68.52	66.96	65.22	62.79	
S ₂ M ₂	82.25	79.72	78.68	78.25	76.36	74.51	73.79	72.51	70.69	68.29	
S ₂ M ₃	82.81	80.19	79.35	78.95	77.06	75.08	74.34	73.15	71.63	69.19	
S ₂ M ₄	83.57	81.01	80.23	79.91	77.99	76.11	75.36	74.30	72.79	70.41	
S ₃ M ₁	74.85	71.89	70.83	70.57	68.42	66.15	64.80	63.69	62.50	59.91	
S ₃ M ₂	78.08	75.41	74.14	74.18	72.38	70.57	69.75	68.92	67.74	65.27	
S ₃ M ₃	78.76	75.99	75.25	75.00	73.20	71.23	70.38	69.64	68.77	66.26	
S ₃ M ₄	79.67	76.99	76.30	76.15	74.29	72.43	71.55	70.94	70.05	67.59	
S ₄ M ₁	72.12	69.76	68.86	67.98	65.89	63.19	62.43	61.07	59.84	58.32	
S ₄ M ₂	76.69	74.72	73.66	72.87	71.15	69.70	68.73	67.59	66.13	64.50	
S ₄ M ₃	77.43	75.32	74.50	73.74	72.01	70.38	69.38	68.34	67.22	65.51	
S ₄ M ₄	78.40	76.35	75.58	74.94	73.15	71.61	70.60	69.69	68.55	66.87	
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
CV%	4.50	6.57	4.97	7.56	6.51	8.61	5.43	9.38	7.79	5.87	

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowingM₁= No mulchingS₂= 2 December sowingM₂= Water hyacinth mulchingS₃= 17 December sowingM₃= Rice straw mulchingS₄= 1 January sowingM₄= Black polythene mulching

Moisture retention capacity (MRC) of flag leaves at different times of the day except 8.30 am varied significantly due to variety in both the years (Appendices XVIa and XVIb). Variety Bijoy had higher MRC than variety Gourab at each time of the day in both the years (Tables 18a and 18b).

Mulching had significant effect on MRC of flag leaves at different times of the day in both the years (Appendices XVIa and XVIb). The highest MRC was observed in M_4 crops and the lowest was observed in the control (M_1) at each time of the day in both the years (Tables 18a and 18b). M_4 is statistically identical with M_3 and M_2 in both the years. Effect of mulching on MRC of two wheat varieties at different times of the day of both the years are shown in Figures 13a and 13b. In all the mulching treatments of both the varieties and years, higher MRC values were also found at the initial stages or early hours of the day and MRC decreased gradually at the later part of the day (Figures 13a and 13b).

The mean squares from the analysis of variance revealed that sowing date $\times$ variety, variety $\times$ mulching and sowing date $\times$ mulching effects were non-significant for MRC at different times of the day in both the years (Appendices XVIa and XVIb). Early sown crops (S_1) with black polythene mulching (M_4) showed the highest MRC values at each time of the day in both the years while delayed sowing with no mulch (M_1) showed the lowest values (Tables 19a and 19b).

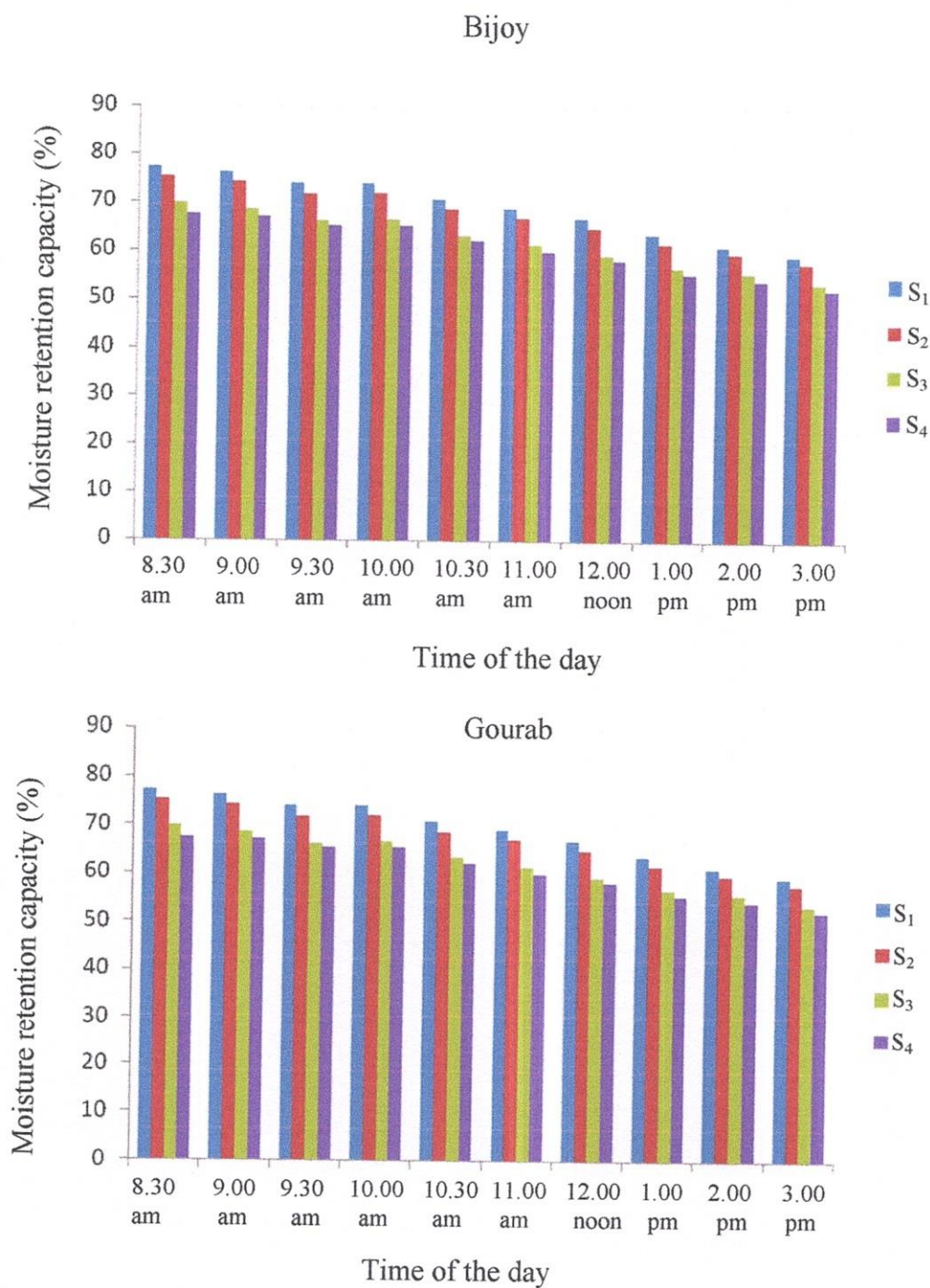


Figure 12a: Moisture retention capacity (MRC) of the flag leaf of two wheat varieties at the different times of the day as affected by different sowing dates (2008-2009)

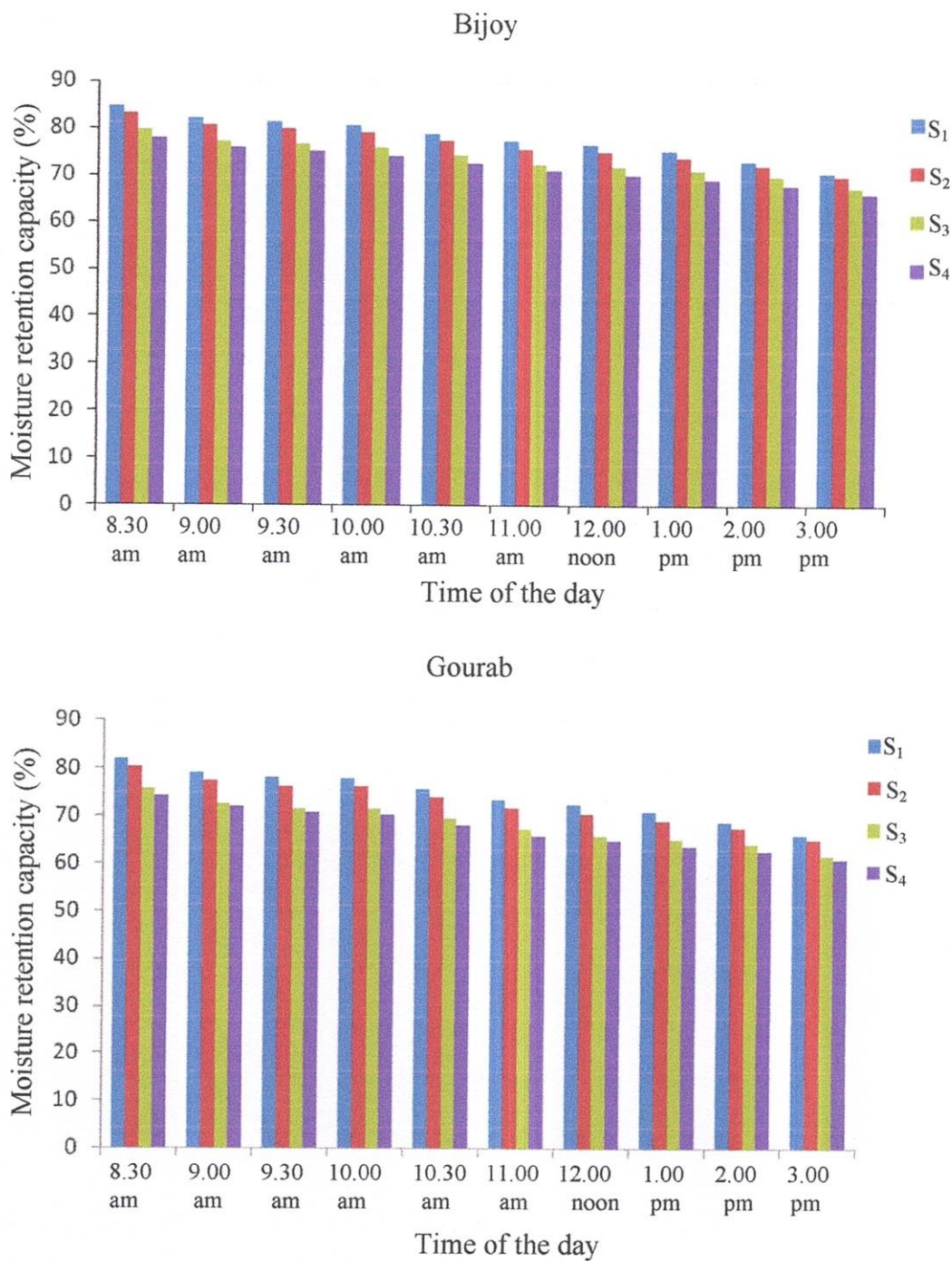


Figure 12b: Moisture retention capacity (MRC) of the flag leaf of two wheat varieties at the different times of the day as affected by different sowing dates (2009-2010)

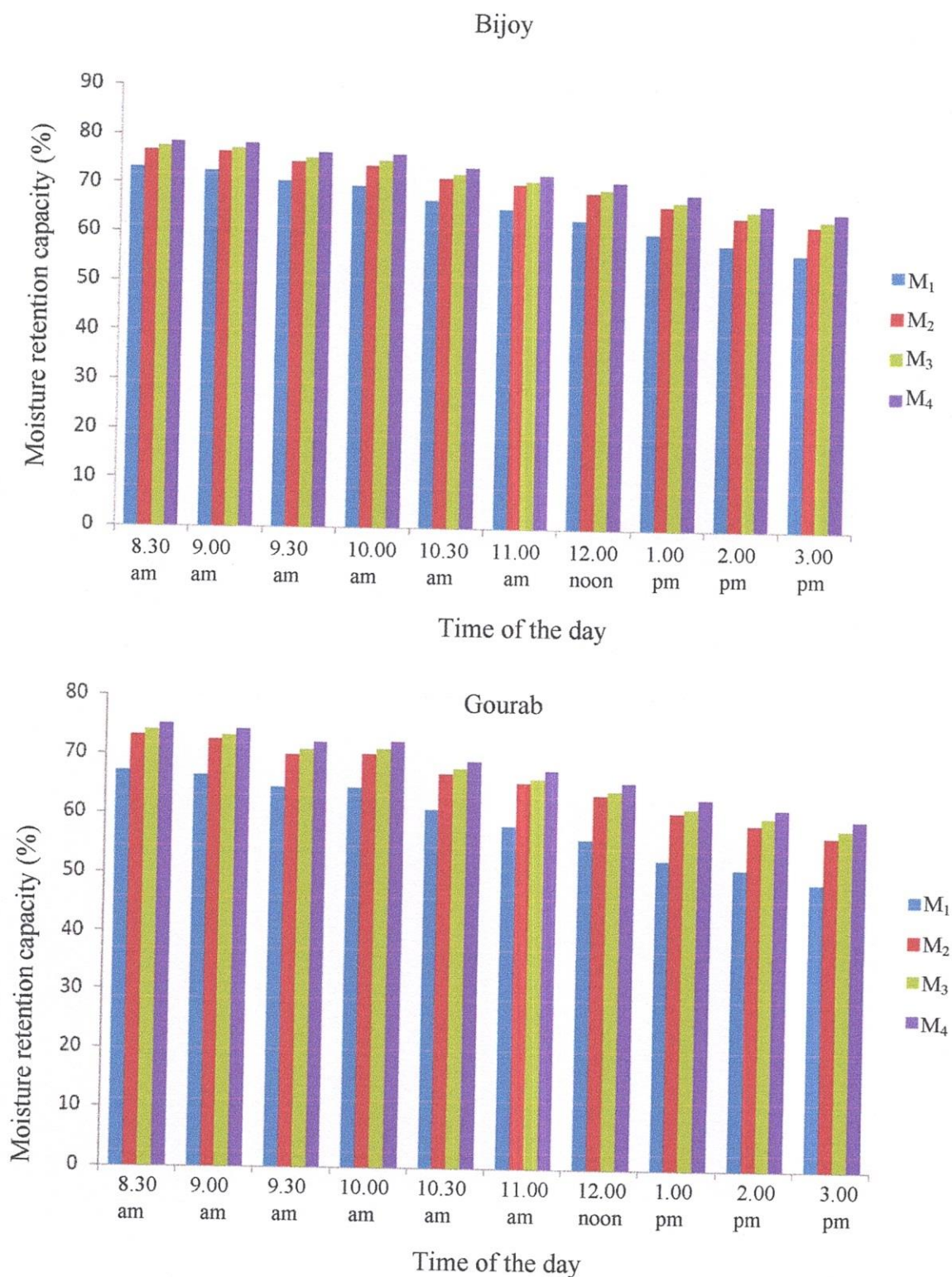


Figure 13a: Moisture retention capacity (MRC) of the flag leaf of two wheat varieties at the different times of the day as affected by mulching (2008-2009)

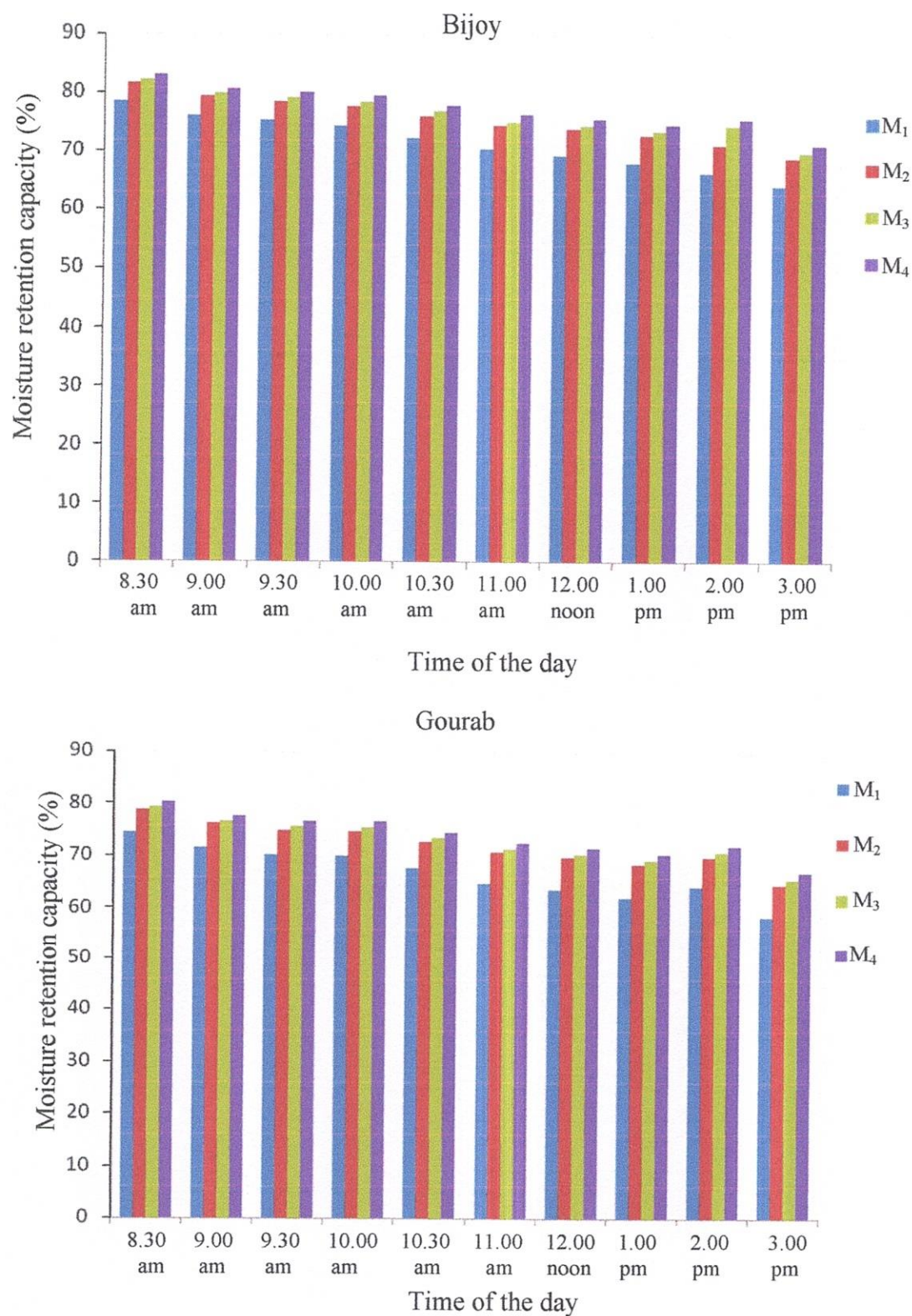


Figure 13b: Moisture retention capacity (MRC) of the flag leaf of two wheat varieties at the different times of the day as affected by mulching (2009-2010)

4.5.2 Relative Leaf Water Content (RLWC)

Relative leaf water content (RLWC) of flag leaves at different times of the day during anthesis was significantly influenced by sowing dates in both the years (Appendices XVIIa and XVIIb). At every occasion, the S_1 plants always had the highest RLWC which was at par with S_2 except 8.00 am in the first year. The lowest RLWC was observed in S_4 plants in both the years which was at par with S_2 except 8.00 am in the first year (Tables 20a and 20b).

Relative leaf water content (RLWC) of flag leaves at different times of the day varied significantly due to variety in both the years (Appendices XVIIa and XVIIb). Variety Bijoy had higher RLWC than variety Gourab at each time of the day in both the years (Tables 20a and 20b).

Mulching had significant effect on RLWC of flag leaves during anthesis at different times of the day in both the years (Appendices XVIIa and XVIIb). The highest RLWC was observed in M_4 crops and the lowest was observed in the control (M_1) at each time of the day (Tables 20a and 20b). M_4 is statistically identical with M_3 and sometimes M_2 in both the years.

The mean squares from the analysis of variance revealed that sowing date $\times$ variety, variety $\times$ mulching and sowing date $\times$ mulching effects were non-significant for RLWC at different times of the day in both the years (Appendices XVIIa and XVIIb). Early sown crops (S_1) with black polythene mulching (M_4) showed the highest RLWC values at each time of the day in both the years while delayed sowing with no mulch (M_1) showed the lowest values (Tables 21a and 21b).

Table 20a: Effect of sowing date, variety and mulching on RLWC (%) of wheat in 2008-2009

Treatment	Time of the day		
	8.00 am	12.00 noon	4.00 pm
a) Sowing Date			
S ₁	85.27a	65.16a	81.43a
S ₂	83.23ab	63.30a	79.21a
S ₃	79.64bc	59.57b	74.82b
S ₄	76.08c	57.41b	71.72b
LS	**	**	**
b) Variety			
V ₁	82.89a	63.38a	78.80a
V ₂	79.22b	59.34b	74.79b
LS	**	**	**
c) Mulching			
M ₁	77.83b	58.37b	73.22b
M ₂	81.10ab	61.57a	76.96a
M ₃	81.89a	62.15a	77.67a
M ₄	83.40a	63.35a	79.32a
LS	**	**	**
CV%	7.33	5.33	6.21

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 20b: Effect of sowing date, variety and mulching on RLWC (%) of wheat in 2009-2010

Treatment	Time of the day		
	8.00 am	12.00 noon	4.00 pm
a) Sowing Date			
S ₁	85.36a	66.62a	83.17a
S ₂	83.14a	64.83a	80.91a
S ₃	78.61b	60.87b	76.45b
S ₄	75.90b	58.75b	73.29b
LS	**	**	**
b) Variety			
V ₁	82.97a	64.67a	80.43a
V ₂	78.53b	60.92b	76.47b
LS	**	**	**
c) Mulching			
M ₁	77.27b	59.54b	74.93b
M ₂	80.90ab	63.00a	78.61a
M ₃	81.52a	63.72a	79.31a
M ₄	83.31a	64.92a	80.96a
LS	**	**	**
CV%	6.77	4.73	6.01

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

V₁= Bijoy

S₂= 2 December sowing

M₂= Water hyacinth mulching

V₂= Gourab

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

Table 21a: Interaction effect of sowing date and mulching on RLWC (%) of wheat in 2008-2009

Interactions	Time of the day		
	8.00 am	12.00 noon	4.00 pm
S ₁ M ₁	81.94	62.15	77.78
S ₁ M ₂	85.34	65.39	81.63
S ₁ M ₃	86.14	65.96	82.33
S ₁ M ₄	87.66	67.14	83.99
S ₂ M ₁	79.84	60.22	75.48
S ₂ M ₂	83.33	63.55	79.42
S ₂ M ₃	84.12	64.12	80.13
S ₂ M ₄	85.64	65.31	81.79
S ₃ M ₁	76.96	57.01	71.78
S ₃ M ₂	79.51	59.63	74.80
S ₃ M ₃	80.30	60.22	75.52
S ₃ M ₄	81.79	61.43	77.16
S ₄ M ₁	72.57	54.10	67.86
S ₄ M ₂	76.23	57.71	71.99
S ₄ M ₃	77.02	58.31	72.71
S ₄ M ₄	78.49	59.52	74.32
LS	NS	NS	NS
CV%	7.33	5.33	6.21

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowingM₁= No mulchingS₂= 2 December sowingM₂= Water hyacinth mulchingS₃= 17 December sowingM₃= Rice straw mulchingS₄= 1 January sowingM₄= Black polythene mulching

Table 21b: Interaction effect of sowing date and mulching on RLWC (%) of wheat in 2009-2010

Interactions	Time of the day		
	8.00 am	12.00 noon	4.00 pm
S ₁ M ₁	81.78	63.43	79.55
S ₁ M ₂	85.54	66.95	83.35
S ₁ M ₃	86.15	67.66	84.05
S ₁ M ₄	87.96	68.84	85.72
S ₂ M ₁	79.48	61.47	77.22
S ₂ M ₂	83.34	65.07	81.11
S ₂ M ₃	83.96	65.79	81.82
S ₂ M ₄	85.78	66.98	83.48
S ₃ M ₁	75.68	68.05	73.47
S ₃ M ₂	78.58	60.93	76.42
S ₃ M ₃	79.20	61.66	77.13
S ₃ M ₄	80.98	62.86	78.77
S ₄ M ₁	72.13	55.20	69.46
S ₄ M ₂	76.15	59.05	73.55
S ₄ M ₃	76.77	59.78	74.26
S ₄ M ₄	78.53	60.99	75.88
LS	NS	NS	NS
CV%	6.77	4.73	6.01

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

4.6 Biochemical Characters

4.6.1 Chlorophyll Content

The mean values of chlorophyll a, chlorophyll b and total chlorophyll (a+b) were significantly influenced by sowing dates in both the years but chlorophyll a:b was significantly influenced by sowing date in the second year (Appendices XVIIIa and XVIIIb). It was observed that the S₁ plants contained the highest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b) than the other sowings. The S₄ plants contained the lowest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b) ((Tables 22a and 22b).

