EFFECTS OF POPULATION DENSITY ON TILLERING AND YIELD OF WHEAT VARIETIES

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JUNE 2020

EFFECTS OF POPULATION DENSITY ON TILLERING AND YIELD OF WHEAT VARIETIES

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REGISTRATION NO. 13-05382

A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE (M.S.)

IN

AGRONOMY

SEMESTER: JANUARY–JUNE, 2020

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CERTIFICATE

*This is to certify that thesis entitled, "**EFFECTS OF POPULATION DENSITY ON TILLERING AND YIELD OF WHEAT VARIETIES**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **SURAIEA AKHTER**, Registration no. **13-05382** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

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ACKNOWLEDGEMENTS

All praises are putting forward to Allah (SWT) Who is the Supreme Planner and has blessed the author to complete this piece of study as required for the degree Master of Science.

It is a great pleasure for the author to make delighted her respected parents, ***Md. Israfil*** *and* ***Amrita Begum*** *who had been shouldering all kinds of hardship to establish a favorable platform thereby receiving proper education until today.*

The author is happy to express her sincere appreciation and profound gratitude to her respective supervisor ***Prof. Dr. H. M. M. Tariq Hossain****, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka for his dynamic guidance, constant encouragement, constructive criticism and valuable suggestions encompassed the research work and thesis writing times.*

It is a great pleasure for the author to express her deep sense of gratitude and sincere regards to her Co-Supervisor ***Prof. Dr. A. K. M. Ruhul Amin****, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka for his adept guidance, supervision, kind cooperation, and valuable suggestions in preparation of the thesis.*

It is highly appreciating words for ***Prof. Dr. Md. Shahidul Islam****, Chairman, along with faculties of the Department of Agronomy, Sher-e-Bangla Agricultural University for their rendered novel services towards me as their student.*

The author also expresses heartfelt thanks to the staff of Department of Agronomy and central farm, SAU, for their cordial help and encouragement during the period of research work.

The author wishes to extend her special thanks to her classmates and friends Md. Sawgat Hossain, Md. Touhidul Alam Shohan, Akhi Badrunnesa and

Shapla Akter for their keen help as well as heartfelt co-operation and encouragement.

The author expresses her heartfelt thanks to her brothers, sisters, uncles, aunts and other relatives who continuously prayed for her success and without whose love, affection, inspiration and sacrifice this work would not have been completed.

May Allah bless and protect them all.

The Author
June, 2020

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ABSTRACT

The experiment was conducted at the agronomy research field of Sher-e-Bangla Agricultural University, Dhaka during November 2018 to March 2019; to find out the effect of variety and population densities on the growth characters and yield parameters of wheat. The experiment comprised of two factors; Factor A: three improved wheat varieties *viz.* (i) V_1 = BARI Gom 30 , (ii) V_2 = BARI Gom 31 and (iii) V_3 = BARI Gom 32; Factor B: four plant population densities *viz*. D_0 = no thinning (control), D_1 = 100 plants m^{-2}, D_2 = 125 plants m^{-2} and D_3 = 150 plants m^{-2}. The experiment was laid out in Split-plot design with three replications. Variety was assigned in the main plot and plant population densities was in the sub-plots. The data were collected on plant height (cm), number of leaves plant^{-1}, number of tillers plant^{-1}, dry weight (g m^{-2}), crop growth rate (CGR), relative growth rate (RGR), weight of 1000-seeds (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%). It was evident from the results that morpho-physiological and yield-contributing characters of wheat were significantly influenced by variety and plant population densities either individually or in combination except relative growth rate (RGR). Experimental results indicated that plant height and dry matter weight increased up to harvest while number of leaves plant^{-1} and number of tillers plant^{-1} increased up to 60 DAS (days after sowing) and there after declined. CGR and RGR increased up to 45–60 DAS and then became steady. The combined effect of BARI Gom 30 along with 125 plants m^{-2} (V_1D_2) population density showed significantly the tallest plant (78.31 cm) at harvest. The maximum dry matter weight (4394.00 g m^{-2}) was obtained from the combination of the variety BARI Gom 32 with no thinning (V_3D_0). The combined effect of BARI Gom 32 along with 125 plants m^{-2} population density (V_3D_2) produced the maximum number of leaves plant^{-1} (18.70), tillers plant^{-1} (5.35),highest weight of 1000-seeds (55.44 g), grain yield (3.20 t ha^{-1}), biological yield (4.55 t ha^{-1}) which were positively supported by maximum value of harvest index (70.67 %) except dry weight m^{-2} which was highest at V_3D_0. The highest straw yield (2.80 t ha^{-1}) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment. The combination of wheat variety BARI Gom 32 with 125 plant m^{-2} was found to be the best treatment combination for wheat production.

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
BBS	Bangladesh Bureau of Statistics
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
eds.	editors
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agricultural Organization
L.	Linnaeus
LSD	Least Significant Difference
i.e.	id est (that is)
MoP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TDM	Total Dry Matter
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	variety
viz.	namely

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum*) is an important cereal crop of tropical and subtropical regions of the world. It ranks first in area (218.50 million hectares) and second in production (756.636 million metric tons) among the grain crops in the world (FAO, 2013). It is the third important cereal crop next to rice (Al-Musa *et al.*, 2012) in Bangladesh. It ranks next to rice in respect of production (13, 48,186 tons) and total area of 4, 45,003 hectares (FAO, 2013). The area under wheat cultivation during 2018–2019 was about 3 lakh 30 thousand 348 hectare producing 10 lakh 16 thousand 811 metric tons of wheat with an average yield of 3.078 ton ha^{-1}(BBS, 2019).

Wheat is cool-loving crop and adopted for cultivation in regions with cooler climatic conditions. Its production is concentrated between latitudes 30° and 60° North and 27° and 40° South (Nuttonson, 1955). Nevertheless, wheat flourishes in many different agro climatic zones. Bangladesh lies in the warmer part of the world and wheat is grown in the winter or cold season of the country. In consideration of the facts that growing of wheat in a location is decided by the temperature limits of 20° and 25°C (Ray and Nathan, 1986) and its grain growth and development depend on temperature range of 15°/10°C to 18°/15°C (Thorne *et al.*, 1968); the best time of sowing of wheat in Bangladesh is the second half of November that needed around 105 days to complete its life cycle.

About one-third people of the world live on wheat. It is a staple food for about one billion in as many as 43 countries and provides about 20% of total food calories. It contains carbohydrate (78.1%), protein (14.17%), minerals (2.1%), fat (2.1%) and considerable proportion of vitamins (Peterson, 1965). According to USDA (2014), one-cup of whole-wheat grain contains 33% Protein, 29% Carbohydrate and 5% Fat and currently about 65% of wheat crop is used for food, 17% for animal feed and 12% in industrial applications. CIMMYT predicted that demand for wheat in the developing world is projected to increase 60% by 2050 from now (CIMMYT, 2013). Wheat contains about 12.1% protein on an average, which is only 8.29% in rice (Mattern *et al.*, 1970).

The average growth and yield of wheat is very low in Bangladesh compared to the average growth and yield of New Zealand, The Netherlands, Ecuador and France (8.9, 8.6, 8.0 and 7.6 t ha^{-1} respectively) (FAO, 2013). There can be a range of reasons for low yield of wheat including inadequate knowledge, lack of specifically adapted varieties, lack of good quality seed, untimely seeding, low fertilization, irrigation scheduling, seed rate and inadequate extension efforts etc. The growth and yield of wheat can be augmented with the use of high yielding varieties and suitable agronomic practices.

Population densities significantly affect the yield of wheat. Optimum plant population ensures proper growth of the aerial and underground part of the plant through efficient utilization of solar radiation, nutrient uptake as well as air, space and water (Nierobca, 2002). Establishment of plant population through optimum seed rate is one of the important factors for securing good yield of wheat (Iqbal *et al.*,2010; Kabir *et al.*, 2009). Sowing of seeds is an important factor for higher production as it contributes to achieving a good crop stand establishment and higher yield (Kraft and Spiss, 1988). Plant spacing determines the area available to each plant, which in turn determines nutrient and moisture availability to the plant (Govil and Pandey, 1995). Many farmers in developing countries prefer to use a higher seed rate than recommended, because they perceive it as a good strategy to control weeds and reduce the risks of crop production. Seed rate was found to have influence on yield and yield contributing characters of wheat (Singh and Singh, 1987). Optimum plant density produces optimum number of plant per unit area resulting better yield contributing characters leading to better grain and straw yields of wheat (Singh, 1992). However, higher seed rate than the recommended one generally increases plant population resulting intra-crop competition thereby affecting the yield. Tiller mortality is greater at high planting density, and the number of fertile spikelets per spike, along with the yield components are mostly affected byplanting density (Saradon *et al.,* 1988). Decreasing the planting density increases the amount of photosynthetic assimilation and provides a canopy structure, which gives increased physiological activities after anthesis leading to a decreased rate of photosynthesis, increased total photosynthetic assimilation and increased sink effect on grain yield (Zhenhua and Yuyog, 1995). On the other hand, lower seed rate may reduce the yield drastically.

Keeping in mind the above consideration, the experiment was conducted to fulfill the following objectives:

1. To evaluate the effect of population density on tillering, yield and yield components of wheat, and
2. To optimize the population density for yield maximization of wheat varieties.

CHAPTER II

REVIEW OF LITERATURE

This chapter presents a comprehensive review of the research works which have been undertaken and studied on the impact of different population densities on growth and yield of diverse wheat varieties under different ecological situations over the world. To get a clear understanding on this subject, some of the relevant research works regarding the above parameters are reviewed in this chapter under different headings and sub-headings.

2.1 Review of population density

2.1.1 Plant height

Dixit and Gupta (2004) conducted an experiment to investigate the effects of seed rates (100, 125 and 150 kg ha^{-1}) on the growth and yield of wheat cv. HUW-234 during Rabi season of 1995–1996. They reported that increasing the seeding rate significantly increased the plant height.

Pandey *el al.* (2004) carried out a field trial to investigate the effect of seed rates on growth and yield of surface seeded wheat. They used three different levels of seed rate such as 125, 150 and 175 kg seed ha^{-1}. They observed that in case of plant height, there were no significant difference among the seed rate treatments.

An observation was undertaken by Arif *et al.* (2002) to study the effect of different sowing rates on yield and yield components of wheat cultivars (Inqilab-91 and Bakhtawar-92). They used four seed rates (50, 100, 120 and 150 kg ha^{-1}) in the experiment. Maximum plant height (97 cm) was recorded at sowing rates of 150 kg seeds ha^{-1}. Inqilab-91 produced the highest plant height (97 cm).

Das (2002) conducted an experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. He used three levels of planting density

(500, 250 and 188 seeds m^{-2}) and concluded that planting density did not significantly influence plant height. The highest plant height was observed in density of 188 seeds m^{-2}.

Mozumder (2001) set up an experiment to investigate the effect of different levels of seed rate on the yield and yield contributing character of wheat. Four levels of seed rate were chosen as treatments for that experiment, i.e. 75, 100, 125 and 150 kg seed ha^{-1}. He reported that there was no significant effect in respect of plant height of wheat due to different seed rate.

Roy and Biswas (1991) carried out an experiment with 100, 200, 300, 400, 500 and 600 seeds m^{-2} to study the effect of population on tillering, growth, yield components and yield of wheat and they observed that there were no significant difference among the seed rates in case of plant height.

Gaffer and Shahidullah (1985) conducted an experiment to study the effect of seed rates on the performance of wheat cv. Inia-66. They used three levels of seed rates such as 100, 140 and 180 kg seeds ha^{-1}. Plant height was significantly higher at 100 kg seeds ha^{-1} than the other rates.

2.1.2 Number of total tillers

Otteson *et al.* (2007) set up a field experiment to study the effect of different seeding rates (2.9 and 4.2 million seeds ha^{-1}) and N levels (140 and 224 kg N ha^{-1}) on yield and yield components of spring wheat. They observed that total tiller number increased significantly with varying seed rates.

Dixit and Gupta (2004) carried out an experiment to investigate the effect of seed rate (100, 125 and 150 kg ha^{-1}) on the growth and yield of wheat. It was observed that increasing the seeding rate significantly reduced the total number of tillers.

Das (2002) conducted an experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. He used three different levels of planting density (500, 250 and 188 seeds m^{-2}) and concluded that total number of tillers plant^{-1} was significantly influenced by planting density. The lowest planting density of 188 seeds m^{-2} produced the highest number of total tillers plant^{-1}.

Hossain (2002) carried out a field research to find out optimum seed rate and harvesting time to obtain maximum yield as well as quality seed of wheat. Three levels of seed rate (110, 120 and 130 kg seed ha^{-1}) were chosen for that experiment. According to the result, seed rates exerted significant effect on total tillers plant^{-1}.

Mozumder (2001) reported that increasing seed rates showed significant effect regarding total tiller plant^{-1}. The highest number of total tiller plant^{-1} was obtained from the lowest seed rate (75 kg seed ha^{-1}).

Sun yuanmin *et al.* (1996) studied on the optimization of plant populations for higher yield of wheat and showed that reducing plant density coupled with early sowing and increased fertilizer application at middle and late growth stages, increased number of tillers plant^{-1} and percentage of fertile tillers m^{-2}.

Kumar *et al.* (1991) set up a field trial where four high yielding recommended wheat cultivars and four new cultivars with longer spikes and more grains spike^{-1} (low tillering) were sown at 100, 125 and 150 kg seed ha^{-1} in a rows 22.5, 18 and 15 cm apart, respectively. The researchers reported that Higher seed sowing rates coupled with decreased in row spacing increased the number of tillers m^{-2} and grain yields.

Al-Fakhry and Ali (1989) evaluated the impact of plant densities and fertilization on yield of two wheat cultivars (*Triticum aestivum* L.) under rain fed conditions in Northern Iraq and reported that narrow row spacing increased number of fertile tillers and total tillers significantly over wider row spacing.

Saradon *et al.* (1988) set up a field trial where wheat seeds were sown to give plant densities of 120–360 plants m^{-2}. The results showed that tiller mortality was higher at high plant density and in the tall cultivar (Klein Toledo).

A field experiment was under taken by Chatha *et al.* (1986) to observe the yield of wheat cultivars as affected by different seed rates (18.5, 37, 55.5, 74 and 92.5 kg seeds ha^{-1}) under irrigated conditions. They found that increasing sowing rates had no significant effect on 1000-grains weight but increased emergence and tillers per unit area and grain yields.

Gaffer and Shahidullah (1985) carried out an experiment to study the effect of seed rates (100, 140 and 180 kg seed ha^{-1}) on the performance of wheat. The researchers observed that tillers $plant^{-1}$ was significantly higher at 100 kg seed ha^{-1} than the other seed rates but grain yields was the highest at 140 kg seed ha^{-1} and straw yield was the highest at 180 kg seed ha^{-1}.

Borojevic and Kraljevic (1983) studied with five cultivar of wheat sown at 300, 500 and 700 seeds m^{-2}. The number of plant produced was 12.7, 14.4 and 15.9 %, respectively. They also found that production of tillers was 50% higher at the lower sowing rate and 25% lower at the higher sowing rate then at the intermediate rate and was the most intensive at the low sowing rate in 6 cm rows.

In a field trial to find out the seed rate of wheat for optimum grain yield, Black and Aase (1982) sown three wheat cultivar with different seed rates along with different dose of N fertilizer. The varying seed rates were used to give density of 148–480 plants m^{-2} and N fertilizer were given at 0 and 45 kg ha^{-1}. They recorded that sowing rate and N application had little effect on grain yield while higher sowing rate produced on an average of 14–46 % higher number of tillers m^{-2} than lower planting density.

Bagga and Tomar (1981) conducted an experiment with three levels of planting densities (200, 250 and 300 plants m^{-2}) to find out the effect of planting density on the growth and yield of wheat. At lower plant densities, both the main shoot and the tillers showed better growth.

2.1.3 Number of effective tillers

Pandey *et al.* (2004) carried out a research work to investigate the effect of seed rates (125, 150 and 175 kg ha^{-1}) on the growth and yield of surface seeded wheat. They reported that seed rate of 175 kg ha^{-1} recorded significantly higher effective tillers m^{-2}.

Hossain (2002) conducted a field trial to find out optimum seed rate and harvesting time to obtain maximum yield as well as quality seed. Three levels of seed rate (110, 120 and 130 kg seed ha^{-1}) were chosen as experimental material and noticed significant effect on effective tillers m^{-2}.

Sun yuanmin *et al.* (1996) studied on the optimization of plant populations for high yield of wheat production. Their experimental results revealed that reducing plant density coupled with early sowing and increased fertilizer application at middle and late growth stages increased the number of tillers m^{-2} and percentage of fertile tillers and biomass at maturity.

Mahajan *et al.* (1991) conducted an experiment with three seed rates of 100, 125 and 150 kg ha^{-1} and with three seed treatments (unsoaked, water soaked and sprouted). They recorded that number of effective tillers m^{-2} decreased with the increase in sowing rate and was the highest with unsoaked seeds.

Kraft and Spiss (1988) from their field research work on relationship between stand density and yield components in wheat reported that increasing seed rate increased the fertile tillers and total tillers significantly.

Sharar *et al.* (1987) observed that increasing the sowing density of wheat from 125–313 seeds m^{-2} increased plant densities from 44.7 to 100.4 plants/3600 cm^2 and fertile tiller number from 146–182.9/3600 cm^2 and decreased average number of grains ear^{-1} from 56 to 44.5.

2.1.4 Dry matter production

The effect of crop density (300, 450 and 600 seeds m^{-2}) on dry matter accumulation and distribution in spring triticale and spring wheat were studied by Nierobca (2002). At crop densities of 300 and 450 plants m^{-2}, spring triticale showed greater dry matter accumulation in shoots than spring wheat; however, at 600 plants m^{-2} spring wheat exhibited greater dry matter accumulation in shoots than spring triticale. Higher dry matter accumulation was reported in case of spring wheat in well developed shoots (4, 5 and 6 labels) than in non-productive shoots (1, 2 and 3 labels).

Nag *et al.* (1998) conducted an experiment during winter season of 1994–1995 to investigate the response on growth and yield of wheat to different seed rates. It appeared that increasing seed rate resulted in increased total dry matter in wheat. They also found that per plant dry matter production decreased with increasing the seed rate.

Roy and Biswas (1991) carried out a field research with six different population densities i.e. 100, 200, 300, 400, 500 and 600 seeds m^{-2} to study the effect of population on tillering, growth, yield components and yield of wheat. They observed that dry matter production per plant was the highest with 100 seeds m^{-2}.

Saradon *et al.* (1988) conducted a research work where wheat cv. Klein Toledo, San Agustin and Marcos Juarez were sown with plant densities of 120–360 plants m^{-2}. They reported that at higher plant densities translocations of dry matter to the ear was greater than in plants grown at lower densities. Dry matter distribution at harvest was unaffected by plant density.

Bagga and Tomar (1981) conducted an experiment with three levels of planting densities (200, 250 and 300 plants m^{-2}) to observe the impact of planting density on growth and yield of wheat. They reported that dry matter production $plant^{-1}$ was higher at lower plant densities.

2.1.5 Crop growth rate (CGR)

Nag *et al.* (1998) carried out a field experiment to investigate the response of growth and yield of wheat to different seed rates. They recorded that crop growth rate differed significantly at different growth stages of wheat. However, CGR was uninfluenced significantly due to varying seed rates.

2.1.6 Relative growth rate (RGR)

Nag *et al.* (1998) conducted a field research to investigate the response of different seed rates on growth and yield of wheat. The researchers observed that RGR value was influenced significantly at maximum tillering stage. At the ripening stage, RGR was negligible. On the other hand, the maximum RGR value was obtained from the seed rate at 200 kg ha^{-1} and minimum from 100 kg seed ha^{-1}.

Govil and Pandey (1995) carried out a field trial to study the growth analysis of wheat and maize with classical and regression methods as affected by different plant population. In that trial, plant densities were 27, 54 and 81 plants m^{-2} and growth indices were analysed using classical and regression methods. RGR value decreased with increasing age of plants due to the increase level of self-shading.

2.1.7 Number of spikes m^{-2}

Fazli *et al*. (2004) set up a three years (1990–1991 to 1992–1993) experiment to study the effect of sowing date, seed rate and weed control method on grain yield and yield components of bread wheat. Seed rate 100 kg ha^{-1} significantly increased grains $spike^{-1}$, 1000-grain weight and grain yield. The maximum seed rates of 150 kg ha^{-1} produced the maximum number of spikes m^{-2} compared to others.

2.1.8 Spike length

Dixit and Gupta (2004) conducted an experiment to investigate the effects of seed rates (100, 125 and 150 kg ha^{-1}) on growth and yield of wheat and recorded that increasing the seed rate significantly reduced the spike length.

Das (2002) set up a field experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. Three levels of planting densities (500, 250 and 188 seeds m^{-2}) were used and it was concluded that planting density frequencies differed significantly in respect of length of spike of wheat.

Hossain (2002) carried out an experiment to evaluate the optimum seed rate and harvesting time for wheat to obtain maximum yield as well as quality seed. Three levels of seed rate (110, 120, 130 kg seeds ha^{-1}) were used. In that experiment, seed rate exerted significant effect on spike length.

Mozumder (2001) set up a field experiment to investigate the effect of different levels of seed rate on the yield and yield contributing characters of wheat. Four levels of seed rate were chosen as treatments for that experiment, i.e. 75, 100, 125 and 150 kg seed ha^{-1}. Spike length varied significantly due to increasing seed rate. The longest spike of 8.98 cm was produced from the treatment where 75 kg seed ha^{-1}, which was followed by 8.76 cm and 8.40 cm obtained from the seed rate of 100 and 125 kg ha^{-1}.

Torofder (1993) conducted an experiment to study the effect of seed rates on the performance of different high yielding varieties of wheat. Three seed rates (80, 100 and 120 kg ha^{-1}) and four varieties (Akbar, Barkat, Ananda and Kanchan) were included in that study where the length of spike decreased with the increase of seed rate.

Gaffer and Shahidullah (1985) carried out a field research to study the effect of seed rates on the performance of wheat cv. Inia-66. Three levels of seed rates such as 100, 140 and 180 kg seeds ha^{-1} were chosen for that study. It was reported that the ear length increased significantly at 100 kg seeds ha^{-1} than at the other rates of seed.

