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Original Article

Growth and yield of five irrigated spring wheat varieties as influenced by seeding rate in Old Himalayan Piedmont Plain of Bangladesh

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Abstract

Farmers in Bangladesh are always seeking an optimal seed rate to reduce production costs and increase wheat yield. The Wheat Research Centre (WRC) of Bangladesh has developed new wheat varieties over several years. To reduce production costs and obtain higher grain yield (GY) from these varieties, optimum seeding rates are needed. In this context, a two-year field experiment was conducted with five newly released wheat varieties (‘BARI Gom 24’, ‘BARI Gom 25’, ‘BARI Gom 26’, ‘BARI Gom 27’ and ‘BARI Gom 28’) and three seeding rates (100, 120 and 140 kg ha^{-1}). These treatments were performed under irrigation in the WRC research field in Northern Bangladesh to determine the optimum seeding rates for these varieties. Significantly higher GY ($p \leq 0.05$) was obtained with a seeding rate of 140 kg ha^{-1} for all varieties, compared to other rates. A seeding rate less than the recommended rate (120 kg ha^{-1}) for all varieties failed to produce comparable GY in both years. Among all varieties, ‘BARI Gom 26’ had the highest GY while ‘BARI Gom 25’ had the lowest GY in both years. Although the interaction effect of variety and seeding rate on GY did not vary significantly ($p \leq 0.05$) in both years, surplus GY was 467 and 233 kg ha^{-1}, respectively for ‘BARI Gom 24’, 63 and 75 kg ha^{-1} for ‘BARI Gom 25’, 81 and 93 kg ha^{-1} for ‘BARI Gom 26’, 23 and 66 kg ha^{-1} for ‘BARI Gom 27’, and 152 and 220 kg ha^{-1} for ‘BARI Gom 28’ in the first and second year when seeded at 140 kg ha^{-1}. For the same seed rate, the GY of ‘BARI Gom 24’ increased by 5.3 to 9.6% and that of ‘BARI Gom 28’ increased from 2.8 to 5% over the two years. Therefore, a seeding rate of 140 kg seed ha^{-1} is recommended for ‘BARI Gom 24’ and ‘BARI Gom 28’, while the current recommended rate (120 kg ha^{-1}) should be continued for the other three varieties when grown under irrigation on the Old Himalayan Piedmont Plain of Bangladesh.

Keywords: seeding rate, wheat, plant population, tillers, yield

1. Introduction

Wheat (*Triticum aestivum* L.) is the most widely grown crop in the world (FAO & WFP, 2015). It is projected that the world demand for food needs to double by 2050, and that high-quality food is required for a healthy diet (Singh *et al.*, 2016). As there is little scope to increase agricultural lands suitable for cultivation globally, wheat production could be increased by increasing yield or by adopting improved agronomic management practices (Reynolds *et al.*, 2009). Therefore, in order to increase wheat yield, greater efforts are needed to develop new wheat varieties with a higher potential

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for grain yield (GY) and to develop and adopt improved crop management practices (Li *et al.*, 2016).

In Bangladesh, wheat is ranked as the second most important cereal after rice and plays an important role in meeting the country's food security for an increasing population (Hossain & Teixeira da Silva, 2013a, 2013b; Timsina *et al.*, 2016). According to the BBS (2016), 1.35 million tons of wheat was harvested from 0.44 million ha in 2015-16, of which 30.65 % was in Northern Bangladesh (or Old Himalayan Piedmont Plain only). However, average GY of wheat was only 3.03 t ha^{-1} in 2015-16 (BBS, 2016). According to the Bangladesh Agricultural Research Institute (BARI), the attainable average GY of current wheat varieties is 4.0–4.5 t ha^{-1} (BARI, 2016), while climatic GY potential is as high as 6.0 t ha^{-1} (Timsina *et al.*, 2010). Such wide gaps among potential, attainable and actual GY need to be reduced to improve food security in Bangladesh (Timsina *et al.*, 2016).