The mean values of chlorophyll a, chlorophyll b and total chlorophyll (a+b) were significantly influenced by variety (Appendices XVIIIa and XVIIIb). It was observed that variety V₁ (Bijoy) contained the higher amount of chlorophyll a, chlorophyll b, total chlorophyll (a+b) and chlorophyll a:b ratio than V₂ (Gourab) in both the years (Tables 22a and 22b).

Mulching had significant effect on chlorophyll a, chlorophyll b and total chlorophyll (a+b) in both the growing season but chlorophyll a:b ratio was significantly influenced by mulching in the first year (Appendices XVIIIa and XVIIIb). It was found that the M₄ plants (black polythene mulch) contained the highest amount of chlorophyll a, chlorophyll b, total chlorophyll (a+b) and chlorophyll a:b ratio and the M₁ (no mulch i.e., control) plants contained the lowest amount of chlorophyll a, chlorophyll b, total chlorophyll (a+b) and chlorophyll a:b ratio in both the years (Tables 22a and 22b).

The mean squares from the analysis of variance revealed that sowing date $\times$ variety, variety $\times$ mulching, sowing date $\times$ mulching effects were not significant for chlorophyll a, chlorophyll b, total chlorophyll (a+b) and chlorophyll a:b ratio in both the years (Appendices XVIIIa and XVIIIb).

Table 22a: Effect of sowing date, variety and mulching on chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2008-2009

Treatment	Chlorophyll content of flag leaf (mg dm^{-2})			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
a) Sowing Date				
S ₁	2.414a	1.183a	3.597a	2.038
S ₂	2.249b	1.099b	3.348b	2.046
S ₃	1.962c	0.979c	2.941c	2.002
S ₄	1.627d	0.802d	2.429d	2.028
LS	**	**	**	NS
b) Variety				
V ₁	2.203a	1.075a	3.279a	2.046a
V ₂	1.923b	0.956b	2.879b	2.011b
LS	**	**	**	**
c) Mulching				
M ₁	1.811c	0.903c	2.714c	2.004c
M ₂	2.069b	1.021b	3.090b	2.026b
M ₃	2.135b	1.051ab	3.186b	2.029b
M ₄	2.238a	1.088a	3.325a	2.055a
LS	**	**	**	**
CV%	5.65	5.59	5.50	2.53

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Table 22b: Effect of sowing date, variety and mulching on chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2009-2010

Treatment	Chlorophyll content of flag leaf (mg dm^{-2})			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
a) Sowing Date				
S ₁	2.485a	1.232a	3.717a	2.015a
S ₂	2.311b	1.143b	3.454b	2.020b
S ₃	2.021c	1.017c	3.038c	1.986c
S ₄	1.657d	0.843d	2.500d	1.964d
LS	**	**	**	**
b) Variety				
V ₁	2.261a	1.126a	3.387a	2.005
V ₂	1.975b	0.992b	2.967b	1.988
LS	**	**	**	NS
c) Mulching				
M ₁	1.845c	0.929c	2.774c	1.984
M ₂	2.128b	1.066b	3.194b	1.994
M ₃	2.193b	1.096b	3.289b	1.997
M ₄	2.307a	1.145a	3.452a	2.010
LS	**	**	**	NS
CV%	4.21	4.24	4.09	2.13

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation LS=Level of significance

S₁=17 November sowing
 S₂= 2 December sowing
 S₃= 17 December sowing
 S₄= 1 January sowing

M₁= No mulching
 M₂= Water hyacinth mulching
 M₃= Rice straw mulching
 M₄= Black polythene mulching

V₁= Bijoy
 V₂= Gourab

Table 23a: Interaction effect of sowing date and mulching on chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2008-2009

Interactions	Chlorophyll content of flag leaf (mg dm^{-2})			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
S ₁ M ₁	2.118	1.053	3.171	2.012
S ₁ M ₂	2.421	1.188	3.608	2.037
S ₁ M ₃	2.497	1.225	3.722	2.038
S ₁ M ₄	2.618	1.268	3.886	2.065
S ₂ M ₁	1.978	0.975	2.953	2.028
S ₂ M ₂	2.254	1.107	3.361	2.036
S ₂ M ₃	2.327	1.136	3.463	2.047
S ₂ M ₄	2.439	1.176	3.615	2.073
S ₃ M ₁	1.722	0.871	2.593	1.977
S ₃ M ₂	1.968	0.983	2.951	2.002
S ₃ M ₃	2.030	1.014	3.044	2.003
S ₃ M ₄	2.128	1.049	3.177	2.026
S ₄ M ₁	1.427	0.713	2.140	2.000
S ₄ M ₂	1.633	0.805	2.438	2.028
S ₄ M ₃	1.684	0.830	2.515	2.028
S ₄ M ₄	1.765	0.859	2.624	2.056
LS	NS	NS	NS	NS
CV%	5.65	5.59	5.50	2.53

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowingM₁= No mulchingS₂= 2 December sowingM₂= Water hyacinth mulchingS₃= 17 December sowingM₃= Rice straw mulchingS₄= 1 January sowingM₄= Black polythene mulching

Table 23b: Interaction effect of sowing date and mulching on chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2009-2010

Interactions	Chlorophyll content of flag leaf (mg dm^{-2})			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
S ₁ M ₁	2.170	1.084	3.254	2.001
S ₁ M ₂	2.496	1.239	3.735	2.015
S ₁ M ₃	2.574	1.274	3.848	2.020
S ₁ M ₄	2.698	1.332	4.030	2.024
S ₂ M ₁	2.005	0.998	3.004	2.007
S ₂ M ₂	2.320	1.152	3.472	2.013
S ₂ M ₃	2.393	1.184	3.577	2.020
S ₂ M ₄	2.526	1.238	3.764	2.040
S ₃ M ₁	1.759	0.892	2.651	1.972
S ₃ M ₂	2.032	1.025	3.057	1.985
S ₃ M ₃	2.093	1.054	3.147	1.985
S ₃ M ₄	2.198	1.098	3.296	2.001
S ₄ M ₁	1.445	0.740	2.185	1.954
S ₄ M ₂	1.663	0.848	2.511	1.962
S ₄ M ₃	1.713	0.872	2.585	1.963
S ₄ M ₄	1.805	0.913	2.718	1.976
LS	NS	NS	NS	NS
CV%	4.21	4.24	4.09	2.13

CV = Co-efficient of variation

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

LS=Level of significance

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

Early sown crops (S_1) with black polythene mulching (M_4) contained the highest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b) while delayed sowing with no mulch (M_1) contained the lowest amount of chlorophyll a, chlorophyll b, and total chlorophyll (a+b) in both the growing seasons (Tables 23a and 23b).

4.7 Yield and Yield Components

4.7.1 Plant Height

Plant height varied significantly owing to variation in sowing dates in both the years (Appendices XIXa and XIXb). Early sowing produced the tallest plant than the late sowing. The highest plant height was observed in November 17 sowing (S_1) plants and the lowest plant height was recorded in January 1 sowing (S_4) plants in both the years (Tables 24a and 24b).

Significant variation was observed in respect of plant height due to different varieties (Appendices XIXa and XIXb). The tallest plant was given by the variety Bijoy (V_1) and the shortest plant was given by the variety Gourab (V_2) in the two growing seasons (Tables 24a and 24b).

Mulching had significant effect on plant height (Appendices XIXa and XIXb). The highest plant height was obtained from black polythene mulching (M_4) and the lowest was obtained from M_1 i.e., no mulching in both the years (Tables 24a and 24b).

From the analysis of variance it was revealed that sowing date $\times$ mulching effects was non-significant for plant height in both the years (Appendices XIXa and XIXb). Numerically the highest plant height was obtained from S_1M_4 combination and the lowest was obtained from S_4M_1 combination in both the years (Tables 25a and 25b).

4.7.2 Number of Total Tillers Plant⁻¹

Number of total tillers plant⁻¹ varied significantly owing to variation in sowing dates (Appendices XIXa and XIXb). Number of total tillers plant⁻¹ decreased with delay in sowing. November 17 sowing produced the maximum number of total tillers plant⁻¹ followed by S₂, S₃ and S₄ and January 1 sowing produced the minimum number of total tillers plant⁻¹ in both the years (Tables 24a and 24b).

Significant variation was observed in respect of number of total tillers plant⁻¹ due to different varieties (Appendices XIXa and XIXb). Variety Bijoy produced significantly higher number of total tillers plant⁻¹ than Gourab in both the years (Tables 24a and 24b).

Number of total tillers plant⁻¹ was significantly influenced by mulching in both the years (Appendices XIXa and XIXb). The maximum number of total tillers plant⁻¹ was obtained from black polythene mulching (M₄) and the minimum number was obtained from M₁ (control) in both the years (Tables 24a and 24b).

From the analysis of variance it was observed that sowing date × mulching effects was non-significant for number of total tillers plant⁻¹ in both the years (Appendices XIXa and XIXb). Numerically the maximum number of total tillers plant⁻¹ was obtained from S₁M₄ combination and the lowest was obtained from S₄M₁ combination in both the years (Tables 25a and 25b).

4.7.3 Number of Effective Tillers Plant⁻¹

Sowing date had significant effect on the number of effective tillers plant⁻¹ in both the years (Appendices XIXa and XIXb). Number of

effective tillers plant⁻¹ decreased with delay in sowing. November 17 sowing (S₁) produced the maximum number of effective tillers plant⁻¹ followed by S₂, S₃ and S₄ and January 1 sowing (S₄) produced the minimum number of effective tillers plant⁻¹ in both the years (Tables 24a and 24b).

Significant variation was observed in respect of number of effective tillers plant⁻¹ due to different varieties (Appendices XIXa and XIXb). Variety Bijoy produced significantly higher number of effective tillers plant⁻¹ than Gourab in both the years (Tables 24a and 24b).

Mulching had significant effect on the number of effective tillers plant⁻¹ in both the years (Appendices XIXa and XIXb). The maximum number of effective tillers plant⁻¹ was obtained from black polythene mulch (M₄) and the minimum number was obtained from control (M₁) in both the years (Tables 24a and 24b).

From the analysis of variance it was observed that sowing date × mulching effects was significant for the number of effective tillers plant⁻¹ (Appendices XIXa and XIXb). Significantly the maximum number of effective tillers plant⁻¹ was obtained from S₁M₄ combination and the lowest number was obtained from S₄M₁ combination (Tables 25a and 25b).

4.7.4 Spike Length

Significant variation in spike length was observed with the variation of sowing date (Appendices XIXa and XIXb). The S₁ plants had the highest spike length and the S₄ plants had the lowest spike length in both the years (Tables 24a and 24b). The results indicated that the spike length decreased with delay in sowing.

Table 24a: Effect of sowing date, variety and mulching on yield and yield contributing characters of wheat in 2008-2009

Treatments	Plant height (cm)	Number of total tillers plant ⁻¹	Number of effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike ⁻¹	Number of fertile spikelets spike ⁻¹	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
a) Sowing date												
S ₁	98.79a	4.80a	4.32a	16.76a	18.87a	20.29a	18.25a	49.22a	4.62a	7.55a	12.17a	37.87a
S ₂	92.50b	4.41b	3.76b	15.73b	17.62b	18.86b	16.73b	45.24b	4.25b	7.30a	11.55b	36.79a
S ₃	81.50c	3.97c	3.17c	13.83c	15.49c	16.98c	14.51c	38.36c	3.55c	6.55b	10.10c	35.09b
S ₄	41.31d	3.05d	1.93d	8.53d	9.56d	12.99d	9.83d	21.28d	1.97d	4.13c	6.10d	32.26c
LS	**	**	**	**	**	**	**	**	**	**	**	**
b) Variety												
V ₁	84.07a	4.52a	3.80a	14.93a	16.79a	19.00a	16.65a	43.57a	4.07a	7.18a	11.25a	35.69
V ₂	72.98b	3.60b	2.79b	12.50b	13.98b	15.55b	13.01b	33.48b	3.12b	5.59b	8.71b	35.32
LS	**	**	**	**	**	**	**	**	**	**	**	NS
c) Mulching												
M ₁	66.63c	3.50c	2.51d	11.86c	13.33d	13.85d	10.89d	32.72c	2.85c	5.19c	8.04c	34.90
M ₂	78.94b	4.04b	3.22c	13.65b	15.32c	17.45c	14.91c	38.59b	3.68b	6.57b	10.24b	35.47
M ₃	82.24b	4.20b	3.43b	14.24b	15.96b	18.20b	15.89b	40.21b	3.82b	6.72ab	10.54b	35.75
M ₄	86.29a	4.48a	4.01a	15.11a	16.93a	19.62a	17.62a	42.58a	4.05a	7.06a	11.10a	35.90
LS	**	**	**	**	**	**	**	**	**	**	**	NS
CV%	5.88	5.48	5.82	7.38	4.27	4.39	3.42	5.98	7.27	7.19	4.76	6.14

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourb

Table 24b: Effect of sowing date, variety and mulching on yield and yield contributing characters of wheat in 2009-2010

Treatments	Plant height (cm)	Number of total tillers plant ⁻¹	Number of effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike ⁻¹	Number of fertile spikelets spike ⁻¹	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
a) Sowing date												
S ₁	104.18a	5.16a	4.32a	17.89a	20.38a	20.85a	18.86a	52.87a	4.81a	7.95a	12.76a	37.73a
S ₂	96.16b	4.70b	3.76b	16.79b	18.81b	19.38b	17.02b	48.24b	4.40b	7.54b	11.93b	36.87ab
S ₃	85.83c	4.26c	3.17c	14.76c	16.71c	17.17c	14.45c	40.88c	3.73c	6.81c	10.54c	35.40b
S ₄	44.92d	3.26d	1.93d	9.06d	10.23d	13.14d	10.25d	22.74d	2.06d	4.31d	6.37d	32.36c
LS	**	**	**	**	**	**	**	**	**	**	**	**
b) Variety												
V ₁	88.67a	4.84a	3.80a	15.92a	18.15a	19.39a	17.00a	46.55a	4.26a	7.54a	11.79a	35.62
V ₂	76.88b	3.85b	2.79b	13.33b	14.92b	15.88b	13.30b	35.82b	3.24b	5.76b	9.01b	35.56
LS	**	**	**	**	**	**	**	**	**	**	**	NS
c) Mulching												
M ₁	71.55c	3.69c	2.51d	12.56c	14.16c	14.10c	11.31d	34.82c	2.96c	5.32c	8.28d	35.25
M ₂	82.69b	4.26b	3.22c	14.53b	16.39b	17.80b	15.29c	41.25b	3.82b	6.79b	10.60c	35.57
M ₃	86.15b	4.44b	3.43b	15.15b	17.07b	18.56b	16.15b	42.98b	4.03a	7.10ab	11.12b	35.76
M ₄	90.71a	4.99a	4.01a	16.26a	18.51a	20.10a	17.83a	45.69a	4.20a	7.40a	11.60a	35.78
LS	**	**	**	**	**	**	**	**	**	**	**	NS
CV%	6.41	8.45	5.82	8.20	6.22	6.34	4.91	5.70	6.09	7.98	5.54	6.22

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

S₁=17 November sowing

S₂= 2 December sowing

S₃= 17 December sowing

S₄= 1 January sowing

LS=Level of significance

M₁= No mulching

M₂= Water hyacinth mulching

M₃= Rice straw mulching

M₄= Black polythene mulching

V₁= Bijoy

V₂= Gourb

Spike length was significantly influenced by variety in both the years (Appendices XIXa and XIXb). Between the two varieties, Bijoy showed higher spike length than Gourab (Tables 24a and 24b).

Mulching had significant effect on spike length in both the years (Appendices XIXa and XIXb). The M_4 plants had the highest spike length and the M_1 plants had the lowest spike length in both the years (Tables 24a and 24b).

From the analysis of variance it was observed that sowing date $\times$ mulching effects was non-significant for spike length in both the years (Appendices XIXa and XIXb). The highest spike length was obtained from S_1M_4 combination and the lowest spike length was obtained from S_4M_1 combination (Tables 25a and 25b).

4.7.5 Extrusion Length

Significant variation in extrusion length was observed with the variation of sowing date (Appendices XIXa and XIXb). The S_1 plants had the highest extrusion length. The lowest extrusion length was observed in S_4 plants in both the years (Tables 24a and 24b).

Extrusion length was significantly influenced by variety (Appendices XIXa and XIXb). Between the two varieties, Bijoy showed higher extrusion length than Gourab (Tables 24a and 24b).

Mulching had significant effect on extrusion length in both the years (Appendices XIXa and XIXb). The M_4 plants had the highest extrusion length. The lowest extrusion length was observed in M_1 plants in both the years (Tables 24a and 24b).

From the analysis of variance it was observed that sowing date $\times$ mulching effects was significant for extrusion length in 2008-2009 and in 2009-2010 sowing date $\times$ mulching effects was non-significant for extrusion length (Appendices XIXa and XIXb). The highest extrusion length was obtained from S₁M₄ combination and the lowest extrusion length was obtained from S₄M₁ combination in both the years (Tables 25a and 25b).

4.7.6 Number of Spikelets Spike⁻¹

Sowing date had significant effect on the number of spikelets spike⁻¹ in both the years (Appendices XIXa and XIXb). Number of spikelets spike⁻¹ decreased with delay in sowing. November 17 sowing (S₁) produced the maximum number of spikelets spike⁻¹ and January 1 sowing (S₄) produced the minimum number of spikelets spike⁻¹ in both the years (Tables 24a and 24b).

Significant variation was observed in respect of number of spikelets spike⁻¹ due to different varieties (Appendices XIXa and XIXb). Variety Bijoy produced significantly higher number of spikelets spike⁻¹ than Gourab (Tables 24a and 24b).

Mulching had significant effect on the number spikelets spike⁻¹ in both the years (Appendices XIXa and XIXb). The maximum number of spikelets spike⁻¹ was obtained from black polythene mulch (M₄) and the minimum number was obtained from M₁ (control) in both the years (Tables 24a and 24b).

From the analysis of variance it was observed that sowing date $\times$ mulching effects was non-significant for the number of spikelets spike⁻¹ in both the years (Appendices XIXa and XIXb). Numerically the

maximum number of spikelets spike⁻¹ was obtained from S₁M₄ combination and the lowest number was obtained from S₄M₁ combination in both the years (Tables 25a and 25b).

4.7.7 Number of Fertile Spikelets Spike⁻¹

The number of fertile spikelets spike⁻¹ varied significantly due to different sowing dates (Appendices XIXa and XIXb). The highest number of fertile spikelets spike⁻¹ was observed in November 17 sowing (S₁). However, the lowest number of fertile spikelets spike⁻¹ was observed in January 1 sowing (S₄) in both the years. (Tables 24a and 24b).

Significant variation was observed in respect of number of fertile spikelets spike⁻¹ due to different varieties (Appendices XIXa and XIXb). Variety Bijoy produced significantly higher number of fertile spikelets spike⁻¹ than Gourab in both the years (Tables 24a and 24b).

Mulching had significant effect on the number fertile spikelets spike⁻¹ in both the years (Appendices XIXa and XIXb). The maximum number of fertile spikelets spike⁻¹ was obtained from black polythene mulching (M₄) and the minimum number was obtained from control (M₁) in both the years (Tables 24a and 24b).

A significant sowing date × mulching effects was observed in producing the number of fertile spikelets spike⁻¹ in both the years (Appendices XIXa and XIXb). Significantly the maximum number of fertile spikelets spike⁻¹ was obtained from S₁M₄ combination and the lowest number was obtained from S₄M₁ combination in both the years (Tables 25a and 25b).

4.7.8 1000-Grain Weight

1000-grain weight varied significantly owing to variation in sowing dates in both the years (Appendices XIXa and XIXb). The S_1 plants produced the highest 1000-grain weight and the S_4 plants produced the lowest 1000-grain weight in both the years (Tables 24a and 24b).

Significant variation was observed in respect of 1000-grain weight due to different varieties (Appendices XIXa and XIXb). Between the two varieties, Bijoy produced higher 1000-grain weight than Gourab in both the years (Tables 24a and 24b).

Mulching had significant effect on 1000-grain weight in both the years (Appendices XIXa and XIXb). Significantly the highest 1000-grain weight was obtained from black polythene mulch (M_4) and the lowest 1000-grain weight was obtained from M_1 (control) in both the years (Tables 24a and 24b).

The mean squares from the analysis of variance it was revealed that sowing date $\times$ mulching effects was significant for 1000-grain weight in both the years (Appendices XIXa and XIXb). Significantly the highest 1000-grain weight was observed in the crops sown in November 17 (S_1) with black polythene mulching (M_4) and the lowest 1000-grain weight was observed in the crops sown in January 1 (S_4) with control (M_1) in both the years (Tables 25a and 25b).

4.7.9 Grain Yield

Grain yield differed significantly due to variation in sowing dates in both the years (Appendices XIXa and XIXb). The S_1 plants produced the highest grain yield and the S_4 plants produced the lowest grain yield in both the years (Tables 24a and 24b).