2.1.9 Weight of 1000-seeds

Das (2002) conducted an experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. Three levels of planting density (500, 250 and 188 seeds m^{-2}) showed that planting density did not significantly influence the weight of 1000 grains. The maximum weight of 1000-grains was observed in density of 188 seeds m^{-2} and the minimum from 500 seeds m^{-2}.

Hossain (2002) set up a field experiment to evaluate the optimum seed rate and harvesting time for wheat to obtain maximum yield as well as quality seed. Three levels of seed rate (110, 120, 130 kg seeds ha^{-1}) were used as experimental material. In that experiment, seed rate exerted significant effect on 1000-seed weight.

Mozumder (2001) conducted a field trial to investigate the effect of different levels of seed rate on the yield and yield contributing characters of wheat. Four levels of seed rate were chosen as treatments for that experiment, i.e. 75, 100, 125 and 150 kg seeds ha^{-1} and revealed that the lowest seed rate produced the highest 1000-grains weight.

Ahmed *et al*. (1995) researched on two cultivars using seeding rates from 40–120 kg seed ha^{-1} and revealed that 1000-grains weight decreased from 40.47 g to 39.69 g with the corresponding seeding rates.

Ionescu (1994) set up an experiment with winter wheat cv. Albota and Fundulea-4, where plant density were 100–500 plants m^{-2} in rows (a) 12.5 cm and (b) 25 cm apart. He found that grain yield were higher in (b) than in (a). Grain yield was affected by plant density in (a) but decreased with increased in plant density in Albota and increased in Fundulea-4 in (b) while 1000-grain weight was unaffected there.

Torofder (1993) conducted an experiment to study the effect of seed rates on the performance of different high yielding varieties of wheat. Three seed rates (80, 100 and 120 kg ha^{-1}) and four varieties (Akbar, Barkat, Ananda and Kanchan) were included in the study and found that 1000 grains weight decreased with the increase of seed rate.

Mahajan *et al*. (1991) set up an experiment with three seed rates of 100, 125 and 150 kg ha^{-1}. Their experimental results revealed that grain yield increased with increasing seeding rate and was the highest with sprouted seed (av. 3.51 t ha^{-1}). The highest 1000-grains weight (41 g) was recorded from 150 kg sprouted seeds ha^{-1}.

Kraft and Spiss (1988) from their research on relationship between stand density and yield components in wheat reported that 1000-grain weight reduced at the highest stand density.

Chatha *et al.* (1986) used 18.5, 37.0, 55.5, 74.0 and 92.5 kg seeds ha^{-1} as experimental treatments and found that increasing seeding rate had no significant effect on 1000-grain weight.

Gaffer and Shaidullah (1985) carried out an experiment to study the effect of seed rates on the performance of wheat cv. Inia-66. Three levels of seed rates such as 100, 140 and 180 kg seeds ha^{-1} were used and found that 1000-grains weight was significantly higher at 100 kg seeds ha^{-1} than at the other seed rates.

Bagga and Tomar (1981) conducted an experiment with three levels of planting densities (200, 250 and 300 plants m^{-2}) to find out the effect of planting density on the growth and yield of wheat. They reported that 1000-grain weight remained unaffected by reduction in plant population.

2.1.10 Grain yield

Iqbal *et al.*(2010) conducted a field experiment during 2006–2007 season to evaluate the effect of different seed rates and row spacings on the growth and yield of wheat (*Triticum aestivum* L.). Four levels of seed rates (125, 150, 175 and 200 kg/ha) and three row spacings (11.25, 15.0 and 22.5 cm) were used for the trial (cv. Uqab-2002). The results showed that seed rate of 150 kg/ha gave higher grain yield (4.10 t/ha) for late sowing of wheat up to 28th November. Among row spacings, 22.5 cm row spacing produced higher grain yield (3.96 t/ha) as compared to 11.25 and 15.00 cm row spacings (3.82–3.87 t/ha). Interaction effect of seed rates and row spacings was non-significant.

Kabir *et al*. (2009) set up a field trial to study the effect of seed rate and irrigation level on the performance of wheat cv. Gourab. The experiment comprises of two factors namely (1) four seed rate *viz*. 100, 120, 140 and 160 kg ha^{-1} and (2) four levels of irrigation namely (i) no irrigation i.e. control, (ii) one irrigation given at Crown root initiation (CRI) stage, (iii) two irrigations given at CRI and Panicle initiation stages and (iv) three irrigation given at CRI, panicle initiation and grain filling stages. All of the yields contributing characters were significantly affected by seed rate except 1000-grain weight. The highest plant height (82.36 cm), total tillers $plant^{-1}$ (8.99), effective tillers $plant^{-1}$ (3.49), spike length (8.05 cm), spikelets $spike^{-1}$ (15.50), filled grain $spike^{-1}$ (31.05), grain yield (2.82 t ha^{-1}), straw yield (3.73 t ha^{-1}), biological yield (6.55 t ha^{-1}) and harvest index (42.43%) were recorded from the seed rate of 140 kg ha^{-1}. The interaction between seed rate and irrigation level influenced significantly all the plant characters except plant height, spikelets $spike^{-1}$ and 1000-grains weight. The highest spike length (8.63 cm), grain yield (3.70 t ha^{-1}), biological yield (8.06 t ha^{-1}) and harvest index (45.91%) were observed from the seed rate of 140 kg ha^{-1} combined with one irrigation applied at CRI stage.

Qu *et al.* (2009) from their experiment on the effects of plant density and seeding date on accumulation and translocation of dry matter and nitrogen in winter wheat cultivar 'Lankao Aizao 8' reported that grain yield was increased with increasing plant density because of the increased spikelets number.

Roy (2007) conducted a field experiment during the Rabi season from November 2006 to March 2007 with the objective to find out the influence of sowing depth and population density on growth and yield of wheat. The experiment was set up with three sowing depths viz. 2 cm, 4 cm and 6 cm in main plot and 6 population densities viz. 100 seeds m^{-2}, 200 seeds m^{-2}, 300 seeds m^{-2}, 400 seeds m^{-2}, 500 seeds m^{-2} and 600 seeds m^{-2}. Result showed that population densities had significant effect on plant height at 30 Days After Sowing (DAS), weight of dry matter at 30 DAS, number of spikes m^{-2}, length of spike, number of grains $spike^{-1}$, grain yield, straw yield and harvest index. The highest grain yield (3.36 t ha^{-1}) was produced from 300 seeds m^{-2} treatment whereas, 100 seeds m^{-2} treatment produced the lowest grain yield (2.29 t ha^{-1}). The highest straw yield was observed with 400 seeds m^{-2} and the lowest from 100 seeds m^{-2}. The highest harvest index was recorded with 100 seeds m^{-2}.

Bhullar and Walia (2004) set up a field investigation to study the effect of seed rate and row spacing on the efficacy of clodinafop for combating isoproturon resistant *Phalaris minor* Retz. in wheat. The results revealed that the crop sown with 50% higher seed rate (i.e. 150 kg ha^{-1}) produced more dry matter, which in turn reduced the dry matter accumulation of *P. minor* by 35.4% resulting in increased grain yield of wheat by 12.3% over recommended seed rate. Grain yield of wheat crop sown at 100 kg ha^{-1} with a spacing of 15 cm was at par to the crop sown at 125 kg ha^{-1} with a spacing of 22.5 cm.

Dixit and Gupta (2004) conducted an experiment to investigate the effects of seed rate (100, 125 and 150 kg ha^{-1}) on the growth and the yield of wheat cv.

HUW-234 during Rabi 1995–1996 and reported that increasing the seeding rate significantly increased the grain yield.

Pandey *et al.* (2004) set up an experiment to investigate the effect of seed rates on growth and yield of surface seeded wheat. Three different levels of seed rate such as 125, 150 and 175 kg seed ha^{-1} were used for that experiment. They reported that use of 175 kg seeds ha^{-1} resulted in the highest grain yield.

Talukdar *et al.* (2004) reported that seed rate affected the initial plant population, spike length, grains $spike^{-1}$, 1000-seed weight and grain yield significantly. The highest number of spikes m^{-2} was obtained with 100 kg seed rate ha^{-1} but there was no significant difference with 120 kg seed rate ha^{-1} seeded plot. Similar trends were also observed in case of grain yield and total biomass. The highest grain yield of 4.16 t ha^{-1} in 2001–2002 and 4.20 t ha^{-1} in 2002–2003 was observed at 100 and 120 kg seed rate ha^{-1}, respectively. In both the years, there were no statistical difference between the seed rates.

A field study was undertaken by Volynkina and Volynkin (2003) to observe the effect of planting density on the yield and grain quality of spring wheat. According to their report, the highest grain yield was obtained at a sowing rate of 2–3 million seeds ha^{-1}.

An experiment was undertaken by Arif *et al.* (2002) to study the effect of different sowing rates on yield and yield components of wheat cultivars (Inqilab-91 and Bakhtawar-92). Four seed rates (50, 100, 120 and 150 kg ha^{-1}) were used in the experiment. The maximum grain yield (3346 kg ha^{-1}) was recorded at sowing rates of 150 kg seeds ha^{-1}.

Das (2002) conducted an experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. Three levels of planting density (500, 250 and 188 seeds m^{-2}) were used. Planting density significantly influenced the grain yield. Data revealed that the highest grain yield was produced from the optimum planting density of wheat (250 seeds m^{-2}).

Hossain (2002) carried out an experiment to evaluate the optimum seed rate and harvesting time for wheat to obtain maximum yield as well as quality seed. Three levels of seed rate (110, 120 and 130 kg seeds ha^{-1}) were used as an experimental material. In that experiment, seed rate exerted significant effect on grain yield.

Mozumder (2001) set up an experiment to investigate the effect of different levels of seed rate on the yield and yield contributing characters of wheat. Four levels of seed rate were chosen as treatments for that experiment, i.e. 75, 100, 125 and 150 kg seed ha^{-1}. Seed rate of 125 kg seed ha^{-1} produced the highest grain yield and 75 kg seed ha^{-1} produced the lowest grain yield while they differed significantly with each other.

Nazir *et al.* (2000) from their research work on the response of late sown wheat to seeding density and nitrogen management concluded that seed rate of 150 kg/ha gave significantly higher grain yield (3101 kg/ha) than 100 kg/ha seed rate.

Nag *et al.* (1998) conducted an experiment to investigate the response on growth and yield of wheat to different seed rates. It was observed that increasing seed rate resulted in increased total dry matter in wheat. Seed rate resulted in increased total dry matter of plant and leaf area index but did not increase grain yield in wheat.

Ionescu (1994) set up an experiment with winter wheat cv. Albota and Fundulea-4, where plant density were 100–500 plants m^{-2} in rows (a) 12.5 and (b) 25 cm apart. The grain yield was higher in (b) than in (a). Grain yield was affected by plant density in (a) but decreased with increased in plant density in Albota and increased in Fundulea-4.

Singh and Uttam (1994) conducted a field experiment to observe the effect of seed rate and sowing depth on yield of wheat and reported that the highest yield of wheat was obtained by using a seed rate of 125 kg.

Mishra (1993) carried out a field trial where 100, 125 and 150 kg seeds ha^{-1} were used as experimental treatment which resulted in the average grain yields of 1.24, 1.37 and 1.28 t ha^{-1}, respectively.

Torofder (1993) conducted an experiment to study the effect of seed rates on the performance of different high yielding varieties of wheat. Three seed rates (80, 100 and 120 kg ha^{-1}) and four varieties (Akbar, Barkat, Ananda and Kanchan) were included in the study. Statistically similar yields were found with seed rate of 100 and 120 kg ha^{-1}.

Roy and Biswas (1991) carried out an experiment with 100, 200, 300, 400, 500 and 600 seeds m^{-2} to study the effect of population on tillering, growth, yield components and yield of wheat and reported that grain yield was significantly the highest with 400 seeds m^{-2}.

Endres and Joba (1989) reported that the grain yield of wheat was the highest (5.2 t ha^{-1}) with the closer row-to-row spacing (10 cm) and was the lowest (3.3 t ha^{-1}) with the widest row-to-row spacing (40 cm). Yield increased from 3.5 t ha^{-1} with 150 plants m^{-2} to 3.8 t ha^{-1} with 450 plants m^{-2}. In that experiment, wheat seeds were sown at 2.25, 4.50 and 6.75 million germinable seeds ha^{-1}. The maximum grain yield was achieved at the highest sowing rate.

Ram *et al.* (1988) carried out a field research to study the effect of seed rate and spacing on grain yield of late sown wheat variety WH-291 and suggested seed rate of 160 kg for getting maximum yield of wheat.

Singh and Singh (1987) from their experiment to evaluate the response of late sown wheat to seed rate and nitrogen revealed that seed rate influences the yield and yield attributes of wheat.

Ali (1980) applied different seed rates on yield of wheat and found no significant difference in yield among the seed rates of 80, 90, 110, and 120 kg/ha in variety Sonalika and recommended a seed rate of 80 kg/ha for rain-fed condition.

2.1.11 Straw yield

Dixit and Gupta (2004) conducted an experiment to investigate the effects of seed rate (100, 125 and 150 kg ha^{-1}) on the growth and the yield of wheat cv. HUW-234 during Rabi season of 1995–1996. Increasing the seeding rate significantly increased the straw yield and the highest straw yield was 150 kg ha^{-1}.

Pandey et *al.* (2004) carried out an experiment to investigate the effect of seed rates on growth and yield of surface seeded wheat where three different levels of seed rate such as 125, 150 and 175 kg seed ha^{-1} were used. They reported that use of 175 kg seeds ha^{-1} resulted in the highest straw yield.

Das (2002) set up an experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. Three levels of planting density (500, 250 and 188 seeds m^{-2}) were used. Planting density significantly influenced the straw yield. It was recorded that the highest straw yield obtained from the optimum planting density of wheat (250 seeds m^{-2}).

Hossain (2002) conducted an experiment to evaluate the optimum seed rate and harvesting time for wheat to obtain maximum yield as well as quality seed. Three levels of seed rate (110, 120 and 130 kg seeds ha^{-1}) were used as an experimental material. In that experiment, seed rate exerted significant effect on straw yield. The highest straw yield was associated with the seed rate of 130 kg ha^{-1}.

Mozumder (2001) carried out an experiment to investigate the effect of different levels of seed rate on the yield and yield contributing characters of wheat. The levels of seed rate in that experiment were 75, 100, 125 and 150 kg seed ha^{-1}. Seed rate at 125 kg seed ha^{-1} produced the highest straw yield.

Torofder (1993) conducted an experiment to study the effect of seed rates on the performance of different high yielding varieties of wheat. Three seed rates (80, 100 and 120 kg ha^{-1}) and four varieties (Akbar, Barkat, Ananda and

Kanchan) were included in that study. Yield of straw increased significantly with higher seed rates as compared to that with the lower seed rates.

Paul (1992) noted that sowing rates (120, 140 and 160 kg seed ha^{-1}) did not significantly affect grain or straw yield inlate sown rain-fed wheat.

2.1.12 Harvest index

Begum (2008) carried out a field research to investigate the response of wheat cv. Shourav to different levels of nitrogen and plant spacing. The treatment consisted of three nitrogen levels (120, 180 and 240 kg ha^{-1}) and four plant spacing (3, 5, 7 and 10 cm) in rows with 20 cm apart. Results revealed that nitrogen level and plant spacing influenced plants towards higher yield either singly or in combination. The maximum grain yield (3.76 t ha^{-1}) was achieved at plant spacing of 20 cm × 5 cm. The combined effect of nitrogen 180 kg ha^{-1} along with 20 cm × 5 cm plant spacing produced greater effective tillers $plant^{-1}$ (5.46), length of spike $plant^{-1}$ (12.07 cm). 1000-grain weight (44.73 g) and grain yield (3.94 t ha^{-1}), which were positively supported by maximum value of harvest index (46.27%).

Panday *et al.* (2004) researched with three different levels of seed rate i.e. 125, 150 and 175 kg seed ha^{-1} and reported that harvest index was unaffected by the variation of seed rates.

Das (2002) conducted an experiment to evaluate the effect of planting density on the yield of wheat cv. Kanchan. Three levels of planting density (500, 250 and 188 seeds m^{-2}) were used. The highest harvest index was observed from the optimum planting density at 250 seeds m^{-2} and the lowest harvest index was recorded from 500 seeds m^{-2}.

Hossain (2002) set up an experiment to evaluate the optimum seed rate and harvesting time for wheat to obtain maximum yield as well as quality seed. Three levels of seed rate (110, 120 and 130 kg seeds ha^{-1}) were used as experimental material. In that experiment, seed rate exerted significant effect on straw yield and harvest index.

Mozumder (2001) conducted a research work to investigate the effect of different levels of seed rate on the yield and yield contributing character of wheat. Four levels of seed rate were chosen as treatments for that experiment, i.e. 75, 100, 125 and 150 kg seeds ha^{-1}. Harvest index significantly varied due to different seed rates. The highest harvest index was observed in seed rate at 125 kg ha^{-1}.

Roy and Biswas (1991) carried out an experiment with 100, 200, 300, 400, 500 and 600 seeds m^{-2} to study the effect of population on tillering, growth, yield components and yield of wheat. They observed that harvest index increased up to 400 seeds m^{-2} and after that, the value decreased.

Borojevic and Kraljevic (1983) conducted an experiment to determine the optimum density and row spacing for different genotypes of wheat. The seeds were sown at the rate of 300, 500 and 700 seeds m^{-2}. The number of plant produced was 12.7, 14.4 and 15.9%, respectively. Increasing the seeding rate reduced the harvest index significantly.

Bagga and Tomar (1981) set up an experiment with three levels of planting densities (200, 250 and 300 plants m^{-2}) to find out the effect of planting density on the growth and yield of wheat. The harvest index remained unaffected from reduction in plant population.

2.2 Review of wheat variety

Ahamed and Farooq (2013) accumulated photo thermal units, growth attributes and phenology of three wheat varieties (Chakwal-50, Wafaq-2001 and an advance line NR-268) which were sown in four planting windows from 20th October–5th December at 15 days interval during 2008–2009. The late sown conditions induced the maximum epicuticular wax deposition (0.0071 g cm^{-2}) and synthesis of proline contents (37.08 μg g^{-1}) in leaf tissues at flag leaf stage and it was typically related to Chakwal-50 (44.45 μg g^{-1}). The Wafaq-2001 did well with respect to stomatal conductance and photosynthetic rates over tested NR-268 even in delayed sowing. Sustaining the growth in late sown conditions of Wafaq-2001 was clear indication of its adoptability measures to terminal heat stress. On overall basis, the Chakwal-50 was the best performer and seeding at 5th November must be ensured to maintain desirable growth pattern.

Alam (2013) conducted an experiment to study growth and yield potentials of wheat as affected by agronomic practices. The experiment consisted of three factors such as (a) two methods of planting *viz*. conventional and bed planting (b) four wheat varieties namely Protiva, Sourav, Shatabdi and Prodip and (c) four levels of nitrogen viz. 0, 60, 110 and 160 kg N ha^{-1}. Prodip produced the highest total dry matter up to grain filling stage and the maximum grain yield with the application of 160 kg N ha^{-1}. The overall results indicated that Prodip showed better performance in bed planting system with 160 Kg N ha^{-1}.

Naher (2013) an experiment to find out the effect of variety, sowing time and irrigation on growth of wheat. The experiment comprised of three factors: Factors A: four improved wheat varieties, *viz.* (i) BARI Gom 21 (Shatabdi), (ii) BARI Gom 25, (iii) BARI Gom 26 and (iv) BARI Gom 27; Factor B: three sowing times, *viz*. (a) Sowing at 18 November, (b) Sowing at 03 December and (c) Sowing at 19 December; Factor C: two irrigation, *viz.* (a) Irrigation; (b) No irrigation, i.e. control. Experimental results indicated that plant height and LAI, number of tillers $plant^{-1}$ and leaf $plant^{-1}$ increased up to 45 DAS and there after declined. Seed and husk gained weight 78 and 94 DAS respectively and thereafter remained constant. Dry matter per plant increased up to maturity while CGR and RGR up to 60–90 DAS stage. Variety, sowing time, irrigation and their interactions had significant effect on the morphological parameters except CGR and RGR. At maturity, the treatment combination of BARI Gom 21 (Shatabdi) sown at 18 November with irrigation showed significantly the highest plant height (98.95 cm), number of tillers $plant^{-1}$ (7.58) and leaves plant^{-1} (39.89), LAI (2.02), individual grain weight (0.05 g) and individual husk weight (0.017 g) and dry matter plant^{-1} (19.24 g).

Rahman *et al*. (2013) carried out a field trail to examine the response of seven wheat varieties at two levels of lime. The wheat varieties used in this study were Shatabdi, Sufi, Sourav, Bijoy, Prodip, BARI Gom-25 and BARI Gom-26. There were variations in lime response among the wheat varieties. The index of relative adaptability (IRA %) for yield of BARI Gom-26 and Bijoy was more than 100% for both the years. The results indicated that these two wheat varieties are relatively tolerant to low pH and could be adapted in acidic soil.

Al-Musa *et al*. (2012) conducted a pot experiment to study the performance of some BARI wheat varieties in coastal region. Four wheat varieties *viz.* BARI ghom-23, BARI ghom-24, BARI ghom-25 and BARI ghom-26 were planted in the field to evaluate their comparative performance in respect of germination percentage, growth, yield and yield attributing characters. Among the four varieties, BARI ghom-26 showed superior performance irrespective of all parameters studied except total dry matter content (TDM) and yield reduction percentage. Among the BARI varieties, BARI ghom-26 produced greater germination (61.00%) at 13 days judged against other varieties. The taller plant (47.91 cm), higher LAI (1.84), maximum TDM (17.37 g plant^{-1}) and effective tillers plant^{-1} (18.08) were also obtained with the similar variety. BARI ghom-26 was also most effective to produce the maximum grains spike^{-1} (38.52), higher weight of 1000-grains (49.38 g), higher grain yield (3.35 t ha^{-1}), straw yield (8.50 g plant^{-1}) and greater harvest index (4.03%).