Optimum seeding rate is considered to be an important management strategy for improving the GY of wheat (Sarker, Malaker, Saifuzzaman, & Pandit, 2007; Sarker, Malaker, Bodruzzaman, & Barma, 2009; Laghari *et al.*, 2010). This is particularly important because it is controlled by farmers (Laghari *et al.*, 2010). However, seeds are a costly input for farmers (Sarker, Malaker, Bodruzzaman, & Barma, 2009; Farooq *et al.*, 2016). Optimum plant density, which can be achieved by maintaining optimum seeding rate, may vary greatly with area, climatic conditions, soil, sowing time, variety and management skills (Li *et al.*, 2016). Iqbal *et al.* (2010) and Chauhdary *et al.* (2015) noticed that if optimum seeding rate is exceeded, wheat GY may be reduced by stunting the development of tillers and main stem spikes, but this can be favorable for cultivars that produce few tillers (Chauhdary *et al.*, 2015; Xie *et al.*, 2016).

A seeding rate of 120 kg ha^{-1} is recommended by Wheat Research Centre (WRC) in Bangladesh, irrespective of the variety, from the very initial stage of wheat introduction and expansion in Bangladesh (Razzaque *et al.*, 2000; Islam *et al.*, 2004). However, studies using varieties released up to 2005 showed that in order to achieve maximum (or optimum) GY, seeding rate for varieties with medium to large sized seed is 120 kg ha^{-1} and that for the varieties with small seed is 100 kg ha^{-1} (Sarker, Malaker, Saifuzzaman, & Pandit, 2007; Sarker, Malaker, Bodruzzaman, & Barma, 2009). In contrast, farmers are using a much higher seeding rate, sometimes even double the recommended rate, with the aim of controlling weeds, repelling birds, and achieving higher GY (Sarker, Malaker, Saifuzzaman, & Pandit, 2007). At the same time, wheat seeds are also considered to be an expensive input and farmers often use low quality and recycled seeds due to the high cost of seed from new and improved varieties (Sarker, Malaker, Bodruzzaman, & Barma, 2009; Farooq *et al.*, 2016).

The WRC of BARI developed several new high-yielding varieties at the turn of the century with varying seed sizes (Hossain *et al.*, 2013; Hossain & Teixeira da Silva, 2012; BARI, 2016; Table 2). Therefore, it is necessary to evaluate various seeding rates for existing wheat varieties and determine their optimum rates to reduce production costs and achieve higher GY. Since Northern Bangladesh, and particularly the Old Himalayan Piedmont Plain, produces the largest amount of wheat in the country, the present research was conducted to determine the optimum seeding rate for five recently released varieties (Table 2) for the Old Himalayan Piedmont Plain of Bangladesh.

2. Materials and Methods

2.1 Site description

2.1.1 Location of the experiment

The experiment was conducted in the WRC, BARI, Dinajpur over two consecutive years (2013-14 and 2014-15) in wheat-growing seasons (Nov. to April). The geographical position of the area is between 25º 44.574" N and 88º 40.344" E, and 40 m above sea level. The Agro Ecological Zone (AEZ) of the area is the Old Himalayan Piedmont Plain (AEZ-1). This zone has largest wheat area and also produces largest amount of wheat in the country.

2.1.2 Soil characteristics in the experimental field

Soils of the experimental sites were analyzed before sowing wheat (Table 1). The pre-seeding total soil N was 0.06%, indicating a deficiency in soil N. Soil available K was 0.18 meq 100 g^{-1} soil, and available P, S, Zn and B were 18.5, 5.5, 0.79 and 0.15 µg g^{-1} soil, respectively. Based on the critical level of these plant nutrients, K, S, Zn and B were low, but P was high. Soil pH was 5.3 and organic matter was 1.3%.

Table 1. Nutrient status of soil showing critical levels before wheat seeds were sown (recorded in 2013-14).