Table 25a: Interaction effect of sowing date and mulching on yield and yield contributing characters of wheat in 2008-2009

Interactions	Plant height (cm)	Number of total tillers plant ⁻¹	Number of effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike ⁻¹	Number of fertile spikelets spike ⁻¹	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
S ₁ M ₁	85.77	4.12	3.35f	14.49	16.29gh	16.32	13.83g	41.68e	3.65fg	6.13	9.78gh	37.35
S ₁ M ₂	98.57	4.73	4.25c	16.69	18.72cd	20.47	18.41c	49.17bc	4.68bc	7.76	12.43bc	37.64
S ₁ M ₃	102.70	4.93	4.50b	17.40	19.51b	21.35	19.42b	51.23b	4.93ab	7.95	12.88ab	38.21
S ₁ M ₄	108.10	5.40	5.17a	18.47	20.97a	23.02	21.34a	54.81a	5.21a	8.38	13.58a	38.27
S ₂ M ₁	80.15	3.83	2.91h	13.60	15.28j	15.17	12.56h	38.47f	3.39g	5.98	9.37h	36.26
S ₂ M ₂	92.50	4.40	3.69e	15.66	17.57ef	19.02	16.84e	45.38d	4.35d	7.53	11.87cd	36.62
S ₂ M ₃	96.38	4.59	3.91d	16.33	18.31de	19.84	17.87cd	47.28cd	4.48cd	7.67	12.15bc	36.93
S ₂ M ₄	100.98	4.83	4.55b	17.33	19.31bc	21.39	19.66b	49.82bc	4.79b	8.02	12.81b	37.37
S ₃ M ₁	69.42	3.45	2.47i	11.96	13.44k	13.66	10.50ij	32.62g	2.79h	5.32	8.10i	34.34
S ₃ M ₂	81.89	3.97	3.09gh	13.77	15.45ij	17.14	14.53g	38.48f	3.66fg	6.73	10.39fg	35.24
S ₃ M ₃	85.32	4.13	3.28fg	14.36	16.10hi	17.87	15.62f	40.09ef	3.77ef	6.91	10.68ef	35.39
S ₃ M ₄	89.39	4.35	3.85de	15.24	16.980fg	19.27	17.38de	42.24e	3.98e	7.26	11.23de	35.41
S ₄ M ₁	31.16	2.62	1.36k	7.38	8.29n	10.24	6.68k	18.10i	1.56j	3.35	4.90k	31.64
S ₄ M ₂	42.79	3.05	1.87j	8.50	9.53m	13.17	9.85j	21.35h	2.03i	4.25	6.27j	32.38
S ₄ M ₃	44.58	3.17	2.03j	8.86	9.93lm	13.73	10.66i	22.24h	2.09j	4.36	6.45j	32.48
S ₄ M ₄	46.70	3.34	2.46i	9.40	10.47l	14.81	12.11h	23.44h	2.21i	4.58	6.79j	32.54
LS	NS	NS	**	NS	**	NS	**	*	*	NS	**	NS
CV%	5.88	5.48	5.82	7.38	4.27	4.39	3.42	5.98	7.27	7.19	4.76	6.14

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS = Level of significance

S₁ = 17 November sowing

S₂ = 2 December sowing

S₃ = 17 December sowing

S₄ = 1 January sowing

M₁ = No mulching

M₂ = Water hyacinth mulching

M₃ = Rice straw mulching

M₄ = Black polythene mulching

Table 25b: Interaction effect of sowing date and mulching on yield and yield contributing characters of wheat in 2009-2010

Interactions	Plant height (cm)	Number of total tillers plant ⁻¹	Number of effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike ⁻¹	Number of fertile spikelets spike ⁻¹	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
S ₁ M ₁	90.05	4.38	3.35f	15.36	17.50	16.69	14.23f	44.73e	3.79gh	6.33	10.12gh	37.50
S ₁ M ₂	104.07	5.05	4.25c	17.77	20.19	21.03	19.01bc	52.87bc	4.90bc	8.09	12.98bc	37.76
S ₁ M ₃	108.43	5.26	4.50b	18.53	21.03	21.93	26.05b	55.08b	5.16ab	8.47	13.64ab	37.94
S ₁ M ₄	114.17	5.94	5.17a	19.89	22.81	23.75	22.14a	58.79a	5.39a	8.91	14.30a	37.74
S ₂ M ₁	83.12	4.01	2.91h	14.42	16.15	15.52	12.87g	40.88f	3.46h	6.07	9.53h	36.39
S ₂ M ₂	96.06	4.61	3.69e	16.68	18.64	19.55	17.20d	48.32d	4.48de	7.71	12.19cd	36.80
S ₂ M ₃	100.09	4.80	3.91d	17.39	19.42	20.39	18.14cd	50.34cd	4.72cd	8.03	12.75bc	37.08
S ₂ M ₄	105.39	5.39	4.55b	18.67	21.05	22.08	19.89b	53.42b	4.93bc	8.33	13.25b	37.21
S ₃ M ₁	74.20	3.63	2.44i	12.68	14.35	13.74	10.78h	34.65g	2.94i	5.43	8.37i	35.15
S ₃ M ₂	85.74	4.18	3.09gh	14.67	16.55	17.32	14.59ef	40.95f	3.80gh	6.95	10.74fg	35.38
S ₃ M ₃	89.33	4.35	3.28fg	15.29	17.24	18.07	15.39e	42.66ef	4.00fg	7.28	11.28ef	35.53
S ₃ M ₄	94.07	4.89	3.85de	16.41	18.70	19.56	17.04d	45.28e	4.17ef	7.58	11.76de	35.56
S ₄ M ₁	38.83	2.73	1.36k	7.78	8.65	10.44	7.38i	19.01i	1.63k	3.46	5.09k	31.95
S ₄ M ₂	44.87	3.20	1.87j	9.00	10.17	13.28	10.37h	22.87h	2.10j	4.40	6.50j	32.36
S ₄ M ₃	46.75	3.34	2.027j	9.38	10.60	13.85	11.00h	23.82h	2.21j	4.61	6.82j	32.51
S ₄ M ₄	49.23	3.75	2.46i	10.07	11.49	14.99	12.26g	25.28h	2.31j	4.78	7.09j	32.62
LS	NS	NS	*	NS	NS	NS	**	*	**	NS	**	NS
CV%	6.41	8.45	5.82	8.20	6.22	6.34	4.91	5.70	6.09	7.98	5.54	6.22

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

CV = Co-efficient of variation

LS=Level of significance

S₁=17 November sowing

M₁= No mulching

S₂= 2 December sowing

M₂= Water hyacinth mulching

S₃= 17 December sowing

M₃= Rice straw mulching

S₄= 1 January sowing

M₄= Black polythene mulching

Significant variation was observed in respect of grain yield due to different varieties (Appendices XIXa and XIXb). Between the two varieties, Bijoy produced higher grain yield than Gourab (Tables 24a and 24b).

Mulching had significant effect on grain yield in both the years (Appendices XIXa and XIXb). Significantly the highest grain yield was obtained from black polythene mulching (M_4) and the lowest was obtained from control in both the years (Tables 24a and 24b).

The mean squares from the analysis of variance it was revealed that sowing date $\times$ mulching effects was significant for grain yield in both the years (Appendices XIXa and XIXb). Significantly the highest grain yield was observed in the crops sown in November 17 (S_1) with black polythene mulch (M_4) and the lowest was observed in the crops sown in January 1 (S_4) with control (M_1) in both the years (Tables 25a and 25b).

4.7.10 Straw Yield

Sowing dates had significant effect on straw yield in both the years (Appendices XIXa and XIXb). Significantly the S_1 plants produced the highest grain yield and the S_4 plants produced the lowest grain yield in both the years (Tables 24a and 24b).

Significant variation was observed in respect of straw yield due to different varieties (Appendices XIXa and XIXb). Between the two varieties, Bijoy produced higher straw yield than Gourab in both the years (Tables 24a and 24b).

Mulching had significant effect on straw yield in both the years (Appendices XIXa and XIXb). Significantly the highest straw yield was

obtained from black polythene mulch (M_4) and the lowest was obtained from non-mulched crops (M_1) in both the years (Tables 24a and 24b).

The mean squares from the analysis of variance it was revealed that sowing date $\times$ mulching effects was non-significant for straw yield (Appendices XIXa and XIXb). Numerically the highest straw yield was observed in the crops sown in November 17 (S_1) with black polythene mulch (M_4) and the lowest was observed in the crops sown in January 1 (S_4) with control (M_1) in both the years (Tables 25a and 25b).

4.7.11 Biological Yield

Biological yield also yield differed significantly due to variation in sowing dates in both the years (Appendices XIXa and XIXb). The S_1 plants produced the highest biological yield and the S_4 plants produced the lowest biological yield in both the years (Tables 24a and 24b).

Significant variation was observed in respect of biological yield due to different varieties (Appendices XIXa and XIXb). Between the two varieties, Bijoy produced higher biological yield than Gourab in both the years (Tables 24a and 24b).

Mulching had significant effect on biological yield in both the years (Appendices XIXa and XIXb). Significantly the highest biological yield was obtained from black polythene mulch (M_4) and the lowest was obtained from control (Tables 24a and 24b).

The mean squares from the analysis of variance it was revealed that sowing date $\times$ mulching effects was significant for biological yield (Appendices XIXa and XIXb). Numerically the highest biological yield was observed in the crops sown in November 17 (S_1) with black

polythene mulch (M_4) and the lowest was observed in the crops sown in January 1 (S_4) with control (M_1) in both the years (Tables 25a and 25b).

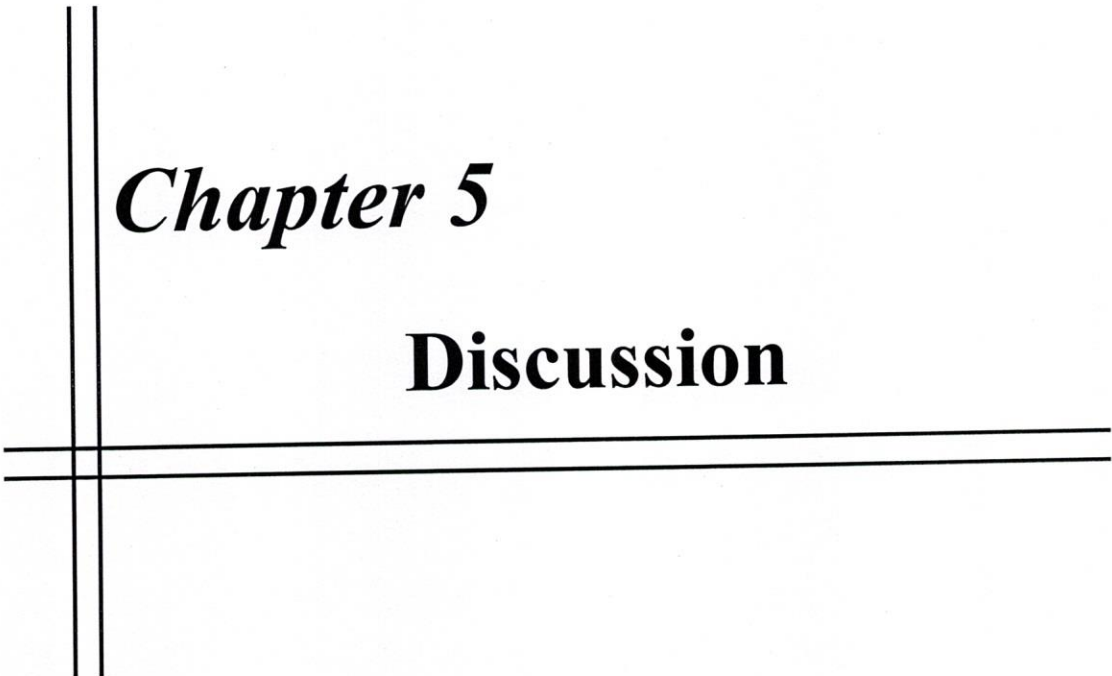
4.7.12 Harvest Index

A significant variation in harvest index was observed with the variation of sowing dates in both the years (Appendices XIXa and XIXb). The S_1 plants had the highest harvest index in both the years which was at par with S_2 in 2008-2009 growing season and the S_4 plants had the lowest HI in both the years (Tables 24a and 24b).

Significant variation was not observed in respect of HI due to different varieties (Appendices XIXa and XIXb). Between the two varieties, Bijoy showed higher HI than Gourab in both the years (Tables 24a and 24b).

Mulching had non-significant effect on HI in both the years (Appendices XIXa and XIXb). Numerically the highest harvest index was obtained from black polythene mulch (M_4) and the lowest was obtained from M_1 i.e., control (Tables 24a and 24b).

The mean squares from the analysis of variance it was revealed that sowing date $\times$ mulching effects was non-significant for HI in both the years (Appendices XIXa and XIXb). Numerically the highest HI was observed in the crops sown in November 17 (S_1) with black polythene mulch (M_4) and the lowest was observed in the crops sown in January 1 (S_4) with control (M_1) in both the years (Tables 25a and 25b).



Chapter 5

Discussion

DISCUSSION

The results of the present investigation indicated that sowing date was significant for total dry matter (TDM) at all the harvests in both the years. TDM was found to be significantly greater in S_1 (17 November) plants than the other sowings in both the years. It was also found that delayed sowing resulted in lower TDM in both the years. Similar results were reported in wheat and barley by Berrada (1979), Bonari and Macchia (1980), Abdel-Raouf *et al.* (1983a), Alam *et al.* (2005), Paul and Sarker (2005), Bahadur (2008) and Mohiuddin (2010). TDM increased slowly at the early stages of growth and then increased rapidly with the advancement of plant age. The rapid increase in TDM at the later stages of growth was due to the development of a considerable number of late tillers. Similar result was reported by Talukder (1987) in wheat. The plants sown on 17 November (S_1) produced higher total dry matter due to the highest growth rate, longer duration of vegetative phase and higher numbers of tillers with the tallest plant influenced by optimum temperature throughout its growth period. Delay in sowing reduced tiller number, which resulted in lower TDM in both the years. Photiades and Hadjichristodoulou (1984) and Zhao *et al.* (1986) also found similar results in barley. In both the years, between the two varieties, higher total dry matter production was reported for Bijoy (V_1) than Gourab (V_2). The results of the present study also showed that total dry matter production in both the years were significantly greater in the mulched plants than the control. The M_4 plants (black polythene mulching) had the highest TDM

and the M_1 plants (control) had the lowest TDM in both the years. Islam *et al.* (2006) reported that the mulched plant increased dry matter production than the non-mulched plants.

Leaf area index (LAI) was found to be significantly greater in S_1 plants than the other sowings in both the years. Delay in sowing resulted in lower LAI in both the years (Tables 2a and 2b). Similar result was reported by Paul and Sarker (2005) and Ahmed and Farooq (2013) in wheat and Abdel-Raouf *et al.* (1983a,b) in barley. LAI of both the varieties for all the sowings and mulching treatments started from a lower value and reached highest level at a certain stage of growth and then declined thereafter (Figures 4a and 4b). Bijoy attained higher LAI than Gourab in both the years. The value of LAI in the mulched plants was greater than the control at all the harvests in both the years. The highest LAI was produced by M_4 mulching (black polythene mulching) in both the years (Tables 2a and 2b). The increase of LAI occurred due to increase of leaf expansion in the mulched plants. Increase in soil moisture resulted in increased turgor pressure in the cells and turgor forces played a part in the process of leaf expansion. Soil moisture increased relative leaf water content which increased cell expansion and ultimately leaf area was increased. The possible reason for the increase of LAI in the mulched plants is greater expansion of leaf blades. The depletion of LAI at the later stages was possibly due to the senescence of the older leaves.

CGR is regarded as the most meaningful growth function, since it represents the net results of photosynthesis, respiration and canopy area interaction. As noted by Williams *et al.* (1965), CGR is also representative of the most common agronomic measurement such as yield

of dry matter per unit land area. In the present investigation, CGR was found higher for S_1 (17 November sowing) in both the years. Delay in sowing resulted in lower CGR in both the years. This result is agreed with Mohiuddin (2010) and Ahmed and Farooq (2013) in wheat and Abdel-Raouf *et al.* (1983), Alam (2003) and Alam *et al.* (2005) in barley. Between the two varieties, Bijoy showed significantly higher crop growth rate than Gourab at all the harvests in both the years. The highest CGR values were found in plants grown with black polythene mulching (M_4). Statistically similar result was obtained from rice straw mulching (M_3) at 70-80 DAS in the first year and both rice straw mulching (M_3) and water hyacinth mulching (M_2) at 40-50 and 50-60 DAS in the second year (Tables 3a and 3b). Starting from a lower value, CGR increased slowly at the early stage of growth and reached the peak at 60-70 DAS and thereafter it declined with lower positive values in both the years for all the sowing dates and mulching treatments (Figures 5a and 5b). Higher CGR was obtained from mulched treatment than control was reported by Islam *et al.* (2006) in wheat.

With some exceptions, numerically the highest RGR was obtained from 17 November (S_1) sowing and the lowest was obtained from S_4 sowing (1 January sowing) in both the years at all the harvests (Tables 4a and 4b). More or less similar result was reported by Ahmed and Farooq (2013) in wheat. RGR showed a downward trend with moderate fluctuation and this decreasing trend continued till maturity (Figures 6a and 6b). RGR declined with increasing plant age. Similar results were reported for RGR in wheat by Sarker and Paul (1998) and Haque (2000) and in sugarcane, potato and barley by Thorne (1960). It had been suggested that the decrease in RGR could be attributed to self shading of lower leaves by

upper leaves Thorne (1961). The reason for higher RGR values at the early stages of growth is possible to have the juvenility of the plants and less effects on accumulation of dry matter. No clear cut superiority was observed between the varieties for RGR. No clear cut pattern of mulching on RGR was observed in both the years. Decrease in RGR with increasing plant age and late sowing after 17 November has been reported in barley by Alam *et al.* (2006). Thorne (1961) suggested that the decrease in RGR could be attributed to self-shading of lower leaves by upper leaves. In addition, Chanda *et al.* (1987) concluded that the declining tendency in RGR with age was possibly due to decline in LAR.

No clear cut pattern of sowing dates effect on NAR was observed in both the years. With some exceptions, higher NAR values were obtained from mulched treatment and the lowest values were obtained from control (Tables 5a and 5b). NAR values for all the treatments fluctuated heavily throughout the growing period. NAR values in both the varieties for all the sowings and mulching treatments decreased with fluctuations till 50-60 DAS and then increased and showed highest NAR at 60-70 DAS. After that NAR values decreased (Figures 7a and 7b).

In the present study, numerically the highest LAR values were observed at S₄ sowing at the early stages of growth and at the later stages S₁ sowing showed the highest value in 2008-2009 but in 2009-2010 growing season, numerically the highest LAR values were observed at S₂ sowing at all the harvests. No clear cut superiority was observed between the varieties in both the years. Mulching had significant effect on LAR at all the harvests. Higher LAR values were obtained from non-mulched plants in both the years (Tables 6a and 6b). With a few exceptions, different mulched

treatments showed statistically similar results. Starting from higher values, LAR declined with increasing plant age in both the years. The highest LAR values were observed at the early stages of growth and then declined with increasing plant age in both the years and this decreasing trend continued till maturity. LAR values of both the varieties in both the years declined with increasing plant age (Figures 8a and 8b). It might be due to the abscission of mature and older leaves at the later growing stages. Similar results were reported in wheat by Rahman (1993) and Saha and Paul (1995) and in sugarbeet, potato and barley by Thorne (1960), in black gram by Pandey *et al.* (1978).

In the present investigation, RLGR values were found to decrease with increasing plant age. Similar results were reported by Rahman (1993), Saha and Paul (1995), Sarker and Paul (1998) and Sarker *et al.* (1999) in wheat. RLGR of both the varieties for all the sowing dates and mulching started from higher positive values at the early stages of growth and declined with fluctuations and ended in a negative value at the later stages of growth in both the years (Figures 9a and 9b). The cause of decline of RLGR at the later stages was due to abscission of older leaves. It was also observed that high temperature at the later stages of growth accelerated the abscission of older leaves. The abscission of older leaves resulted in the decline of RLGR at the later stages of growth Pandey *et al.* (1978). With some exceptions, numerically the highest RLGR was obtained from S₁ sowing and the lowest was obtained from S₄ sowing in both the years at all the harvests. No clear cut superiority was observed between the varieties for RLGR. No clear cut pattern of mulching effect on RLGR was observed in both the years (Tables 7a and 7b).

No clear cut pattern of sowing dates and varietal effects on SLA was observed in both the years. Mulching showed significant effects on SLA at all the harvests. With some exceptions, the highest SLA values were obtained from control treatment (M_1) and the lowest values were obtained from M_4 mulching in both the years. With some exceptions, M_2 , M_3 and M_4 showed statistically similar SLA value in both the years (Tables 8a and 8b). SLA values fluctuated moderately throughout the growing period.

The values of leaf weight ratio (LWR) were the highest at the beginning and declined with the increasing plant age in both the years for all the treatments. The decrease of LWR was caused by increased plant dry weight and decreased LAI at the later stages. Saha and Paul (1995) studied LWR in wheat and reported that the sharp decrease in LWR at the later stages might be due to sharp increase of TDM. The decline of LWR with plant age was also observed in wheat by Rahman (1993). This result was also supported by Thorne (1960) in wheat. In the present investigation, with some exceptions, numerically the highest LWR was obtained from S_1 sowing and the lowest was obtained from S_4 sowing in both the years at all the harvests. No clear cut superiority was observed on LWR between the varieties. With few exceptions the highest LWR was obtained from M_4 mulching in both the years (Tables 9a and 9b).

In both the years significant sowing date differences were found for all the phenological stages. Comparatively higher values for all the phenological stages were found for S_1 sowing in both the years. Number of days for attaining the different phenological stages, such as crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity

varied in different sowing dates and the required days were decreased for every late sowing (Tables 10a and 10b). Similar results were reported in wheat by Rajput *et al.* (1987), Hossain *et al.* (1987), Sharma and Thakur (1996), Saifuzzaman *et al.* (1996), Sandhu *et al.* (1999), Ghosh *et al.* (2000), Paul and Sarker (2000) and Singh *et al.* (2005) and in barley by Tomar and Mathur (1966) and Alam *et al.* (2007a). November 17 sowing (S_1) required the maximum days for crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity in both the years. Days to crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity decreased with delay in sowing. It was observed that delayed sowing required comparatively lesser days to attain different phenological stages in both the years (Tables 10a and 10b). In the present study, late sowing caused unfavourable high temperature at the reproductive phase and low temperature at the early vegetative phase resulting in reduced number of days for attaining different phenological stages. Haque (2000) reported that longer duration of the phenological stages for optimum sowing may be due to more tillering, maximum leaf emergence, higher plant height and higher number of florets and higher 1000-grain weight. These occurred due to favourable environmental conditions, particularly temperature for optimum sowing at the vegetative stage ($20-25^{\circ}\text{C}$) and subsequently at the reproductive stage ($12-18^{\circ}\text{C}$). On the other hand, the late-sown plants beyond November passed the lower temperature at the vegetative stages ($8-10^{\circ}\text{C}$) and higher temperature ($28-32^{\circ}\text{C}$) at the reproductive stages. He also mentioned that fluctuated unfavourable temperature in the late-sown condition reduced the number of days for all the phenological stages by supplying the lower amount of assimilates which reflected to the different growth stages resulting in

quick maturity of the plants. Day and Intalap (1970) opined that maturity of wheat plants was hastened due to stress at the flowering and dough stages. Gales and Wilson (1979) observed that the stressed plants matured earlier than the control. Variety Gourab attained its crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity stages earlier than Gourab in both the years. Mulching increased the length of the growing period, the duration from flowering to harvest was reported by Feng-Min *et al.* (1999). In the present study, it was observed that mulching had significant effect on the days to attain different phenological stages in both the years. The plants grown in M₄ condition required higher days to attain crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity stages and M₁ plants required the lowest days for attaining these stages in both the years (Tables 10a and 10b).

The requirement of heat units (GDD) was higher in S₁ at all the phenological stages in both the years than the other sowings. This was due to longer period for all the phenological stages in the optimum sowing. Delayed sowing decreased the duration of phenology as compared to S₁ (17 November sowing) due to fluctuated temperature, sunshine hours and scarce soil moisture in the later part of the growth period. So, the requirement of heat units decreased for different phenological stages with delay in sowing. Rajput *et al.* (1987), Masoni *et al.* (1990), Sandhu *et al.* (1999) and Paul and Sarker (2000) in wheat and Sharratt (1999) and Alam *et al.* (2007a) in barley also reported that requirement of heat units decreased for different phenological stages with delay in sowing. Between the two varieties, Bijoy (V₁) obtained higher heat units than Gourab (V₂) for all the phenological stages in both the

growing seasons. The highest heat units of growing degree days (GDD) were required in M_4 plants and was successively followed by M_3 , M_2 and M_1 plants at all the phenological stages in both the years. The lowest heat unit requirement for all the phenological stages in both the varieties was found in the non-mulched plants (Tables 12a and 12b). Tarafder *et al.* (1996) observed that addition of mulch increased soil moisture content in the root zone and decreased soil temperature and provided more stable environment for seedling establishment and growth than the non-mulched soil. Water deficiency decreased the duration of phenology as compared to the well-watered condition and thereby the requirement of heat units decreased for different phenological stages with non-mulched condition.

Helio-thermal unit (HTU) of a definite phenology is the product of the length of sunshine hour of a day and required days of the phenology accumulated heat units by plants. In the present work, among the different sowing dates, the requirement of HTU was higher for S_1 (17 November sowing) than the other sowings in both the years (Tables 14a and 14b). The S_1 plants passed through their growth period with bright sunlight that influenced the photosynthesis effectively. On the other hand, the late-sown plants passed their most of the growth period with foggy humid condition and suffered from high temperature at the later stages of growth that hampered the photosynthetic efficiency. So, HTU of the late-sown plants compelled to complete their life cycle with a short period of time than the early sowing or optimum sowing plants that produced lower grain yield in the present study. HTU of different phenological stages decreased with delay in sowing was supported by Rajput *et al.* (1987), Masoni *et al.* (1990), Paul and Sarker (2000) and Haque (2000) in wheat and Alam *et al.* (2007a) in barley. Generally, the M_4 plants had the

highest HTU at all the phenological stages in both the years. The mulched plants passed their growth period with bright sunlight and sufficient water that influenced the photosynthesis effectively. In contrast, the non-mulched plants passed their growth period with bright sunlight and insufficient water that hampered the different metabolic activities. So, the HTU of non-mulched plants was lower than the mulched plants and the non-mulched plants produced lower grain yield in the present study. Higher HTU was observed in Bijoy (V_1) at all the phenological stages than Gourab (V_2) in both the years (Tables 14a and 14b).

The values of PTI for different phenological stages were nearly constant irrespective of sowing date in both the years and this result is in agreement with Rajput *et al.* (1987) and Alam *et al.* (2007a). Among the different sowing dates, with a few exceptions, the highest PTI value was observed in S_1 (17 November sowing) and the lowest was observed in S_4 (1 January sowing) in both the years at most of the phenological stages. With some exceptions, Bijoy had the higher PTI than Gourab. With some exceptions, the highest PTI was observed in M_4 and the lowest was observed in control (M_1) at all the phenological stages (Tables 16a and 16b).

The S_1 plants used heat more efficiently than the other sowings. The lowest HUE was observed in S_4 plants in both the years. As the temperature was optimum throughout the S_1 growing periods, it accumulated heat more efficiently and increased biological activities that confirmed higher grain yield. Similar result was reported by Rajput *et al.* (1987), Paul and Sarker (2000), Haque (2000) and Alam *et al.* (2007a).