Hussain *et al.* (2012) evaluated phenology, growth and yield of three elite varieties of wheat (Gourab, BARI Gom-25 and BARI Gom-26) under two sowing conditions: optimum (sown on November 15) and late heat stress condition (sown on December 27). All wheat varieties, when sown late, faced severe temperature stress that significantly affected phenology, growth and finally yield. Taking into consideration phenological variation, dry matter (fresh and dry weight) partitioning and grain yield, BARI Gom-26 performed better both in optimum and late heat stress, followed by BARI Gom-25 while Gourab performed the least. On the basis of heat tolerance parameters [Relative Performance (RP) and Heat Susceptibility Index (HSI)], BARI Gom-25 (RP-79%; HSI-0.7) was the best performing variety followed by BARI Gom-26 (RP-74%; HSI-0.9) under heat stress while Gourab (RP-61%; HSI-1.3) was sensitive to heat.

Khakwani *et al*. (2012) conducted an experiment of 6 bread wheat varieties (Damani, Hashim-8, Gomal-8, DN-73, Zam-04 and Dera-98) which were subjected to 2 treatments i.e., control treatment (100% field capacity) and stressed treatment (20 days water stress was given during booting stage and 20 days water stress after anthesis). The findings revealed highly significant differences among means of wheat varieties in both physiological and yield traits. Almost all varieties showed their best adaptation under stressed environment. However, Hashim-8 and Zam-04 behaved exclusively and indicated higher relative water content (RWC), mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) whereas stress susceptibility index (SSI) and tolerance (TOL) estimated at its lowest, as these traits are recognized beneficial drought tolerance indicators for selection of a stress tolerant variety. Similarly, total grain yield per plant, biological yield per plant and harvest index was also higher in the same wheat varieties that put them as good candidates for selection criteria in wheat breeding program for drought resistant.

Abdelmulaa (2011) evaluating the result of an experiment in consecutive two years concluded that the induced terminal heat stress during both years was severe enough to cause a reduction in yield of the tested genotypes. The determined differential genotypic variability to terminal heat stress and the estimated correlation between yield and its components could be exploited in breeding programs to identify and develop new heat tolerant widely adapted cultivars. Such cultivars could be suitable for optimum sowing date as well as for terminal heat stress, for example, genotype OASIS / KAUZ / 3BCN. Moreover, the genotype KAUZ"S"657C1-3-6-2-2-1-2 which exhibited a specific adaption and high yielding only under late sowing, could be identified and selected for improving tolerance to terminal heat stress.

Ahamed *et al.* (2010) observed the effect of high temperature stress on the leaf growth and dry matter partitioning of 5 wheat varieties (Sourav, Pradip, Sufi, Shatabdi and Bijoy) from a field experiment which was conducted with normal sowing (sowing at November 30) and late sowing (sowing at December 30). It was observed that stem dry weight was the highest in Shatabdi under both normal (2.267 g) and heat stressed (1.801 g) environment and Pradip (1.202 g) and Sufi (1.166 g) produced the lowest stem dry weight in those conditions. Leaf number of Pradip (5.37) and Shatabdi (5.01) was the highest in the normal and late sowing condition, respectively and it was lowest in the variety Bijoy (4.87) followed by Sufi (3.62) under the normal and late sowing condition. Both under normal and late sown heat stressed condition the variety Shatabdi showed the highest leaf area, longest leaf sheath and lamina with concomitant increase of dry matter (5.976 g and 4.459 g tiller^{-1} under normal and heat stress, respectively). However, the spike dry weight was highest in Bijoy and lowest was in Sourav and Sufi regardless of the growing condition. In normal sowing, the ear weight and husk of main stem was the highest in Shatabdi (2.933 g), whereas seed weight per main stem was highest in Bijoy (2.167 g). In late sown condition, ear weight, seed weight per stem was highest in Bijoy and husk weight was found the highest in Shatabdi. 1000-grain weight of variety Bijoy (34.94 g) and Shatabdi (33.30 g) were higher in late sowing, whereas Sufi had lowest 1000-grain weight (23.81 g) and finally Bijoy produced the highest grain yield both under normal sowing and late sown mediated heat stressed condition. Considering all, Bijoy can be identified as the best performing variety amongst all and Sufi is the worst one considering specifically the yield components and yield.

Hussain *et al*. (2010) conducted an experiment to assess the growth and yield response of three wheat varieties (Inqalab-91, Kharchia and Parwaz-94) under different seeding densities *viz*. 100, 125 and 150 kg ha^{-1}. The results indicated that seeding densities significantly affected various growth and yield parameters like germination count, total number of tillers m^{-2}; number of grains $spike^{-1}$ and grain yield; but total leaf area $plant^{-1}$, straw yield and harvest index were not affected significantly. The varieties differed significantly from one another with respect to the yield and yield contributing parameters. Wheat variety Inqalab-91 when sown @ 150 kg ha^{-1} gave the highest yield.

Tariq (2010) carried out an experiment where two wheat genotypes *viz.* a) Mairaj-2008 and b) Fareed-2006 were used to evaluate the effect of drought introduced conditions at different crop growth stages according to the given irrigation schedules, i.e. (i): Control (no drought), (ii): Irrigation skip at tillering (20–40 DAS), (iii): Irrigation skip at jointing (40–75 DAS), iv: Irrigation skip at spike emergence (75–90 DAS) and v: Irrigation skip at grain formation (105–115 DAS). It was recorded that Mairaj-2008 produced significantly higher plant height, number of productive tillers per pot, number of spikelet per spike, spike length, weight of spike per pot, biological yield, harvest index, moisture contents, and relative leaf water contents than that of Fareed-2006. Both of the wheat varieties have no genetic potential to withstand against drought. However, skipping irrigation at grain formation stage abruptly reduced the grain yield followed by skipping irrigation at tillering stage as compared to rest of the crop growth stages. It is therefore suggested that irrigation at grain formation and tillering stage should never be missed in successful crop husbandry.

Alam *et al.* (2008) carried out a research work with twenty wheat varieties / lines to study the effect of source-sink manipulation on grain yield in wheat. Significant variations among the genotypes were observed for grains spike, 100-grain weight and grain yield in main spike. Removal of flag leaf caused decreased in grains spike, 100-grain weight and grain yield in main spike by

9.94%, 7.65% and 16.88%, respectively. Similarly, removal of all leaves caused reduction of grains spike, 100-grain weight and grain yield in main spike by 17.17%, 13.27% and 27.92%, respectively. On the other hand, removal of 50% spikelet decreased 41.03% and 37.01% in grains spike and grain yield in main spike while increased 9.44% in 100-grain weight. Similarly, 25% spikelets removal reduced grains spike and grain yield main spike by 25.13% and 23.38%, respectively but increased 4.08% in 100-grain weight. The variety/lines BL-1020, Ananda and Akbar showed higher decrease in grains spikes, 100-grain weight and grain yield in main spike by defoliation treatment.

Mehmet and Telat (2006) conducted field trials in two locations over two years to observe the adaptation and stability statistics of 20 bread wheat genotypes for yield performances. All the genotypes showed stability for their traits of plant density and days to heading. There were differences in stability performances among the genotypes for the traits of plant height, grain numbers spike^{-1}, grain weight spike^{-1}, 1000 kernels weight and grain yield. The instability for plant height and grain weight spike^{-1} among the genotypes were originated from the mean squares of deviation from regression; for the other traits, it was resulted from not only the mean squares of deviation from regression but also from the differences among regression coefficients of genotypes.

Jalleta (2004) conducted an experiment at farmers' level with a number of improved bread wheat varieties for production in different climatic zones. Farmers identified earliness, yield and quality as the main criteria for adaptation of wheat varieties and they found that the variety HAR-710 gave 2.56 t ha^{-1} and PAVON-76 gave 2.49 t ha^{-1}.

Sulewska (2004) carried out an experiment with 22 wheat genotypes for comparing vegetation period, plant height, number of stems and spikes, yield per spike and plant, resistance to powdery mildew and brown rust. He found a greater variability of plant and spike productivity and of other morphological characters. The researcher also reported that the variety Waggershauser, Hohenh, Weisser and Kolben gave the highest economic value among the tested genotypes.

BARI (2003) conducted an experiment to test varietal performance of different wheat varieties and found that Shatabdi produced the highest grain yield (3.20 t ha^{-1}) followed by Gourab (3.13 t ha^{-1}) and the lowest yield was produced by Kanchan (2.96 t ha^{-1}).

WRC (2003) conducted an experiment in Heat Tolerant Screening Nursery in Barisal region with 50 advance lines/varieties. The descending sequence of grain yield among the advanced varieties/lines was as follows–E50 (3.94 t ha^{-1}), BAW 1048 (3.85 t ha^{-1}), BAW 1021 (3.64 t ha^{-1}), BAW 1024 (3.60 t ha^{-1}) and E45 (3.58 t ha^{-1}). Among the varieties released from BARI (WRC), Protiva produced the highest yield (2.97 t ha^{-1}).

Sikder *et al*. (2001) conducted an experiment with ten recommended wheat (*Triticum aestivum* L.) varieties with two sowing conditions i.e. optimum sowing (November 30) and late sowing (December 30). The experiment was conducted to determine the relative heat tolerance of the wheat varieties and to evaluate the relative yield performance of heat tolerant and heat sensitive wheat varieties under late seeded conditions. Based on membrane thermo-stability (MT) test, four varieties (Ananda, Pavon, Aghrani, and Barkat) took maximum heat killing time and were classified as relative heat tolerant, three varieties (Akbar, Kanchan and Protiva) as moderately tolerant and the rest three varieties (Balaka, Sawgat and Sonora) took the shortest heat killing time and considered as heat sensitive. The grain number per ear, 1000-grains weight and main shoot grain weight of tolerant and moderately tolerant varieties showed higher relative performance compared to sensitive varieties, But the relative ear number per plant and relative grain yield were found to range from low-to-high in heat tolerant and moderately tolerant varieties. In heat sensitive varieties, the relative ear number per plant and relative grain yield were moderate to high. Thus, the results suggested that in addition to membrane thermo-stability test, the high relative grain number per ear, 1000-grain weight and main shoot grain weight could be used to determine the heat tolerance of wheat varieties under late seeded warmer conditions.

Zhu *et al.* (1999) conducted experiments with 100 varieties of wheat in Zhejiang since 1954 and 27 of these have been grown over 34,000 ha. Yields have increased greatly because of selective breeding. In 1990, mean production was 1.60 t ha^{-1}, 1.4 times higher than in 1959. In 1994 production was 2.52 t ha^{-1}, 57% higher than in 1970, while in 1997 it reached 2.94 t ha^{-1}. Varieties had also been selected for quality as well as yield improvement.

Litvinenko (1998) reported that winter wheat with high grain quality for bread making is produced in Southern Ukraine. Wheat breeding began more than 80 years ago. Over this time, seven wheat varieties were selected where yield potential increased from 2.73 to 6.74 t ha^{-1}. This increase was due to a decrease in photoperiodic sensitivity and the introduction of semi-dwarf genes. Genes for photoperiodic sensitivity (Ppd) and vernalization requirement (Vrn) were combined and the effect of those genes on grain yield, frost and drought resistance and growth and development rate of plant in autumn and early spring were studied. Breeding was carried out, utilising traditional and non-traditional methods such as anther culture, biochemical and molecular markers, and screening in artificial environments using phytotrons. This approach resulted in the release of several winter wheat varieties with high yield potentials and well expressed adaptation features.

Srivastava *et al*. (1998) conducted an experiment with nine wheat varieties promising for rain fed conditions, together with their 36 F_1 hybrids. Data were recorded on vegetative growth period, grain development period, flag leaf area (cm^2), Spikelets $spike^{-1}$ and grain yield $plant^{-1}$. The genotypes were grouped into 10 clusters. Promising crosses for rain fed conditions were WL 2265 ×

P20302, CPAN 1992 × P20302, WL 2265 × HDR 87 and WL 2265 × CPAN 1992.

Arabinda *et al.* (1994) observed that the grain yield was significantly affected by different varieties in Bangladesh. The genotypes CB-15 produced higher grain yield (3.70 ha^{-1}) due to more number of spikes m^{-2} and grains $spike^{-1}$.

Jahiruddin and Hossain (1994) observed that 1000-grain weight varied among the three varieties namely Sonalika, Kanchan and Aghrani.

Bakhshi *et al.* (1992) conducted field experiments with eight bread wheat and seven durum wheat varieties sown on 1st or 15 November or 15 December, and given 0, 40, 80 or 120 kg N ha^{-1} with one or two irrigation. Seed yield was the highest when wheat was sown on 1st November with 120 kg N ha^{-1} and two irrigations. Varieties Raj 3037, HD-4594, WL-711 and WH-841 gave the highest seed yield.

2.3 Review on interaction effect of population density and wheat variety

Azevedo *et al.* (2017) conducted a field experiment to quantify wheat yield response to seeding rates by contrasting genotypes (high tillering vs. low tillering). One study was set up at two locations: Ashland Bottoms (dryland and conventional tillage) and at Topeka (irrigated and no-tillage) field research stations (Kansas). The two winter wheat varieties were sown at four different seeding rates (40, 80, 120, and 160 lb/a). For the first year, average yield was greater at Ashland Bottoms (79.8 bushels per acre) than at Topeka (50.4 bushels per acre). Statistically, neither seeding rate, variety, nor their interaction resulted in significant differences at Topeka. Seeding rate significantly affected yields at Ashland Bottoms, with positive yield response as seeding rate increased but plateauing at 120 lb/a.

Lollato *et al.* (2017) carried out a field research to evaluate the tillering and yield response of different modern wheat varieties to seeding rate. Seven wheat varieties (Everest, KanMark, 1863, Joe, Tatanka, Larry, and Zenda) were sown at five different seeding rates (0.6, 0.95, 1.3, 1.65, and 2 million seeds per acre). Increasing plant population decreased the number of spring tillers sustained by the different varieties from more than eight tillers per plant at 600,000 seeds per acre to fewer than four tillers per plant at 2 million seeds per acre. There were varietal differences in tillers per plant, with the variety Joe standing out as a high-tillering variety. Wheat grain yield increased with increased seeding rates and was the maximum at approximately 0.8–0.95 million emerged plants per acre. Further increases in seeding rate did not affect grain yield.

Li *et al.* (2016) conducted a field trial in order to study the effect of plant density on the grain number and grain weight of two winter wheat cultivars at different spikelet and grain positions. The grain number and grain weight vary significantly at different spikelet and grain positions among wheat cultivars grown at different plant densities. In that study, two winter wheat (*Triticum aestivum* L.) cultivars, 'Wennong6' and 'Jimai20', were grown under four different plant densities (75, 225, 375 and 525 plants m^{-2}) for two seasons. FSN (number of fertile spikelets per spike), GN (number of grains per spike) and SGW (single-grain weight) significantly decreased with the increasing plant density. Overall, plant density affected the yield by controlling the seed-setting characteristics of the tiller spike while the seed-setting characteristics in the main stem spike were relatively stable.

Sarker *et al.* (2009) set up a field experiment with three wheat varieties of varying seed sizes at five seed rates with medium and high management to determine the appropriate seed rates for the varieties under different management practices. Two managements: a) medium management-fertilizer nutrients for moderate yield goal i.e., N-P-K-S-B @ 100-27-35-18-1 kg ha^{-1} and b) high management (integrated)-fertilizer nutrients for high yield goal i.e., N-P-K-S-Zn-B-Cowdung @ 120-33-60-22.5-4-1-10,000 kg ha^{-1} with Furadan 5G and Tilt 250 EC were as the main plots. The sub-plots were assigned to three varieties viz., Sufi, Shatabdi, and Prodip, and five seed rates viz., 80, 100, 120, 140, and 160 kg ha^{-1} were assigned to the sub-sub plots. Higher grain yield was obtained from varieties Shatabdi (medium sized seed) and Prodip (large sized seed) compared to Sufi (small sized seed) in high management, whereas in medium management, all the varieties produced similar grain yield. Considering yield performance and BCR analysis, the seed rates of Sufi and Shatabdi might be 100 and 120 kg ha^{-1}, respectively, for both the managements. Seed rates of Prodip might be 120 and 140 kg ha^{-1} for medium and high management, respectively.

According to annual report from WRC (Wheat Research Centre) (2004), it was observed from WRC field that the varieties with bolder seed failed to produce the expected higher yield even with higher seed rate and it has been suggested that high management may be an option to obtain the expected yield from those varieties.

From their respective research works and findings, Razzaque *et al.* (2000) and Islam *et al.* (2004) recommended a common seed rate of 120 kg ha^{-1} for all the wheat varieties.

Saunders (1990) from his research findings concluded that farmers are using very high seed rate, sometimes even double of the recommendation for controlling weed as extra benefit.

In the early stages of wheat research in Bangladesh, Gaffer and Rahman (1979) in their research to find out the effects of nitrogen, phosphorus, potassium and seeding methods on wheat used a spacing of 5cm between seeds planted in rows 20 cm apart, which is impractical to some extent and seems to be costly.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials and methods of the experiment with a brief description on experimental site, climate, soil, land preparation, planting materials, experimental design, land preparation, fertilizer application, irrigation and drainage, intercultural operation, data collection, data recording and their analysis. The details of investigation for achieving stated objectives are described below.

3.1 Site description

The experiment was conducted at the Sher-e-Bangla Agricultural University research farm, Dhaka, during the period from November 2018 to March 2019. The experimental site was located at 23°46′ N latitude and 90°23′ E longitude with an altitude of 8.45 m.

3.2 Agro-ecological Zone

The experimental site belongs to the agro-ecological zone of "Madhupur Tract", AEZ-28. This was a region of complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (FAO-UNDP, 1988). For better understanding, the experimental site is shown in the AEZ Map of Bangladesh in Appendix I (A).

3.3 Climate and weather

The geographical location of the experimental site was under the sub-tropical climate characterized by three distinct seasons. The monsoon or rainy season extending from May to October, which is associated with high temperature, high humidity and heavy rainfall. The winter or dry season from November to February which is associated with moderately low temperature and the pre-monsoon period or hot season from March to April which is associated with less rainfall and occasional gusty winds. Information regarding monthly maximum and minimum temperature, rainfall, relative humidity and sunshine during the period of study of the experimental site was collected from Bangladesh Meteorological Department, Agargaon and is presented in Appendix III.

3.4 Soil

The soil of the experimental area was silty clay in texture, red brown terrace soil type, olive–gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.5 and had organic carbon 0.43% [Appendix II(B)]. The land was well drained with good irrigation facilities. The experimental site was a medium high land. It was above flood level and sufficient sunshine was available during the experimental period. The morphological characters of soil of the experimental plots are as following - Soil series: Tejgaon, General soil: Non-calcareous dark grey [Appendix I (B)]. The physicochemical properties of the soil are presented in Appendix II.

3.5 Planting materials

Three improved varieties of wheat - namely, BARI Gom-30, BARI Gom-31 and BARI Gom-32 was used as planting material for the present study. These varieties are recommended for Rabi season in Bangladesh. These are slightly heat tolerant varieties and suitable for cultivation all over the country except saline area of southern belt. The feature of these varieties is presented below:

Name of Variety	:	BARI Gom-30
Height	:	95–100 cm
Maturity	:	100–105 days
Number of grains $spike^{-1}$	:	45–50
Grain colour	:	White and shiny
1000 grain weight	:	44–46 g
Yield	:	4.0–5.0 t ha^{-1}

Name of Variety	:	BARI Gom-31
Height	:	91–98 cm
Maturity	:	100–108 days
Number of grains spike^{-1}	:	47–52
Grain colour	:	White and shiny
1000 grain weight	:	48–52 g
Yield	:	4.6–5.0 t ha^{-1}

Name of Variety	:	BARI Gom-32
Height	:	89–91 cm
Maturity	:	100–105 days
Number of grains spike^{-1}	:	44–48
Grain colour	:	White and shiny
1000 grain weight	:	48–52 g
Yield	:	4.0–5.0 t ha^{-1}

3.6 Treatments

There were two sets of treatments in the experiment. The treatments were varieties of wheat and population density. Those are shown below:

Factor A: Varieties

i. BARI Gom-30
ii. BARI Gom-31
iii. BARI Gom-32

Factor B: Population Densities

i. Controlled (No thinning)
ii. 100 plants m^{-2}(20 plants per 1 linear meter)

iii. 125 plants m^{-2} (25 plants per 1 linear meter)

iv. 150 plants m^{-2}(30 plants per 1 linear meter)

3.7 Experimental design

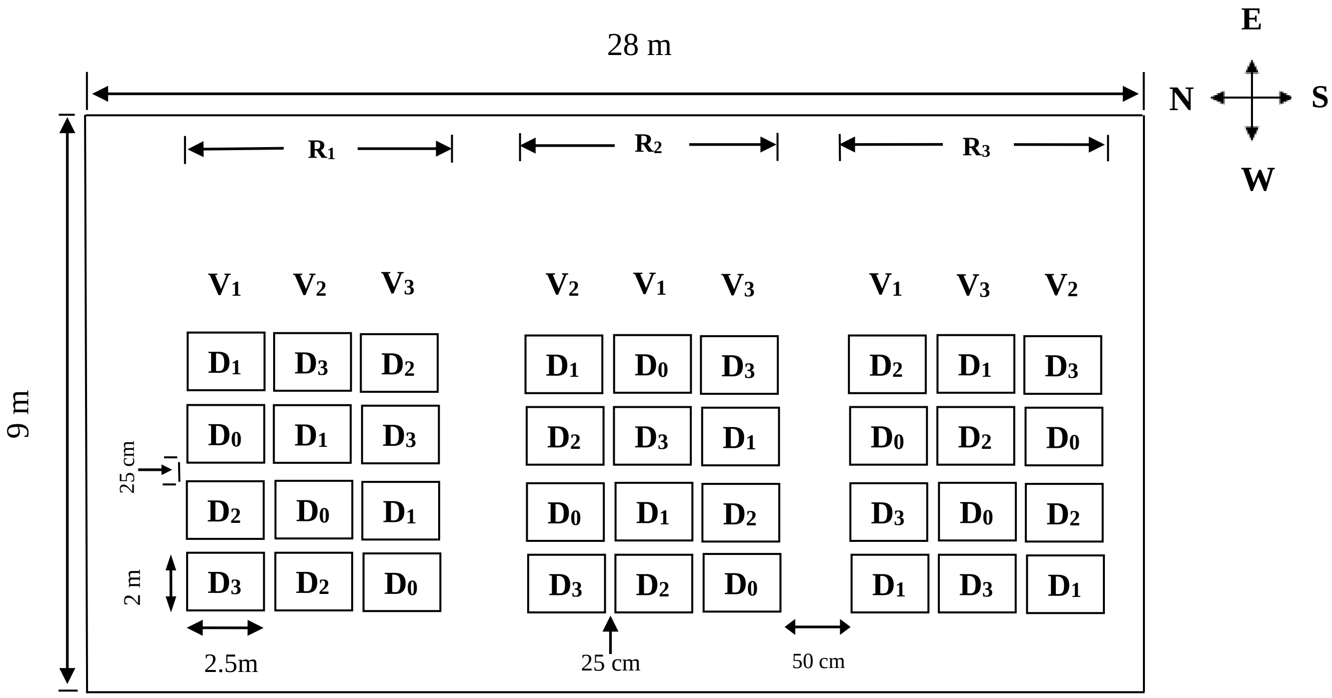
The experiment was laid out in a split-plot design with three replications. The experimental area was divided into three blocks each of which representing a replication. Each block was divided into 3 main plots in which varieties of wheat were applied at random. Each main plot was further divided into 4 unit plots or sub-plots for the treatment of different plant density and treatments were arranged at random. Therefore, the total number of unit plots in the entire experimental plot were 3 × 4 × 3 = 36. Size of each plot was 2.5 m × 2 m = 5 m^2. The distance maintained between two blocks was 50 cm and between sub-plots 25 cm. The treatments were randomly distributed to each block following the experimental design (Figure 1).