Soil parameters	Nutrient status before sowing	Critical level
Soil pH	5.30	-
Organic matter (%)	1.30	-
Total N (%)	0.06	0.12
Available P (µg g^{-1} soil)	18.50	14.0
Exchangeable K (Meq100 g^{-1} soil)	0.18	0.20
Available S (µg g^{-1} soil)	5.55	14.0
Available Zn (µg g^{-1} soil)	0.79	2.00
Available B (µg g^{-1} soil)	0.15	0.20
Exchangeable Ca (Meq100 g^{-1} soil)	0.75	2.00
Exchangeable Mg (Meq100 g^{-1} soil)	0.53	0.80

2.1.3 Temperature, humidity and rainfall in 2013-14 and 2014-15

Weather data on weekly average temperature, humidity and rainfall in both years were recorded regularly by the HOBO U12 Family of Data Loggers (MicroDAQ.com) at the meteorological station, at Dinajpur WRC. Data are presented in Figure 1.

2.2 Experimental design and treatments

The experiment was conducted in a completely randomized block design with three replications. Treatments were three seeding rates (100, 120 and 140 Kg ha^{-1}) and five elite existing wheat varieties ('BARI Gom 24', 'BARI Gom

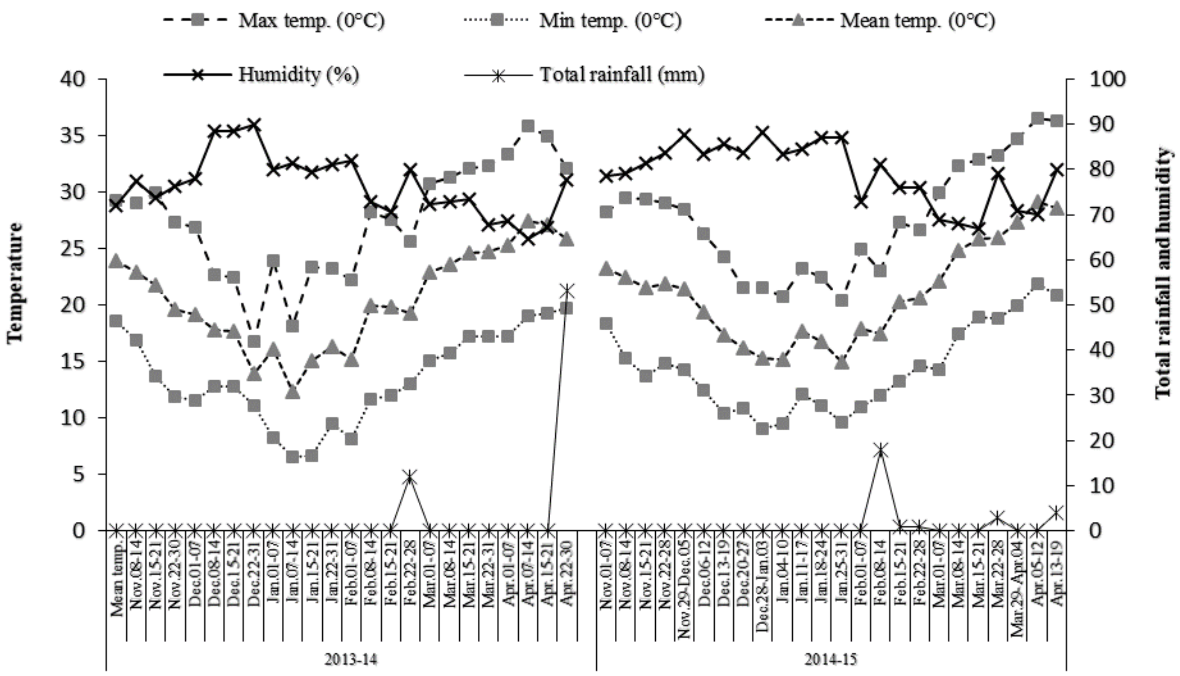

Figure 1. Weekly average temperature, rainfall and humidity during the wheat season inboth years (2013-14 and 2014-15).

25', 'BARI Gom 26', 'BARI Gom 27' and 'BARI Gom 28'). The unit plot size (3×3 m) consisted of 15 rows, each 3 m long, and a row-to-row distance of 20 cm and a block-to-block distance of 1.5 m.