Significantly higher HUE was observed in Bijoy than Gourab. The mulched plants had the highest HUE than the non-mulched plants in both the years (Tables 16a and 16b). Mulching resulted in higher grain yield via optimum metabolic activities and thereby the mulched plants had higher HUE in both the growing seasons. On the other hand, deficiency of water during the various growth stages hampered the normal metabolic activities and resulted in lower grain yield as well as lower HUE.

Moisture retention capacity (MRC) of flag leaves at different times of the day was significantly influenced by sowing dates in both the years. Higher moisture retention capacity was found at the early hours of the day but it decreased gradually at the later part of the day. At every occasion, the highest moisture retention capacity was observed in both S_1 and S_2 plants than the other sowings (Tables 18a and 18b). More or less similar result was reported by Haque (2000) in wheat. Findings of Haider (2002) also supported the present results. Quaiyyum (1995) in a separate experiment with mulberry plant found similar results. The mulched plants had higher moisture retention capacity than the non-mulched plants. The highest MRC was observed in M_4 plants and the lowest was observed in the control (M_1) at each time of the day in both the years (Tables 18a and 18b). The ability of a leaf to retain higher moisture may be due to its higher sensitivity of stomatal opening with higher leaf area. Moreover, both the varieties exhibited maximum moisture retention capacity at 8.30 am and thereafter decreased gradually. This might be due to increased dryness and also because of higher transpiration rates. Variety Bijoy had higher MRC than variety Gourab at each time of the day in both the years (Tables 18a and 18b).

Relative leaf water content (RLWC) is the relation between the actual and fully turgid water contents of leaf tissues (Baker, 1984) and it represents the severity of dehydration of leaf when it experiences water stress and closely associated with the developmental and physiological activities (Morgan, 1971). During the S₁ and S₂ sowing conditions, temperature was optimum for favourable growth. That increased the relative turgidity of cells which enhanced higher relative leaf water content of the flag leaf. Relative leaf water content of leaf decreased with delay in sowing causing the heat stress in the leaves (Haque, 2000 and Alam and Haider, 2007). The highest leaf water content was observed at 8.30 am in both the years. Rahman and Paul (1998) found highest relative leaf water content in wheat leaves at 8.00 am. RLWC of all the varieties higher in the morning, fell during noon, showing some recovery in the afternoon and this result was in agreement with Nazrul-Islam (1988), Begum and Paul (1993), Rahman (1993), Sarker *et al.* (1999), Haider (2002) and Paul *et al.* (2002). The decrease of relative leaf water content at the mid-day might be due to higher evapotranspiration owing to increased temperature and light intensity. The highest RLWC was recorded in black polythene mulching (M₄) and the lowest was observed in the control (M₁) at each time of the day in both the years. The mulched plants of both the varieties at different times of the day always had higher RLWC than the non-mulched plants (Tables 20a and 20b).

In the photosynthetic process, chlorophyll a and chlorophyll b are the most important pigments in plants. In the present study, significant effect of sowing date and mulching on chlorophyll a, chlorophyll b and total

chlorophyll (a+b) of two wheat varieties was observed in both the years but chlorophyll a:b was significantly influenced by sowing date in the second year and chlorophyll a:b ratio was significantly influenced by mulching in the first year (Appendices XVIIIa and XVIIIb). In the present study, it was observed that S₁ plants contained the highest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b) in both the years than the other sowings. The S₁ plants contained higher chlorophyll was due to higher helio-thermal unit (HTU) obtained by the plants of that sowing which enhanced more chlorophyll formation and increased the rate of photosynthesis more efficiently in flag leaves. The S₄ plants contained the lowest amount of chlorophyll a, chlorophyll b and total chlorophyll (a+b) (Tables 22a and 22b). Chlorophyll formation decreased with delayed sowing because of low temperature and scarce soil moisture at the vegetative stages. Delayed sowing (late sowing) decreased chlorophyll content in the flag leaves. Similar results were also reported by Haider (2002) in wheat and Alam (2003) and Alam and Haider (2007) in barley. Khatkar and Kuhd (2000) also reported similar findings in their experiment with two wheat varieties. Reduction of chlorophyll formation due to scarce soil moisture was reported by Chetal *et al.* (1982), Sarker *et al.* (1999), Chandrashekar *et al.* (2000), Nyachiro *et al.* (2001), Deora *et al.* (2001) and Paul *et al.* (2002). In the present study chlorophyll a, chlorophyll b, total chlorophyll (a+b) content were found to be affected by sowing date but chlorophyll a:b ratio was less affected in both the years. Several workers have reported that the rate of photosynthesis in flag leaves is positively associated with chlorophyll content (Muramoto *et al.* 1965, Kariya and Tsunada, 1971). But, Hesketh (1963) and Kumari and Sinha (1972) have failed to find out any relationship between

chlorophyll and the rates of photosynthesis. Mulched plants had higher chlorophyll a, chlorophyll b, total chlorophyll (a+b) than the non-mulched plants in their flag leaves. M₄ plants (black polythene mulching) contained the highest amount of chlorophyll a, chlorophyll b, total chlorophyll (a+b) and chlorophyll a:b ratio and the M₁ (no mulch) plants contained the lowest amount of chlorophyll a, chlorophyll b, total chlorophyll (a+b) and chlorophyll a:b ratio in both the years (Tables 22a and 22b).

Crop yield is a complex character depending upon a large number of environmental, morphological and physiological characters. In the present study, yield and yield components were significantly affected by sowing date and mulching. Plant height is an important morphological character directly linked with the productive potential of plant in terms of grain yield. Significant reduction in plant height was noticed due to delay in sowing in both the years. Similar results were also reported by Makki and Habib (1979), Kozłowska-Ptaszyńska (1993) and Alam *et al.* (2007b) in barley. Early sowing produced the tallest plant than the late sowing. The highest plant height was observed in 17 November sowing (S₁) plants and the lowest plant height was observed in 1 January sowing (S₄) plants in both the years. The highest plant height was obtained from black polythene mulching (M₄) and the lowest was obtained from M₁ (no mulching) in both the years (Tables 24a and 24b). Similar results were reported in wheat by Patel *et al.* (1971), Islam (1977), Jana and Mitra (1995), Sarker and Paul (1997), Pandit *et al.* (2001) and Rahman *et al.* (2001) and in barley by Paramjit *et al.* (2001) and Mollah (2007). Number of total tillers plant⁻¹ decreased with delay in sowing. The S₁ sowing (17 November sowing) produced the maximum number of total

tillers plant⁻¹ followed by S₂, S₃ and S₄ in both the years. The minimum number of total tillers plant⁻¹ was observed in 1 January sowing in both the years. Mulching increased the number of total tillers plant⁻¹ which corroborated the findings of Feng-Min *et al.* (1999) and Khan *et al.* (2014). The maximum number of total tillers plant⁻¹ was obtained from black polythene mulching (M₄) and the minimum number was obtained from M₁ (control) in both the years (Tables 24a and 24b).

Number of effective tillers plant⁻¹ is the most important character, which ensures highest yield. 17 November sowing (S₁) produced the maximum number of effective tillers plant⁻¹ followed by S₂, S₃ and S₄ and 1 January sowing (S₄) produced the minimum number of effective tillers plant⁻¹ in both the years (Tables 24a and 24b). Delay in sowing after 16 November reduced the number of effective tillers plant⁻¹, which corroborated the findings of Abdel-Raouf *et al.* (1983b), Jepsen (1985), Noworolink (1989 a,b), Noworolink and Pecio (1990), Conry and Hegarty (1992), Noworolink and Leszczynska (1997), Chun JongUn *et al.* (2000), Paul and Sarker (2003) and Alam *et al.* (2007b). The maximum number of effective tillers plant⁻¹ was obtained from black polythene mulching (M₄) and the minimum number was obtained from M₁ (control) in both the years (Tables 24a and 24b).

Delay in sowing reduced the spike length in the present investigation, which agreed with the findings of Abdel-Raouf *et al.* (1983 b) and Kaor *et al.* (2010). Reduction of spike length at the later sowing dates might be due to low temperature at the vegetative stage and scarce soil moisture as well. Similar result was observed in barley by Alam *et al.* (2007b). In the present study mulched plants had the higher spike length than the control.

Similar result was reported in wheat by Islam *et al.* (2006) and Khan *et al.* (2014). The highest spike length was produced by M₄ plants (black polythene mulching) and the lowest spike length was produced by M₁ plants (control) in both the years (Tables 24a and 24b).

Significant variation in extrusion length was observed with the variation of sowing date. The S₁ plants had the highest extrusion length and the S₄ plants had the lowest extrusion length in both the years. Delay in sowing resulted in the reduction of extrusion length. It might be due to low temperature at the vegetative stage and scarce soil moisture at the later sowing dates. Similar result was reported in wheat by Haider (2002) and in barley by Alam *et al.* (2007b). Mulching had significant effect on extrusion length. The M₄ plants had the highest extrusion length and the M₁ plants had the lowest extrusion length in both the growing seasons (Tables 24a and 24b).

Sowing date had significant effect on the number of spikelets spike⁻¹. Number of spikelets spike⁻¹ decreased with delay in sowing. The highest number of spikelets spike⁻¹ was observed in 17 November sowing (S₁) and the lowest number of spikelets spike⁻¹ was observed in 1 January sowing (S₄) in both the growing seasons (Tables 24a and 24b). Similar result was reported in barley by Alam *et al.* (2007b). Mulching had significant effect on the number of spikelets spike⁻¹ in both the years. The maximum number of spikelets spike⁻¹ was obtained from black polythene mulching (M₄) and the minimum number was obtained from control (M₁) in both the years (Tables 24a and 24b).

The number of fertile spikelets spike⁻¹ varied significantly due to different sowing dates in both the years. The highest number of fertile spikelets

spike⁻¹ was observed in 17 November sowing (S₁) in both the years. Similar result was reported in barley by Alam *et al.* (2007b). The lowest number of fertile spikelets spike⁻¹ was observed in 1 January sowing (S₄) in both the years. Mulching had significant effect on the number of fertile spikelets spike⁻¹ in both the years. The maximum number of fertile spikelets spike⁻¹ was obtained from black polythene mulching (M₄) and the minimum number was obtained from M₁ (control) in both the years (Tables 24a and 24b).

1000-grain weight is the most important yield component as stated by Petr *et al.* (1979). In the present investigations, 1000-grain weight was highest in S₁ and thereafter declined with delay in sowing. Similar results were reported in barley and wheat by many workers, such as Abdel-Raouf *et al.* (1983 b), Choi *et al.* (1986), Zhao *et al.* (1988), Noworolink (1989 a, b), Conry and Hegarty (1992), Ram *et al.* (2004) and Alam *et al.* (2007b). Between the two varieties, Bijoy produced higher 1000-grain weight than Gourab in both the years. This might be due to genetic constitution. Significantly the highest 1000-grain weight was obtained from black polythene mulching (M₄) and the lowest 1000-grain weight was obtained from control (M₁) in both the years (Tables 24a and 24b).

Grain yield differed significantly due to variation in sowing dates and mulching in both the years. Generally, delay in sowing reduced grain yield. Similar results were reported in wheat by Khokhar *et al.* (2010) and Jat *et al.* (2013) and in barley by Ekeberg (1994), Noworolink and Leszczynska (1997) and Alam *et al.* (2007b). In the present investigation, yield and yield components were more or less reduced by late sowing as compared to 17 November (S₁) sowing. Usanova (1985) reported that a

delay of 10 days in sowing decreased the yield by 0.5-0.51 t ha⁻¹ or 12.9 - 14.6%. The main reason for the yield reduction was low utilization of photosynthetically active radiation during the first 1.5 months after sowing. Ekeberg (1994) reported that on an average, cereal grain yield decreased by 21 kg ha⁻¹ with each day delay in sowing. The present investigation also supported the result of Nass *et al.* (1975). They reported that yield reduction in the late sowing was due to shorter growing period at the vegetative phase and steep rise in temperature at the grain filling stage. High temperatures are known to hasten spike development from floral initiation to anthesis and also have been found to reduce the number of spikelets spike⁻¹ (Dawson and Wardlaw, 1989). Frank *et al.* (1992) reported that fertile spikelet number decreased significantly in barley cv. Azure as temperature increased from 10°C to 18°C. High temperature also hastened phenological development (Boonkhoo *et al.* 1998). In the present investigation, 17 December (S₃) and 1 January (S₄) sowings also experienced shorter growing period and steep rise in temperature at the later stages of growth. Miralles *et al.* (2000) reported that increased duration of stem elongation period in wheat and barley increased floret fertility and grain number. On the other hand, shorter photoperiods reduced the rate of floret development. Green *et al.* (1985) found linear decrease in maximum grain yield due to delayed sowing. They also found that early sowing induced faster production of tillers and consequently gave higher maximum tillers and tended to accumulate dry matter at a faster rate and provided the highest grain yield led by optimum temperature during the growth period. High temperature at the later stages of growth reduced grain yield in 17 December (S₃) and 1 January (S₄) sowings in the present study. High

temperature at the later stages of growth (particularly at the grain filling period) reduced grain weight, which resulted in lower grain yield. Similar results were reported by Stone and Nicolas (1995), Savin and Nicolas (1996), Savin *et al.* (1996), Wallwork *et al.* (1998), Savin and Nicolas (1999), Borowczak *et al.* (2003), Afzal *et al.* (2006) and Alam *et al.* (2007b). In the present study, higher grain yield was obtained from 17 November (S_1) sown crops in both the years. It might be due to effect of optimum temperature at the vegetative and reproductive stages that provided highest number of fertile tillers plant⁻¹, number of spikelets spike⁻¹ and highest 1000-grain weight.

In the present study, higher grain yield was obtained from the mulched plants than non-mulched plants. Similar results were reported by Niu *et al.* (2004), Huang *et al.* (2005), Islam *et al.* (2005), YanJun *et al.* (2005), Islam *et al.* (2006), Singh *et al.* (2011) and Khan *et al.* (2014). Among the mulch treatments significantly the highest grain yield was obtained from black polythene mulching (M_4) and the lowest was obtained from M_1 (control) in both the years (Tables 24a and 24b). Similar result was reported in wheat by Mondal *et al.* (2007).

Significantly the S_1 plants produced the highest straw yield and the S_4 plants produced the lowest straw yield in both the years (Tables 24a and 24b). Late sowing gave lower straw yield in the present study. Similar result was reported in wheat by Rani *et al.* (2000) and Ram *et al.* (2004) and in barley by Ahmed *et al.* (2006). Mulched plants gave the higher straw yield and the control treatment produced the lowest straw yield in both the years. Significantly the highest straw yield was obtained from black polythene mulching (M_4) and the lowest was obtained from control

(M₁). Between the two varieties, Bijoy produced higher straw yield than Gourab in both the years (Tables 24a and 24b).

Biological yield also differed significantly due to variation in sowing dates in both the years. The S₁ plants produced the highest biological yield and the S₄ plants produced the lowest biological yield in both the years. Between the two varieties, Bijoy produced higher biological yield than Gourab. Mulching had significant effect on biological yield in both the years. Significantly the highest biological yield was obtained from black polythene mulching (M₄) and the lowest was obtained from control (M₁) in both the years.

Harvest index is the proportion of economic yield and biological yield. As grain yield was higher in S₁ (November 17 sowing), harvest index was also to be higher in S₁ followed by S₂, S₃ and S₄ in both the years. Similar results were reported in wheat by Samuel *et al.* (2000), Haque (2000) and Ram *et al.* (2004) and in barley by Alam (2003) and Alam *et al.* (2007b). Numerically the highest harvest index was obtained from black polythene mulching (M₄) and the lowest was obtained from M₁ (control) in both the years. Between the two varieties, Bijoy showed higher HI than Gourab in both the years (Tables 24a and 24b).

The overall results of the present investigation revealed that TDM, LAI, CGR, RGR, RLGR and LWR were higher for 17 November sowing (S₁) and the lowest for S₄ sowing (1 January) in both the years. Delay in sowing decreased the number of days for attaining different phenological stages. Moisture retention capacity (MRC) and relative leaf water content (RLWC) of the flag leaves were higher in the early-sown crops (S₁) and the lowest values were recorded in the late-sown crops (S₄). The S₁ crops

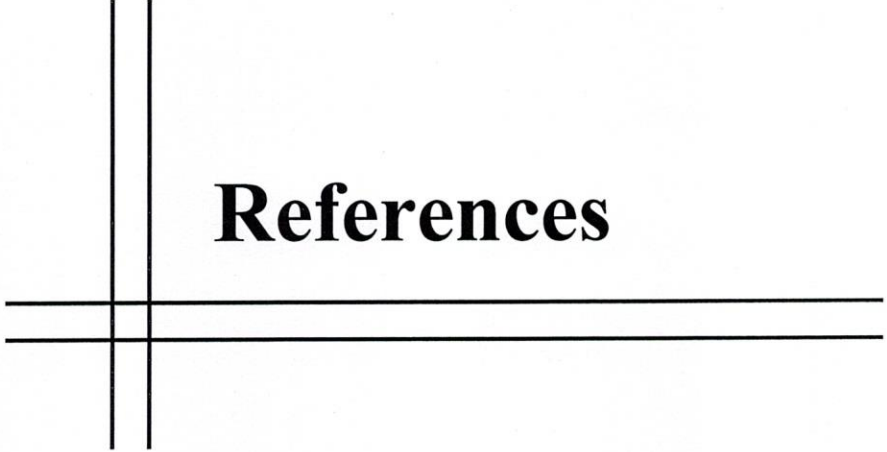
contained the highest amount of chlorophyll a, chlorophyll b and the total chlorophyll (a+b) than the other sowings. Sowing dates were less effective on chlorophyll a:b. Chlorophyll a, chlorophyll b and the total chlorophyll (a+b) were higher in the early-sown crops and declined with delay in sowing. The highest heat units were required in the early-sown crops. Early sown crops had the highest HTU, PTI and HUE at all the phenological stages. All the yield components i.e., plant height, number of effective tillers plant⁻¹, number of fertile spikelets spike⁻¹, spike length, 1000-grain weight, straw yield, grain yield and harvest index were higher in the S₁ (17 November sowing) crops and the lowest values were found in S₄ (1 January sowing) crops.

Between the two varieties, Bijoy produced higher TDM, LAI and CGR values. Higher MRC, RLWC, chlorophyll content, GDD, PTI, HTU and HUE were found in Bijoy. Higher plant height, number of effective tillers plant⁻¹, number of fertile spikelets spike⁻¹, spike length, 1000-grain weight, straw yield, grain yield and harvest index were observed in Bijoy.

The investigation also indicated that the mulched crops gave the better performance than the non-mulched crops. With few exceptions, growth characters like TDM, LAI, CGR, NAR and LWR values were higher in M₄ crops. The M₄ crops contained the highest amount of chlorophyll a, chlorophyll b and the total chlorophyll (a+b) than the other mulching. The highest heat units were required in the M₄ crops. The crops mulched with black polythene had the highest HTU, PTI and HUE at all the phenological stages. All the yield components i.e., plant height, number of effective tillers plant⁻¹, number of fertile spikelets spike⁻¹, spike length, 1000-grain weight, straw yield, grain yield, biological yield and harvest

index were higher in the M_4 crops and the lowest values were found in M_1 crops (control).

From the results of the present study, it can be concluded that the crops sown in 17 November performed better for all the yield and yield contributing characteristics as well as growth and all other parameters. Other sowings like 2 December, 17 December and 1 January may be harmed by the weather and climatic hazards. Application of black polythene mulch performed better for all the growth parameters, yield and yield contributing characters and all other characteristics. Therefore, to get higher yield of wheat, variety Bijoy may be recommended for sowing at 17 November with black polythene mulching.



References

REFERENCES

- Abdel-Raouf, M.S., A. Kandil, E.M.S. Gheith and N. Mahros. 1983a. Associations between growth attributes of barley and grain yield under different seeding dates. *Ann. Agric. Sci.* 19(1): 45-55.
- Abdel-Raouf, M.S., A. Kandil, E.M.S. Gheith and N. Mahros. 1983b. Barley grain yield and its components as affected by seeding and harvesting dates. *Ann. Agric. Sci.* 19(1): 57-67.
- Abrol, Y.P., A.K. Bagga, N.V.K. Chakravarty and P.N. Wattal. 1991. Impact of rise in temperature on the productivity of wheat in India. *In: Abrol, Y.P. et al., Impact of global climatic change on photosynthesis and plant productivity*, Oxford and IBH Pub. New Delhi, India.
- Acevedo, E., M. Nachit and G.O. Ferrana. 1991. Effects of heat stress on wheat and possible selection tools for use in breeding for tolerance *In: Saunders D.A. (ed.). Wheat for the non-traditional warm areas.* pp. 401-420.
- Afzal, A., S. Ahmad, A. Khan and M. Amin. 2006. Comparison of wheat and barley for yield and yield components under different irrigation patterns. *Sarhad J. Agric.* 22 (1): 7-11.
- Ahamed, K.U., K. Nahar, M. Fujita and H. Mirza. 2010. Variation in plant growth, tiller dynamics and yield components of wheat (*Triticum aestivum* L.) due to high temperature stress. *AAB-Bioflux.* 2(3): 213-224.

- Ahmed, M. and S. Farooq. 2013. Growth and physiological responses of wheat cultivars under various planting windows. *J. Animal and Plant Sci.* 23(5): 1407-1414.
- Ahmed, S., M.S. Islam, A. Salam and M.F. Hossain. 2006. Effect of sowing time on the yield attributes of barley in High Barind Tract. *Bangladesh J. Agril. Res.* 31(2): 231-239.
- Ahmed, S.M., A. Razzaque and A.B.S. Hossain. 1976. Effect of seeding time and spacing on yield of wheat under irrigated and non-irrigated condition. *Bangladesh. J. Agric.* 1(1): 9-11.
- Ahmed, S.M., E. Hoque and M.A. Hossain. 1975. Studies on the effect of time of sowing on the yield of Mexican wheat. *Bangladesh J. Agric. Res.* 1(2): 1-6.
- Ahmed, Z.I., M. Ansar, M. Iqbal and N.M. Minhas. 2007. Effect of planting geometry and mulching on moisture conservation, weed control and wheat growth under rainfed conditions. *Pak. J. Bot.* 39(4): 1189-1195.
- Ahmed, Z.I., M. Ansar, M. Iqbal and N.M. Minhas. 2009. Effect of different planting geometry and wheat straw mulch on performance of wheat under rainfed conditions of Pothowar. *Pak. J. Agric. Res.* 22 (3,4): 112-115.
- Alam, M.N., M.M. Akhter, M.M. Hossain and S.M.M. Alam. 2013. Phenological changes of different wheat genotypes (*Triticum aestivum* L.) in high temperature imposed by late seeding. *J. Biodiversity & Environ. Sci.* 3(8): 83-93.

- Alam, M.Z. 2003. Influence of planting dates and nitrogen levels on growth, grain yield and nitrogen utilization of barley (*Hordeum vulgare* L.) Ph.D. Thesis. Crop Physiology Laboratory, Department of Botany, Rajshahi University, Rajshahi. pp. 61-292.
- Alam, M.Z. and S.A. Haider. 2007. Accumulation of protein, chlorophyll and relative leaf water content in barley (*Hordeum vulgare* L.) in relation to sowing time and nitrogen fertilizer. Res. J. Agric. & Biol. Sci. 3(3): 149-152.
- Alam, M.Z., S.A. Haider and N.K. Paul. 2005. Effects of sowing time and nitrogen fertilizer on barley (*Hordeum vulgare* L.) Bangladesh. J. Bot. 34 (1): 27-30.
- Alam, M.Z., S.A. Haider and N.K. Paul. 2006. Growth attributes of barley (*Hordeum vulgare* L.) cultivars in relation to sowing time. Bangladesh J. Bot. 35(2): 185-187.
- Alam, M.Z., S.A. Haider and N.K. Paul. 2007a. Influence of sowing date and nitrogen fertilizer on the phenology and accumulated heat units in barley. Plant Environ. Dev. 1(2): 75-81.
- Alam, M.Z., S.A. Haider and N.K. Paul. 2007b. Yield and yield components of barley (*Hordeum vulgare* L.) in relation to sowing times. J. Bio-sci. 15: 139-145.
- Alam, P., M. Srivastava, J.B. Khan and N.B. Singh. 2010. Influence of sowing dates on yield contributing traits in bread wheat (*Triticum aestivum* L.). Progressive Agriculture. 10(2): 381-383.