3.8 Seed collection

The seeds of the crop were collected from the Wheat Research Centre, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.9 Preparation of the field

The selected plot for the experiment was opened in 9 November 2018 with a power tiller and was exposed to the sun for a week. Larger clods were broken into small pieces. Weeds and stubbles were removed. Final ploughing and land preparation were done on 16 November 2018 and a desired tilth was obtained finally for seed sowing. Layout was done as per experimental design on 18 November 2018.



Unit Plot Size = 2.5 m × 2 m

Plot Spacing = 0.25 m

Between replication = 0.50 m

Legend:

V_1 = BARI Gom-30

V_2 = BARI Gom-31

V_3 = BARI Gom-32

D_0 = Controlled

D_1 = 100 plants m^{-2}

D_2 = 125 plants m^{-2}

D_3 = 150 plants m^{-2}

Figure 1: Field layout of the experiment with Split-plot Design.

3.10 Fertilizer application

The field was fertilized with Urea, TSP, MoP and Gypsum. The full doses of all fertilizers and one third of urea were applied as basal dose to the individual plot during final land preparation. The first split of urea was applied at crown root initiation (21 days after sowing) stage and the second split of urea was applied at prior to spike initiation stage (55 days after sowing) as top dressing.

Nutrient	Source	Dose (kg ha^{-1})
N (Nitrogen)	Urea (46% N)	220
P (Phosphorus)	TSP (44% P_2O_5)	180
K (Potassium)	MoP (60% K_2O)	50
S (Sulphur)	Gypsum (23% S)	120

Source: Krishi Projukti Hatboi (BARI, 2008).

3.11 Sowing of seeds

Seeds were sown continuously in line on 19 November 2018 as per experimental treatment. The row-to-row distance was 20 cm. After sowing, seeds were covered with soil and slightly pressed by hand.

3.12 Thinning

The thinning of crop was done when needed following the treatment variables maintaining plant population as per treatment and plant-to-plant distance 3–5 cm. (approx.). There were 12 lines in a plot. Five lines were selected for collecting plant samples within 1 linear meter area. There were 20 plants in 1 linear meter with 5 cm plant-to-plant distance, 25 plants in 1 linear meter with 4 cm plant-to-plant distance and 30 plants in 1 linear meter with 3 cm plant-to-plant distance.

3.13 Intercultural operations

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

3.13.1 Irrigation and drainage

The experimental field was irrigated with adequate water and was maintained throughout the crop growth period. Two irrigations were given at crown root initiation (21 days after sowing) stage and prior to spike initiation stage (55 days after sowing). During irrigation, care was taken so that water could not flow from one plot to another or overflow the boundary of the plots. A good drainage facility was also maintained for immediate release of excess water from the field.

3.13.2 Weeding

The experimental plots were infested with some common weeds, which were removed twice by uprooting. Weeds infested the experimental plots. So two weeding were done manually at 25 and 50 days after sowing. Both thinning and weeding were done simultaneously during first weeding. During weeding, the weeds identified were Durba (*Cynodon dactylon* L.), Shama (*Echinochloa crusgalli L.*), Arail (*Leersia bexandra*),Chelaghash (*Parapholis incurve* L.), Mutha (*Cyperus rotundus L.*), Bathua (*Chenopodium album L.*), Banmasur (*Vicia sativa L.),* Shaknotey (*Amaranthus viridis L.*), Foskabegun (*Physalis heterophylla*) and Titabegun (*Solanum torvum*). First hand weeding was done from each plot at 20 DAS and second hand weeding was done from each plot at 55 DAS.

3.13.3 Plant protection measures

Plants were infested with aphid; which was successfully controlled by application of insecticides such as Malathion 57 EC @ 2 ml/liter of water. The crop was protected from birds and rats during the grain-filling period. Zinc phosphide was applied to control rat. A guard was appointed to protect the wheat grain from bird especially Parrots from mid-February to March until harvest.

3.13.4 Harvesting and post-harvest operation

The wheat plants were harvested depending upon the maturity at 113 DAS. Harvesting was done manually from each plot on 12 March 2019. Maturity of crop was determined when 80% of the grains became white shiny in color. Random samples of five wheat plants were collected from different places of each plot leaving undisturbed one square meter in the centre. The selected sample plants were then harvested, bundled, tagged and carefully carried to the threshing yard in order to collect data. Samples of one meter square and rest of the crop was harvested as of plot wise, bundled and tagged. The crop bundles were sun dried by spreading those on the threshing floor. The grains were separated from the plants by beating the bundles with bamboo sticks. Fresh weight of grain and straw were recorded plot wise. The grains were cleaned and sun dried for 3 days. Straw was also sun dried properly. Finally, grain and straw yield m^{-2} were recorded and converted to t ha^{-1}.

3.14 Recording of plant data

The growth parameters during study were recorded at 15 days interval started from 45 DAS up to 75 DAS from randomly preselected plants grown in destructive line and the yield and following other parameters were taken at harvest from pre-demarcated area.

3.14.1 Crop growth parameters

a) Plant height (cm)
b) Number of leaves $plant^{-1}$
c) Total dry matter (above and below ground) weight of plants m^{-2} (g)
d) Crop growth rate (CGR) (g m^{-2} day^{-1})
e) Relative growth rate (RGR) (g. g^{-1}.day^{-1})

3.14.2 Yield contributing parameters

a) Number of tillers plant^{-1}
b) Weight of 1000-grains (g)

3.14.3 Yield parameters

c) Grain yield (t ha^{-1})
d) Straw yield (t ha^{-1})
e) Biological yield (t ha^{-1})
f) Harvest index (%)

3.15 Procedure of recording data

3.15.1 Plant height (cm)

The height of plant was recorded at 45, 60 and 75 DAS. Data were recorded by making average of five (5) tillers selected at random in each plot. The height of the plant was determined by measuring the distance from the soil surface to the tip of the leaves before spike emergence and up to the tip of spike after spike emergence.

3.15.2 Number of leaves plant^{-1}(no.)

The number of leaves plant^{-1} was recorded at 45, 60 and 75 DAS by counting total leaves as the average of five (5) tillers selected at random in each plot.

3.15.3 Number of tillers plant^{-1} (no.)

The number of tillers plant^{-1} was recorded at 45, 60 and 75 DAS by counting total tillers within a linear meter selected at random from each plot.

3.15.4 Total dry matter (above and below ground) weight of plants within a linear meter (g)

Total dry matter (above and below ground) weight of plants within a linear meter was recorded at 45, 60 and 75 DAS by drying plant samples. The plant samples were oven dried at 72°C temperature until a constant level from which the weight of total dry matter were recorded. Data were recorded from wheat plants within a linear meter selected at random and expressed in gram.

3.15.5 Crop Growth Rate (CGR)

The dry matter accumulation of the crop per unit land area in unit of time is referred to as crop growth rate (CGR), expressed as g m^{-2} day^{-1}. The mean CGR values for the crop during the sampling intervals have been computed by using the formula of Brown (1984):

$$\frac{1}{GA} \times \frac{W_2 - W_1}{T_2 - T_1} \qquad g\ m^{-2}\ day^{-1}$$

Where,

GA = Ground area occupied by the plant at each sampling (m^2)

W_1 = Total dry matter production at previous sampling date (g)

W_2 = Total dry matter production at current sampling date (g)

T_1 = Date of previous sampling

T_2 = Date of current sampling

3.15.6 Relative growth rate (RGR)

The rate at which a plant incorporates new material into its sink is measured by relative growth rate of dry matter accumulation and is expressed in g. g^{-1}.day^{-1}. Relative growth rate was calculated by following the formula of Radford (1967).

$$\frac{Ln(W_2) - Ln(W_1)}{T_2 - T_1} \qquad g.\ g^{-1}.day^{-1}$$

Where,

W_1 = Total dry matter production at previous sampling date (g)

W_2 = Total dry matter production at current sampling date (g)

T_1 = Date of previous sampling

T_2 = Date of current sampling

Ln = Natural Logarithm

3.15.7 Weight of 1000-grains (g)

One thousand cleaned dried seeds were counted randomly from the total cleaned harvested grains of each individual plot and then weighed with a digital electronic balance at the stage the grain retained approximately 12% moisture and the mean weight were expressed in gram.

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

The grain of each plot, 1 m^2 was harvested, cleaned, threshed, dried in the sun for 3 days and weighed. Finally, grain yield m^{-2} was converted and expressed in t ha^{-1} on approximately 12% moisture basis.

3.15.9 Straw yield (t ha^{-1})

The dry weight of straw of each plot, 1 m^2 was harvested, cleaned, threshed, dried in the sun for 2 days and weighed. Finally, straw yield m^{-2} was converted and expressed in t ha^{-1}.

3.15.10 Biological yield (t ha^{-1})

Biological yield is the summation of grain yield and straw yield. It was calculated from the following formula:

Biological yield (t ha^{-1}) = (Grain yield + Straw yield) t ha^{-1}

3.15.11 Harvest index (%)

Harvest Index denotes the ratio of economic yield to biological yield. Harvest index was determined with the following formula of Donald (1963):

$$\text{Harvest Index (\%)} = \frac{\text{Economic Yield (Grain weight)}}{\text{Biological Yield (Total dry weight)}} \times 100$$

It was expressed in percentage.

3.16 Statistical analysis

The collected data were compiled and analysed following the analysis of variance (ANOVA) techniques by split-plot design to find out the statistical significance of experimental results. The collected data were analysed by computer package program MSTAT-C software (Russell. 1986). The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability.

CHAPTER IV

RESULTS AND DISCUSSION

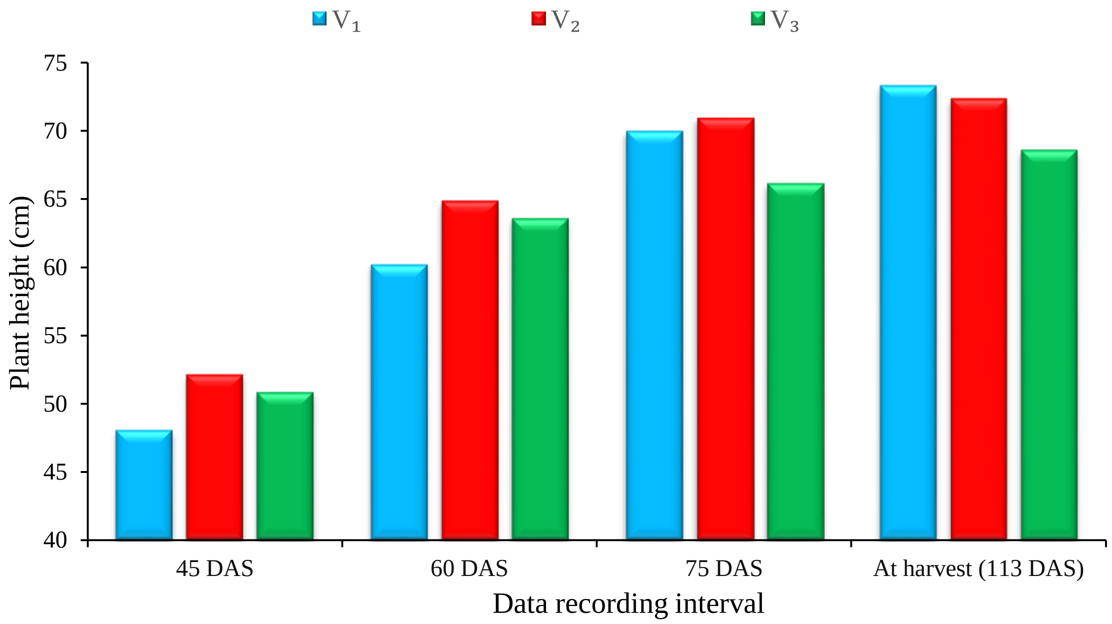
This chapter comprises of presentation and discussion of the results obtained from the study to investigate the effects of plant density on yield of wheat varieties. The results of the growth characters and yield parameters of the crop as influenced by different plant density treatments have been presented and discussed in this chapter. Data on different crop characters have been presented in Table 1–7 and Figure 2–21. The analyses of variance on different parameters were determined and presented in Appendices IV to X.

4.1 Crop growth parameters

4.1.1 Plant height (cm)

4.1.1.1 Effect of variety

Plant heights of all the varieties increased gradually with the advancement of growth stages up to 75 DAS. Across the varieties, plant height ranged from 48.09 to 52.10, 60.23 to 64.88, 66.16 to 70.96 and 68.60 to 73.34 cm at 45, 60, 75 DAS and harvesting time, respectively (Figure 2 and Appendix IV). At 45 and 60 DAS, the variety BARI Gom 31 (V_2) produced the tallest plant height (52.10 and 64.88 cm, respectively) which was statistically similar to those of the variety BARI Gom 32 (V_3) (50.91 and 63.60 cm, respectively). On the other hand, the variety BARI Gom 30 (V_1) produced the dwarf stature plant from 45 and 60 DAS (48.09 and 60.23 cm, respectively). At 75 DAS, plant height (cm) showed statistically non-significant variation due to the effect of variety. At harvesting time, plant height (cm) showed statistically significant variation due to the effect of variety. The variety BARI Gom 30 (V_1) produced the tallest plant height (73.34 cm) which was statistically similar to those of the variety BARI Gom 31 (V_2) (72.38 cm). On the other hand, the variety BARI Gom 32 (V_3) produced the dwarf stature plant in harvesting time (68.60 cm). The results obtained from the present study were in conformity with the findings of Tariq (2010), Rahman *et al*. (2013) and Mehmet and Telat (2006).

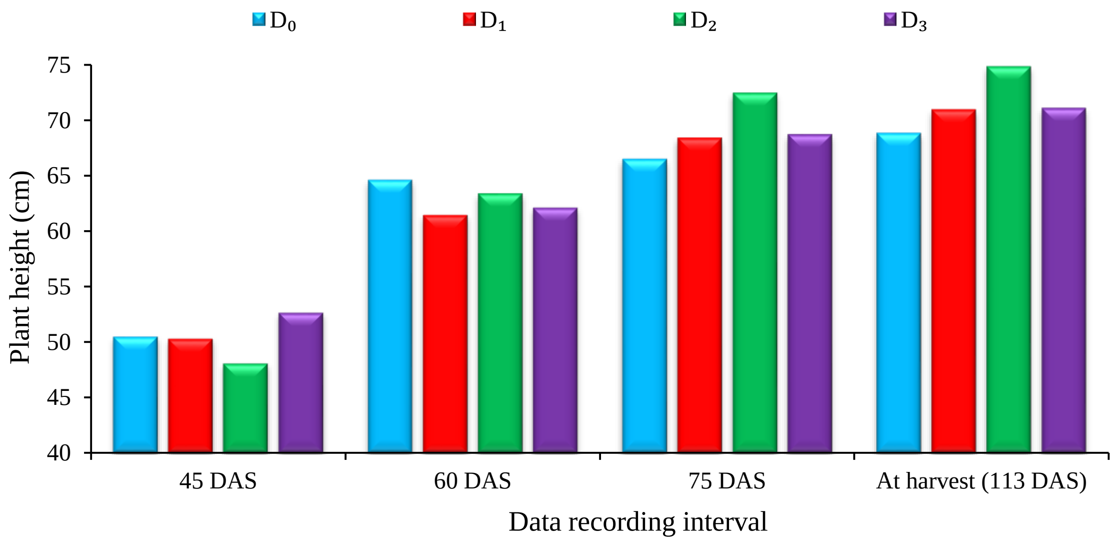


V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 2: Effect on plant height (cm) as influenced by three improved varieties of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 3.73, 1.73, NS and 2.95 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.1.2 Effect of plant density

Statistically significant variation was found for plant height of wheat at 45, 60, 75 DAS and at harvesting time due to different population densities (Figure 3 and Appendix IV). At 45 DAS, the tallest plants (52.66 cm) were observed from 150 plants m^{-2} (D_3) treatment which were statistically similar to those obtained in control/no thinning (D_0) (50.48 cm) and 100 plants m^{-2} (D_1) (50.28 cm) . The shortest plants (48.05 cm) were recorded from 125 plants m^{-2} (D_2). At 60 DAS, the tallest plants (64.62 cm) were observed from no thinning (D_0) treatment and the shortest plants (61.44 cm) were recorded from 100 plants m^{-2} (D_1) which were statistically similar to those obtained in 150 plants m^{-2} (62.14 cm) (D_3). At 75 DAS and at harvesting time, the tallest plants (72.50 and 74.86 cm, respectively) were observed from 125 plants m^{-2} (D_2) treatment and the shortest plants (66.49 and 68.83 cm, respectively) were recorded from no thinning (D_0) which were statistically similar to be obtained in 100 plants m^{-2} (D_1) (68.42 and 70.94 cm, respectively) and 150 plants m^{-2} (D_3) (68.75 and 71.13 cm, respectively). This results were similar to the findings of Chatha *et* *al.* (1986) and Dixit *et al.* (2004) who reported that increasing the seeding rate significantly increased the plant height. Partially similar opinion was given by Roy and Biswas (1991). Mozumder (2001), Das (2002) and Pandey (2004). Pandey (2004) stated that in case of plant height there were no significant difference among the seed rates. Das (2002) reported that population density did not significantly influence plant height.



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

Figure 3: Influence of population densities on plant height (cm) of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 2.92, 1.14, 2.49 and 3.67 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.1.3 Interaction effect of variety and plant density

Interaction effect of improved wheat variety and population densities showed significant differences on plant height of wheat at all sampling dates (Table 1 and Appendix IV). At 45 DAS, results showed that the tallest plant was obtained from V_2D_3 (58.95 cm) which was statistically similar to that of the V_3D_0 (56.43 cm) whereas, the shortest plant was obtained from V_1D_2 (44.53 cm) which was statistically similar to that of the V_3D_1 (47.01 cm). At 60 DAS, results showed that the tallest plant was obtained from V_2D_2 (66.89 cm) which was statistically similar to those of the V_3D_0 (66.12 cm), V_2D_3 (65.89 cm) and the shortest plant was obtained from V_1D_3 (55.11 cm). At 75 DAS, results showed that the tallest plant was obtained from V_1D_2 (75.95 cm) which was statistically similar to those of the V_2D_3 (74.39 cm) and the shortest plant was obtained from V_3D_3 (64.58 cm) which was statistically similar to those of the V_3D_1 (64.62 cm), V_2D_0 (65.50 cm), V_3D_0 (66.50 cm), V_1D_0 (67.47 cm) and V_2D_1 (67.49 cm).

Table 1: Interaction effect of varietal performance and population densities on plant height (cm)of wheat recorded at different Data recording interval

Treatment Combination	**Plant height (cm) at different DAS**			
	45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
V_1D_0	47.52 de	62.50 c	67.47 cd	69.78 bc
V_1D_1	51.36 bc	61.77 cd	73.15 b	75.51 a
V_1D_2	44.53 f	61.53 cd	**75.95 a**	**78.31 a**
V_1D_3	48.96 c-e	55.11 e	67.27 cd	69.76 bc
V_2D_0	47.48 de	65.23 b	65.50 d	67.85 bc
V_2D_1	52.48 b	61.49 cd	67.49 cd	70.09 bc
V_2D_2	49.51 c-e	**66.89 a**	72.60 b	75.06 a
V_2D_3	**58.95 a**	65.89 ab	**74.39 ab**	**76.54 a**
V_3D_0	**56.43 a**	**66.12 a**	66.50 cd	68.85 bc
V_3D_1	47.01 ef	61.07 d	64.62 d	67.22 c
V_3D_2	50.12 b-d	61.77 cd	68.95 c	71.21 b
V_3D_3	50.08 b-d	65.42 b	64.58 d	67.10 c
LSD $_{(0.05)}$	2.92	1.14	2.49	3.67
CV (%)	8.38	6.06	7.10	8.00

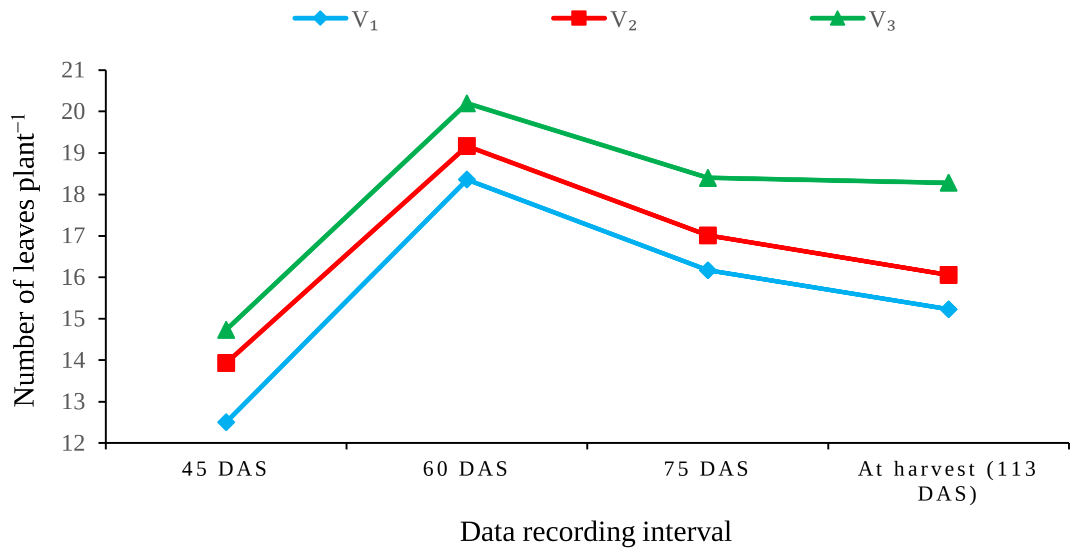
In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.
V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32
D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

At Harvesting time, results showed that the tallest plant was obtained from V_1D_2 (78.31 cm) which was statistically similar to those of the V_2D_3 (76.54 cm), V_1D_1 (75.51 cm) and V_2D_2 (75.06 cm). On the other hand, the shortest plant was obtained from V_3D_3 (67.10 cm) which was statistically similar to those of the V_3D_1 (67.22 cm), V_2D_0 (67.85 cm), V_3D_0 (68.85 cm), V_1D_3 (69.76 cm), V_1D_0 (69.78 cm) and V_2D_1 (70.09 cm).