2.3 Experimental procedure and crop management

2.3.1 Variety, seeding rate, sowing time, seed treatment and insecticide

The characteristics of the five wheat varieties used in this research are presented in Table 2. In both wheat seasons, all varieties were sown in lines by hand on November 21. Seeding rate was as indicated for each treatment. Before sowing, seeds of all varieties were treated with a popular fungicide, Provax-200 WP, which contains carboxin and thiram (marketed by Hossain Enterprise CC Bangladesh Ltd., in association with Chemtura Corp., USA). Furadan 5G (containing Carbofuran, marketed by FMC International S.A. Bangladesh Ltd.) was broadcasted at 10 kg ha^{-1} for controlling soil-borne insects.

2.3.2 Fertilizer, irrigation, mulching and weeding

Fertilizer N, P, K, S, Zn and B, respectively, at 100, 27, 40, 20, 10 and 1 kg ha^{-1} was applied as recommended by the WRC. During final land preparation, two-thirds of N and a full amount of the other fertilizers were applied as basal. The remaining N fertilizer was applied immediately after the first irrigation, namely 18 days after sowing (DAS), while second, third and fourth irrigations were applied at 50, 73 and 88 DAS. Mulching was done at 28 DAS and hand weeding at 45 DAS.

2.3.3 Data collection

Initial plants m^{-2} was recorded at 12 DAS, while number of tillers m^{-2} was recorded at 30, 40 and 50 DAS. The crop was harvested on 28 March in 2014 (for the 2013-14 season), and 30 March 2015 (for the 2014-15 season). GY, biomass yield (BY), and yield-related attributes were recorded from a 2.5 × 2.6 m area from the center of each plot. Samples from the harvested area from each plot were bundled separately, tagged and manually threshed on a threshing floor. Bundles were thoroughly dried in bright sunshine before their weights were recorded. Data on plant height (cm), productive tillers m^{-2}, spike length (cm), spikelets $spike^{-1}$, grains $spike^{-1}$, 1000-grain weight (g; TGW), GY (kg ha^{-1}) and BY (kg ha^{-1}) were recorded. GY and TGW were recorded at 12% moisture content (Hellevang, 1995), while BY at harvest was recorded on a sun-dry basis.

$$Y(M_2) = \frac{100 - M_1}{100 - M_2} \times Y(M_1)$$

where Y (M_2) = grain weight at 12% moisture; Y (M_1) = grain weight at actual moisture %; M_1 = actual moisture %; M_2 = expected moisture %.

2.4 Data analysis

Data collected during this study were statistically analyzed using MSTAT statistical package of Michigan State University, USA (Russell, 1986). Duncan's new multiple range test (DNMRT) at a 5% probability level was used to test differences among mean values (Steel and Torrie, 1984).

Table 2. Characteristics of existing wheat varieties used in the present research

Variety	Stress tolerance capacity	Life span (days)	1000-grain weight (g)	Year of release	Major diseases
BARI Gom 24	High yielding, but heat sensitive	102-110	48-55	2005	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
BARI Gom 25	Moderate level of tolerance to heat stress	102-110	54-58	2010	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
BARI Gom 26	Tolerant to terminal heat stress in late seeding	104-110	48-52	2010	Tolerant to *Bipolaris* leaf blight and resistant to leaf rust (stem rust) race Ug 99
BARI Gom 27	Moderate level of tolerance to heat stress	105-110	38-42	2012	Tolerant to *Bipolaris* leaf blight and resistant to leaf rust (stem rust) race Ug 99
BARI Gom 28	Tolerant to terminal heat stress in late seeding	100-105	42-44	2012	Resistant to leaf rust and tolerant to *Bipolaris* leaf blight

3. Results

3.1 Plant density (plants m^{-2})

In both seasons, the number of plants m^{-2} at 12 DAS was significantly ($p \leq 0.01$) influenced by seeding rate and variety, but was not by their interaction (Table 3). In both years, the highest number of plants m^{-2} was found in plots with the higher seeding rate (140 kg ha^{-1}) and the lowest in plots with the lowest seeding rate (100 kg ha^{-1}). The highest number of plants m^{-2} was observed in 'BARI Gom 27' while the lowest number of plants m^{-2} was observed in 'BARI Gom 24'.