- Al-Khatib, K. and G.M. Paulsen. 1999. High temperature effect on photosynthetic processes in temperate and tropical cereals. *Crop Sci.* 39: 119-125.
- Amrawat, T., N.S. Solanki, S.K. Sharma, D.K. Jajoria and M.L. Dotaniya. 2013. Phenology, growth and yield of wheat in relation to agrometeorological indices under different sowing dates. *Afr. J. Agri. Res.* 8(49): 6366-6374.
- Ansari, A.H., A.M. Khushk, N.A. Arain and M.Y. Memon. 1989. Effect of sowing dates on the growth and yield of wheat cultivars. *Pak. J. Sci. & Indust. Res.* 32(1): 39-42.
- Arabinda, S. and Dolgodvorov. 1994. Study on the growth phase of spring wheat. *Bangladesh J. Agril. Sci.* 21:167-173.
- Asana, R.D. and A.D. Saini. 1962. Studies in physiological analysis of yield. Grain development in wheat relation to temperature, soil moisture and changes with age in sugar content of the stem and in the photosynthetic surface *Indian J. Plant Physiol.* 5:128-171.
- Ashraf, M.Y. and A.S. Bhatti. 1998. Effect of delayed sowing on some parameters of photosynthesis in wheat (*Triticum aestivum* L.). *Wheat information service.* 86: 46-48.
- Ataur Rahman, M., M. Mohabbatullah, C.K. Das, U.K. Sarker and M.M. Alam. 2015. Sowing time and varietal performance of wheat at higher elevation in hill environment at Khagrachari. *Bangladesh J. Agril. Res.* 40(4): 521-528.

- Bagga, A.K. and H.M. Rawson. 1977. Contrasting response of morphologically similar wheat cultivars to temperatures appropriate to warm temperate climates with hot summer-A study in controlled environments. *Aust. J. Plant Physiol.* 4:877-887.
- Bahadur, M.M. 2008. Physiological attributes and their relationship to yield of barley (*Hordeum vulgare* L.) as affected by irrigation and sowing time. Ph.D. Thesis. Crop Physiology Laboratory, Department of Botany, University of Rajshahi, Rajshahi.
- Bahadur, M.M., M.A. Hasan, M.O. Islam, M.Z.R. Chawdhury and S. Sikder. 2004. Effect of different sowing dates on phenology, morphology and yield of three modern wheat varieties. *J. Sci. Tech.* 2: 77-83.
- Baker, R.C. 1984. Water relations *In: Advanced Plant Physiology* (edited by Wilkins, M.B.). Pitman Publishing Ltd. London. pp. 297-318.
- Baloch, M.S., I.T.H. Shah, M.A. Nadim, M.I. Khan and A.A. Khakwani. 2010. Effect of seeding density and planting time on growth and yield attributes of wheat. *J. Animal & Plant Sci.* 20(4): 239-242.
- BARI (Bangladesh Agricultural Research Institute). 1997. Increase wheat cultivation and decrease irrigation cost (A folder in Bangla). Wheat Research Centre, Bangladesh Agril. Res. Inst. Nashipur, Dinajpur.
- BARI (Bangladesh Agricultural Research Institute). 2004. Krishi Projukti Hatboi (Hand book of Agrotechnology) (3rd Edn). Bangladesh Agril. Res. Inst. Joydevpur, Gazipur.

- BARI (Bangladesh Agricultural Research Institute). 2006. *Krishi Projukti Hatboi* (Hand book of Agrotechnology) (4th Edn). Bangladesh Agril. Res. Inst. Joydevpur, Gazipur. pp. 8-11.
- BARI (Bangladesh Agricultural Research Institute). 1992. Effect of sowing time and nitrogen levels on plant growth, nitrogen uptake pattern and yield of wheat. Annual Report of 1991-92. Bangladesh Agril. Res. Inst. Joydevpur, Gazipur. p.33.
- Barrs, H.D. and P.E. Weatherly. 1962. A re-examination of the relative turgidity technique for estimating deficits in leaves. *Aust. J. Biol. Sci.* 15: 413-428.
- BBS (Bangladesh Bureau of Statistics). 2012. Statistical Yearbook of Bangladesh Statistical Division, Ministry of Planning, Government of the People's Republic of Bangladesh.
- Begum, F.A. and N.K. Paul. 1993. Influence of soil moisture on growth, water use and yield of mustard. *J. Agron. & Crop Sci.* 170: 136-141.
- Berrada, A. 1979. Trials on barley cultivation in the arid zone. *Hommes. Terre et Eau.* 9(35): 17-27.
- Bhatta, M.R., J.E. Hernandez and J.S. Lates. 1994. Possibilities of selection wheat with fast grain filling rate for warmer areas. pp. 375-378. *In: Saunders, D.A. and G.P. Hattel (eds.), Wheat in heat stress environments, irrigated, dry areas and rice-wheat farming system, Mexico, D.F. CIMMYT.*

- Bishnoi, O.P., R. Niwas, S. Singh and M. Singh. 1996. Study of micro climate conditions under different environments in wheat crop. *Agril. Meteorol.* 47:81-84.
- Bishnoi, O.P., S. Singh and R. Niwas. 1995. Effect of temperature on phenological development of wheat (*Triticum aestivum*). *Indian J. Agril. Sci.* 65(3): 211-214.
- Biswas, S.K and S.S.L. Srivastava. 2010. Influence of sowing date on occurrence of spot blotch and yield of wheat varieties in eastern Uttar Pradesh. *Indian Phytopathology.* 63(2): 203-206.
- Bonari, E. and M. Macchia. 1980. Autumn and spring barley cultivars and sowing date. *Sementi Elette.* 26(1):23-29.
- Boonchoo, S., S. Fukai and E. Suzan Hetherington. 1998. Barley yield and grain protein concentration as affected by assimilate and nitrogen availability. *Aust. J. Agril. Res.* 49:695-706.
- Borowczak, F., S. Grzes and K. Rebarz. 2003. Influence of irrigation and cultivation system on the yields, yielding components and quality of sowing materials of winter wheat, spring barley and pea. *J. Res. Applications in Agril. Eng.* 48(3): 38-42.
- Bu, Y.S., H.L. Shao and J.C. Wang. 2002. Effects of different mulch materials on corn seedling growth and soil nutrients' contents and distributions. *J. Soil Water Cons.* 16 (3): 40-42.
- Campbell C.A. and D.W.L. Read. 1968. Influence of air temperature, light intensity and soil moisture on the growth, yield and some growth analysis characteristics of chioiolo wheat grown in the growth chamber. *Can. J. Plant Sci.* 48: 299-311.

- Chakrabarti, B., S.D. Singh, V. Kumar, R.C. Harit and S. Misra. 2013. Growth and yield response of wheat and chickpea crops under high temperature. *Indian J. Plant Physiol.* 18(1): 7-14.
- Chakraborty, D., S. Nagarajan, P. Aggarwal, V.K. Gupta, R.K. Tomar, R.N. Garg, R.N. Sahoo, A. Sarkar, U.K. Chopra, K.S. Sarma and N. Kalra. 2008. Effect of mulching on soil and plant water status and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agril. Water Managt.* 95 (2): 1323-1334.
- Chakravarty, N.V.K., B.N. Murty and P.S.N. Pandey. 1984. Degree days and biomass accumulation in different genotypes of barley. *Indian J. Plant Physiol.* 27: 290-294.
- Chanda, S.V., A.K. Joshi, P.P. Vaishnav and Y.D. Singh. 1987. Growth analysis using classical and curve-fitting methods in relation to productivity in pearl millet (*Pennisetum americanum* L.). *J. Agron. & Crop Sci.* 159: 312-319.
- Chandrasekar, V., R.K. Sairam and G.C. Srivastava. 2000. Physiological and biochemical responses of hexaploid and tetraploid wheat to drought stress. *J. Agron. & Crop Sci.* 185(4): 219-227.
- Chaturvedi, G.S., P.K. Aggarwal, A.K. Singh and S.K. Sinha. 1985. Effect of date of sowing on the relative behaviour of mother shoot and tillers of wheat. *Indian J. Agric. Sci.* 55:87-98.
- Chaves, M.M. 1991. Effects of water deficits on carbon assimilation. *J. Exp. Bot.* 234: 1-16.

- Chawla, S.L. 2006. Effect of irrigation regimes and mulching on vegetative growth, quality and yield of flowers of African marigold. Ph.D. Thesis, Department of Horticulture, Maharana Pratap University of Agriculture and Technology, Udaipur, India.
- Chetal, S., D.S. Wagle and H.S. Nainawatee. 1982. Chemical composition of wheat and barley leaves under water stress. Haryana Agril. University J. Res. 12(1): 50-54.
- Chinoy, J.J. and S.N. Sharma. 1957. The development of grains in cereals: Varietal differences in the growth of wheat grains in three dimensions and the influence external conditions. (In Russian) Plant Breed. Abstr. 28: 1526.
- Chinoy, J.J. and S.N. Sharma. 1958. The development of grains in cereals: II. Varietal differences in the process of grain filling and dessication as affected by temperature. (In Russian) Plant Breed. Abstr. 29:1396.
- Choi, H.G., K.J. Choi, H.K. Lim and D.K. Lee. 1986. Effect of plant density on yield and protein content of malting barley. Research Reports of the Rural Development Administration, Korea Republic. 28(1): 107-112.
- Chowdhury, S.I. and I.F. Wardlaw. 1978. The effect of temperature on kernel development in Cereals. Aust. J. Agric. Res. 29: 205-223.
- Chowdhury, M.Z.R. 2002. Effect of different sowing dates on morpho physiological feature, yield and yield contributing characters of three modern wheat varieties. M.S. Thesis, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh. p.41.

- Chun JongUn, Choi HaeSik and Nam Jungllyun. 2000. Effect of seeding date and rate on growth and yield of barley cultivar 'Duwonchapssalbori' in southern region. Korean J. Crop Sci. 45(1): 14-19.
- Conry, M.N. and A. Hegarty. 1992. Effect of sowing date and seeding rate on the grain yield and protein content of winter barley. J. Agril. Sci. 118(3): 279-287.
- Dabre, W.M., S.B. Lall and G.L. Ingole. 1993. Effect of sowing dates on yield, ear number, stomatal frequency and stomata index in wheat. J. Maharashtra Agric. Univ. 18(1):65-66.
- DAE (Department of Agricultural Extension). 2013. Ministry of Agriculture, Government of the People's Republic of Bangladesh.
- Darwinkel, A., B.A. Ten Hag and J. Kuizenga. 1977. Effect of sowing date and seed rate on crop development and grain production of winter wheat. Neth. J. Agric. Sci. 25:83-94.
- Dawson, I.A. and I.F. Wardlaw. 1989. The tolerance of wheat to high temperatures during reproductive growth. III. Booting to anthesis. Aust. J. Agril. Res. 40: 965-980.
- Day, A.D. and S. Intalap. 1970. Some effect of soil moisture stress on the growth of wheat (*Triticum aestivum* L.). Agron. J. 62: 27-29.
- Deora, V.S., M.A.A. Shah and A. Joshi. 2001. Effect of moisture stress on wheat genotypes. Crop Res. Hisar. 21(1): 24-26.

- Depar, N., J.A. Shahi and M.Y. Memon. 2014. Effect of organic mulching on soil moisture conservation and yield of wheat (*Triticum aestivum* L.). Pak. J. Agri. Eng. Vet. Sci. 30(1): 54-66.
- Dogiwal, G. and R.K. Panu. 2003. Effect of sowing time on phenology, thermal requirement and yield of wheat varieties. Research on Crops. 4(1): 19-26.
- Ekeberg, E. 1994. Trials with different sowing dates in 1985-89. Norsk Landbruksforskning. 8(2): 155-175.
- Englemann, R. 1982. The relation between maximum rate of photosynthesis and concentration of chlorophyll. Gen. Physiol. 12:609-622.
- Eslami, H., H.N. Navae, A.R. Alazmani and A.N. Shojaei. 2014. Effect of sowing dates and seeding density on yield of wheat (*Triticum aestivum* L.). International Res. J. App. & Basic Sci. 8(7):836-838.
- FAO (Food and Agriculture Organization). 2010. Production Yearbook. Food and Agriculture Organization, Rome.
- FAO (Food and Agriculture Organization). 2013. Production Yearbook. Food and Agriculture Organization, Rome.
- Farzadi, H. and S.N.S. Masoum. 2013. Effect of cover crops on weeds dry matter and grain yield of wheat cv. Chamran in north Khuzestan in Iran. J. Seed & Plant Production. 29(4): 569-581.
- FengMin, L., W. Jun, X. JinZhang and X. HuiLian. 2004a. Productivity and soil response to plastic film mulching durations for spring

- wheat on entisols in the semiarid Loess Plateau of China. *Soil and Tillage Res.* 78(1): 9-20
- FengMin, L., W. Ping, W. Jun and X. JinZhang. 2004b. Effects of irrigation before sowing and plastic film mulching on yield and water uptake of spring wheat in semiarid Loess Plateau of China. *Agril. Water Management.* 67(2): 77-88.
- Fergani, M.A., M.S. El-Habbal and M.E. El-Temsah. 2014. Interpretation of three wheat cultivars yield and its components with reference to sowing dates. *Field Crops Res.* 91(1): 71-81.
- Fischer, R.A. 1985. Physiological limitations to producing wheat in semi-tropical and tropical environments and possible criteria. In: R.C. Vaillareal and A.R. Klatt (Eds.), *Wheat for more tropical environments.* p. 209-230.
- Fischer, R.A. and R. Maurer. 1976. Crop temperature modification and yield potential in a dwarf spring wheat. *Crop Sci.* 16: 855-859.
- Frank, A.B., A. Bauer and A.L. Black. 1992. Effects of air temperature and fertilizer nitrogen on spike development in spring barley. *Crop Sci.* 32(3): 793-797.
- Gales, K. and N.J. Wilson. 1979. Effect of water shortage on growth and yield of winter wheat. *Agricultural Research Council, Letcomb Laboratory, Wantage, UK.* pp. 44-45.
- Gardner, F.P., R.B. Pearce and R.I. Mitchell. 1985. *Physiology of Crop Plants.* Iowa State Univ. p. 66.

- Gavhane, V.N., P.N. Rasal, K.D. Bhoite and D.A. Gadekar. 2007. Evaluation of bread wheat (*Triticum aestivum* L.) genotypes for growth, heat unit consumption and thermal use efficiency under high temperature stress conditions. *New Botanist*. 34(1/4): 135-140.
- Gheith, E.M.S., O.Z. El-Badry and S.A. Wahid. 2013. Sowing dates and nitrogen fertilizer levels effect on grain yield and its components of different wheat genotypes. *Research J. Agril. & Bio. Sci.* 9(5): 176-181.
- Ghosh, D.C., P. Nandi and B. De. 2000. Phenological development and productivity of wheat (*Triticum aestivum* L.) at different dates of sowing. *Indian J. Agric. Sci.* 70(6):390-395.
- Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research. 2nd Edn. John Willey and Sons, New York. pp. 97-111.
- Green, C.F. and J.D. Ivins. 1985. Time of sowing date and the yield of winter wheat. *J. agric. Sci., Camb.* 104:235-238.
- Green, C.F., D.T. Furmsion and J.D. Ivins. 1985. Effect of time of sowing and the yield of winter barley (*Hordeum distichum* L. cv. Igri.). *J. agric. Sci., Camb.* 104: 405-411.
- GuiXia, Y., Z. GuangCai, Xu-Ke, C. XuHong, Y. YuShuang, M. ShaoKang, F. Ming and X. FengJiao. 2010. Effect of sowing date and density on grain yield and nutrition quality and physiological index of wheat. *J. Triticeae Crops*. 30(4): 687-692.

- Gupta, K.P., S.P. Kurchaina and S.P. Singh. 1968. A study of the dates and rates of planting on the yielding abilities of the dwarf wheat. *Indian J. Agron.* 13(4): 271-275.
- Gupta, R.K., R.K. Naresh, P.R. Hobbs, Z. Jiaguo and J.K. Ladha. 2002. Sustainability of Post-Green Revolution Agriculture. The Rice-Wheat cropping systems of the Indo-Gangetic Plains and China. *In: Ladha, J.K. et al. (eds). Improving the productivity and sustainability of Rice-wheat systems. Issues and impacts.*
- Hafiz, M.H.R. 2007. Response of barley to sowing date and irrigation frequency. M.S. Thesis. Department of Crop Botany, Hajee Mohammad Danesh Science and Technologys University, Dinajpur, Bangladesh.
- Haider, S.A. 2002. Effect of water stress on the physiology and grain yield of four bread wheat (*Triticum aestivum* L.) cultivars. Ph.D. Thesis. Crop Physiology Laboratory, Department of Botany, Rajshahi University. Rajshahi.
- Haque, M.M. 2000. Physiological analysis of yield of wheat (*Triticum aestivum* L.) in relation to sowing date. Ph.D. Thesis. Rajshahi University. Rajshahi.
- Haque, M.M., M.A. Bari Miah, N.K. Paul and M.Z. Alam. 2004. Duration of grain filling and grain weight of wheat as affected by temperature. *J. bio-sci.* 12:61-64.
- Hasan, M. A. and J.U. Ahmed. 2005. Kernal growth physiology of wheat under late planting heat stress. *J. Natn. Sci. Foundation Sri Lanka.* 33(3): 193-204.

- Hesketh, J.D. 1963. Limitations of photosynthesis responsible for differences among species. *Crop Sci.* 3: 493-496.
- Hossain, M.A. and S.M. Farid. 1988. Influence of sowing date and seed rate on two varieties of wheat. *Bangladesh J. Agril. Res.* 13: 36-41.
- Hossain, M.A., N.C.D. Barna, S. Rahman, M.K. Mosumder and M.A. Islam. 1987. Effect of seeding dates on the yield and maturity of spring wheat. *In: Proc. 12th Annual Bangladesh Sci. Conf. BAAS.* pp. 10-11.
- Huang, Y., L. Chen, B. Fu, Z. Huang and J. Gong. 2005. The wheat yields and water use efficiency in the Loess Plateau: straw mulch and irrigation effects. *Agri. Water Management.* 72(3): 209-222.
- Islam, M.S., A.J. Karim, M.S. Hossain and M.M. Masud. 2005. Tillage and mulch effects on some soil physical properties and yield of wheat in shallow red brown terrace soils of Bangladesh. *Sarhad J. Agric.* 21(4): 655-665.
- Islam, M.S., A.J.M. Sirajul Khan and Q.A. Khaliq. 2006. Effect of tillage and mulch on yield and yield attributes of wheat in shallow red brown terrace soils of Bangladesh. *Bangladesh J. Agril. Res.* 31(1): 9-24.
- Islam, N., S.M. Ahmed, A. Sufian and A. Sadeque. 1990. Effect of seeding dates and yield of wheat varieties. *Bangladesh Agron. J.* 3(1&2): 25-30.

- Islam, N., S.M. Ahmed, M.A. Razzaque, A. Sufian and M.A. Hossain. 1993. A study on the effect of seeding dates on the yield of wheat varieties. Bangladesh J. Agril. Res. 18 (1): 102-107.
- Jain M.P., J.P. Dixit, P.V.A. Pillai and R.A. Khan. 1992. Effect of sowing date on wheat varieties under late sown irrigated condition. Indian J. Agric. Sci. 62: 669-671.
- Jana, P.K. and A.K. Mitra. 1995. Effect of irrigation on growth, yield and consumptive use efficiency of wheat in terai soils of North Bengal. In: Mandal, N.C., M.K. Dasgupta, D.C. Ghosh, S.K. Mokhopadhyay, D. Desgupta and D. Majumdar. (eds.) Proc. Agroecosystem Management. Birbhum, India. pp. 52-184.
- Jat, L.K., S.K. Singh, A.M. Latore, R.S. Singh and C.B. Patel. 2013. Effect of dates of sowing and fertilizer on growth and yield of wheat (*Triticum aestivum*) in an Inceptisol of Varanasi. Indian J. Agron. 58(4):611-614.
- Jepsen, H.M. 1985. Sowing date and sowing rate for different soil types Nordisk Jordbrugsforskning. 67(2): 182.
- Joshi, N.L. and H.G. Singh. 1983. Performance of wheat varieties under different sowing dates on semiarid lands. Indian J. Agron. 28(1): 54-58.
- Karim, M.A., A. Hamid and M.S. Rahman. 1999. Grain growth and yield performance of wheat under subtropical conditions. I. Effect of sowing dates. Cereal Res. Comm. 27(4): 439-446.

- Kariya, K. and S. Tsunoda. 1971. Relationship of chlorophyll content, chloroplast area index and leaf photosynthesis rates in *Brassica*. Tohoku J. Agril. Res. 23:1-14.
- Karmakar, S. and M.L. Shrestha. 2000. Recent climate change in Bangladesh. SMRC No.4. SAARC Meteorological Research Centre, Agargaon, Dhaka, Bangladesh.
- Kaur, A., R.K. Pannu and G.S. Buttar. 2010. Splitting of nitrogen dose affects yield and net returns in wheat sown on different dates. Indian J. Ecol. 37(1): 18-22.
- Kaur, V. and R.K. Behl. 2010. Grain yield in wheat as affected by short periods of high temperature, drought and their interaction during pre- and post-anthesis stages. Cereal Res. Comm. 38(4): 514-520.
- Kerr, N.J., R.J. Delance and K.H.M. Siddique. 1992. Early sowing wheat cultivar of suitable maturity increase grain yield of spring wheat in a short season environment (Western Australia). Aust. J. Exp. Agric. 32 (6): 717-723.
- Khan, R.H., A.H. Khalid and M.R. Sajjad. 2014. Effect of different types of mulches on grain yield and yield components of wheat (*Triticum aestivum*) under rainfed condition. J. Biol. Agric. & Healthcare. 4(12): 85-91.
- Khatkar, D.A. and M.S. Kuhad. 2000. Short term salinity induced changes in two wheat cultivars at different growth stages. Biol. Planta. 43(4): 624-632.

- Khokhar, Z., I. Hussain, B. Khokhar and M. Sohail. 2010. Effect of planting date on yield of wheat genotypes in Sindh. Pak J. Agril. Res. 23(3/4): 103-107.
- Khurshid, K., M. Iqbal, M.S. Arif and A. Nawaz. 2006. Effect of tillage and mulch on soil physical properties and growth of maize. Internat. J. Agric. & Biol. 8: 593-596.
- Kifayat-Ur-Rahman, A. Jabber, T. Mohammad and S.A. Shah. 1991. Investigations on heading time and grain yield of wheat mutants as affected by different seeding dates. Sarhad J. Agric. 7(3): 351-356.
- Kour, M., K.N. Singh, D. Kachroo and N.P. Thakur. 2011. Yield potential and simulation studies of wheat (*Triticum aestivum*) genotypes as influenced by sowing dates under temperate Kashmir. Indian J. Ecol. 38(1): 44-48.
- Kozłowska-Ptaszynska, Z. 1993. Changes in the structure and architecture of the plant canopy of two and six-rowed spring barley cultivars as influenced by sowing date. Pamietnik Pulawski. 102:53-64.
- Kumar, R. and S.N. Sharma. 1999. Effect of nitrogen on dry matter and nutrient accumulation pattern in wheat (*Triticum aestivum*) under different dates of sowing Indian J. Agron. 44(4): 738-744.
- Kumar, R., G. Mahajan, M.K. Yadav and D.C. Keim. 2010. Effect of sowing dates and varieties on growth, yield and quality of wheat (*Triticum aestivum* L. emend Fiori & Paol.). Environ. & Ecol. 28(3A): 1920-1924.