4.1.2 Number of leaves plant^{-1}

4.1.2.1 Effect of variety

Number of leaves plant^{-1} increased rapidly from 45 to 60 DAS and thereafter reduced gradually up to harvesting. This may be attributed to the compensation of the early produced leaves for the newly produced ones mobilizing assimilate towards leaves. Across the varieties, number of leaves plant^{-1} ranged from 12.50 to 14.73, 18.36 to 20.20, 16.17 to 18.40 and 15.23 to 18.28 at 45, 60, 75 DAS and at harvesting time, respectively (Figure 4 and Appendix V). The result relating the effect of variety on number of leaves plant^{-1} showed significant variation at all growth stages except 75 DAS. The variety BARI Gom 32 (V_3) produced the maximum number of leaves plant^{-1} at 45, 60, 75 DAS and at harvesting time (14.73, 20.20, 18.40 and 18.28, respectively). On the other hand, the variety BARI Gom 30 (V_1) produced the minimum number of leaves plant^{-1} at 45, 60, 75 DAS and at harvesting time (12.50, 18.36, 16.17 and 15.23, respectively). It might be attributed to varietal character or genetic variability. Similar findings was reported by Alam *et al.* (2008).

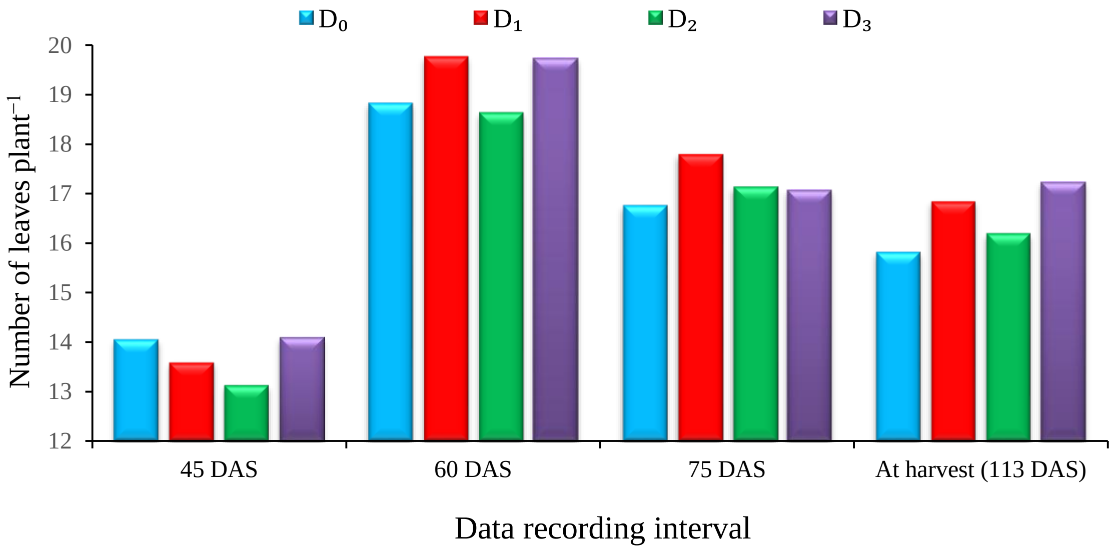


V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 4: Effect on number of leaves plant^{-1} as influenced by three improved varieties of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 0.49, 0.49, NS and 0.55 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.2.2 Effect of plant density

Significant variation was observed on number of leaves plant^{-1} in case of different population densities except 75 DAS (Figure 5 and Appendix V). At 45 DAS, it was found that the maximum number of leaves plant^{-1} (14.10) was found with 150 plants m^{-2} (D_3) treatment which was statistically similar (14.05) with no thinning (D_0) treatment and the minimum (13.13) was found in 125 plants m^{-2} (D_2) treatment. At 60 and 75 DAS, it was found that the maximum number of leaves plant^{-1} (19.77, 17.80 and respectively) was found with 100 plants m^{-2} (D_1) treatment which was statistically similar (19.74 and 17.07 respectively) with 150 plants m^{-2} (D_3) treatment at 60 DAS and (17.14) 125 plants m^{-2} (D_2) treatment at 75 DAS. At harvesting, results indicated that maximum number of leaves plant^{-1} (17.24) was found with 150 plants m^{-2} (D_3) treatment which was statistically similar (16.85) with 100 plants m^{-2}(D_2) treatment. On the other hand, the minimum number of leaves plant^{-1} (18.64) was found in 125 plants m^{-2} (D_2) treatment at 60 DAS but at 75 DAS and at harvesting time, minimum number of leaves plant^{-1} (16.76 and 15.82, respectively) was found from no thinning treatment (D_0).



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants m^{-2}and D_3 – 150 plants m^{-2}

Figure 5: Influence of population densities on number of leaves plant^{-1} of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 0.35, 0.40, NS and 0.50 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.2.3 Interaction effect of variety and population densities

Interaction effect of improved wheat variety and population densities showed significant differences on number of leaves plant^{-1} of wheat at all sampling dates (Table 2 and Appendix V). At 45 and 60 DAS, results showed that the maximum number of leaves plant^{-1} (15.89 and 21.60, respectively) was obtained from the combination of BARI Gom 32 with 150 plants m^{-2} (V_3D_3) and the minimum (11.00 and 16.71, respectively) was obtained from the combination of BARI Gom 30 with 100 plants m^{-2} (V_1D_2). At 75 DAS and harvesting time, results showed that the maximum number of leaves plant^{-1} (19.65 and 18.70, respectively) was obtained from the combination of BARI Gom 32 with 125 plants m^{-2} (V_3D_2) and the minimum (15.65 and 14.71, respectively) was obtained from the combination of BARI Gom 30 with no thinning (V_1D_0).

Table 2: Interaction effect of varietal performance and population densities on number of leaves plant^{-1} of wheat recorded at different DAS

Treatment Combination	Number of leaves plant^{-1} at different DAS			
	45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
V_1D_0	13.50 d	17.70 f	15.65 b	14.71 l
V_1D_1	12.50 f	20.01 bc	17.20 ab	16.25 g
V_1D_2	11.00 g	16.71 g	16.00 b	15.05 i
V_1D_3	13.00 e	19.01 d	15.85 b	14.90 j
V_2D_0	14.01 c	19.79 c	16.61 b	15.66 h
V_2D_1	14.70 b	19.30 d	17.87 ab	16.92 d
V_2D_2	13.60 d	19.00 d	15.78 b	14.83 k
V_2D_3	13.40 d	18.60 e	17.78 ab	16.83 e
V_3D_0	14.63 b	19.00 d	18.03 ab	17.08 c
V_3D_1	13.60 d	20.00 bc	18.32 ab	17.37 b
V_3D_2	14.80 b	20.21 b	**19.65 a**	**18.70 a**
V_3D_3	**15.89 a**	**21.60 a**	17.59 ab	16.64 f
LSD $_{(0.05)}$	0.35	0.40	2.89	0.05
CV (%)	6.47	6.21	9.89	7.17

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

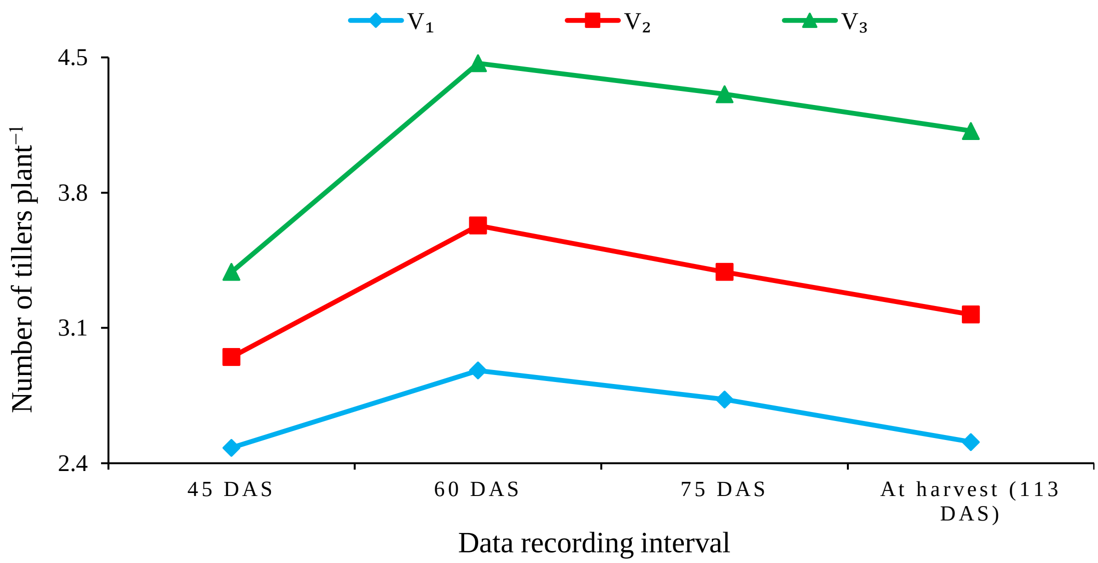
V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants m^{-2}and D_3 – 150 plants m^{-2}

4.1.3 Number of tillers plant^{-1}

4.1.3.1 Effect of variety

The result revealed that the effect of variety on number of tillers plant^{-1} was significant at all growth stages. Among the varieties, number of tillers ranged from 3.39 to 2.48, 4.47 to 2.88, 4.42 to 3.01 and 4.12 to 2.41 plant^{-1} at 45, 60, 75 DAS and at harvesting time, respectively (Figure 6 and Appendix VI). The variety BARI Gom 32 (V_3) produced the highest number of tillers plant^{-1} (3.39, 4.47, 4.31 and 4.12 at 45, 60, 75 DAS and harvesting time, respectively). On the other hand, the variety BARI Gom 30 (V_1) produced the lowest number of tillers plant^{-1} at 45, 60, 75 DAS and harvesting time (2.48, 2.88, 2.73 and 2.51, respectively). Number of tillers increased rapidly up to 60 DAS and thereafter declined up to maturity. Declining tillers after 60 DAS may be attributed to inter tiller competition for resources, probably compensation of the late produced ones for the early produced ones. The results obtained from the present study were similar to the findings of Nadim *et al*. (2012), Hussain *et al*. (2010) and Tariq (2010).



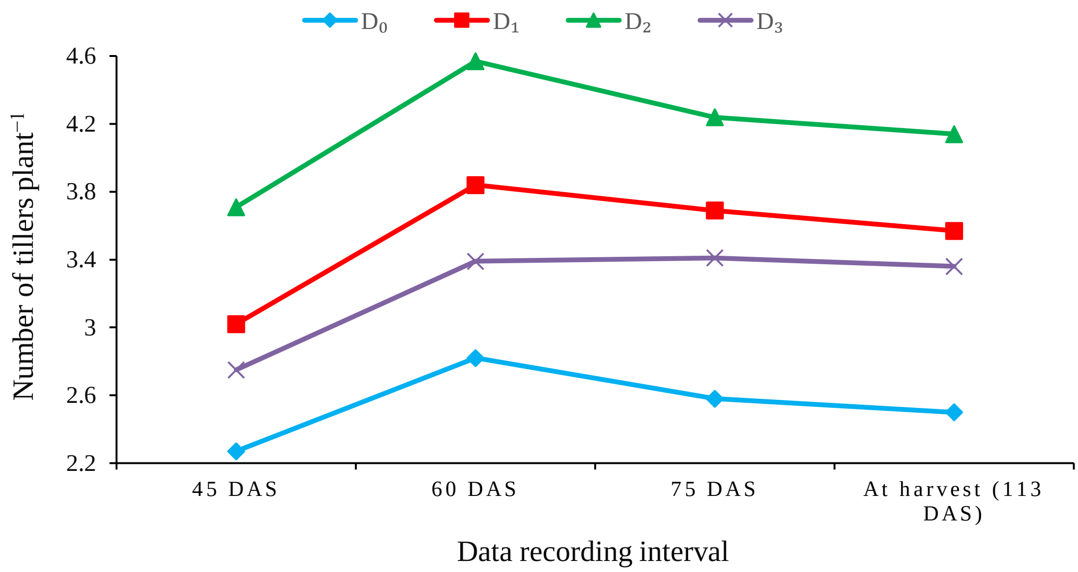
V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 6: Effect on number of tillers plant^{-1} as influenced by three improved varieties of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 0.30, 0.12, 0.59 and 0.25 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.3.2 Effect of plant density

Significant variation was observed on number of tillers plant^{-1} in case of different population densities (Figure 7 and Appendix VI). It was found that the highest number of tillers plant^{-1} (3.71, 4.57, 4.24 and 4.14 at 45, 60, 75 DAS and harvesting time, respectively) was found with 125 plants m^{-2} (D_2)

treatment. On the other hand, the lowest number of tillers plant^{-1} (2.27, 2.82, 2.58 and 2.50 at 45, 60, 75 DAS and harvesting time, respectively) was found in no thinning (D_0) treatment.



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants m^{-2}and D_3 – 150 plants m^{-2}

Figure 7: Influence of population densities on number of tillers plant^{-1} of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 0.25, 0.16, 0.66 and 0.25 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.3.3 Interaction effect of variety and population densities

Interaction effect of improved wheat variety and population densities showed significant differences on number of tillers plant^{-1} of wheat at all sampling dates (Table 3 and Appendix V). At 45, 60, 75 DAS and harvesting time, results showed that the highest number of tillers plant^{-1} (4.52, 5.78, 5.62 and 5.35, respectively) was obtained from the combination of BARI Gom 32 with 125 plants m^{-2} (V_3D_2). On the other hand, the lowest number of tillers plant^{-1} (1.95, 2.24, 2.33 and 2.03, respectively) was obtained from the combination of BARI Gom 30 with no thinning (V_1D_0) treatment.

Table 3: Interaction effect of varietal performance and population densities on number of tillers plant^{-1} of wheat recorded at different Data recording interval

Treatment Combination	Number of tillers plant^{-1} at different DAS			
	45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
V_1D_0	1.95 e	2.24 i	2.33 g	2.03 f
V_1D_1	2.40 d	3.10 fg	3.26 de	2.98 e
V_1D_2	3.00 c	3.30 e	3.39 d	3.11 de
V_1D_3	2.56 d	2.87 h	3.07 ef	2.79 e
V_2D_0	2.40 d	2.96 gh	2.98 f	2.70 e
V_2D_1	3.20 c	3.72 d	3.92 c	3.64 cd
V_2D_2	3.60 b	4.64 b	4.51 b	4.25 bc
V_2D_3	2.60 d	3.18 ef	3.26 de	2.98 e
V_3D_0	2.47 d	3.27 e	3.26 de	2.98 e
V_3D_1	3.47 b	4.70 b	4.73 b	4.46 b
V_3D_2	**4.52 a**	**5.78 a**	**5.62 a**	**5.35 a**
V_3D_3	3.10 c	4.12 c	4.06 c	4.45 b
LSD$_{(0.05)}$	0.25	0.16	0.25	0.66
CV (%)	5.08	7.53	8.97	11.01

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

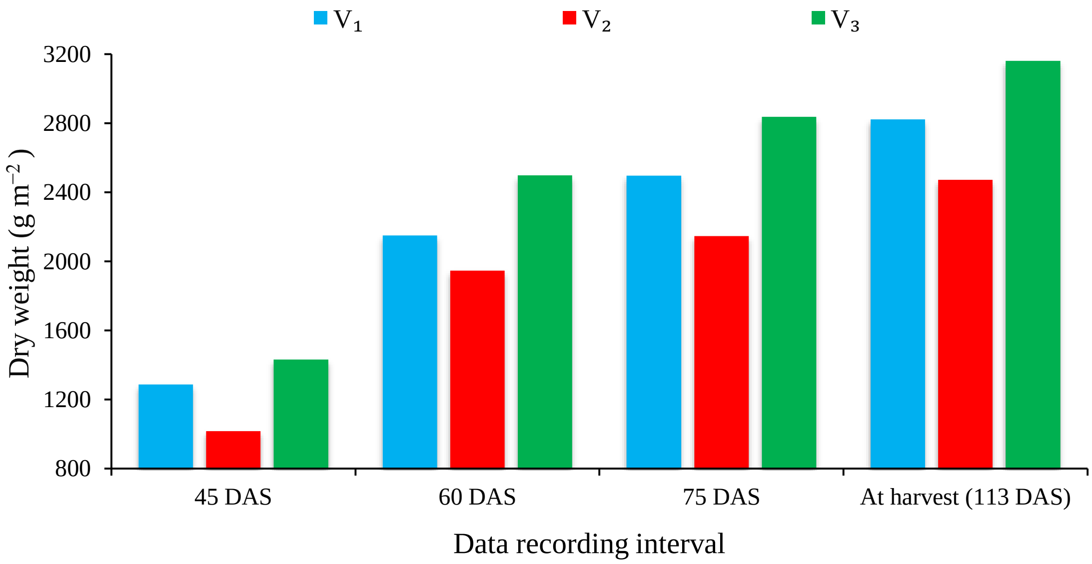
V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants m^{-2}and D_3 – 150 plants m^{-2}

4.1.4 Total Dry matter weight (g m^{-2})

4.1.4.1 Effect of variety

Dry matter weight (g m^{-2}) of all the varieties of wheat increased as the age of the plant increased up to the harvest. Among the varieties, the dry matter weight ranged from 1016.00 to 1431.00, 1946.00 to 2499.00, 2147.00 to 2838 and 2472.00 to 3162.00 g m^{-2} at 45, 60, 75 DAS and harvesting time, respectively. Significant variation was observed in terms of dry matter weight (g m^{-2}) at all growth stages (Figure 8 and Appendix VII). Results indicated that at 45, 60, 75 DAS and harvesting time, the variety BARI Gom 32 (V_3) produced the maximum dry matter weight (1431.00, 2499.00, 2838.00 and 3162.00 g m^{-2}, respectively). Results also showed that the variety BARI Gom 31 (V_2) produced the lowest dry matter weight at 45, 60, 75 DAS and harvesting time as 1016.00, 1946.00, 2147.00 and 2472.00 g m^{-2}, respectively. The results obtained on dry matter weight with different varieties might be due to the cause of genetical characters and or nutrient availability, nutrient uptake capacity of the varieties that helps to increase dry weight (g m^{-2}). Similar finding was observed by Al-Musa *et al*. (2012).

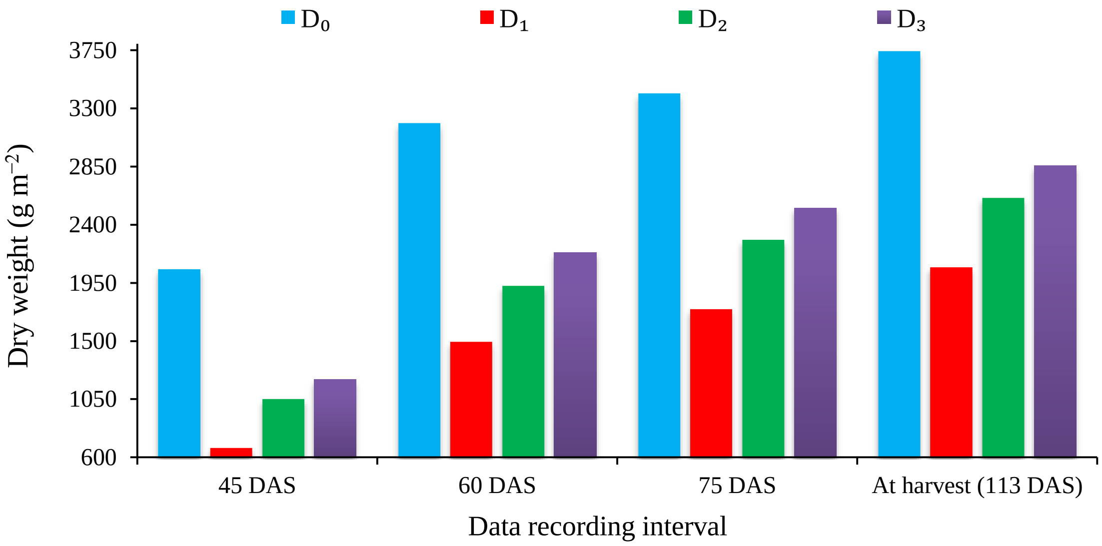


V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 8: Effect on dry matter weight (g m^{-2}) as influenced by three improved varieties of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 38.11, 10.37, 26.52 and 24.25 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.4.2 Effect of plant density

Different plant density of wheat showed significant influence on dry matter weight (g m^{-2}) accumulation at 45, 60, 75 DAS and harvesting time (Figure 9 and Appendix VII). At 45, 60, 75 DAS and harvesting time, the maximum (2055.00, 3187.00, 3417.00 and 3742.00 g m^{-2}, respectively) dry matter weight was observed in no thinning (D_0) treatment. On the other hand, results also showed that minimum weight of dry matter (672.00, 1495.00, 1747.00 and 2071 .00 g m^{-2}, respectively) was observed at 100 plants m^{-2} (D_1) treatment. Similar finding was observed by Roy (2007).