3.2 Tiller density (tillers m^{-2}) at different days after sowing

Tillers m^{-2} at different DAS was significantly ($p \leq 0.01$) influenced by seeding rate and variety, but not by their interaction (Table 3). The highest number of tillers m^{-2} at different DAS was observed with 140 kg seed ha^{-1} while the fewest number with 100 kg seed ha^{-1}. The number of tillers m^{-2} at different DAS was highest in 'BARI Gom 27 but lowest in 'BARI Gom 24'. The latter had large seed, so the plant population per unit area and tiller-producing capacity were least in both years (Table 3).

3.3 Productive tillers m^{-2}

Productive tillers m^{-2} at harvest was also significantly ($p \leq 0.01$) influenced by seeding rate and variety, but their interaction was not significant (Table 3). Similar to tillers m^{-2}, higher seeding rates produced a maximum number of productive tillers while lower seeding rates resulted in the lowest number of productive tillers in both years. Likewise, the highest number of productive tillers m^{-2} was observed in 'BARI Gom 26' while the lowest number of productive tillers m^{-2} was observed in 'BARI Gom 24' in both years (Table 3).

3.4 Plant height at harvest

Plant height at harvest did not differ significantly for different seeding rates, but varietal differences were significant in both years. 'BARI Gom 25' was the tallest variety while 'BARI Gom 28' was the shortest in both years (Table 4).

3.5 Spike length

Similar to growth parameters, spike length was also significantly ($p \leq 0.01$) influenced by seeding rate and variety, while their interaction did not influence this parameter significantly (Table 4). A seeding rate greater than 120 kg ha^{-1} significantly ($p \leq 0.01$) reduced spike length, but a seeding rate of 100 kg ha^{-1} significantly ($p \leq 0.01$) increased spike length in both years. Longest spikes formed with 100 kg ha^{-1} and shortest spikes with 140 kg ha^{-1} in both years. Across varieties, 'BARI Gom 24' had the longest spikes while 'BARI Gom 28' had shortest spikes in both years (Table 4).

3.6 Number of spikelets $spike^{-1}$

Number of spikelets $spike^{-1}$ varied significantly ($p \leq 0.01$) in response to both seeding rate and variety, but their interaction effect was not significant (Table 4). Significantly, the highest number of spikelets $spike^{-1}$ was found with a seeding rate of 120 kg ha^{-1} while the lowest number of spikelets $spike^{-1}$ was found with 140 kg seed ha^{-1}. Considering varieties, 'BARI Gom 24' produced significantly ($p \leq 0.01$) highest number spikelets $spike^{-1}$ and 'BARI Gom 28' produced the fewest in both years (Table 4).

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

A seeding rate higher than 100 kg ha^{-1} significantly increased the number of grains $spike^{-1}$ ($p \leq 0.01$), especially at 120 and 140 kg ha^{-1}. Significant ($p \leq 0.01$) varietal differences were also noticed for this parameter. Highest number of grains $spike^{-1}$ was recorded in 'BARI Gom 26' but fewest in 'BARI Gom 28' in both years (Table 4).

3.8 1000-grain weight

Similar to other yield attributes, TGW in both years varied significantly ($p \leq 0.01$) in response to seeding rate and variety, but their interaction did not differ significantly (Table 4). TGW significantly ($p \leq 0.01$) decreased as seeding rate increased. Largest seeds formed when 100 kg seed ha^{-1} was used and smallest seeds formed with 140 kg seed ha^{-1} in both years. In terms of varietal differences, 'BARI Gom 24' resulted in significantly ($p \leq 0.01$) largest grains while 'BARI Gom 27' resulted in significantly ($p \leq 0.01$) smallest grains (Table 4).

Table 3. Seedling emergence, tillers m^{-2} of wheat as influenced by seeding rate and variety in two consecutive years (2013-14 and 2014-15).