- Kumar, S.D. and B.R. Lal. 2012. Effect of mulching on crop production under rainfed condition: A review. *Int. J. Res. Chemistry & Environ.* 2 (2): 8-20.
- Kumari, P.S. and S.K. Sinha. 1972. Variation in chlorophylls and photosynthetic rate in cultivars of Bengal gram (*Cicer arietinum* L.) *Photosynthetica*. 6: 189-199.
- Kuroyanagi, T. and G.M. Paulsen. 1985. Mode of temperature injury to wheat. II. Comparisons of wheat and rice with and without inflorescence. *Plant Physiol.* 65:203-208.
- Laghari, K.A., M.A. Sial and M.A. Arain. 2012. Effect of high temperature stress on grain yield and yield components of wheat (*Triticum aestivum* L.). *Sci. Tech. & Dev.* 31(2): 83-90.
- Lupu, C. 2001. Influence of sowing time on yield and productivity elements in winter wheat in hilly region of Moldavia. *Analele Institutului de Cercetari Pentru Cereal si Plante Tehnice, Fundulea*. 68:207-214.
- Maecka, I. 2002. Successive effect of cover crops and nitrogen fertilization on winter triticales yield. *Folia Universitatis Agriculturae Stetinensis, Agricultura*. 91: 75-80.
- Makki, Y.M. and M.M. Habib. 1979. Effect of sowing date on yield and yield components of barley grown in the central region of Saudi Arabia. *Proceedings of the Saudi Biological Society*. 3: 25-34.
- Masoni, A., L. Ercoli and F. Massantini. 1990. Relationship between number of days, growing degree days and phenothermal units and

- growth in wheat (*Triticum aestivum* L.) according to seeding time. *Agricultura-Mediterranea*. 120: 41-51.
- Miralles, D.J., R.A. Richards and G.A. Slafer. 2000. Duration of the stem elongation period influences the number of fertile florets in wheat and barley. *Aust. J. Plant Physiol.* 27(10): 931-940.
- Mohiuddin, G. 2010. Growth and yield of some HYVs of wheat (*Triticum aestivum* L.) as affected by sowing dates and soil moisture. Ph. D. Thesis. Crop Physiology Laboratory, Department of Botany, Rajshahi University, Rajshahi.
- Mollah, M.S.I. 2007. Physiological attributes of barley as affected by soil moisture regimes and NPK fertilizer. Ph.D. Thesis. Rajshahi University, Bangladesh.
- Mondal, N.A., S.M.A. Hossain, S.U. Bhuiya and M. Jahiruddin. 2007. Influence of tillage and mulching on the growth and yield of rainfed wheat. *Bangladesh J. Agril. Res.* 32(4): 649-661.
- Morgan, J.M. 1971. The death of spikelets in wheat due to water stress. *Aust. J. Exp. Agric. & Animal Husb.* 11: 249-251.
- Moula, M.G., S. Begum and M.M. Haque. 1996. Effect of sowing date and row direction on the yield of wheat, *Triticum aestivum* L. *J. bio-sci.* 4: 27-32.
- Mucci, F., L. Postiglione and M.M.R. Lanza. 1985. A study on growth development and yield of wheat (*Triticum durum* Desf. and *Triticum aestivum* L.) and lupins (*Lupinus albus* L.) under different

- environmental conditions. *Rivista-di-Agronomia* 19:4
(Supplement): 333-346.
- Mudholkar, N.J. 1981. Evaluation of dwarf durum and aestivum wheat under varying planting dates in North eastern plains of India. *Indian J. Agron.* 26(1): 32-36.
- Muhammad, A.P., I. Muhammad, S. Khuram and Anwar-ul-Hassan. 2009. Effect of mulch on soil physical properties and NPK concentration in maize (*Zea mays*) shoots under two tillage system. *Int. J. Agric. & Biol.* 11: 120-124.
- Muramoto, H., J.D. Hesketh and M. El-Sharkawy. 1965. Relationship among rate of leaf area development, photosynthetic rate and rate of dry matter production among cultivated cottons and other species. *Crop Sci.* 5: 163-166.
- Narayanasamy, G. 1999. Fundamentals of Soil Science, Indian Society of Soil Science, IARI, New Delhi. pp.145-157.
- Nass, H.G., H.W. Johnston, J.A. Macleod and D.E. Sterling. 1975. Effect of seeding date, seed treatment and foliar sprays on yield and other agronomic characters of wheat, oats and barley. *Can. J. Plant Sci.* 55: 41-47.
- Nazrul-Islam, A.K.M. 1988. Tissue water relations of *Cassia tora* from sun and shaded habitats. In: Proceedings of 3rd International Rangeland Congress, Held at New Delhi. pp. 243-246.
- Ning, Y., P. XueBiao, Z. LiZhen, W. Jing, D. WanLin, Hu-Qi, L. QiuYue, W. XiaoXiao, T. JianZhao, L. Zhe and Z. PeiYi. 2014.

- Optimal sowing dates improving yield, water and nitrogen use efficiencies of spring wheat in agriculture and pasture ecotone. Transactions of the Chinese Society of Agril. Eng. 30(8): 81-90.
- Niu, J.Y., Y.T. Gan and G.B. Huang. 2004. Dynamics of root growth in spring wheat mulched with plastic film. Crop Sci. 44(5): 1682-1688.
- Noworolnik, K. 1989a. Sowing date effect on spring barley grain yield and its structure. Biuletyn Instytutu Hodowli Aklimatyzacji Roslin. 169: 177-181.
- Noworolink, K. 1989b. Response of winter barley to soil conditions, nitrogen application, sowing date and sowing rate. Pamietnik Pulawski. 94: 237-244.
- Noworolink, K. and A. Pecio. 1990. Effect of nitrogen fertilizer application and sowing date and rate on the magnitude and structure of grain yield of winter barley cultivars. Biuletyn Instytutu Hodowli Aklimatyzacji Roslin. 175: 55-62.
- Noworolink, K. and D. Leszczynska. 1997. Yields of spring barley cultivars and lines depending on sowing date. Biuletyn Instytutu Hodowli Aklimatyzacji Roslin. 201: 225-230.
- Nyachiro, J.M., K.G. Briggs, J. Hoddinott and A.M. Johnson-Flangun. 2001. Chlorophyll content, chlorophyll fluorescence and water deficit in spring wheat. Cereal Res. Comm. 29(1-2): 135-142.

- Pahwa, S. and D.S. Gill. 2010. Influence of sowing date on yield and its components of wheat (*Triticum aestivum* L.) genotypes. *Environ. & Ecol.* 28(4): 2232-2234.
- Pakdel, P., A. Tehranifar, H. Nemati, A. Lakzian and M. Kharrazi. 2013. Effect of different mulching materials on soil properties under semi-arid conditions in northeastern Iran. *Wudpecker. J. Agric. Res.* 2 (3): 80-85.
- Pal, B.P. and W.T. Butany. 1947. Influence of late sowing on yield and other plant characters in wheat and the possibility of breeding varieties specially for the late sowing. *Indian J. Genet.* 7: 43-54.
- Pandey, R.K., M.C. Saxena and V.B. Singh. 1978. Growth analysis of black gram genotypes. *Indian J. Agric. Sci.* 48: 466-473.
- Pandit, J.C., A.M.A. Kamal, S.M.A. Hossain and M.I. Ali. 2001. Effect of variety and irrigation on yield and protein content of wheat. *Bangladesh J. Crop Sci.* 12(1&2): 87-95.
- Paramjit, V.P. Singh and K. Anureet. 2001. Effect of different levels of nitrogen and irrigation on growth and yield of malt barley var. Alfa-93. *Crop Res. Hisar, India.* 21(3): 261-264.
- Patel, C.S., V. Singh and A. Prasad. 1971. Critical stages for irrigation in dwarf wheat Kalyansona. *Indian J. Agron.* 16(3): 165-167.
- Patil, K.S., D.V. Durge and R.S. Shivankar. 2003. Effect of temperature on yield and yield components of early wheat cultivars. *J. Maharashtra Agril. Univ.* 28(1): 34-36.

- Paul, N.K. and D.K. Sarker. 2000. Accumulated heat units and phenology relationship in wheat as influenced by sowing dates. Bangladesh J. Bot. 29(1): 49-54.
- Paul, N.K. and D.K. Sarker. 2003. Grain yield and its components of wheat (*Triticum aestivum* L.) as influenced by sowing date. Rajshahi Univ. Studies. J. Sci. 31: 169-176.
- Paul, N.K. and D.K. Sarker. 2005. Effect of sowing date on leaf area index, dry matter production and growth of wheat (*Triticum aestivum* L.). J. Bio-sci. 13: 37-43.
- Pauli, A.W., F.C. Stickler and J.R. Lawless. 1964. Developmental phases of grain sorghum (*Sorghum vulgare* Pers.) as influenced by variety, location and planting date. J. Crop Sci. 5: 10-12.
- Pawar, S.N., S.P. Divekar, S.B. Ghule and A.S. Kadale. 2004. Effect of mulching on moisture conservation and yield of summer groundnut crop. J. Soils & Crops. 14(2): 410-413.
- Peng, Z., W. Ting, W. Haixia, W. Min, M. Xiangping, M. Siwei, Z. Rui, J. Zhikuan and H. Qingfang. 2015. Effects of straw mulch on soil water and winter wheat production in dryland farming. J. Environ. Sci. 10:7-25.
- Petr, J., P. Hnilica and J. Schmidt. 1979. Yield formation in spring barley: tillering, ear formation and grains per ear. Rostlinna Vyroba. 25(4): 433-444.

- Photiades, I. and A. Hadjichristodoulou. 1984. Sowing depth, seed rate and row spacing of wheat and barley under dry land condition. *Field Crops Res.* 9(2): 151-162.
- Pirasteh, B. and J.R. Welsh. 1980. Effect of temperature on the heading date of wheat cultivars under a lengthening photoperiod. *Crop Sci.* 20: 453-456.
- Porwal, M.K., L.L. Dhakar, G.S. Bhatnagar and P.C. Chaplot. 1991. Response of barley (*Hordeum vulgare*) varieties to sowing date in Southern, Rajasthan. *Indian J. Agron.* 36(4):596-597.
- Puranik, H.V. and S.R. Patel. 2014. Effect of sowing dates on yield and yield components of wheat cultivars. *J. Agril. Res. & Tech.* 39(2): 347-350.
- Puri, Y.P., C.O. Qualset, M.F. Miller, K.G. Baghott, C.C. Jan and C.D. Pace. 1985. Barley, wheat and triticale grain yield in relation to solar radiation and heat units. *Crop Sci.* 25(6):893-900.
- Qaiyyum, M.A. 1995. Physiological analysis of soil moisture effect on mulberry (*Morus* sp.). Ph.D. Thesis. University of Rajshahi, Bangladesh.
- Radford, P.J. 1967. Growth analysis formulae-their use and abuse. *Crop Sci.* 7: 171-175.
- Radhika, S.K., N. Thind, S. Bains and P. Chhonneja. 2014. Physiological growth - yield relationships in wheat genotypes under sowing date mediated heat stress. *J. Plant Sci. Res.* 30(1): 73-79.

- Rahman, M.A., J. Chikushi, M. Saifuzzaman and J.G. Lauren. 2005. Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. *Field Crops Res.* 91(1): 71-81.
- Rahman, M.S. 1993. Studies on drought adaptation of wheat (*Triticum aestivum* L.) M. Sc. Thesis. University of Rajshahi, Bangladesh.
- Rahman, M.S. and N.K. Paul. 1998. Effect of soil moisture regimes on physiological characters and yield of wheat cultivars. *J. Bio-sci.* 6: 5-10.
- Rahman, M.S., A.M. Sarker, M.A. Islam and N.K. Paul. 2001. Effect of soil moisture on grain yield of wheat (*Triticum aestivum* L.) cultivars. *Environ. & Ecol.* 19(2): 304-308.
- Rajput, R.P. 1980. Response of soyabean crop to climatic and soil environments. Ph.D. Thesis. IARI, New Delhi. India.
- Rajput, R.P., M.R. Deshmukh and V.K. Paradkar. 1987. Accumulated heats units and phenology relationships in wheat (*Triticum aestivum* L.) as influenced by planting dates under late sown conditions. *J. Agron. & Crop Sci.* 159: 345-348.
- Ram, B., S.S. Pahuja and D. Singh. 2004. Effect of sowing time and row spacing on the yield attributes and yield of wheat variety C-306. *Haryana J. Agron.* 20(1/2):105-106.
- Randhawa, A.S. and R.S. Jolly. 1974. Response of wheat variety Sonalika to sowing date, row-spacing and seed rate. *J. Res. Punjab Agric. Univ.* 11(2): 164-167.

- Rani.T., S. Kumar and R.D. Sharna. 2000. Studies on recovery and use efficiency of nitrogen in wheat crop on Typic Ustochrept of Western Uttar Pradesh. J. Indian Soc. Soil. Sci. 48 (2): 292-297.
- Rao, M.H., M.N. Sinha and R.K. Rai. 1980. Effect of dates of sowing and phosphorus levels on wheat and phosphorus utilization. Indian J. Agric. Sci. 50: 236-239.
- Rasal, P.N., V.N. Gavhane, D.V. Kusalkar, A.B. Gosavi and G.N. Shirpurkar. 2006. Effect of high temperature stress on heat susceptibility index and thermal requirement of bread wheat (*Triticum aestivum* L.) genotypes. Research on Crops. 7(3): 811-813.
- RiYao, F., T. Yan'-an and L. DongLi. 2004. Comprehensive effects of different mulching materials on winter wheat productions in Weibei highland. Chinese Society of Agril. Eng. 20(1): 72-75.
- RiYao, F., Z. HuiQing and F. Juan. 2006. Water-saving benefits of different mulching cultivation mode for winter wheat in Weibei Highland. Transactions of the Chinese Soc. Agril. Eng. 22(2): 46-49.
- Saha, S.K. and N.K. Paul. 1995. Growth of five wheat (*Triticum aestivum* L.) cultivars as affected by soil moisture. J. Bio. Sci. 3: 103-112.
- Saifuzzaman, M., S.N. Begum, F. Begum and W. Sultana. 1996. Effect of sowing dates on growth stages of short and long duration wheat (*Triticum aestivum* L.) Bangladesh J. Sci. Ind. Res. 14(1): 31-37.

- Saini, A.D. and V.K. Dadhwal. 1986. Heat unit requirement during the period of grain growth in wheat and its application for adjusting sowing dates in different regions. *Indian J. Agric.* 56(4): 447-452.
- Saini, A.D., V.K. Dadhwal, B.N. Phandnawis and R. Nanda. 1986. Influence of sowing dates on pre-anthesis phenology in wheat. *Indian J. Agric. Sci.* 56:503-511.
- Samanta, S.C., M.A. Gaffer, A.M.A. Kamal and M.A. Samad. 1997. Growth and yield of prosomillet cultivars as influenced by sowing date. *Bangladesh J. Agric. Sci.* 24: 37-41.
- Samuel, S.R., P.S. Deshmukh, R.K. Sairam and S.R. Krshwaha. 2000. Influence of benzyl adenine application on yield and yield components in wheat genotypes under normal and late planting condition. *Indian J. Plant Physiol.* 5(3): 240-243.
- Sandhu, I.S., A.R. Sharma and H.S. Sur. 1999. Yield performance and heat unit requirement of wheat (*Triticum aestivum* L.) varieties as affected by sowing dates under rainfed conditions. *Indian J. Agric. Sci.* 69: 175-179.
- Sarker, S. and M.G.S. Torofder. 1992. Effect of date of sowing and seed rate on wheat (*Triticum aestivum*) under rainfed condition. *Indian J. Agron.* 37(2): 352-354.
- Sarker, A.M. and N.K. Paul. 1997. Effect of soil moisture on growth, yield and quality of wheat. *Rajshahi Univ. Studies. J. Sci.* 25: 247-256.

- Sarker, A.M. and N.K. Paul. 1998. Studies on the growth attributes of wheat under irrigated and rainfed conditions. *Bangladesh J. Bot.* 27(2): 119-126.
- Sarker, A.M., M.S. Rahman and N.K. Paul. 1999. Effect of soil moisture on relative leaf water content, chlorophyll, proline and sugar accumulation in wheat. *J. Agron & Crop Sci.* 183: 225-229.
- Sarker, M.A., R.M.A. Islam and A.K.M. Zakaria. 1986. Performance of some modern cultivars of wheat under different dates of planting. *Bangladesh J. Agril. Sci.* 23:81-86.
- Saunders, D.A. 1988. Crop management research: Summary of results, 1983-88. Monograph No. 5: Wheat Research Centre, Dinajpur, Bangladesh.
- Savin, R. and M.E. Nicolas. 1996. Effect of short periods of drought and high temperature on grain growth and starch accumulation of two malting barley cultivars. *Aust. J. Plant Physiol.* 23(2): 201-210.
- Savin, R. and M.E. Nicolas. 1999. Effects of timing of heat stress and drought on growth and quality of barley grain. *Aust. J. Agril. Res.* 50(3): 357-361.
- Savin, R., P.J. Stone and M.E. Nicolas. 1996. Response of grain growth and malting quality of barley to short periods of high temperature in field studies using portable chambers. *Aust. J. Agril. Res.* 47(3): 465-477.

- Shaid, M.A. and G. Kabir. 1997. Influence of genotype, temperature and photoperiod on post flowering development of wheat. Bangladesh J. Bot. 26(1): 31-36.
- Sharma, K.C. and M. Singh. 1972. Yielding abilities of dwarf wheat (*Triticum aestivum* L.) at different dates of sowing and seed rates. Indian J. Agric. Sci. 42: 1110-1115.
- Sharma, V. and D.R. Thakur. 1996. Effect of irrigation and seed rate on two row malt barley (*Hordeum distichum*) in Kullu valley of H. P. Himachal. J. Agric. Res. 22(1/2): 5-9.
- Sharratt, B. 1999. Thermal requirements for barley maturation and leaf development in interior Alaska. Field Crops Res. 63(2): 179-184.
- Sial, M.A., A.A. Arain, S. Khanzada, M.H. Naqvi, M.U. Dahot and N.A. Nizamani. 2005. Yield and quality parameters of wheat genotypes as affected by sowing dates and high temperature stress. Pakistan J. Bot. 37(3): 575-584.
- Sikder, S. 2008. Physiological basis of heat tolerance in wheat (*Triticum aestivum* L.). Ph.D. Thesis. Crop Physiology Laboratory, Department of Botany, University of Rajshahi, Rajshahi.
- Singh, A.K. and G.L. Jain. 2000. Effect of sowing time, irrigation and nitrogen on grain yield and quality of durum wheat (*Triticum durum*). Indian J. Agric. Sci. 70(8):532-533.
- Singh, B., E. Humphreys, P.L. Eberbach, A. Katupitiya, Y. Singh and S.S. Kukal. 2011a. Growth, yield and water productivity of zero

- tilled wheat as affected by rice straw mulch and irrigation schedule. *Field Crops Res.* 121(2): 209-225.
- Singh, P., P. Dwivedi and J.P. Srivastava. 2014. Response of biochemical, yield and yield components of wheat (*Triticum aestivum* L.) genotypes as affected by different sowing dates. *Vegetos.* 27(1): 149-157.
- Singh, R., A.R. Sharma, S.K. Dhyan and R.K. Dube. 2011b. Tillage and mulching effects on performance of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system under varying land slopes. *Indian J. Agril. Sci.* 81(4): 330-335.
- Singh, R., D. Singh and V.U. Rao. 1992. Effect of date of sowing and row spacing on the yield of wheat (*Triticum aestivum* L.). *Crop Res.* 5(2): 199-206.
- Singh, S., A.S. Dhindwal, P. Sheoran and M.S. Bhattoo. 2005. Dry matter accumulation, partitioning and translocation in late-sown wheat (*Triticum aestivum*) under different irrigation levels. *Ann. Agri-Bio. Res.* 10(2): 151-154.
- Singh, S.K., V.K. Mishra, A. Kumar and U. Srivastva. 2012. Impact of mulching materials on growth, yield and quality of wheat (*Triticum aestivum* L.). *New Agriculturist.* 23(2): 163-170.
- Singha, P., J. Bhowmick and B.K. Chaudhuri. 2006. Effect of temperature on yield and yield components of fourteen wheat (*Triticum aestivum* L.) genotypes. *Environ. & Ecol.* 24(3): 550-554

- Sokoto, M.B. and A. Singh. 2013. Yield and yield components of bread wheat as influenced by water stress, sowing date and cultivar in Sokoto, Sudan Savannah, Nigeria. *American J. Plant Sci.* 4(12): 122-130.
- Stagnari, F., A. Galieni, S. Speca, G. Cafiero and M. Pisante. 2014. Effects of straw mulch on growth and yield of durum wheat during transition to Conservation Agriculture in Mediterranean environment. *Field Crops Res.* 16(7): 51-63.
- Stone, P.J. and M.E. Nicolas. 1995. Effect of timing of heat stress during grain filling on two wheat varieties differing in heat tolerance. *Aust. J. Plant Physiol.* 22: 927-934.
- Sufian, M.A., M.A. Samad, M.A.K. Miah and M.A. Razzaque. 1983. Effect of time of sowing on some important characters of ten wheat genotypes. *Bangladesh J. Agril. Res.* 8: 143-144.
- Tahir, I.S.A., N. Nakata, A.M. Ali, H.M. Mustafa, A.S.I. Saad, K. Takata, N. Ishikawa and O.S. Abdalla. 2006. Genotypic and temperature effects on wheat grain yield and quality in a hot irrigated environment. *Plant Breeding.* 125(4): 323-330.
- Talukder, M.S.U. 1987. Growth and development of wheat as affected by soil moisture stress. *Indian J. Agric. Sci.* 57: 559-564.
- Tarafder, I.H., N.M. Rahmatullah, B.C. Sarker and A. Ahmed. 1996. Effect of tillage and mulching on wheat and maize seedling growth in the himalayan piedmont soil. *Bangladesh J. Agril. Res.* 21(2):211-218.

- Tashiro, T. and I.F. Wardlaw. 1989. A comparison of the effect of high temperature on grain development in wheat and rice. *Ann. Bot.* 64:59-65.
- Thorne, G. N. 1961. Effects of age and environment on net assimilation rate of barley. *Ann. Bot.* 25: 29-38.
- Thorne, G.N. 1960. Variation with age in net assimilation rate and other growth attributes of sugarbeet, potato and barley in a controlled environment. *Ann. Bot.* 24: 256-272.
- Tolk, J.A., T.A. Hawell and S.R. Evett. 1999. Effect of mulch, irrigation and soil type on water use and yield of maize. *Soil Till. Res.* 50: 137-147.
- Tomar, P.S and O.P. Mathur. 1966. Effect of time of sowing on yield of different varieties of barley under water scarcity condition in Rajasthan. *Indian J. Agron.* 11(2): 173-177.
- Usanova, Z.I. 1985. Yield formation of barley and oats sown at different dates. *Izvestiya Timiryazevskoi Sel Skokhozyaistvennoi Akademii.* 6: 27-38.
- Volkova, A.M. and V.A. Koshkin. 1984. The influence of high temperature on photosynthesis and chlorophyll content in spring wheat varieties differing in heat resistance. *Aust. J. Plant Physiol.* 87: 76-81.
- Wahid, A., S. Gelani, M. Ashraf and M.R. Foolad. 2007. Heat tolerance in plants: An overview. *Environ. Exper. Bot.* 61: 199-223.

- Wallwork, M.A.B., S.J. Logue, L.C. Macleod and C.F. Jenner. 1998. Effects of a period of high temperature during grain filling on the grain growth characteristics and malting quality of three Australian malting barleys. *Aust. J. Agril. Res.* 49(8): 1287-1296.
- Wardlaw, I.F., I.A. Dawson and P. Munibi. 1989. The tolerance of wheat to high temperatures during reproductive growth. *Aust. J. Agric. Res.* 40: 15-24.
- Williams, W.A., R.S. Loomis and C.R. Lepley. 1965. Vegetative growth of corn as affected by population density. II. Components of growth, net assimilation rate and leaf area index. *Crop Sci.* 5: 215-219.
- Wood, C.W., H. Brenda Kipling, S. Balkcom, J. Kemble and D. Shannon. 2008. High biomass cover crops and organic mulch effects on soil moisture and weed distribution during collard production. Dept. of Agronomy and Soils, Auburn University.
- YanJun, D., L. ZiZhen and L. WenLong. 2005. Effect of water control and plastic-film mulch on growth and the range of size inequalities in spring wheat (*Triticum aestivum*) populations. *New-Zealand J. Crop & Horticultural Sci.* 33(3): 251-260.
- YanMin, Y., L. XiaoJing, L. WeiQiang and L. CunZhen. 2006. Effect of different mulch materials on winter wheat production in desalinized soil in Heilongjiang region of North China. *J. Zhejiang Univ. Sci.* 7(11): 858-867.
- Zacharias, M., S.D. Singh, S.N. Kumar, R.C. Harit and P.K. Aggarwal. 2010. Impact of elevated temperature at different phenological

stages on the growth and yield of wheat and rice. *Indian J. Plant Physiol.* 15(4): 350-358.