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

Figure 9: Influence of population densities on dry matter weight (g m^{-2}) of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 23.50, 22.81, 34.19 and 34.89 at 45, 60, 75 DAS and Harvesting, respectively)

4.1.4.3 Interaction effect of variety and population densities

Dry matter weight (g m^{-2}) was significantly influenced by interaction of variety and population densities at different days after sowing (DAS) (Table 4 and Appendix V). Results showed that the maximum dry matter weight (2552.00, 3801.00, 4069.00 and 4394.00 g m^{-2}, respectively) was obtained from the combination of the variety BARI Gom 32 with no thinning (V_3D_0) treatment at

45, 60, 75 DAS and harvesting time. On the other hand, the minimum dry matter weight (g m^{-2}) at 45, 60, 75 DAS and harvesting time was observed as 440.00, 1252.00, 1568.00 and 1893.00 g m^{-2}, respectively with the combination of the variety BARI Gom 31 and 100 plant m^{-2} (V_2D_1) treatment.

Table 4: Interaction effect of varietal performance and population densities on dry matter weight (g m^{-2}) of wheat recorded at different Data recording interval

Treatment Combination	Dry weight (g m^{-2}) at different DAS			
	45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
V_1D_0	1784.00 c	2944.00 b	3140.00 b	3466.00 b
V_1D_1	851.30 h	1373.00 j	1643.00 k	1968.00 k
V_1D_2	1223.00 e	2171.00 f	2564.00 f	2890.00 f
V_1D_3	1288.00 d	2235.00 e	2642.00 e	2968.00 e
V_2D_0	1829.00 b	2817.00 c	3042.00 c	3367.00 c
V_2D_1	440.00 k	1252.00 k	1568.00 l	1893.00 l
V_2D_2	771.60 i	1696.00 i	1803.00 j	2128.00 j
V_2D_3	1022.00 g	1896.00 g	2175.00 h	2500.00 h
V_3D_0	**2552.00 a**	**3801.00 a**	**4069.00 a**	**4394.00 a**
V_3D_1	725.60 j	1861.00 h	2029.00 i	2351.00 i
V_3D_2	1155.00 f	1910.00 g	2479.00 g	2805.00 g
V_3D_3	1292.00 d	2426.00 d	2774.00 d	3099.00 d
LSD $_{(0.05)}$	23.50	22.81	34.19	34.89
CV (%)	7.10	6.60	6.80	6.72

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

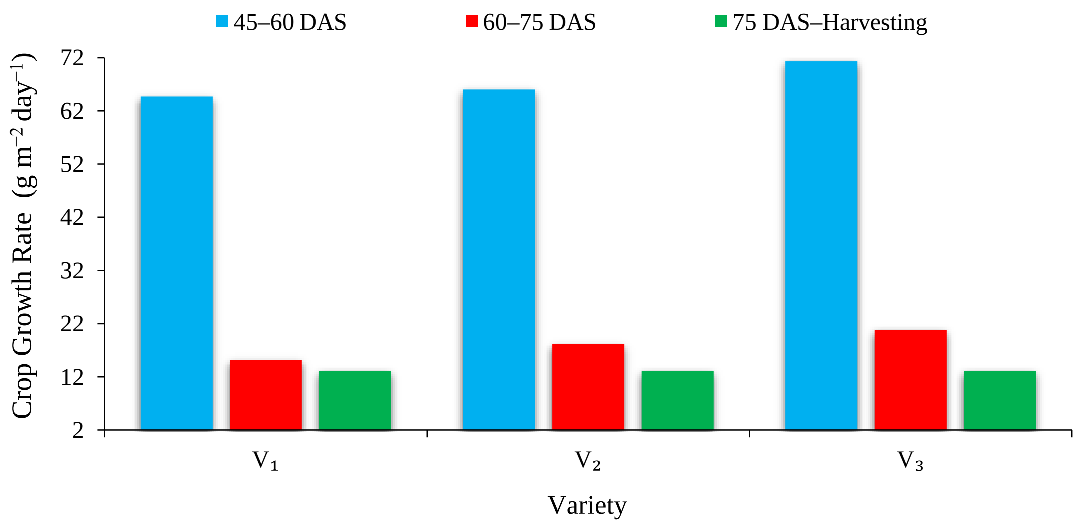
V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

4.1.5 Crop Growth Rate (CGR) (g m^{-2} day^{-1})

4.1.5.1 Effect of variety

Different varieties showed significant variation in respect of crop growth rate at 45–60 DAS and 60–75 DAS. Crop growth rate (CGR) of wheat showed statistically non-significant variation due to different variety of wheat at 75 DAS–harvesting time (Figure 10 and Appendix VIII). The highest CGR (71.32 g m^{-2} day^{-1}) was obtained from wheat variety BARI Gom 32 (V_3) at 45–60 DAS, but BARI Gom 31 (V_1) had the lowest (64.71 g m^{-2} day^{-1}) CGR at 45–60 DAS. At 60–75 DAS, the highest CGR (20.81 g m^{-2} day^{-1}) was obtained from wheat variety BARI Gom 32 (V_3) and the lowest CGR (15.15 g m^{-2} day^{-1}) was found from wheat variety BARI Gom 30 (V_1). Similar findings was observed by Naher (2013).

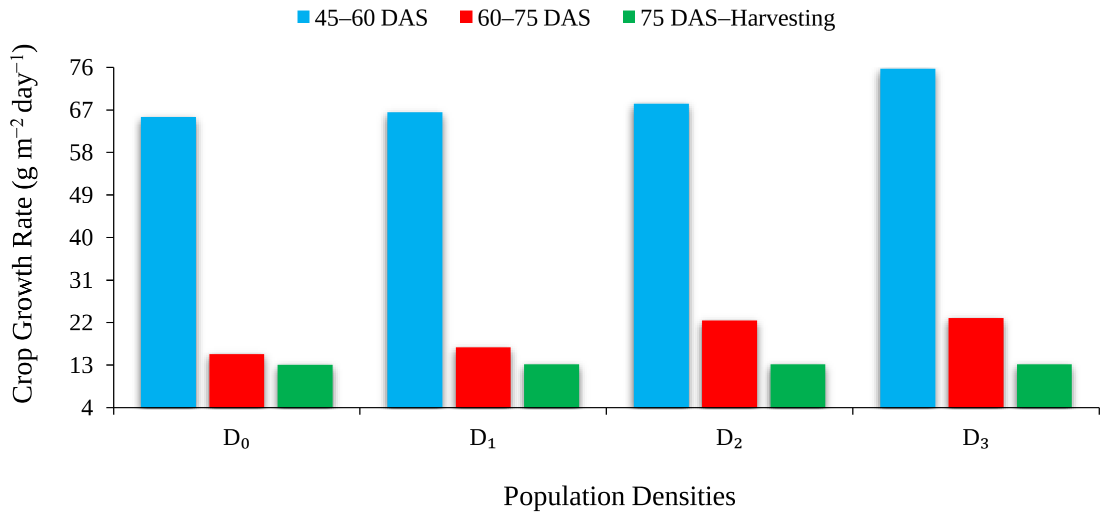


V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 10: Effect on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) as influenced by three improved varieties of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 2.33, 0.17 and NS at 45–60 DAS, 60–75 DAS and 75 DAS–Harvesting, respectively)

4.1.5.2 Effect of plant density

Population densities showed significant variation in respect of crop growth rate at 45–60 DAS and 60–75 DAS. Crop growth rate (CGR) of wheat showed statistically non-significant variation due to different population densities of wheat at 75 DAS–harvesting time (Figure 11 and Appendix VIII). The highest CGR (75.74 g m^{-2} day^{-1}) was obtained from the 150 plants m^{-2}(D_3) treatment at 45–60 DAS, but no thinning (D_0) had the lowest CGR (65.49 g m^{-2} day^{-1}). At 60–75 DAS, the highest CGR (22.99 g m^{-2} day^{-1}) was obtained from 150 plants m^{-2} (D_3) and the lowest CGR (15.32 g m^{-2} day^{-1}) was found from the no thinning (D_0) treatment.



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

Figure 11: Influence of population densities on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) of wheat recorded at different Data recording interval (LSD $_{0.05}$ = 1.06, 0.32 and NS at 45–60 DAS, 60–75 DAS and 75 DAS–Harvesting, respectively)

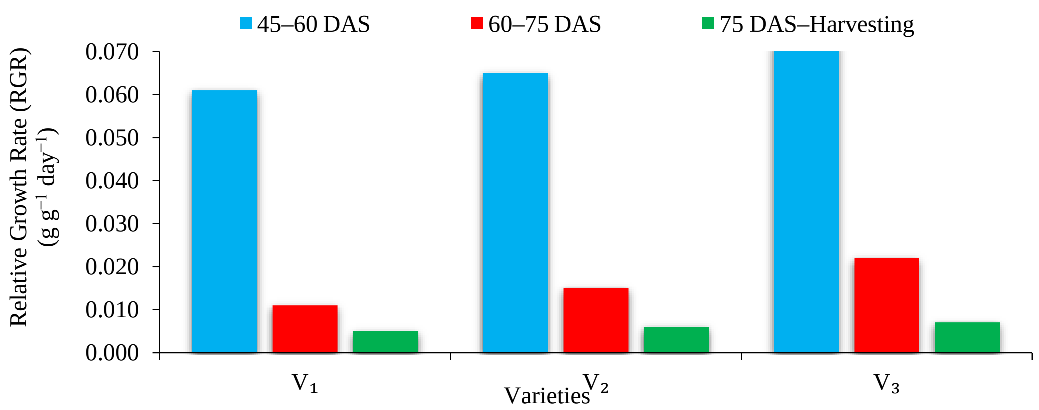
4.1.5.3 Interaction effect of variety and population densities

Interaction effect of improved wheat varieties and population densities showed significant variation in respect of crop growth rate (CGR) at 45–60 DAS, 60–75 DAS and 75 DAS–harvesting time (Table 5 and Appendix VIII). At 45–60 DAS, the highest CGR (83.25 g m^{-2} day^{-1}) was observed in the combination of wheat variety BARI Gom 32 with no thinning (V_3D_0) treatment and the lowest CGR (50.27 g m^{-2} day^{-1}) was observed in the combination of wheat variety BARI Gom 32 with 125 plants m^{-2} (V_3D_2) treatment. At 60–75 DAS, the highest CGR (30.97 g m^{-2} day^{-1}) was observed in the combination of wheat variety BARI Gom 32 with 125 plants m^{-2} (V_3D_2) treatment and the lowest CGR (10.11 g m^{-2} day^{-1}) was observed from the combination of wheat variety BARI Gom 31 with 125 plants m^{-2} (V_2D_2) treatment. At 75 DAS–Harvesting time, the highest CGR (13.21 g m^{-2} day^{-1}) was observed in the combination of wheat variety BARI Gom 32 with no thinning (V_3D_0) treatment which was statistically similar to V_3D_3 (13.16 g m^{-2} day^{-1}), V_3D_2 (13.15 g m^{-2} day^{-1}), V_1D_2 (13.15 g m^{-2} day^{-1}), V_2D_3 (13.13 g m^{-2} day^{-1}), V_1D_1 (13.11 g m^{-2} day^{-1}), V_1D_3 (13.11 g m^{-2} day^{-1}), V_2D_1 (13.11 g m^{-2} day^{-1}) and V_2D_0 (13.09 g m^{-2} day^{-1}) treatment combination. The lowest CGR (12.85 g m^{-2} day^{-1}) was recorded from the combination of wheat variety BARI Gom 32 with 100 plants m^{-2} (V_3D_1) treatment which was statistically similar to V_1D_0 (12.89 g m^{-2} day^{-1}) treatment combination.

4.1.6 Relative Growth Rate (RGR) (g g^{-1} day^{-1})

4.1.6.1 Effect of variety

Relative growth rate (RGR) did not differ significantly at 45–60 DAS, 60–75 DAS and 75 DAS–Harvesting time. RGR of wheat showed statistically non-significant variation due to different varieties of wheat i.e. BARI Gom 30 (V_1), BARI Gom 31 (V_2) and BARI Gom 32 (V_3) (Figure 12 and Appendix IX).



V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 12: Effect on Relative Growth Rate (RGR) (g g^{-1} day^{-1}) as influenced by three improved varieties of wheat recorded at different Data recording interval

(LSD $_{0.05}$ = NS, NS and NS at 45–60DAS, 60–75 DAS and 75 DAS–Harvesting, respectively)

Table 5: Interaction effect of varietal performance and population densities on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) of wheat recorded at different Data recording interval

Treatment Combination	Crop Growth Rate (CGR) (g m^{-2} day^{-1}) at		
	45–60 DAS	**60–75 DAS**	**75 DAS–Harvesting**
V_1D_0	77.27 b	13.11 h	12.89 c
V_1D_1	55.24 h	26.07 c	13.11 ab
V_1D_2	63.24 e	26.24 c	13.15 ab
V_1D_3	63.10 e	27.19 b	13.11 ab
V_2D_0	65.96 d	14.98 g	13.09 ab
V_2D_1	62.40 ef	13.00 h	13.11 ab
V_2D_2	61.54 f	10.11 j	13.04 b
V_2D_3	58.24 g	18.60 e	13.13 ab
V_3D_0	**83.25 a**	17.87 f	**13.21 a**
V_3D_1	75.90 c	11.20 i	12.85 c
V_3D_2	50.27 i	**30.97 a**	13.15 ab
V_3D_3	75.88 c	23.19 d	13.16 ab
LSD $_{(0.05)}$	1.06	0.32	0.12
CV (%)	8.94	7.95	8.52

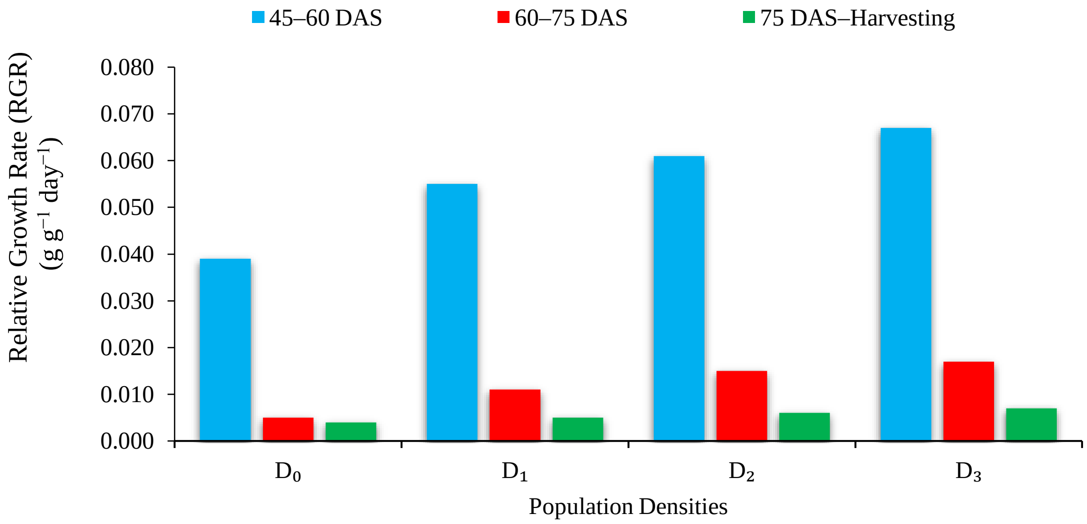
In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

4.1.6.2 Effect of plant density

Relative growth rate (RGR) of wheat showed statistically non-significant variation due to different population densities of wheat at 45–60 DAS, 60–75 DAS and 75 DAS–harvesting time (Figure 13 and Appendix IX).



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

Figure 13: Influence of population densities on Relative Growth Rate (RGR) (g g^{-1} day^{-1}) of wheat recorded at different Data recording interval (LSD $_{0.05}$ = NS, NS and NS at 45–60DAS, 60–75 DAS and 75 DAS–Harvesting, respectively)

4.1.6.3 Interaction effect of variety and population densities

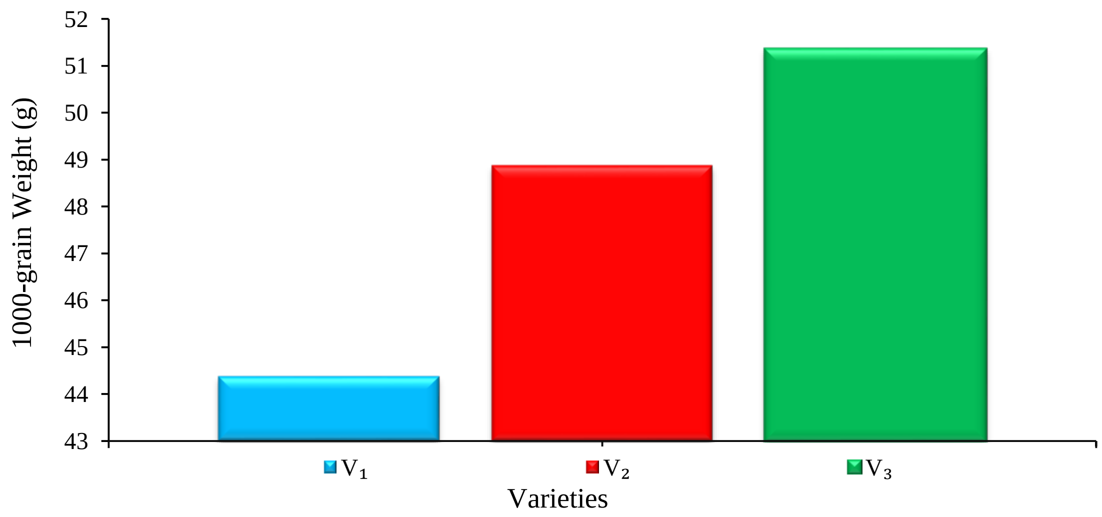
Interaction effect of improved wheat varieties and population densities show significant variation in respect of relative growth rate (RGR) at 45–60 DAS and 60–75 DAS except at 75 DAS–Harvesting time (Table 6 and Appendix IX). At 45–60 DAS, the maximum RGR (0.148 g g^{-1} day^{-1}) was observed in the combination of wheat variety BARI Gom 30 with 150 plants m^{-2} (V_1D_3) treatment, which was statistically similar to V_2D_1 and V_3D_1 treatment. The minimum RGR (0.026 g g^{-1} day^{-1}) was recorded from the combination of wheat variety BARI Gom 30 with 100 plants m^{-2} (V_1D_1) treatment which was statistically similar to V_1D_0, V_1D_2, V_2D_0, V_2D_2, V_2D_3, V_3D_0, V_3D_2 and V_3D_3 treatment. At 60–75 DAS, the maximum RGR (0.068 g g^{-1} day^{-1}) was observed from the combination of wheat variety BARI Gom 32 with 125 plants m^{-2} (V_3D_2) treatment, which was statistically similar to V_1D_1 treatment. The minimum RGR (0.004 g g^{-1} day^{-1}) was observed in the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) and BARI Gom 31 with 125 plants m^{-2} (V_2D_2) treatment which was statistically similar to V_1D_2, V_1D_3, V_2D_0, V_2D_1, V_2D_3, V_3D_0, V_3D_1 and V_3D_3 treatment. At 75 DAS–Harvesting time, the numerically maximum RGR value (0.008 g g^{-1} day^{-1}) was observed from the combination of wheat variety BARI Gom 31 with 100 plants m^{-2} (V_2D_1) treatment while the numerically minimum RGR value (0.003 g g^{-1} day^{-1}) was observed in the combination of wheat variety BARI Gom 32 with no thinning (V_3D_0) treatment.

4.2 Yield contributing parameters

4.2.1 Weight of 1000-grains (g)

4.2.1.1 Effect of variety

Weight of 1000 grains showed significant variation among the different varieties of wheat (Figure 14 and Appendix X). BARI Gom 32 (V_3) produced maximum 1000-grain weight (51.36 g). On the other hand, the minimum 1000-grain weight (44.38 g) was obtained from BARI Gom 30 (V_1).



V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 14: Effect of three improved varieties of wheat on 1000-grain weight (LSD $_{0.05}$ = 1.70)

Table 6: Interaction effect of varietal performance and population densities on Relative Growth Rate (RGR) (g g^{-1} day^{-1}) of wheat recorded at different Data recording interval

Treatment Combination	Relative Growth Rate (RGR) (g g^{-1} day^{-1}) at		
	45–60 DAS	**60–75 DAS**	**75DAS–Harvesting**
V_1D_0	0.032 b	0.004 b	0.004
V_1D_1	0.026 b	0.018 ab	0.007
V_1D_2	0.038 b	0.011 b	0.005
V_1D_3	**0.148 a**	0.011 b	0.005
V_2D_0	0.029 b	0.005 b	0.004
V_2D_1	0.076 ab	0.009 b	**0.008**
V_2D_2	0.052 b	0.004 b	0.007
V_2D_3	0.041 b	0.009 b	0.006
V_3D_0	0.027 b	0.005 b	0.003
V_3D_1	0.063 ab	0.006 b	0.006
V_3D_2	0.034 b	**0.068 a**	0.005
V_3D_3	0.042 b	0.009 b	0.004
LSD $_{(0.05)}$	0.09	0.05	NS
CV (%)	10.6	9.78	13.98

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

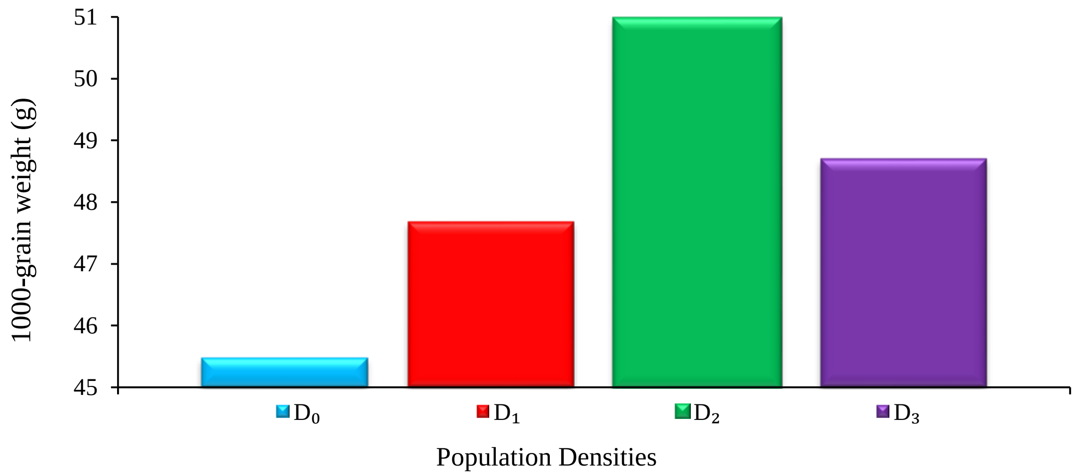
V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

4.2.1.2 Effect of plant density

Plant density had significant effect on weight of 1000 grains. The maximum weight of 1000 grains (50.97 g) was found in 125 plants m^{-2} (D_2), the second highest weight (48.70 g) was observed in 150 plants m^{-2} (D_3) and the lowest weight (45.47 g) was found with no thinning (D_0) (Figure 15 and Appendix X). The result agreed with Chatha *et al.* (1986), Kraft and Spiss (1988) and Das

(2002) who reported that the 1000-grain weight differ significantly due to different population densities of wheat.