Treatments	Plants m^{-2} (at 12 DAS)		Tillers m^{-2} (at DAS) 30 DAS		40 DAS		50 DAS		Productive tillers/spikes m^{-2}	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Seeding rate (kg ha^{-1})										
100	191 c	190 c	366 b	369 b	405 b	419 b	400 b	380 b	293 b	272 c
120	232 b	234 b	400 ab	400 ab	433 ab	436 ab	426 ab	393 ab	300 ab	286 b
140	265 a	262 a	419 a	410 a	443 a	440 a	435 ab	403 ab	310 a	300 a
F-test	**	**	**	**	**	**	**	**	**	**
Varieties										
BARI Gom 24	200 c	206 c	316 c	338 c	322 c	350 c	312 c	335 c	238 c	227c
BARI Gom 25	195 c	221 bc	323 c	404 b	328 c	420 b	320 c	373 b	260 b	256 b
BARI Gom 26	251ab	238 ab	416 b	367 bc	460 b	424 b	437 b	376 b	340 a	328 a
BARI Gom 27	284 a	260 a	564 a	506 a	602 a	551 a	580 a	488 a	315 a	305 a
BARI Gom 28	235 b	219 bc	360 c	349 c	437 b	415 b	440 b	387 b	319 a	310 a
F-test	**	**	**	**	**	**	**	**	**	**
CV (%)	10.65	9.42	10.63	11.00	7.82	9.46	6.42	7.41	3.30	6.01

Figures in the parentheses indicate the thousand grain weigh (g) of the variety. Figures within a column, for a factor, followed by the same letter(s) are not significantly different at 5% level by DMRT. **, * and ns; significant at 1 and 5% level, and not significant, respectively.

Table 4. Yield and yield-contributing characters of wheat as influenced by seeding rate and variety in two consecutive years.

Treatments	Plant height at harvest (cm)		Spike length (cm)		Number of spikelets $spike^{-1}$		Number of grains $spike^{-1}$		1000-grain weight (g)		Grain yield (kg ha^{-1})		Biomass yield at harvest (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Seeding rate (kg ha^{-1})														
100	99.0	95.4	11.7 a	11.5 a	17.0 ab	17.9 ab	50.0 b	49.7 b	51.0 a	53.2 a	5085 b	4279 b	11816 b	10113 b
120	97.0	96.2	12.0 a	11.3 a	18.8 a	18.1 a	51.0 ab	50.8 a	49.0 b	52.4 b	5232 ab	4461 a	12268 a	12396 a
140	99.0	96.8	11.4 b	10.2 b	17.3 b	17.2 b	52.4 a	51.1 a	49.0 b	52.5 b	5389 a	4589 a	12406 a	12652 a
F-test	NS	NS	**	**	**	**	*	*	*	*	**	**	**	*
Varieties														
BARI Gom 24	100.1 b	97.6 ab	14.0 a	12.4 a	19.0 a	19.0 a	50.3 b	50.1 b	54.5 a	58.9 a	4971 c	4403 b	11861 bc	10070 ab
BARI Gom 25	101.6 a	100.0 a	13.0 b	11.8 ab	18.0 ab	18.3 ab	48.4 b	45.5 c	55.0 a	57.1 b	4802 c	4118 c	11729 c	9566 b
BARI Gom 26	97.2 c	94.3 c	11.0 c	10.0 c	17.2 b	17.6 b	57.0 a	55.6 a	50.0 b	50.1 c	5657 a	4666 a	12086 bc	10536 ab
BARI Gom 27	100.0 b	96.8 b	10.8 c	11.7 b	17.0 b	17.3 b	56.0 a	54.4 a	43.0 d	46.9 d	5360 b	4558 ab	12266 b	10810 ab
BARI Gom 28	95.0 d	91.9 c	10.7 c	9.5 c	15.5 c	15.7 c	50.2 b	46.5 c	43.8 c	50.3 c	5386 b	4486 ab	12824 a	10954 a
F-test	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	1.0	2.0	4.0	4.4	3.0	4.6	3.5	4.5	1.80	1.45	3.10	3.52	2.81	8.69

Figures in the parentheses indicate the thousand grain weigh (g) of the variety. Figures within a column, for a factor, followed by the same letter(s) are not significantly different at 5% level by DMRT. **, * and ns; significant at 1 and 5% level, and not significant, respectively.