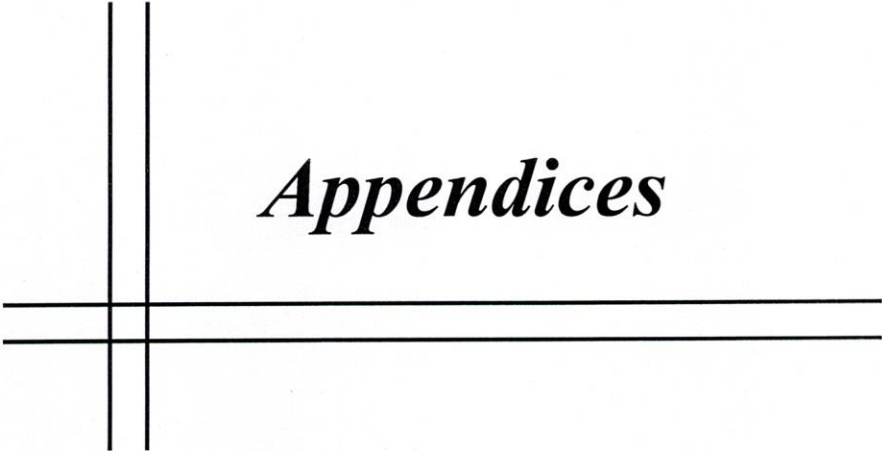
Zamir, M.S.I., G. Yasin, H.M.R. Javeed, A.U.H. Ahmad, A. Tanvir and M. Yaseen. 2013. Effect of sowing technique and mulches on maize. *Cercetari Agronomic in Moldova*.1(153).

Zende, N.B., H.N. Sethi, A.P. Karunakar and D.J. Jiotode. 2005. Effect of sowing time and fertility levels on growth and yield of durum wheat genotypes. *Research on Crops*. 6(2): 190-191.

Zhao, D.C., Z.K. Tang, F.T. Zhu and C. Shi. 1988. Effects of multiple cultural factors on the yield and grain quality of malting barley. *Scientia Agricultura Sinica*. 21(6): 67-73.

Zhao, I.Q., M.Q. Lu and G.M. Li. 1986. Influence of sowing dates on the growth and development of barley cv. Zhepi. *Zhejiang Agril. Sci.* 5: 217-221.

ZhongKui, X., W. YaJun and L. FengMin. 2005. Effect of plastic mulching on soil water use and spring wheat yield in arid region of northwest China. *Agril. Water Management*. 75(1): 71-83.



Appendices

APPENDICES

Appendix I: Morphological characteristics and chemical properties of soils of the experimental area

Constituents	Characteristics	Constituents	Results
Location	Western side of the Dept. of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi	pH	8.5
Land type	Medium high land	Organic matter (OM)	0.84 %
General soil type	Non calcarious dark grey soil	Total Nitrogen (N)	0.04 %
Agro-ecological zone	AEZ-11: High Ganges River Floodplain	Phosphorus (P_2O_5)	19.15 ppm
Topography	Fairly leveled	Potassium (K_2O)	0.27 %
Soil colour	Dark grey	Sulphur (S)	8.90 miliequivalent/100g soil
Drainage	Well drained	Zinc (Zn)	0.10 %

Source: The soil samples of the Agronomy field laboratory, Department of Agricultural Extension as examined by Soil Resources Development Institue, Regional Laboratory, Shyampur, Rajshahi

**Appendix II: Comparative nutritive value of wheat, barley, maize
and rice in every 100 g of available food**

Nutritive value	Wheat	Barley	Maize	Rice
Protein (g)	12.10	11.50	11.10	6.4
Fat (g)	1.7	1.3	3.6	0.4
Fiber (g)	1.9	3.9	2.7	0.2
Carbohydrate (g)	69.4	69.6	66.2	79
Calories	341kcal	336 kcal	342 kcal	346 kcal
Calcium (g)	48	26	10	9
Phosphorus	355 mg	215 mg	348 mg	143 mg
Iron	11.5 mg	3.0 mg	2.0 mg	4 mg
Carotene	29 mg	10 mg	90 mg	-
Thiamine	0.5 mg	0.47mg	0.4 mg	0.2 mg
Riboflavin	0.2 mg	0.20 mg	0.1 mg	0.1 mg
Niacin	4.3 mg	5.40 mg	1.8 mg	3.8 mg
Magnesium	138 mg	127 mg	144 mg	38 mg
Potassium	284 mg	253 mg	286 mg	117 mg
Copper	0.5 mg	0.34 mg	0.2 mg	0.3 mg
Sulphur	128 mg	130 mg	114 mg	79 mg

Ref. Nutritive value of Indian Foods

By Gopalan, C., B.V. Ramasastri and S.C. Basubarnanian (2001)

Appendix IIIa: Mean squares from analysis of variance for total dry matter (g m^{-2}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	0.186	1.93	39.02	25.86	17.71	1852.53	1039.51	6.04
Sowing date (S)	3	239.76**	2404.43**	10404.45**	38626.90**	115279.77**	399548.64**	664250.16**	949822.14**
Error	6	0.124	0.420	21.71	17.93	35.28	480.68	786.38	536.53
Variety (V)	1	225.19**	1903.80**	8316.44**	30606.68**	100270.86**	305066.56**	588125.48**	811394.47**
S×V	3	3.76**	31.05**	139.81**	564.80*	1762.34 NS	5886.27**	14861.19**	18770.10**
Error	8	0.463	4.21	12.56	105.60	744.29	450.61	875.30	2026.59
Mulching (M)	3	4.65*	668.39**	3008.59**	11559.57**	37165.95**	116480.09**	176215.50**	226519.17**
S×M	9	0.082 NS	12.26**	53.579**	224.26*	680.96**	2716.02**	4784.52**	6240.71**
V×M	3	1.419*	10.57 NS	41.80 NS	183.11 NS	609.61**	958.75 NS	5219.42**	5541.89**
S×V×M	9	0.024 NS	0.097 NS	0.702 NS	3.91 NS	11.77 NS	31.48 NS	281.20 NS	183.24 NS
Error	48	0.371	4.04	17.588	91.76	132.54	668.63	710.79	956.59
CV %		5.11	5.40	5.37	6.60	4.47	5.43	4.37	4.38

Appendix IIIb: Mean squares from analysis of variance for total dry matter (g m^{-2}) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	0.169	1.58	96.59	47.04	185.41	438.51	1366.80	1433.95
Sowing date (S)	3	274.09**	3043.25**	13915.79**	49920.72**	140322.95**	595454.24**	849298.64**	1111324.95**
Error	6	0.381	0.537	12.16	75.86	51.45	651.10	668.11	522.972
Variety (V)	1	252.75**	2367.91**	9833.81**	36810.01**	136993.30**	481308.29**	686718.56**	773670.14**
S×V	3	4.39*	41.09**	172.74**	687.27*	2390.921*	9755.40*	16127.21**	18686.26**
Error	8	0.841	5.47	22.24	162.33	418.72	1493.75	541.80	1284.08
Mulching (M)	3	5.81*	855.15**	4292.58**	15715.53**	41212.25**	160454.19**	204071.59**	193382.50**
S×M	9	0.096 NS	15.48 **	77.81**	304.384**	740.40**	3420.35**	4749.70**	5225.26**
V×M	3	1.55**	12.57*	30.92 NS	72.76 NS	1715.31**	2833.25 NS	3666.42 NS	2588.87 **
S×V×M	9	0.031 NS	0.218 NS	0.543 NS	1.35 NS	31.19 NS	58.97 NS	65.17 NS	65.78 NS
Error	48	0.360	3.37	18.51	82.54	207.28	1076.59	1623.79	669.65
CV %		4.73	4.39	4.81	5.55	5.06	5.73	5.94	3.44

Appendix IVa: Mean squares from analysis of variance for leaf area index at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	0.001	0.002	0.117	0.107	0.616	0.006	0.017	0.003
Sowing date (S)	3	0.066 **	0.355**	0.142**	4.24**	11.36**	9.999**	6.76**	1.40**
Error	6	0.000	0.001	0.004	0.026	0.041	0.066	0.026	0.005
Variety (V)	1	0.078**	0.351**	0.833**	3.31**	9.33**	8.68**	5.58**	1.064**
S×V	3	0.001 NS	0.005 NS	0.015 NS	0.063 NS	0.185 **	0.178 NS	0.107**	0.021*
Error	8	0.001	0.003	0.026	0.033	0.023	0.060	0.007	0.004
Mulching (M)	3	0.001 NS	0.047**	0.178**	0.589**	1.55**	1.23**	0.926**	0.130**
S×M.	9	0.000 NS	0.001 NS	0.003 NS	0.012 NS	0.029 NS	0.058 NS	0.018 NS	0.003**
V×M	3	0.001 NS	0.001 NS	0.002 NS	0.009 NS	0.026 NS	0.017 NS	0.021 NS	0.030 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.009 NS	0.001 NS	0.001 NS
Error	48	0.001	0.002	0.007	0.032	0.050	0.033	0.036	0.007
CV %		12.32	8.78	9.75	11.77	9.05	7.65	10.05	9.67

Appendix IVb: Mean squares from analysis of variance for leaf area index at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	0.002	0.005	0.014	0.008	0.020	0.027	0.303	0.044
Sowing date (S)	3	0.080**	0.469**	1.528**	4.873**	11.585**	13.560**	8.806**	1.715**
Error	6	0.001	0.004	0.004	0.003	0.055	0.031	0.061	0.005
Variety (V)	1	0.107**	0.540**	0.645**	2.633**	9.257**	7.667**	7.599**	1.279**
S×V	3	0.002 NS	0.010 NS	0.011 NS	0.046 NS	0.176*	0.142 NS	0.144 NS	0.025**
Error	8	0.002	0.004	0.008	0.023	0.039	0.120	0.091	0.004
Mulching (M)	3	0.003*	0.069**	0.173**	0.679**	1.540**	2.657**	1.190**	0.153**
S×M	9	0.000 NS	0.001 NS	0.002 NS	0.013 NS	0.031 NS	0.053 NS	0.025 NS	0.003 NS
V×M	3	0.003**	0.005 NS	0.002 NS	0.076 NS	0.024 NS	0.067 NS	0.091 NS	0.020*
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.001 NS	0.001 NS	0.002 NS	0.000 NS
Error	48	0.000	0.003	0.010	0.030	0.063	0.051	0.054	0.006
CV %		10.30	11.07	10.73	10.61	10.14	8.41	10.67	8.44

Appendix Va: Mean squares from analysis of variance for crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.023	0.468	0.045	0.078	17.57	3.03	9.07
Sowing date (S)	3	11.26**	28.03**	89.43**	204.48**	856.61**	335.57**	254.81**
Error	6	0.007	0.178	0.512	0.323	3.19	7.91	23.43
Variety (V)	1	8.20*	22.62**	70.13**	200.91**	555.36**	460.38**	179.23*
S×V	3	0.130 NS	0.391 NS	1.43 NS	3.32 NS	12.72 NS	25.25*	3.51 NS
Error	8	0.073	0.169	0.874	12.89	19.72	4.92	20.31
Mulching (M)	3	5.63**	8.41**	27.74**	72.68**	220.70**	64.13**	34.89 NS
S×M	9	0.104*	0.145 NS	0.587 NS	1.24 NS	7.25 NS	4.34 NS	2.09 NS
V×M	3	0.042 NS	0.107 NS	0.496 NS	1.25 NS	4.27 NS	28.51*	2.19 NS
S×V×M	9	0.000 NS	0.003 NS	0.014 NS	0.021 NS	0.253 NS	2.74 NS	0.994 NS
Error	48	0.043	0.138	0.525	2.37	9.39	9.31	13.50
CV %		8.21	9.11	10.81	13.70	14.02	18.68	20.58

Appendix Vb: Mean squares from analysis of variance for crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.019	1.146	0.447	3.714	8.31	12.82	9.55
Sowing date (S)	3	14.91**	39.44**	111.22**	228.56**	1577.36**	229.50**	186.74**
Error	6	0.004	0.122	1.185	0.600	7.48	9.45	4.09
Variety (V)	1	10.71**	25.48**	85.92**	317.63**	1047.88**	182.19**	25.86 NS
S×V	3	0.186 NS	0.452*	1.71 NS	5.16 NS	24.88 NS	8.05 NS	1.09 NS
Error	8	0.102	0.072	2.424	3.10	28.54	15.54	26.59
Mulching (M)	3	7.202**	13.20**	37.10**	60.51**	392.22**	26.25 NS	67.24*
S×M	9	0.132**	0.239 NS	0.768 NS	0.955 NS	9.81 NS	1.19 NS	1.83 NS
V×M	3	0.053 NS	0.122 NS	0.531 NS	11.542**	3.99 NS	1.07 NS	30.85 NS
S×V×M	9	0.001 NS	0.002 NS	0.010 NS	0.211 NS	0.12 NS	0.156 NS	0.878 NS
Error	48	0.030	0.218	0.990	2.565	14.49	22.03	19.48
CV %		5.96	9.82	13.37	13.25	13.23	20.21	22.48

Appendix VIa: Mean squares from analysis of variance for relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sowing date (S)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.003*	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
V×M	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		6.19	7.63	7.15	12.44	11.71	22.16	37.32

Appendix VIb: Mean squares from analysis of variance for relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sowing date (S)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000 NS	0.000*	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.003*	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000**
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
V×M	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		4.77	8.86	11.89	11.81	10.72	19.80	22.00

Appendix VIIa: Mean squares from analysis of variance for net assimilation rate ($\text{g cm}^{-2} \text{day}^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.005	0.061	0.006	0.039	0.007	0.006	0.076
Sowing date (S)	3	0.001 NS	0.000 NS	0.005 NS	0.005 NS	0.002 NS	0.007 NS	0.106 NS
Error	6	0.004	0.002	0.006	0.002	0.007	0.028	0.099
Variety (V)	1	0.030 NS	0.000 NS	0.004 NS	0.000 NS	0.022 NS	0.024 NS	0.016 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.022 NS	0.009 NS
Error	8	0.009	0.004	0.005	0.045	0.039	0.019	0.092
Mulching (M)	3	0.359**	0.026**	0.034**	0.027*	0.040 NS	0.005 NS	0.025 NS
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.005 NS	0.004 NS
V×M	3	0.005 NS	0.000 NS	0.000 NS	0.000 NS	0.007 NS	0.050 NS	0.007 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.003 NS	0.004 NS
Error	48	0.008	0.004	0.002	0.007	0.021	0.022	0.075
CV %		10.71	9.58	8.17	14.61	15.84	21.19	23.28

Appendix VIIb: Mean squares from analysis of variance for net assimilation rate ($\text{g cm}^{-2} \text{ day}^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.021	0.018	0.009	0.010	0.018	0.020	0.132
Sowing date (S)	3	0.001 NS	0.000 NS	0.004 NS	0.010 NS	0.001 NS	0.006 NS	0.112*
Error	6	0.003	0.004	0.007	0.003	0.021	0.008	0.019
Variety (V)	1	0.067*	0.000 NS	0.044 NS	0.038**	0.000 NS	0.001 NS	0.049 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.003 NS	0.000 NS
Error	8	0.009	0.003	0.018	0.004	0.059	0.020	0.101
Mulching (M)	3	0.365**	0.057**	0.054**	0.009 NS	0.044 NS	0.006 NS	0.359**
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.002 NS
V×M	3	0.018*	0.003 NS	0.003 NS	0.031*	0.001 NS	0.001 NS	0.112 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.001 NS
Error	48	0.006	0.005	0.008	0.007	0.026	0.033	0.083
CV %		9.37	10.80	15.48	14.35	14.35	21.21	23.22

Appendix VIIIa: Mean squares from analysis of variance for leaf area ratio ($\text{cm}^2 \text{g}^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	
Replication	2	73.38	581.05	325.92	633.18	55.14	6.51	0.748	
Sowing date (S)	3	0.936 NS	5.46 NS	3.11 NS	16.32 NS	7.95 NS	2.51 NS	0.588 NS	
Error	6	72.62	11.92	15.98	16.99	12.35	5.35	2.71	
Variety (V)	1	432.01*	2.14 NS	19.98 NS	0.086 NS	17.27 NS	5.68 NS	0.192 NS	
S×V	3	0.717 NS	0.095 NS	0.284 NS	0.069 NS	8.93 NS	4.97 NS	0.366 NS	
Error	8	62.35	14.82	75.10	76.83	31.79	9.63	1.10	
Mulching (M)	3	1325.75**	737.59**	742.22**	817.39**	353.62**	82.12**	21.51**	
S×M	9	0.400 NS	0.047 NS	0.050 NS	0.333 NS	1.64 NS	0.800 NS	0.275 NS	
V×M	3	100.17 NS	0.542 NS	0.118 NS	0.018 NS	4.20 NS	4.72 NS	2.18 NS	
S×V×M	9	0.419 NS	0.108 NS	0.099 NS	0.116 NS	0.902 NS	0.478 NS	0.013 NS	
Error	48	101.47	41.22	54.59	38.15	17.78	6.56	2.12	
CV %		7.25	5.64	6.95	6.18	6.20	6.50	7.29	

Appendix VIIIb: Mean squares from analysis of variance for leaf area ratio ($\text{cm}^2 \text{g}^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	363.24	89.63	118.67	6.929	14.87	39.37	30.86
Sowing date (S)	3	12.36 NS	10.51 NS	9.43 NS	17.65 NS	11.83 NS	1.80 NS	0.134 NS
Error	6	128.70	43.28	28.21	18.46	21.60	6.04	0.294
Variety (V)	1	1387.53**	9.91 NS	437.50 NS	84.62 NS	39.55 NS	4.95 NS	0.370 NS
S×V	3	1.01 NS	0.502 NS	0.286 NS	0.346 NS	0.313 NS	0.84 NS	0.360 NS
Error	8	78.41	80.88	116.98	96.21	62.09	34.62	1.57
Mulching (M)	3	1557.00**	1145.14**	995.28**	593.91**	221.54**	61.78**	20.34**
S×M	9	0.339 NS	0.084 NS	0.172 NS	0.051 NS	0.283 NS	0.312 NS	0.138 NS
V×M	3	518.27**	20.19 NS	117.29 NS	83.140 NS	36.38 NS	3.06 NS	4.863*
S×V×M	9	0.349 NS	0.325 NS	0.112 NS	0.104 NS	0.054 NS	0.079 NS	0.019 NS
Error	48	120.71	62.39	49.74	44.325	17.21	10.75	1.729
CV %		7.78	6.91	6.82	7.16	6.61	8.43	6.35

Appendix IXa: Mean squares from analysis of variance for relative leaf growth rate ($\text{cm}^2 \text{cm}^{-2} \text{day}^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.000	0.002	0.003	0.001	0.001	0.000	0.000
Sowing date (S)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000 NS	0.001 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	8	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.003**	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
V×M	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		14.66	20.84	19.25	23.83	24.69	23.62	18.26

Appendix IXb: Mean squares from analysis of variance for relative leaf growth rate ($\text{cm}^2 \text{cm}^{-2} \text{day}^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)						
		20-30	30-40	40-50	50-60	60-70	70-80	80-90
Replication	2	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Sowing date (S)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000 NS	0.003**	0.000 NS	0.000*	0.000*	0.000*	0.000 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	8	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.003**	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
V×M	3	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.000 NS	0.000 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		15.58	24.73	25.72	23.87	25.35	22.69	16.47

Appendix Xa: Mean squares from analysis of variance for specific leaf area ($\text{cm}^2 \text{g}^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	1262.63	27.42	14774.02	3714.36	3384.55	1.87	26.33	98.95
Sowing date (S)	3	28.61 NS	6.16 NS	105.56 NS	0.106 NS	1.19 NS	0.246 NS	0.058 NS	0.338 NS
Error	6	143.73	134.35	147.06	144.56	197.28	404.68	204.40	30.51
Variety (V)	1	1394.38 NS	121.32 NS	575.26 NS	5.26 NS	0.171 NS	5.98 NS	154.13 NS	184.01 NS
S×V	3	0.544 NS	0.376 NS	1.11 NS	0.200 NS	1.15 NS	2.63 NS	0.036 NS	0.316 NS
Error	8	457.65	762.64	157.51	946.45	154.09	175.37	170.05	191.95
Mulching (M)	3	4325.37**	3382.82**	3116.43**	4488.57**	4813.80**	3930.89**	3683.65**	2865.15**
S×M	9	1.09 NS	0.349 NS	1.15 NS	0.118 NS	0.600 NS	0.562 NS	0.438 NS	0.103 NS
V×M	3	2031.68 NS	6.06 NS	4.53 NS	0.177 NS	0.354 NS	1.61 NS	0.720 NS	234.58 NS
S×V×M	9	1.16 NS	1.71 NS	1.17 NS	0.058 NS	0.477 NS	1.16 NS	0.487 NS	0.186 NS
Error	48	378.60	289.62	275.32	276.61	218.72	223.29	195.32	107.60
CV %		8.36	7.34	6.99	6.95	6.49	6.48	6.18	6.38

Appendix Xb: Mean squares from analysis of variance for specific leaf area ($\text{cm}^2 \text{g}^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	477.68	78.89	1167.72	567.09	169.01	1589.50	672.38	2708.55
Sowing date (S)	3	35.81 NS	46.23 NS	56.37 NS	39.52 NS	32.60 NS	94.30 NS	231.57 NS	31.93 NS
Error	6	921.54	444.34	519.65	3.64	151.96	93.29	18.30	27.76
Variety (V)	1	3876.42 NS	1708.51 NS	5627.96**	1030.64 NS	11.36 NS	1598.79 NS	85.26 NS	9.997 NS
S×V	3	2.88 NS	2.83 NS	1.82 NS	1.03 NS	0.505 NS	2.89 NS	2.79 NS	1.853 NS
Error	8	1062.56	323.37	444.91	842.36	524.79	579.69	475.06	190.35
Mulching (M)	3	5758.59 **	3412.20**	5132.13**	6172.44**	3896.39**	3758.66**	4764.13**	4969.56**
S×M	9	1.40 NS	1.42 NS	0.588 NS	1.12 NS	0.186 NS	0.377 NS	0.367 NS	0.477 NS
V×M	3	3756.05**	778.28 NS	398.59 NS	330.41 NS	2.02 NS	938.02 **	349.62 NS	756.95**
S×V×M	9	0.256 NS	3.28 NS	1.59 NS	1.16 NS	0.078 NS	0.428 NS	0.576 NS	1.482 NS
Error	48	470.51	550.80	367.54	442.78	252.63	154.487	366.83	138.19
CV %		9.20	9.94	8.10	9.12	7.76	5.30	8.25	7.18

Appendix XIa: Mean squares from analysis of variance for leaf weight ratio (g g^{-1}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	0.002	0.003	0.001	0.001	0.001	0.000	0.000	0.000
Sowing date (S)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001*	0.000 NS	0.000 NS	0.000 NS
Error	6	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000 NS	0.003*	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	8	0.000	0.000	0.002	0.002	0.001	0.001	0.000	0.000
Mulching (M)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
V×M	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
CV %		2.80	4.44	4.10	4.72	5.09	6.62	8.30	7.44

Appendix XIb: Mean squares from analysis of variance for leaf weight ratio (g g^{-1}) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20	30	40	50	60	70	80	90
Replication	2	0.001	0.005	0.000	0.000	0.002	0.001	0.000	0.001
Sowing date (S)	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.001 NS	0.000 NS	0.000 NS	0.000 NS
Error	6	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Variety (V)	1	0.000 NS	0.002*	0.001 NS	0.000 NS	0.001 NS	0.000 NS	0.000 NS	0.000 NS
S×V	3	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	8	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000 NS	0.000 NS	0.001 NS	0.002 NS	0.001 NS	0.000 NS	0.000 NS	0.000 NS
S×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
V×M	3	0.000 NS	0.000 NS	0.001 NS	0.002 NS	0.001 NS	0.000 NS	0.000 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	-0.000 NS	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000
CV %		2.25	5.09	5.83	6.26	6.16	8.17	6.43	7.08

Appendix XIIa: Mean squares from analysis of variance for time (days after sowing) taken for different phenological stages of wheat (2008-2009)

Sources of variation	df	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
Replication	2	2.247	5.166	24.882	29.508	16.995	8.335	9.488
Sowing date (S)	3	269.32**	441.94**	988.63**	1030.71**	1060.72**	3379.62**	3449.16**
Error	6	1.272	1.783	5.644	6.256	8.272	3.775	1.797
Variety (V)	1	109.36**	338.10**	855.92**	1055.30**	875.02**	1733.07**	1506.31**
S×V	3	0.647 NS	3.87 NS	2.24 NS	10.27*	4.85 NS	17.54 NS	25.02**
Error	8	1.45	2.92	1.51	2.36	11.73	14.78	1.16
Mulching (M)	3	62.46*	92.68**	121.60**	144.68**	106.20**	110.57**	124.31**
S×M	9	1.347 NS	0.193 NS	0.192 NS	1.086 NS	0.250 NS	0.030 NS	0.352 NS
V×M	3	3.041*	1.765 NS	0.599 NS	1.003 NS	0.041 NS	0.010 NS	0.089 NS
S×V×M	9	0.878 NS	0.039 NS	0.278 NS	1.082 NS	0.057 NS	0.016 NS	0.156 NS
Error	48	0.825	1.892	3.895	4.923	4.294	6.683	5.432
CV %		5.22	6.17	3.70	3.77	3.14	2.75	2.21