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants m^{-2}and D_3 – 150 plants m^{-2}

Figure 15: Influence of population densities on 1000-grain weight (LSD $_{0.05}$ = 1.49)

4.2.1.3 Interaction effect of variety and plant density

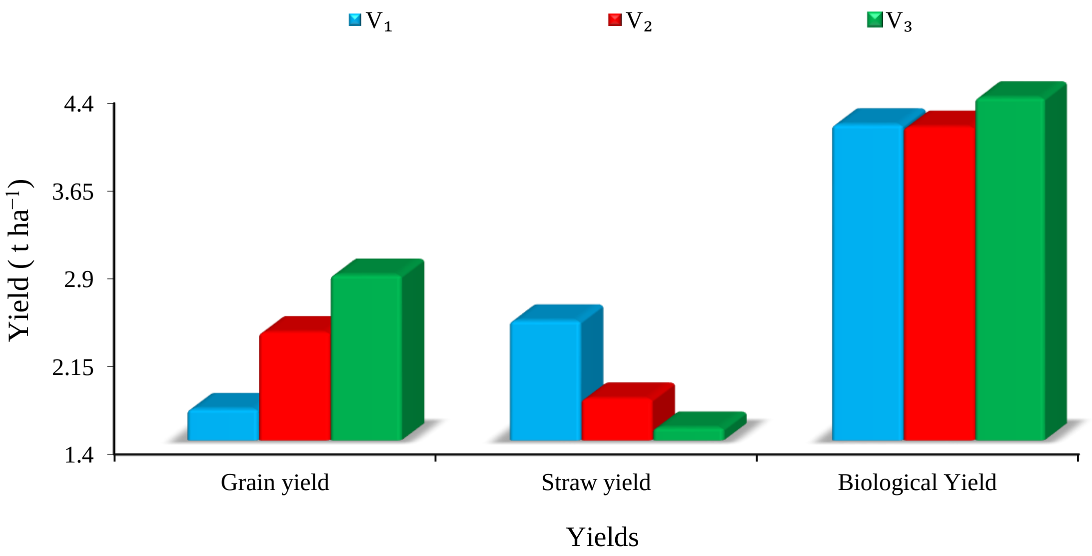
Interaction effect of improved wheat varieties and population densities showed significant variation in respect of weight of 1000-grains (g) (Table 7 and Appendix X). The maximum 1000 grains weight (55.44 g) was observed from the combination of wheat variety BARI Gom 32 with 125-plant m^{-2} (V_3D_2) treatment. On the other hand, the minimum 1000 grains weight (42.89 g) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment which was statistically similar (44.14 g) to the combination of BARI Gom 30 with 100 plant m^{-2} (V_1D_1) treatment.

4.3 Yield parameters

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

4.3.1.1 Effect of variety

Wheat grain yield (t ha^{-1}) varied significantly for different varieties shown in Figure 16 and Appendix X. The highest grain yield (2.82 t ha^{-1}) was recorded from BARI Gom 32 (V_3). The second highest grain yield (2.33 t ha^{-1}) was obtained from BARI Gom 31 (V_2). The lowest grain yield (1.67 t ha^{-1}) was recorded from BARI Gom 30 (V_1).

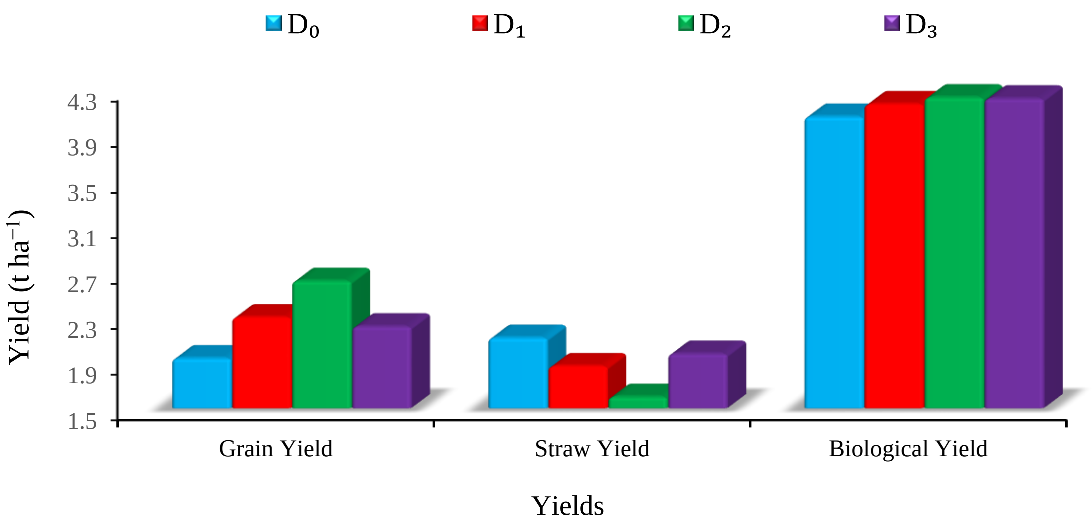


V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 16: Effect of three improved varieties of wheat on Grain Yield, Straw Yield and Biological Yield (LSD $_{0.05}$ = 0.12, 0.61 and NS, respectively)

4.3.1.2 Effect of plant density

Grain yield was significantly influenced by population density. The significantly highest grain yield (2.62 t ha^{-1}) was obtained from 125 plants m^{-2} (D_2) and the lowest amount of grain yield (1.94 t ha^{-1}) was obtained from no thinning (D_0) (Figure 17 and Appendix X). The findings of the present study was in agreement with Roy and Biswas (1991), Mozumder (2001), Hossain (2002), Das (2002), Dixit and Gupta (2004), Roy (2006) who reported that grain yield was significantly influenced by plant density. Roy and Biswas (1991) stated that the highest grain yield obtained with 300–400 seeds m^{-2}. Roy (2007) found that 120 kg seeds ha^{-1} produced the highest grain yield and 80 kg seeds ha^{-1} produced the lowest grain yield. Tripathi and Chauhan (2000) reported that application of 150 kg ha^{-1} gave significantly lower yield than 125 kg ha^{-1} seed rate. Ali (1980) reported a trend of decrease in the number of fertile tiller with the increase of seed rates, which might be due to overcrowding of population. Ballatore *et al.* (1975) also observed the similar effect of seed rates on wheat.



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants m^{-2}and D_3 – 150 plants m^{-2}

Figure 17: Influence of population densities on Grain Yield, Straw Yield and Biological Yield (LSD $_{0.05}$ = 0.13, 0.35 and NS, respectively)

4.3.1.3 Interaction effect of variety and plant density

Interaction effect of improved wheat varieties and population densities showed significant variation in respect of grain yield (t ha^{-1}) (Table 7 and Appendix X). The highest grain yield (3.20 t ha^{-1}) was observed in the combination of wheat variety BARI Gom 32 with 125 plant m^{-2} (V_3D_2) treatment. On the other hand, the lowest grain yield (1.20 t ha^{-1}) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment.

4.3.2 Straw yield (t ha^{-1})

4.3.2.1 Effect of variety

Wheat straw yield (t ha^{-1}) varied significantly for different varieties shown in Figure 16 and Appendix X. The highest straw yield (2.43 t ha^{-1}) was recorded from BARI Gom 30 (V_1). On the other hand, the lowest straw yield (1.51 t ha^{-1}) was recorded from BARI Gom 32 (V_3), which was statistically similar to the wheat variety BARI Gom 31 (1.76 t ha^{-1}).

4.3.2.2 Effect of plant density

Plant density had significant influence on straw yield of wheat (Figure 17 and Appendix X). The significantly highest straw yield (2.12 t ha^{-1}) was observed with no thinning (D_0) treatment which was statistically similar to the 150 plants m^{-2} (1.98 t ha^{-1}) and 100 plants m^{-2} (1.87 t ha^{-1}). On the other hand, the lowest straw yield (1.60 t ha^{-1}) was recorded with 125 plants m^{-2} (D_2). Ali and Ahrned (1988), Torofder (1993), Thakur (1999), Das (2002), Hossain (2002), Dixit and Gupta (2004) and Roy (2006) found the similar results and reported that straw yield was significantly influenced by different population density. Roy and Biswas (1991) reported that yield was the highest with 400 seeds m^{-2}. Das (2002) stated that straw yield varied significantly due to planting densities and reported that maximum straw yield was recorded at optimum planting density of 250 seeds m^{-2}. Paul (1992) noted that sowing rates did not significantly affect straw yield.

4.3.2.3 Interaction effect of variety and plant density

Interaction effect of improved wheat varieties and population densities showed significant variation in respect of straw yield (t ha^{-1}) (Table 7 and Appendix X). The highest straw yield (2.80 t ha^{-1}) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment which was statistically similar to V_1D_3 (2.50 t ha^{-1}) treatment. On the other hand, the lowest straw yield (1.35 t ha^{-1}) was observed in the combination of wheat variety BARI Gom 32 with 125 plants m^{-2} (V_3D_2) treatment which was statistically similar to that of V_2D_2 (1.39 t ha^{-1}), V_3D_1 (1.39 t ha^{-1}), V_3D_3 (1.61 t ha^{-1}) and V_3D_0 (1.67 t ha^{-1}) treatment.

4.3.3 Biological yield (t ha^{-1})

4.3.3.1 Effect of variety

The biological yield (t ha^{-1}) had non-significant data due to the influence of variety, which has been shown in Figure 16 and Appendix X. It was observed that BARI Gom 32 (V_3) produced numerically maximum biological yield (4.33

t ha^{-1}) and the numerically minimum biological yield (4.08 t ha^{-1}) was recorded from BARI Gom 31 (V_2).

4.3.3.2 Effect of plant density

The biological yield (t ha^{-1}) had non-significant data due to the influence different plant density treatments, which has been shown in Figure 17 and Appendix X. Plant density of 125 plant m^{-2} (D_2) gave the numerically maximum biological yield (4.23 t ha^{-1}). No thinning (D_0) treatment revealed the numerically minimum biological yield (4.06 t ha^{-1}).

4.3.3.3 Interaction effect of variety and plant density

Biological yield (t ha^{-1}) was significantly affected by the interaction of different variety and population densities treatment combinations in wheat field (Table 7 and Appendix X). The maximum biological yield (4.55 t ha^{-1}) was obtained from the combination BARI Gom 32 with 125 plants m^{-2} (V_3D_2) which was statistically similar to that of V_3D_3 (4.36 t ha^{-1}), V_2D_1 (4.27 t ha^{-1}), V_1D_3 (4.21 t ha^{-1}), V_3D_1 (4.20 t ha^{-1}) and V_3D_0 (4.19 t ha^{-1}). The minimum biological yield (3.98 t ha^{-1}) was found from the combination BARI Gom 31 with no thinning (V_2D_0) which was statistically similar to that of V_1D_0 (4.00 t ha^{-1}), V_2D_2 (4.00 t ha^{-1}), V_1D_1 (4.04 t ha^{-1}), V_2D_3 (4.08 t ha^{-1}) and V_1D_2 (4.13 t ha^{-1}).

Table 7: Interaction effect of varietal performance and population densities on 1000-seed weight (g), Grain yield (t ha^{-1}), Straw yield (t ha^{-1}), Biological yield (t ha^{-1}) and Harvest index (%)of wheat

Treatment	**1000 seed weight (g)**	**Grain yield (t ha^{-1})**	**Straw yield (t ha^{-1})**	**Biological yield (t ha^{-1})**	**Harvest Index (%)**
V_1D_0	42.89 i	1.20 h	**2.80 a**	4.00 b	29.97 h
V_1D_1	44.14 hi	1.71 g	2.33 bc	4.04 b	42.52 g
V_1D_2	45.95 fg	2.06 f	2.07 cd	4.13 b	49.88 f
V_1D_3	44.53 gh	1.71 g	2.50 ab	4.21 ab	41.01 g
V_2D_0	46.11 f	2.10 ef	1.88 de	3.98 b	53.16 ef
V_2D_1	48.76 de	2.39 d	1.88 de	4.27 ab	55.99 de
V_2D_2	51.52 bc	2.61 c	1.39 f	4.00 b	65.26 b
V_2D_3	49.14 d	2.20 e	1.88 de	4.08 b	53.84 ef
V_3D_0	47.41 ef	2.52 cd	1.67 ef	4.19 ab	60.14 cd
V_3D_1	50.13 cd	2.81 b	1.39 f	4.20 ab	66.90 ab
V_3D_2	**55.44 a**	**3.20 a**	1.35 f	**4.55 a**	**70.67 a**
V_3D_3	52.44 b	2.75 b	1.61 ef	4.36 ab	63.07 bc
LSD (0.05)	1.49	0.13	0.35	0.40	4.74
CV (%)	7.80	3.51	10.82	5.53	5.09

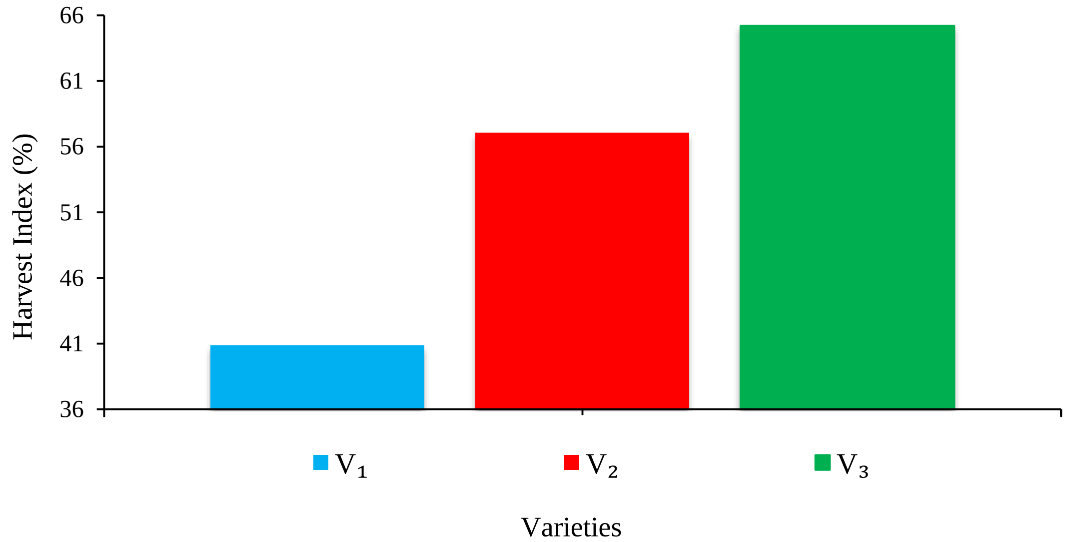
In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32 whereas, D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}.

4.3.4 Harvest Index (%)

4.3.4.1 Effect of variety

Wheat varieties showed significant variation on harvest index (Figure 18 and Appendix X). BARI Gom 32 (V_3) showed the highest harvest index (65.19 %) which was statistically similar to that of BARI Gom 31 (57.06 %) whereas, the lowest harvest index (40.85 %) was recorded from BARI Gom 30 (V_1).

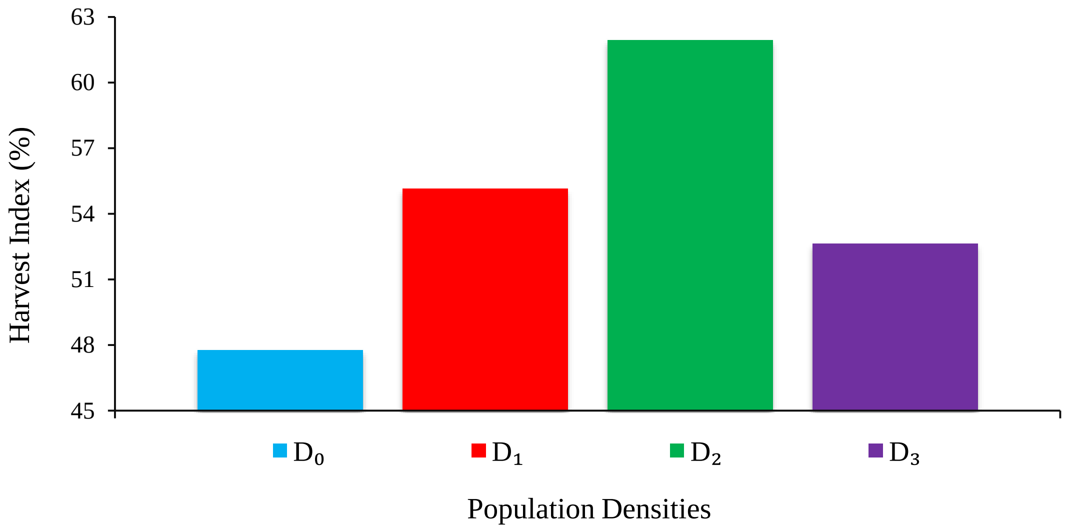


V_1 – BARI Gom 30, V_2 – BARI Gom 31 and V_3 – BARI Gom 32

Figure 18: Effect of three improved varieties of wheat on harvest index (LSD $_{0.05}$ = 8.27)

4.3.4.2 Effect of plant density

Harvest index (%) was significantly influenced by plant density of wheat (Figure 19 and Appendix X). The highest harvest index (61.94 %) was observed with 125 plants m^{-2} (D_2) and the lowest harvest index (47.76 %) was observed with no thinning (D_0) treatment. Borojevic and Krajievic (1983), Roy and Biswas (1991), Mozumder (2001) and Hossain (2002) observed significant influence of population density on harvest index. Borojevic and Kraljevic (1983) reported that increasing the seeding rate reduced the harvest index significantly. On the other hand, Roy and Biswas (1991) reported that the highest harvest index was achieved with 300–400 seeds m^{-2}.



D_0 – Controlled (No thinning), D_1 –100 plants m^{-2}, D_2 – 125 plants $m^{-2}$and D_3 – 150 plants m^{-2}

Figure 19: Influence of population densities on Harvest Index (LSD $_{0.05}$ = 4.74)

4.3.4.3 Interaction effect of variety and plant density

Significant variation was observed in harvest index (%) due to the interaction of variety and plant density (Table 7 and Appendix X). The highest harvest index (70.67 %) was recorded in the interaction of BARI Gom 32 and 125 plants m^{-2}(V_3D_2) which was statistically similar to that of V_3D_1 (66.90 %). On the other hand, the lowest harvest index (29.97 %) was recorded in the interaction of BARI Gom 30 with no thinning(V_1D_0) treatment.

CHAPTER V

SUMMARY AND CONCLUSIONS

The experiment was conducted during the period from November 2018 to March 2019 in the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh to find out the effect of variety and population densities on the growth characters and yield parameters of wheat. The experiment comprised of two factors; Factors A: three improved wheat varieties *viz.* V_1 = BARI Gom 30, V_2 = BARI Gom 31 and V_3 = BARI Gom 32 and Factor B: four plant population densities *viz*. D_0 = no thinning (control), D_1 = 100 plants m^{-2}, D_2 = 125 plants m^{-2} and D_3 = 150 plants m^{-2}.

The experiment was laid out in a split-plot design with three replications. Variety was assigned in the main plot and plant population densities was in the sub-plots. The data were collected on plant height (cm), number of leaves plant^{-1}, number of tillers plant^{-1}, dry weight (g m^{-2}), crop growth rate (CGR) and relative growth rate (RGR), 1000-seeds weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%).

Collected data were compiled and analysed using split-split plot design to find out the statistical significance of experimental results. The means for all recorded data were calculated and the analyses of variance for all characters were performed. The mean separations among the treatments were tested with the least significant difference (LSD) test at 5% level of significance.

Different wheat varieties showed significant variations on all parameters on all the growth stages except relative growth rate (RGR). Different population densities treatment also showed same effect on different plant characters. Interaction effect of variety and different population densities treatment also showed the significant variation on growth and yield parameters.

Plant heights of all the varieties increased gradually with the advancement of growth stages up to 75 DAS. Among the varieties, plant height ranged from

48.09 to 52.10, 60.23 to 64.88, 66.16 to 70.96 and 68.60 to 73.34 cm at 45, 60, 75 DAS and harvesting time, respectively. The variety BARI Gom 30 produced the tallest plant (73.34 cm) which was statistically similar to those of the variety BARI Gom 31 (72.38 cm) and the variety BARI Gom 32 (V_3) produced the dwarf stature plant at harvesting time (68.60 cm). The tallest plants (74.86 cm) were observed from 125 plants m^{-2} and the shortest plants (68.83 cm) were recorded from no thinning at harvesting time. At harvesting time, results showed that the tallest plant was obtained from V_1D_2 combination (78.31 cm) and the shortest plant was obtained from V_3D_3 combination (67.10 cm).

Number of leaves $plant^{-1}$ increased rapidly from 45 to 60 DAS and thereafter reduced gradually up to harvesting. Among the three varieties, number of leaves $plant^{-1}$ ranged from 12.50 to 14.73, 18.36 to 20.20, 16.17 to 18.40 and 15.23 to 18.28 at 45, 60, 75 DAS and harvesting time, respectively. The variety BARI Gom 32 produced the maximum number of leaves $plant^{-1}$ at 45, 60, 75 DAS and harvesting time (14.73, 20.20, 18.40 and 18.28, respectively) and the variety BARI Gom 30 produced the minimum number of leaves $plant^{-1}$ at 45, 60, 75 DAS and harvesting time (12.50, 18.36, 16.17 and 15.23, respectively). Significant variation was observed on number of leaves $plant^{-1}$ in case of different population densities except 75 DAS. At 60, 75 DAS and harvesting time, it was found that the maximum number of leaves $plant^{-1}$ (19.77, 17.80 and 16.85, respectively) was found with 100 plants m^{-2} treatment. At harvesting time, results showed that the maximum number of leaves $plant^{-1}$ (18.70) was obtained from the combination of BARI Gom 32 with 125 plants m^{-2} (V_3D_2) and the minimum (14.71) was obtained from the combination of BARI Gom 30 with no thinning (V_1D_0).