3.9 Grain yield

In both years, GY was also significantly ($p\leq0.01$) influenced by seeding rate and variety, but not by their interaction (Table 4). Significantly ($p\leq0.01$) higher GY was recorded with 140 and 120 kg seed ha^{-1} in comparison with 120 kg seed ha^{-1} (recommended rate). Across varieties, 'BARI Gom 26' resulted in significantly ($p\leq0.01$) highest GY while 'BARI Gom 25' resulted in lowest GY in both years (Table 4).

3.10 Biomass yield at harvest

Similar to GY, BY at harvest was also significantly ($p\leq0.01$) influenced by seeding rate and variety, but not by their interaction (Table 4). In both years, the highest BY was found at 140 kg seed ha^{-1}, which was, however, statistically similar to 120 kg seed ha^{-1}. When varieties were considered, significantly higher but similar BY was recorded for all varieties except BARI Gom 25, which had lowest BY in both years (Table 4).

3.11 Yield (%) increase/decrease under different seeding rates

Although the interaction effect of variety and seeding rate was not significant in both years, relative to the recommended rate (120 kg seed ha^{-1}), the yield advantages of 'BARI Gom 24', 'BARI Gom 25', 'BARI Gom 26', 'BARI Gom 27' and 'BARI Gom 28' were 467 and 233, 63 and 75, 81 and 93, 23 and 66 and 152 and 220 kg ha^{-1} respectively, when seeding rate was 140 kg ha^{-1} (Table 5). The GY of 'BARI Gom 24' increased by 9.6 and 5.3% in 2013-14 and 2014-15 when seeded at 140 kg ha^{-1} followed by 'BARI Gom 28' (2.8 and 5%) at a seeding rate of 140 kg ha^{-1} (Table 5). On the other hand, seeding rate less than the recommended rate, all varieties failed to produce comparable GY in both years.

4. Discussion

Fluctuations in temperature (maximum and minimum), rainfall and relative humidity are the most important climatic factors that affect the GY of wheat (Hossain *et al.*, 2013; Uddin *et al.*, 2016). The optimum temperature required for wheat is 20-25 °C and the maximum temperature is 35 °C (Tewolde *et al.*, 2006; Hossain & Teixeira da Silva, 2012). Relative to those findings, the weather conditions in our experimental period were suitable for good wheat GY (Figure 1). Plant density, i.e., number of plants m^{-2}, is an important factor that influences the growth and yield of wheat (Sarker, Malaker, Saifuzzaman, & Pandit, 2007; Valério *et al.*, 2013). Plant density also influences other yield attributes such number of spikes or/productive tillers per unit area, number of grains spike^{-1} and individual grain weight (Ozturk *et al.*, 2006), depending on the genotype, environment and their interaction (Valério *et al.*, 2013).

In the present study, across varieties, 'BARI Gom 27' produced the most plants m^{-2} and 'BARI Gom 24' the fewest in both years, possibly because 'BARI Gom 27' has smaller seeds (lower TGW), resulting in a higher number of seeds per unit area, and ultimately increasing the number of plants per unit area. In contrast, 'BARI Gom 24' with larger seeds (higher TGW) resulted in fewest seeds per unit area, ultimately decreasing the number of plants per unit area (Table 3). This assumption is also supported by earlier studies from Bangladesh that assessed different wheat varieties (Sarker, Malaker, Saifuzzaman, & Pandit, 2007; Sarker, Malaker, Bodruzzaman, & Barma, 2009), indicating that the plant density of a wheat variety depends on seed size (i.e., TGW of the variety), i.e., the number of plants per unit area. As was also observed in our study, Sarker, Malaker, Saifuzzaman, and Pandit (2007) and Sarker, Malaker, Bodruzzaman, and Barma (2009) also observed highest plants m^{-2} when seeding rate was 140 kg ha^{-1} and lowest plant density at a lower seeding rate (80 kg ha^{-1}).