Appendix XIIb: Mean squares from analysis of variance for time (days after sowing) taken for different phenological stages of wheat (2009-2010)

Sources of variation	df	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
Replication	2	1.49	0.590	10.94	5.82	19.58	29.20	25.31
Sowing date (S)	3	178.13**	389.26**	961.02**	905.78**	1329.19**	3364.52**	3616.28**
Error	6	0.694	0.330	4.30	3.08	3.76	8.57	10.38
Variety (V)	1	109.25**	465.83**	975.12**	1557.60**	1615.24**	1883.90**	1922.10**
S×V	3	0.120 NS	3.386 NS	0.722 NS	21.15*	3.80 NS	14.382 NS	15.82*
Error	8	0.530	3.042	2.45	5.24	1.05	18.44	2.46
Mulching (M)	3	105.54**	87.10**	114.96**	143.34**	159.11**	150.89**	141.46**
S×M	9	0.084 NS	0.087 NS	0.097 NS	0.162 NS	0.194 NS	0.240 NS	0.049 NS
V×M	3	0.098 NS	5.780**	0.026 NS	0.432 NS	1.36 NS	4.72 NS	0.304 NS
S×V×M	9	0.092 NS	0.073 NS	0.151 NS	0.153 NS	0.314 NS	0.296 NS	0.123 NS
Error	48	0.856	1.365	4.895	0.449	4.65	13.09	6.40
CV %		5.06	5.18	4.09	3.45	3.13	3.77	2.36

Appendix XIIIa: Mean squares from analysis of variance for the growing degree day (GDD) of wheat at different phenological stages (2008-2009)

Sources of variation	df	Growing degree day (GDD)						
		Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
Replication	2	155.79	672.46	2218.23	3319.30	2938.78	2509.98	3844.96
Sowing date (S)	3	94139.85**	156153.89**	171035.06**	163021.77**	119661.39**	192060.08**	159304.16**
Error	6	113.74	172.30	546.781	675.752	1359.85	1083.222	579.095
Variety (V)	1	8828.17**	29851.47**	79324.11**	100378.85**	106636.66**	432519.97**	437028.84**
S×V	3	462.91 NS	258.55 NS	586.190*	710.71 NS	2735.574 NS	8038.94 NS	12834.89**
Error	8	142.63	202.89	104.91	224.19	1213.86	3494.85	593.47
Mulching (M)	3	5005.69**	8028.87**	10816.972**	14150.21**	11875.61**	25774.10**	38842.12**
S×M	9	387.85**	32.85 NS	46.59 NS	108.11 NS	68.84 NS	32.93 NS	163.02 NS
V×M	3	301.92*	182.41 NS	93.98 NS	95.58 NS	20.25 NS	19.96 NS	25.69 NS
S×V×M	9	152.27 NS	35.51 NS	23.29 NS	73.81 NS	6.73 NS	16.44 NS	123.91 NS
Error	48	108.24	157.35	336.468	485.91	403.40	1621.785	1469.24
CV %		6.01	5.68	3.74	4.05	3.29	4.08	3.26

Appendix XIIIb: Mean squares from analysis of variance for the growing degree day (GDD) of wheat at different phenological stages (2009-2010)

Sources of variation	df	Growing degree day (GDD)						Maturity stage
		Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	
Replication	2	150.03	3.31	1092.69	376.88	2861.56	8528.54	13645.72
Sowing date (S)	3	102898.28**	160430.71**	117721.92**	69401.23**	41789.42**	64022.09**	34817.11*
Error	6	51.83	10.09	427.48	158.14	576.12	3051.18	5240.41
Variety (V)	1	4244.03**	19306.35**	72114.07**	147591.92**	236155.51**	623916.58**	865658.99**
S×V	3	80.28 NS	332.25 NS	2957.33**	4165.07**	6258.03**	1150.82 NS	15678.67**
Error	8	27.144	210.07	182.00	409.49	194.94	5939.67	1017.19
Mulching (M)	3	4554.06**	3694.76**	8244.29**	13025.01**	21363.34**	46990.55**	61574.83**
S×M	9	138.19**	91.24 NS	286.43 NS	210.07 NS	309.59 NS	280.94 NS	294.32 NS
V×M	3	15.53 NS	119.27 NS	3.52 NS	72.56 NS	292.64 NS	447.79 NS	331.22 NS
S×V×M	9	6.45 NS	10.41 NS	9.07 NS	17.72 NS	19.50 NS	75.51 NS	35.97 NS
Error	48	38.53	63.13	355.26	501.04	695.55	4313.438	2526.29
CV %		4.11	4.41	4.77	4.88	4.87	7.06	4.40

Appendix XIVa: Mean squares from analysis of variance for the helio-thermal unit (HTU) of wheat at different phenological stages (2008-2009)

Sources of variation	df	Helio-thermal unit (HTU)						
		Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain filling stage	Maturity stage
Replication	2	4363.63	19973.45	81522.59	223675.59	113637.30	138100.48	193937.83
Sowing date (S)	3	11039280.65**	15055265.75**	4798643.97**	4415786.85**	2000239.33**	2188517.99**	2101265.69**
Error	6	5244.06	3510.23	44757.88	59771.36	112008.39	58897.00	36889.45
Variety (V)	1	248756.47**	737380.02**	4459130.57**	5896842.45**	7048801.12**	24370036.03**	23936225.04**
S×V	3	52515.35**	13513.44 NS	132524.55**	212404.88**	308791.60*	381635.87 NS	7371.30**
Error	8	3574.21	8417.24	2711.56	10546.24	70090.92	202722.08	27872.60
Mulching (M)	3	150213.99**	196302.01**	568845.15**	824102.45**	735989.09**	1505903.86**	2121529.06**
S×M	9	37567.18**	5161.40 NS	15594.15 NS	22230.86 NS	17017.87 NS	1243.03 NS	12321.07 NS
V×M	3	8991.05 NS	6162.109 NS	21768.63 NS	5455.12 NS	5138.34 NS	699.79 NS	694.12 NS
S×V×M	9	5948.81 NS	7146.43 NS	6644.85 NS	6498.96 NS	2808.39 NS	742.37 NS	5759.36 NS
Error	48	4425.23	4614.76	20041.08	29678.09	27095.718	92388.65	81147.47
CV %		6.59	5.41	5.12	5.45	4.48	4.53	3.52

Appendix XIVb: Mean squares from analysis of variance for the helio-thermal unit (HTU) of wheat at different phenological stages (2009-2010)

Sources of variation	df	Helio-thermal unit (HTU)						
		Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Grain Filling stage	Maturity stage
Replication	2	4911.61	164.94	58442.50	21342.56	162907.73	523538.08	756128.41
Sowing date (S)	3	4119908.95**	5952518.81**	1794467.82**	921879.92**	475083.85**	1390117.26*	816476.77 *
Error	6	866.98	440.45	25444.37	7988.23	36850.68	187504.48	280547.37
Variety (V)	1	79430.52**	599267.17**	3164964.66**	8735355.50**	14470581.96**	37413287.49**	45036502.13**
S×V	3	8545.60**	25294.04 NS	349534.21**	187653.54**	422166.62**	645852.35 NS	704609.03**
Error	8	1221.27	6689.01	13324.69	22483.00	11653.67	367607.86	54475.16
Mulching (M)	3	104291.43**	105481.62**	397523.80**	721616.64**	130754.45**	2745077.23**	3408269.11**
S×M	9	9493.96**	4286.12 NS	31813.10 NS	19311.26 NS	20450.976 NS	12541.12 NS	12740.93 NS
V×M	3	631.01 NS	1973.76 NS	803.45 NS	11545.32 NS	21423.974 NS	39481.32 NS	16032.38 NS
S×V×M	9	730.238 NS	4022.93 NS	695.36 NS	4728.01 NS	1662.048 NS	4644.23 NS	4010.03 NS
Error	48	1068.37	2482.48	18967.02	30184.76	4379.521	247782.80	140261.64
CV %		3.87	5.00	5.89	6.19	6.02	7.66	4.62

Appendix XVa: Mean squares from analysis of variance for the pheno-thermal index (PTI) and heat use efficiency (HUE) of wheat at different phenological stages (2008-2009)

Sources of variation	df	Pheno-thermal index (PTI)						Heat use efficiency (HUE)
		Sowing to crown root initiation stage	Crown root initiation to tillering stage	Tillering to booting stage	Booting to heading stage	Heading to anthesis stage	Anthesis to grain filling stage	Grain filling to maturity stage
Replication	2	0.001	0.114	0.001	0.027	0.065	0.035	0.089
Sowing date (S)	3	80.76**	80.40**	10.03**	6.07**	3.46**	3.77**	6.66**
Error	6	0.023	0.046	0.018	0.021	0.044	0.017	0.013
Variety (V)	1	0.337**	0.001 NS	0.121**	0.148**	0.756**	5.79**	5.12**
S×V	3	0.144*	0.318**	0.188**	0.243**	0.353**	0.326**	0.297**
Error	8	0.023	0.029	0.004	0.002	0.017	0.037	0.007
Mulching (M)	3	0.264**	0.005 NS	0.008 NS	0.029 NS	0.050**	0.314**	0.453**
S×M	9	0.071**	0.071**	0.027**	0.023 NS	0.033**	0.003 NS	0.013 NS
V×M	3	0.060*	0.012 NS	0.002 NS	0.001 NS	0.003 NS	0.002 NS	0.006 NS
S×V×M	9	0.022 NS	0.028 NS	0.001 NS	0.002 NS	0.003 NS	0.001 NS	0.009 NS
Error	48	0.021	0.018	0.004	0.015	0.004	0.021	0.022
CV %		1.50	1.39	0.72	1.31	0.69	1.37	1.34
								8.28

Appendix XVb: Mean squares from analysis of variance for the pheno-thermal index (PTI) and heat use efficiency (HUE) of wheat at different phenological stages (2009-2010)

Sources of variation	df	Pheno-thermal index (PTI)							Heat use efficiency (HUE)
		Sowing to crown root initiation stage	Crown root initiation to tillering stage	Tillering to booting stage	Booting to heading stage	Heading to anthesis stage	Anthesis to grain filling stage	Grain filling to maturity stage	
Replication	2	0.001	0.043	0.055	0.000	0.078	0.232	0.361	0.198
Sowing date (S)	3	139.76**	121.56**	10.71**	5.45**	4.35**	13.21**	22.50**	23.26**
Error	6	0.003	0.027	0.021	0.010	0.020	0.086	0.139	0.028
Variety (V)	1	0.876**	1.51**	0.882**	2.507**	6.80**	15.55**	19.04**	3.21**
S×V	3	0.001 NS	0.478**	1.23**	0.79**	0.990**	0.732**	0.646**	0.346**
Error	8	0.012	0.017	0.009	0.020	0.011	0.152	0.021	0.047
Mulching (M)	3	0.744**	0.328**	0.091**	0.189**	0.538**	0.122**	1.32**	3.09**
S×M	9	0.009 NS	0.048*	0.130**	0.083**	0.076**	0.024 NS	0.022 NS	0.094 NS
V×M	3	0.023 NS	0.220**	0.000 NS	0.022 NS	0.008 NS	0.010 NS	0.003 NS	0.022 NS
S×V×M	9	0.012 NS	0.012 NS	0.005 NS	0.005 NS	0.002 NS	0.002 NS	0.001 NS	0.001 NS
Error	48	0.015	0.019	0.018	0.017	0.027	0.096	0.048	0.062
CV %		1.52	1.79	1.84	1.76	2.08	3.19	2.04	7.71

Appendix XVIa: Mean squares from analysis of variance for the moisture retention capacity (%) of flag leaf of wheat (2008-2009)

Sources of variation	df	Time of the day									
		8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm
Replication	2	64.64	57.37	36.49	55.19	23.22	36.52	21.02	38.21	76.09	40.81
Sowing date (S)	3	397.10**	382.34**	346.63**	359.64**	345.23**	358.93**	361.32**	295.30**	206.15**	206.02**
Error	6	15.69	15.97	8.62	23.05	9.18	10.62	4.32	14.302	16.76	10.35
Variety (V)	1	389.38 NS	488.21**	565.17**	420.01**	544.31**	671.72**	793.04**	882.22**	784.27**	895.18**
S×V	3	6.24 NS	5.47 NS	4.72 NS	3.11 NS	3.71 NS	5.64 NS	4.16 NS	4.76 NS	3.13 NS	2.94 NS
Error	8	81.48	20.35	26.04	16.63	13.85	10.46	37.56	24.675	50.28	45.89
Mulching (M)	3	205.52**	215.28**	212.18**	234.79**	261.26**	321.32**	360.59**	402.06**	407.46**	438.09**
S×M	9	5.81 NS	2.62 NS	0.996 NS	0.908 NS	0.906 NS	2.53 NS	0.928 NS	1.51 NS	1.11 NS	1.35 NS
V×M	3	10.19 NS	7.06 NS	4.86 NS	3.32 NS	3.71 NS	7.63 NS	5.33 NS	6.84 NS	5.54 NS	6.30 NS
S×V×M	9	2.06 NS	0.889 NS	0.845 NS	0.785 NS	0.796 NS	0.852 NS	0.866 NS	0.634 NS	0.359 NS	0.530 NS
Error	48	21.51	33.58	14.50	27.16	21.60	11.55	17.720	17.593	20.34	22.230
CV %		6.23	7.85	5.31	7.28	6.77	5.07	6.45	6.71	7.43	8.02

Appendix XVIb: Mean squares from analysis of variance for the moisture retention capacity (%) of flag leaf of wheat (2009-2010)

Sources of variation	df	Time of the day									
		8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm
Replication	2	34.79	21.48	19.81	12.67	25.92	26.68	15.586	33.33	17.17	23.91
Sowing date (S)	3	272.36**	253.81**	253.37**	255.53**	245.21**	243.98**	253.52**	222.25*	166.88**	129.20**
Error	6	8.01	10.44	12.94	4.13	16.72	5.95	8.10	29.03	13.93	8.18
Variety (V)	1	250.78**	310.50**	394.39**	282.08**	367.07**	460.29**	538.18**	596.36**	551.14**	585.93**
S×V	3	2.75 NS	3.29 NS	3.50 NS	2.53 NS	2.95 NS	3.04 NS	3.87 NS	3.14 NS	2.10 NS	1.95 NS
Error	8	15.05	29.17	14.81	5.98	54.11	30.69	12.92	32.77	31.43	46.78
Mulching (M)	3	121.68**	135.53**	148.11**	156.38**	176.30**	218.98**	235.84**	268.23**	283.64**	284.62**
S×M	9	0.813 NS	0.883 NS	0.717 NS	0.744 NS	0.731 NS	1.62 NS	0.776 NS	0.704 NS	0.506 NS	0.327 NS
V×M	3	2.35 NS	3.22 NS	3.64 NS	2.40 NS	2.70 NS	4.72 NS	4.10 NS	3.67 NS	2.99 NS	2.96 NS
S×V×M	9	0.501 NS	0.548 NS	0.688 NS	0.465 NS	0.482 NS	0.758 NS	0.576 NS	0.458 NS	0.252 NS	0.207 NS
Error	48	12.90	25.75	14.39	32.93	23.16	38.51	14.96	43.12	28.51	15.09
CV %		4.50	6.57	4.97	7.56	6.51	8.61	5.43	9.38	7.79	5.87

Appendix XVIIa: Mean squares from analysis of variance for relative leaf water content of flag leaf of wheat (2008-2009)

Sources of variation	df	Time of the day		
		8.00 am	12.00 noon	4.00 pm
Replication	2	17.62	14.93	45.68
Sowing date (S)	3	394.18**	296.07**	456.05**
Error	6	17.24	9.47	35.72
Variety (V)	1	324.58**	389.98**	385.60**
S×V	3	2.26 NS	1.57 NS	2.88 NS
Error	8	40.83	8.81	20.06
Mulching (M)	3	132.87**	108.61**	159.20**
S×M	9	0.365 NS	0.261 NS	0.360 NS
V×M	3	0.314 NS	0.255 NS	2.54 NS
S×V×M	9	0.360 NS	0.310 NS	0.448 NS
Error	48	35.34	10.69	22.75
CV %		7.33	5.33	6.21

Appendix XVIIb: Mean squares from analysis of variance for relative leaf water content of flag leaf of wheat (2009-2010)

Sources of variation	df	Time of the day		
		8.00 am	12.00 noon	4.00 pm
Replication	2	27.83	15.18	30.47
Sowing date (S)	3	440.84**	316.36**	471.44**
Error	6	15.42	8.40	10.94
Variety (V)	1	474.37**	336.86**	376.72**
S×V	3	0.602	0.136	2.98
Error	8	17.39	15.33	25.38
Mulching (M)	3	154.50**	128.10**	155.98**
S×M	9	0.381 NS	0.258 NS	0.374 NS
V×M	3	1.55 NS	0.256 NS	2.48 NS
S×V×M	9	0.447 NS	0.315 NS	0.463 NS
Error	48	29.88	8.82	22.20
CV %		6.77	4.73	6.01

Appendix XVIIIa: Mean squares from analysis of variance for chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2008-2009

Sources of variation	df	Chlorophyll content of flag leaf (mg dm^{-2})			
		Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
Replication	2	0.011	0.003	0.026	0.000
Sowing date (S)	3	2.86**	0.656**	6.25**	0.009 NS
Error	6	0.006	0.002	0.014	0.002
Variety (V)	1	1.89**	0.341**	3.84**	0.031**
S×V	3	0.009 NS	0.001 NS	0.016 NS	0.001 NS
Error	8	0.006	0.001	0.012	0.003
Mulching (M)	3	0.792**	0.153**	1.64**	0.010**
S×M	9	0.005 NS	0.001 NS	0.011 NS	0.000 NS
V×M	3	0.029 NS	0.005 NS	0.053 NS	0.005 NS
S×V×M	9	0.000 NS	0.000 NS	0.000 NS	0.000 NS
Error	48	0.014	0.003	0.029	0.003
CV %		5.65	5.59	5.50	2.53

Appendix XVIIIb: Mean squares from analysis of variance for chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2009-2010

Sources of variation	df	Chlorophyll content of flag leaf (mg dm^{-2})			
		Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
Replication	2	0.005	0.001	0.011	0.000
Sowing date (S)	3	3.15**	0.684**	6.77**	0.017**
Error	6	0.001	0.001	0.003	0.002
Variety (V)	1	1.96**	0.428**	4.22**	0.007 NS
S×V	3	0.010 NS	0.001 NS	0.018 NS	0.001 NS
Error	8	0.017	0.003	0.032	0.002
Mulching (M)	3	0.927**	0.207**	2.01**	0.003 NS
S×M	9	0.007 NS	0.001 NS	0.014 NS	0.000 NS
V×M	3	0.019 NS	0.004 NS	0.041 NS	0.000 NS
S×V×M	9	0.000 NS	0.000 NS	0.001 NS	0.000 NS
Error	48	0.008	0.002	0.017	0.002
CV %		4.21	4.24	4.09	2.13

Appendix XIXa: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2008-2009)

Sources of variation	df	Plant height (cm)	Number of total tillers plant ⁻¹	Number of effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)
Replication	2	84.31	0.128	0.259	2.77	1.016
Sowing date (S)	3	15998.64**	13.61**	25.22**	321.60**	408.92**
Error	6	23.42	0.028	0.053	0.615	0.268
Variety (V)	1	2947.17**	20.37**	24.80**	142.16**	190.35**
S×V	3	59.82 NS	0.136 NS	0.195*	2.35 NS	3.53**
Error	8	22.32	0.049	0.043	1.49	0.563
Mulching (M)	3	1727.19**	4.06**	9.16**	45.48**	55.77**
S×M	9	10.04 NS	0.060 NS	0.100**	0.812 NS	1.18**
V×M	3	4.74 NS	0.046 NS	0.083 NS	0.370 NS	0.776 NS
S×V×M	9	0.492 NS	0.002 NS	0.001 NS	0.006 NS	0.082 NS
Error	48	21.31	0.049	0.037	1.023	0.432
CV %		5.88	5.48	5.82	7.38	4.27

(Continued)

Appendix XIXa: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2008-2009)

Sources of variation	df	Number of spikelets spike ⁻¹	Number of fertile spikelets spike ⁻¹	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
Replication	2	1.83	1.07	4.12	0.255	0.588	0.515	44.40
Sowing date (S)	3	240.38**	323.58**	3654.16**	32.93**	58.41**	178.54**	143.56**
Error	6	0.320	0.397	0.938	0.058	0.035	0.112	2.89
Variety (V)	1	285.90**	318.39**	2446.73**	21.76**	60.61**	155.12**	3.19 NS
S×V	3	1.59 NS	1.61 NS	59.56**	0.555*	0.772 NS	2.60*	0.112 NS
Error	8	1.26	0.415	3.06	0.085	0.516	0.479	11.65
Mulching (M)	3	145.01**	195.60**	423.88**	6.57**	16.16**	43.31**	4.71 NS
S×M	9	0.903 NS	0.924**	11.91*	0.176*	0.225 NS	0.784**	0.151 NS
V×M	3	0.764 NS	1.53**	8.85 NS	0.111 NS	0.235 NS	0.658*	0.372 NS
S×V×M	9	0.057 NS	0.004 NS	0.556 NS	0.019 NS	0.003 NS	0.030 NS	0.454 NS
Error	48	0.576	0.257	5.31	0.068	0.211	0.225	4.76
CV %		4.39	3.42	5.98	7.27	7.19	4.76	6.14

Appendix XIXb: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2009-2010)

Sources of variation	df	Plant height (cm)	Number of total tillers plant ⁻¹	Number of effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)
Replication	2	14.94	0.108	0.259	2.36	0.910
Sowing date (S)	3	16638.47**	15.85**	25.22**	370.62**	478.28**
Error	6	9.74	0.024	0.053	0.585	0.359
Variety (V)	1	3331.62**	23.92**	24.80**	160.09**	250.94**
S×V	3	75.84*	0.170 NS	0.195*	2.66 NS	3.84*
Error	8	13.09	0.072	0.043	0.915	0.737
Mulching (M)	3	1603.22**	6.96**	9.16**	57.76**	78.77**
S×M	9	40.54 NS	0.053 NS	0.100*	1.04 NS	1.21 NS
V×M	3	6.53 NS	0.089 NS	0.083 NS	0.170 NS	2.32 NS
S×V×M	9	0.149 NS	0.005 NS	0.001 NS	0.003 NS	0.077 NS
Error	48	28.15	0.135	0.037	1.44	1.06
CV %		6.41	8.45	5.82	8.20	6.22

(Continued)

Appendix XIXb: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2009-2010)

Sources of variation	df	Number of spikelets spike ⁻¹	Number of fertile spikelets spike ⁻¹	1000-grain weight (g)	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)
Replication	2	2.07	0.221	16.42	0.116	0.863	1.61	1.47
Sowing date (S)	3	270.90**	333.90**	4210.50**	35.13**	63.69**	193.13**	133.70**
Error	6	0.549	0.531	3.42	0.042	0.213	0.141	6.67
Variety (V)	1	295.19**	328.19**	2764.91**	24.49**	75.63**	186.18**	0.107 NS
S×V	3	2.11 NS	2.26**	62.81**	0.581**	1.06 NS	3.22**	0.024 NS
Error	8	0.953	0.272	1.46	0.069	0.521	0.311	12.36
Mulching (M)	3	155.61**	183.44**	512.61**	7.33**	20.32**	52.04**	1.49 NS
S×M	9	1.27 NS	1.77**	12.15*	0.190**	0.334 NS	1.02**	0.075 NS
V×M	3	0.594 NS	0.698 NS	7.78 NS	0.156*	0.465 NS	1.16*	0.050 NS
S×V×M	9	0.017 NS	0.025 NS	0.497 NS	0.003 NS	0.007 NS	0.02 NS	0.014 NS
Error	48	1.25	0.553	5.51	0.052	0.282	0.332	4.90
CV %		6.34	4.91	5.70	6.09	7.98	5.54	6.22

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