The result revealed that the effect of variety on number of tillers $plant^{-1}$ was significant across all growth stages. Among the three varieties, number of tillers ranged from 3.39 to 2.48, 4.47 to 2.88, 4.42 to 3.01 and 4.31 to 2.73 $plant^{-1}$ at 45, 60, 75 DAS and harvesting time, respectively. It was found that the highest number of tillers $plant^{-1}$ (3.71, 4.57, 4.51 and 4.24 at 45, 60, 75

DAS and harvesting time, respectively) was found with 125 plants m^{-2} and the lowest (2.27, 2.82, 2.86 and 2.58 at 45, 60, 75 DAS and harvesting time, respectively) was found in no thinning treatment. At 45, 60, 75 DAS and harvesting time, results showed that the highest number of tillers $plant^{-1}$ (4.52, 5.78, 5.62 and 5.35, respectively) was obtained from the combination of BARI Gom 32 with 125 plants m^{-2} (V_3D_2) and the lowest (1.95, 2.24, 2.33 and 2.03, respectively) was obtained from the combination of BARI Gom 30 with no thinning (V_1D_0) treatment.

Dry matter weight (g m^{-2}) of all the varieties of wheat increased as the age of the plant increased up to the harvest. Among the three varieties, the dry matter weight ranged from 1016.00 to 1431.00, 1946.00 to 2499.00, 2147.00 to 2838 and 2472.00 to 3162.00 g m^{-2} at 45, 60, 75 DAS and harvesting time, respectively. Results indicated that at 45, 60, 75 DAS and harvesting time, the variety BARI Gom 32 produced the maximum dry matter weight (1431.00, 2499.00, 2838.00 and 3162.00 g m^{-2}, respectively) and BARI Gom 31 produced the lowest (1016.00, 1946.00, 2147.00 and 2472.00 g m^{-2}, respectively). The maximum dry matter weight (2055.00, 3187.00, 3417.00 and 3742.00 g m^{-2}, respectively) was observed in no thinning treatment and the minimum (672.00, 1495.00, 1747.00 and 2071.00 g m^{-2}, respectively) was observed at 100 plants m^{-2} treatment. Results showed that the maximum dry matter weight (2552.00, 3801.00, 4069.00 and 4394.00 g m^{-2}, respectively) was obtained from the combination of the variety BARI Gom 32 with no thinning (V_3D_0) treatment at 45, 60, 75 DAS and harvesting time and the minimum was observed as 440.00, 1252.00, 1568.00 and 1893.00 g m^{-2}, respectively from the combination of the variety BARI Gom 31 and 100 plant m^{-2} (V_2D_1) treatment.

Varieties/population densities showed significant variation in respect of crop growth rate at 45–60 DAS and 60–75 DAS. Crop growth rate (CGR) of wheat showed statistically non-significant variation due to different variety of wheat at 75 DAS–harvesting time. At 75 DAS–Harvesting time, the highest (13.21 g

m^{-2} day^{-1}) CGR was observed from the combination of wheat variety BARI Gom 32 with no thinning (V_3D_0) treatment and the lowest (12.85 g m^{-2} day^{-1}) CGR was observed in the combination of wheat variety BARI Gom 32 with 100 plant m^{-2} (V_3D_1) treatment.

Relative growth rate (RGR) did not differ significantly at 45–60 DAS, 60–75 DAS and 75 DAS–Harvesting time in different varieties/population densities. At 75 DAS–Harvesting time, the numerically maximum (0.007 g g^{-1} day^{-1}) RGR was observed in the combination of wheat variety BARI Gom 30 with 100 plant m^{-2} (V_1D_1) and BARI Gom 31 with 125 plant m^{-2} (V_2D_2) treatment and the numerically minimum (0.003 g g^{-1} day^{-1}) RGR was observed in the combination of wheat variety BARI Gom 32 with no thinning (V_3D_0) treatment.

Weight of 1000-grains showed significant variation among the different varieties of wheat. BARI Gom 32 produced the maximum 1000-grains weight (51.36 g). On the other hand, the minimum 1000-grain weight (44.38 g) was obtained from BARI Gom 30. Plant density had significant effect on weight of 1000-grains. The maximum weight of 1000-grains (50.97 g) was found in 125 plants m^{-2}. The minimum weight of 1000-grains (45.47 g) was found with no thinning treatment. Interaction effect of improved wheat varieties and population densities showed significant variation in respect of weight of 1000-grains. The maximum 1000 grains weight (55.44 g) was observed from the combination of wheat variety BARI Gom 32 with 125-plant m^{-2} (V_3D_2) treatment. On the other hand, the minimum 1000 grains weight (42.89 g) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment.

Wheat grain yield (t ha^{-1}) varied significantly for different varieties. The highest grain yield (2.82 t ha^{-1}) was recorded from BARI Gom 32. The lowest grain yield (1.67 t ha^{-1}) was recorded from BARI Gom 30. Grain yield was significantly influenced by population density. The significantly highest grain yield (2.62 t ha^{-1}) was obtained from 125 seeds m^{-2} and the lowest amount of grain yield (1.94 t ha^{-1}) was obtained from no thinning. Interaction effect of improved wheat varieties and population densities showed significant variation in respect of grain yield. The highest grain yield (3.20 t ha^{-1}) was observed in the combination of wheat variety BARI Gom 32 with 125-plant m^{-2} (V_3D_2) treatment. On the other hand, the lowest grain yield (1.20 t ha^{-1}) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment.

Straw yield of wheat (t ha^{-1}) varied significantly for different varieties. The highest straw yield (2.43 t ha^{-1}) was recorded from BARI Gom 30. On the other hand, the lowest straw yield (1.51 t ha^{-1}) was recorded from BARI Gom 32. Plant density had significant influence on straw yield of wheat. The significantly highest straw yield (2.12 t ha^{-1}) was observed with no thinning (D_0) treatment. The lowest straw yield(1.60 t ha^{-1}) was recorded with 125 plants m^{-2}. Interaction effect of improved wheat varieties and population densities showed significant variation in respect of straw yield (t ha^{-1}). The highest straw yield (2.80 t ha^{-1}) was observed from the combination of wheat variety BARI Gom 30 with no thinning (V_1D_0) treatment. On the other hand, the lowest straw yield (1.35 t ha^{-1}) was observed in the combination of wheat variety BARI Gom 32 with 125 plants m^{-2} (V_3D_2) treatment.

The biological yield (t ha^{-1}) had non-significant data due to the influence of variety. It was observed that BARI Gom 32 produced numerically the maximum biological yield (4.33 t ha^{-1}) and the numerically minimum biological yield (4.08 t ha^{-1}) was recorded from BARI Gom 31. The biological yield (t ha^{-1}) had non-significant data due to the influence different plant density treatments. Plant density of 125 plant m^{-2} (D_2) gave the numerically maximum biological yield (4.23 t ha^{-1}). No thinning (D_0) treatment revealed the numerically minimum biological yield (4.06 t ha^{-1}). Biological yield (t ha^{-1}) was significantly affected by the interaction of different variety and population densities treatment combinations in wheat field. The maximum biological yield (4.55 t ha^{-1}) was obtained from the combination BARI Gom 32 with 125 plants m^{-2} (V_3D_2). The minimum biological yield (3.98 t ha^{-1}) was found from the combination BARI Gom 31 with no thinning (V_2D_0) treatment.

Wheat varieties showed significant variation on harvest index. BARI Gom 32 showed the highest harvest index (65.19 %) whereas, the lowest harvest index (40.85 %) was recorded from BARI Gom 30. Harvest index (%) was significantly influenced by plant density of wheat. The highest harvest index (61.94 %) was observed with 125 plants m^{-2} and the lowest harvest index (47.76 %) was observed with no thinning treatment. Significant variation was observed in harvest index (%) due to the interaction of variety and plant density. The highest harvest index (70.67 %) was recorded in the interaction of BARI Gom 32 and 125 plants m^{-2}(V_3D_2). On the other hand, the lowest harvest index (29.97 %) was recorded in the interaction of BARI Gom 30 with no thinning(V_1D_0) treatment.

Based on the results of the present experiment, the following conclusion can be drawn:

1. Irrespective of the plant population densities, BARI Gom 32 was found to be significantly higher grain producing variety.
2. Plant population density of 125 plants m^{-2} showed significantly higher yield irrespective of the wheat varieties.
3. The combination of wheat variety BARI Gom 32 with 125-plant m^{-2} was found to be the significantly higher yield giving agronomic practice compared with other treatment combinations for wheat production.

From the above discussion, it may be concluded that the higher yield of wheat could be obtained by cultivating BARI Gom 32 variety with a plant population density of 125 plants m^{-2}. However, to reach a specific conclusion and recommendation, more research work on modern and traditional variety and different plant population densities should be done over different agro-ecological zones of the country.

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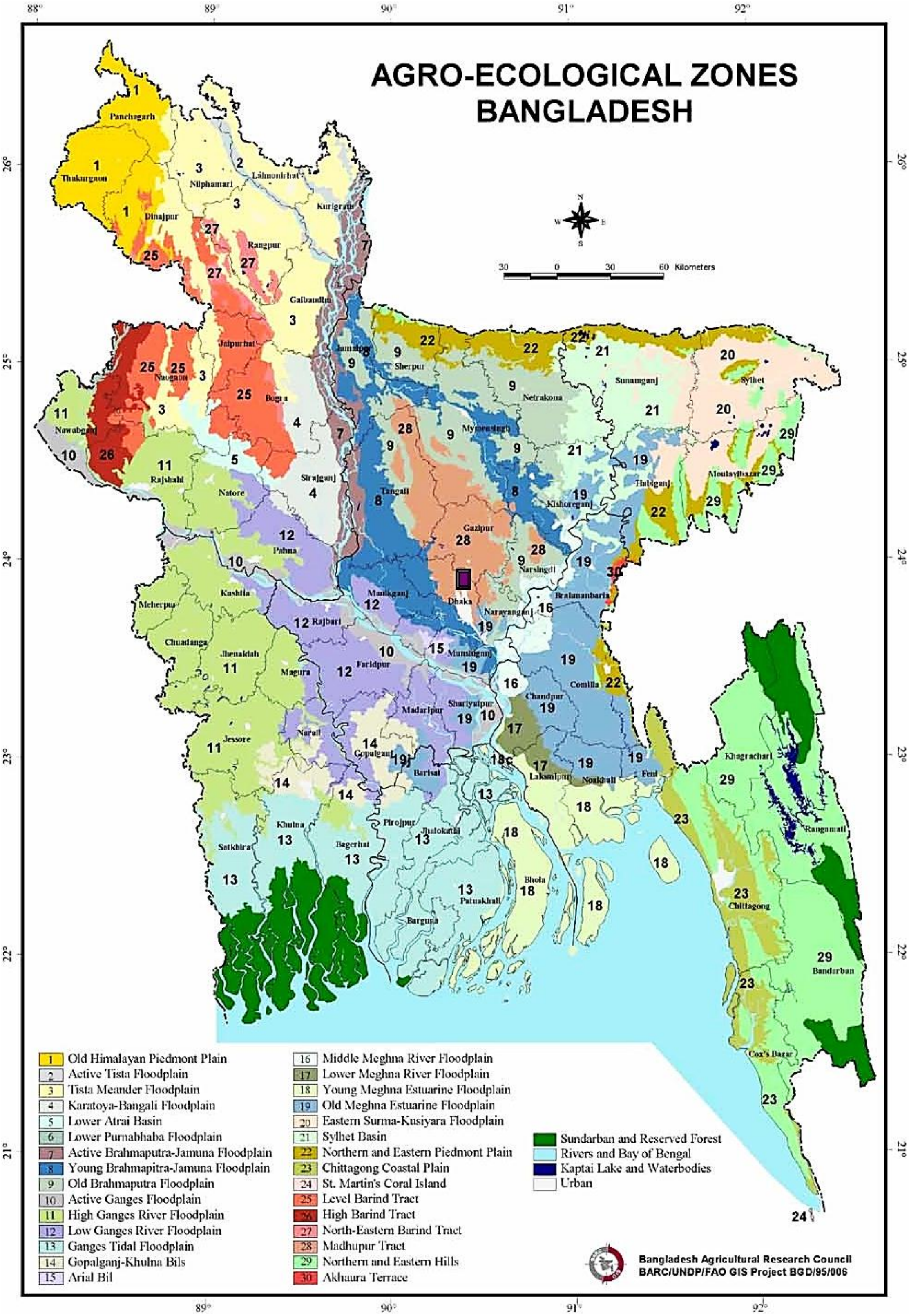
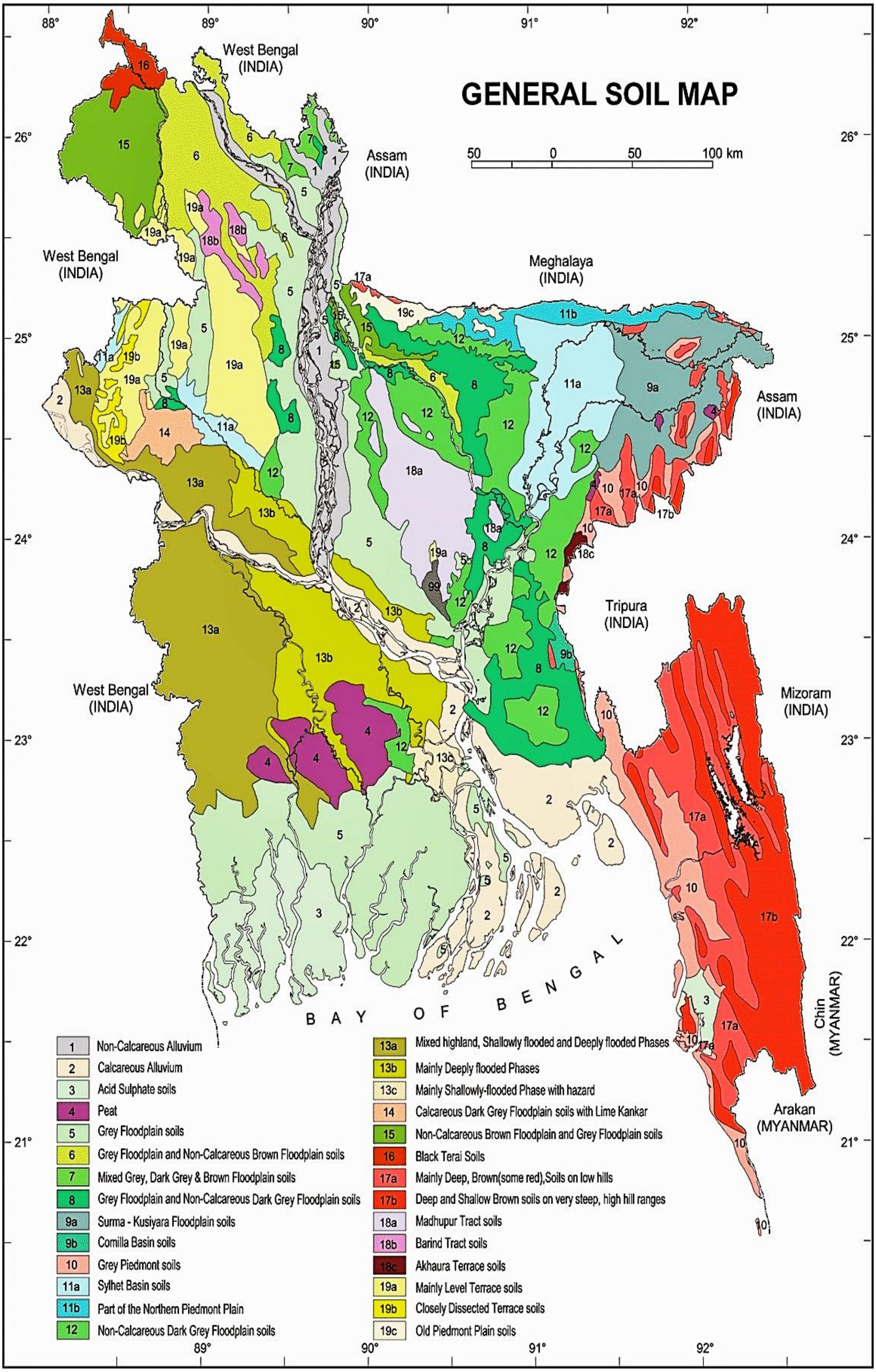
APPENDICES

Appendix I: (A) Map showing the experimental sites under study



The experimental site under study

Appendix I (B): Map showing the general soil sites under study



Appendix II: Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.5
Organic carbon (%)	0.43
Organic matter (%)	0.75
Total N (%)	0.075
Available P (ppm)	21.00
Exchangeable K (meq/ 100 g soil)	0.11
Available S (ppm)	43

Source: SRDI, 2018

Appendix III: Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2018 to March 2019

Year	Month	Air Temperature (°C)			Relative Humidity (%)	Total Rainfall (mm)	Total Sunshine (hour)
		Maximum (°C)	Minimum (°C)	Mean (°C)			
2018	November	33	25	29	51	49.2	210.5
	December	28	20	25	51	103.4	206
2019	January	30	21	26	43	0	232.5
	February	31	21	27	45	760.8	179
	March	34	24	30	44	691.2	301.5

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix IV: Analysis of variance of data on plant height of wheat

	Degree of Freedom (df)	Plant height			
		45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
Replication	2	28.554	14.691	17.508	9.524
Variety (A)	2	50.973*	69.148*	77.319^{NS}	75.554*
Error (1)	4	3.609	0.827	6.60	2.260
Density (B)	3	31.923*	17.695*	56.874*	56.590*
A × B	6	57.312*	26.894*	32.038*	29.779*
Error (2)	18	2.904	0.441	2.102	4.581

* Significant at 5% level of probability
** Significant at 1% level of probability.

Appendix V: Analysis of variance of data on number of leaves plant^{-1} of wheat

	Degree of Freedom (df)	Number of leaves plant^{-1}			
		45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
Replication	2	0.166	0.241	2.831	0.159
Variety (A)	2	15.307*	10.250*	15.112^{NS}	29.997*
Error (1)	4	0.063	0.061	2.792	0.078
Density (B)	3	1.819**	3.171**	1.691^{NS}	3.677**
A × B	6	57.312*	26.894*	32.038*	3.071**
Error (2)	18	2.904	0.441	2.102	0.084

* Significant at 5% level of probability
** Significant at 1% level of probability

Appendix VI: Analysis of variance of data on number of tillers plant^{-1} of wheat

	Degree of Freedom (df)	Number of tillers plant^{-1}			
		45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
Replication	2	0.053	0.035	0.033	0.032
Variety (A)	2	2.495**	7.586*	7.515*	5.938*
Error (1)	4	0.023	0.004	0.090	0.016
Density (B)	3	3.217**	4.913**	4.314**	4.474**
A × B	6	0.232**	0.364**	0.345**	0.312**
Error (2)	18	0.022	0.009	0.147	0.022

* Significant at 5% level of probability
** Significant at 1% level of probability

Appendix VII: Analysis of variance of data on dry weight of wheat

	Degree of Freedom (df)	Dry weight			
		45 DAS	**60 DAS**	**75 DAS**	**At harvest (113 DAS)**
Replication	2	1630.351	660.083	2038.867	1102.528
Variety (A)	2	533533.378*	940800.327*	1431165.457*	1429816.444*
Error (1)	4	376.872	27.897	182.413	152.528
Density (B)	3	3073188.036*	4640513.193*	4369660.017*	4375161.333*
A × B	6	135287.216*	205060.789*	177995.882*	178317.333*
Error (2)	18	187.747	176.856	397.203	413.639

* Significant at 5% level of probability
** Significant at 1% level of probability

Appendix VIII: Analysis of variance of data on Crop Growth Rate (CGR) of wheat

	Degree of Freedom (df)	Crop Growth Rate (CGR)		
		45–60 DAS	**60–75 DAS**	**75 DAS–At harvest (113 DAS)**
Replication	2	5.811	0.250	0.092
Variety (A)	2	274.317*	260.359*	0.003^{NS}
Error (1)	4	1.409	0.007	0.001
Density (B)	3	452.662*	137.345*	0.022 ^{NS}
A × B	6	228.468*	122.930*	0.052 ^{NS}
Error (2)	18	0.386	0.009	0.005

* Significant at 5% level of probability

** Significant at 1% level of probability

Appendix IX: Analysis of variance of data on Relative Growth Rate (RGR) of wheat

	Degree of Freedom (df)	Relative Growth Rate (RGR)		
		45–60 DAS	**60–75 DAS**	**75 DAS–At harvest (113 DAS)**
Replication	2	0.003	0.001	0.001
Variety (A)	2	0.001^{NS}	0.001^{NS}	0.001 ^{NS}
Error (1)	4	0.003	0.001	0.001
Density (B)	3	0.004^{NS}	0.001^{NS}	0.001 ^{NS}
A × B	6	0.004*	0.001*	0.001 ^{NS}
Error (2)	18	0.003	0.001	0.001

* Significant at 5% level of probability

** Significant at 1% level of probability

Appendix X: Analysis of variance of data on 1000-grain weight, Grain yield, Straw yield, Biological yieldand Harvest Index (%)of wheat

	Degree of Freedom (df)	1000-grain weight	Grain yield	Straw yield	Biological yield	Harvest Index
Replication	2	9.918	0.049	0.084	0.255	2.172
Variety (A)	2	150.219*	3.994**	2.713**	0.224 ^{NS}	1844.189*
Error (1)	4	0.750	0.004	0.096	0.063	17.727
Density (B)	3	46.962*	0.714**	0.435**	0.056 ^{NS}	313.671*
A × B	6	3.740**	0.027**	0.051**	0.055 ^{NS}	22.969*
Error (2)	18	0.749	0.006	0.042	0.053	7.646

* Significant at 5% level of probability
** Significant at 1% level of probability

Plate 1: Experimental plot at SAU farm

Plate 2: Emerging wheat seedlings at 5 days after sowing

Plate 3: Experimental plots (Tagging was done at 15 DAS)

Plate 4: Vegetative stage of wheat plants (30 DAS)

Plate 5: Vegetative stage of wheat in experimental plots (45 DAS)

Plate 6: Wheat spikes shown up at 53 DAS

Plate 7: Wheat spikes (70 DAS)

Plate 8: Net given to prevent bird damage of experimental plots (54 DAS)