In both years, higher GY in 'BARI Gom 26', 'BARI Gom 27'and 'BARI Gom 28' were attributed to a higher number of productive tillers m^{-2} and higher number of grains spike^{-1}, which ultimately resulted in higher GY (Table 4). The number of productive tillers m^{-2} was highest due to the highest plant density among these varieties and the lowest plant density in 'BARI Gom 24', attributed to a lower number of productive tillers m^{-2}, indicating that this variety has a weak capacity to produce more tillers (Table 3). Although TGW of 'BARI Gom 24' and 'BARI Gom 25' was highest (i.e., seeds were largest), their GY was lower than the other three varieties because of a lower number of productive tillers

Table 5. Increase/decrease in yield (%) at 100 and 140 kg seed ha^{-1} compared to present recommended seeding rate (120 kg ha^{-1}).

Treatments		Seed yield (kg ha^{-1}) 2013-14	% increase/decrease in yield (kg ha^{-1}) 2013-14	Seed yield (kg ha^{-1}) 2014-15	% increase/decrease in yield (kg ha^{-1}) 2014-15
Seeding rate (kg ha^{-1})					
100		5085	-147 (2.8%)	4279	-182 (4.1%)
120		5232	-	4461	-
140		5389	157 (3.0%)	4598	137 (3.07%)
F-test		**		**	
Variety x Seeding rate interaction					
BARI Gom 24	100	4702	-170 (3.5%)	4180	-220 (5.0%)
	120	4872	-	4398	-
	140	5339	467 (9.6%)	4630	233 (5.3%)
BARI Gom 25	100	4688	-140 (2.9%)	4022	-110 (5.3%)
	120	4828	-	4128	-
	140	4891	63 (1.3%)	4203	75 (1.8%)
BARI Gom 26	100	5579	-80 (1.4%)	4450	-280 (4.7%)
	120	5656	-	4728	-
	140	5737	81 (1.4)	4820	93 (2.0%)
BARI Gom 27	100	5184	-260 (4.8%)	4427	-360 (4.8%)
	120	5436	-	4590	-
	140	5459	23 (0.2%)	4656	66 (1.4%)
BARI Gom 28	100	5270	-100 (1.9%)	4318	-140 (4.9%)
	120	5368	-	4460	-
	140	5520	152 (2.8%)	4680	220 (5.0%)
F-Test		NS		NS	
CV (%)		3.10		3.52	

m^{-2} and a lower number of grains spike^{-1}. Similarly, an earlier study (Haq *et al.*, 2010) reported that plant height and spike length have direct negative effects on GY, while number of productive tillers plant^{-1} (Khan *et al.*, 2010) and number of grains spike^{-1} (Ashfaq *et al.*, 2003) have a direct positive influence on GY (Table 4, 5). Likewise, TGW directly negatively affected GY (Table 4), but showed positive indirect effects on the number of grains spike^{-1} (Shoran *et al.*, 2000).

5. Conclusions and Recommendation

The results of the present study reveal that there were no significant differences in GY at 120 and 140 kg seed ha^{-1}. However, GY was significantly lower at 100 kg seed ha^{-1}. Across the five varieties, 'BARI Gom 26' had significantly highest GY while 'BARI Gom 25' had the significantly lowest GY in both years. Although the interaction effect of varieties and seeding rate on GY was not significant in both years, the yield advantage of 'BARI Gom 24' was highest (467 and 233 kg ha^{-1} surplus yield), followed by 'BARI Gom 28' (152 and 220 kg ha^{-1} surplus yield), but it was lowest for 'BARI Gom 27' (i.e., 23 and 66 kg ha^{-1}) respectively in 2013-14 and 2014-15, when seeded at 140 kg ha^{-1}. The GY of 'BARI Gom 24' increased by 5.3 to 9.6% and that of 'BARI Gom 28' increased by 2.8 to 5%, at a seeding rate of 140 kg ha^{-1} in the two years. Therefore, a seeding rate of 140 kg ha^{-1} is recommended for 'BARI Gom 24' and 'BARI Gom 28' while the current recommended rate of 120 kg ha^{-1} can be continued to be used for the remaining three varieties to obtain higher yield and productivity of wheat for the Old Himalayan Piedmont Plain of Bangladesh.

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