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Title: Variations in Phenological Traits in Wheat and Their Association with Grain Yield under Late Sowing Conditions

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ABSTRACT

Morphological and physiological attributes play crucial roles in wheat yield. Estimation of grain yield of wheat represents a vital necessity for actual crop management. Within this investigation we evaluated the associations between yield, biomass production, plant height and the tillers number in various growth phases. For this initiative, we assessed eleven wheat genotypes in Randomized Complete Block Design (RCBD) with three replications in late sowing conditions. The research was directed at the Prof. Dr. Purnendu Gain Field Laboratory, Agrotechnology Discipline, Khulna University. Data were assembled on diverse growth and yield parameters. Analysis of variance (ANOVA) was performed on different morphological characters and yield. Based on ANOVA it was found that plant height, tillers production, dry matter accumulation, and yield differed among the wheat varieties. The wheat grain yield significantly correlated both with plant height and above-ground biomass. Regression analysis revealed that the involvement of tiller m^{-2} to the change of grain yield was 66.5%; but the influence of dry matter m^{-2} to grain yield was 87.5%. These results underscored the significance of stressing the characters like plant height, tillers m^{-2} and dry matter m^{-2} in wheat development plans to improve grain yield, which had real link with wheat production as these have displayed positive and noteworthy correlations with wheat yield under late sowing environment.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the key cereal food crops cultivated in diverse environments and delivers food to the bulk of people globally. It supplies about 19% of daily calories and 21% of protein necessities of world population (Tadesse et al., 2019). In Bangladesh wheat is the second most important grain crop after rice (Hossain et al., 2021), and occupying a weighty position in attaining food security.

About 1.056 million ha coastal lands of Bangladesh have been suffered by various degrees of saline disorders (SRDI, 2010). In southern coastal part of the country farmers are seldom encouraged to wheat cultivation because of poor yield of wheat owing to brief winter, elevated temperature, late sowing time and salinity (SRDI, 2010; Alam et al., 2014; Alam et al., 2022; Hossain et al., 2021; Hossain et al., 2023). The proper sowing time for wheat in Bangladesh happens between mid-November to end of November (WRC and FAO, 2004). However, a considerable land area in Bangladesh where wheat is grown after *Aman* rice harvest or where land remains moist due to heavy precipitation, sowing is completed up to January and wheat crop faces comparatively heated condition resulting in poorer harvest (Hossain et al., 2012).

Yield is a composite trait consisted of several factors like plant height, number of effective tillers, spike length, number of spikelet per spike, grain filling duration, number of grains per spike, test weight, plant biomass, harvest index, etc. Some of these have a direct effect on yield, while others have a subsidiary influence. It has been described that any decrease in the yield attributes tips to a discount in the ultimate yield (Farooq et al., 2014; Zhang et al., 2018). Due to the multifarious association between grain yield and other factors, straight selection of crop yield in breeding schemes is ambiguous (Ali et al., 2008). Hence, exploration of the connection between yield and its constituents is obligatory. Correlation analysis measures the common link between various plant characters and detects the factors on which selection for yield enhancement depends. Previous studies showed that the positive relationship between grain yield and yield attributes in wheat like harvest index (Ghaderi et al., 2009), biomass (Ghaderi et al., 2009; Kandic et al., 2009), spikes m^{-2} (Leilah and Al-Khateeb, 2005), plant height (Leilah and Al-Khateeb, 2005), grains number (Khan et al., 2010) and test weight (Leilah and Al-Khateeb, 2005). The path and degree of the relation between yield and yield contributing characters need to be considered while selecting superior genotypes from a varied sort of population.

The degree of relationship between two variables is called correlation. Regression analysis detects the change of the dependent variable due to the change of the independent variable. This bivariate study offers knowledge on the parallel features of plants with the extreme deviations in seed yield. Till date, various researchers have applied different regression models to guess the evaluation selection standards. Their findings were diverse based on the ecological settings and the population in which the selection was done (Joshi, 2015).

For yield enhancement, study of yield contributing characters in relation to their genetic mechanism is highly important. Information concerning correlations between plant characters and their influences on grain yield evidenced to be a valuable tool for increasing the wheat yield per unit area (Khan et al., 2010). However, there is few literature available that displays the link between grain yield and its various attributes of the Bangladeshi wheat varieties under different late sowing conditions. This research was, therefore, led to examine the relationship between yield and various traits of diverse wheat cultivars under different late sowing conditions.

MATERIALS AND METHODS

Experimental Site

The research was done at the Prof. Dr. Purnendu Gain Field Laboratory of Agrotechnology Discipline, Khulna University, Khulna from December, 2017 to March, 2018. The study area is situated between 22°48′ N and 22°80’ N latitudes and between 89°31' and 89°53' E longitudes, with an elevation of 8.0 m from the mean sea level. The experimental site belongs to the Agro-ecological Zone of the Ganges Tidal Floodplain (AEZ 13). Soil was well drained, dominated by clay particles with electrical conductivity value of 6.5 dS m^{-1} (SRDI, 2017).

Climatic Conditions

The weather condition during the experimental period is shown in Fig. 1. The highest rainfall occurred in December, 2017 (51.00 mm) followed by March, 2018 (1.00 mm). The other two months were with no rainfall. The maximum temperature was the peak in March, 2018 (33.7°C) trailed by February, 2018 (30.0°C), and the tiniest was in January, 2018 (24.0°C). The fashion of minimum and average monthly temperature maintains the similar

array as found for maximum temperature during the study period (Fig. 1).

Experimental Material

Eleven wheat varieties were taken as plant materials. The seeds of different varieties were collected from the Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. The varieties were BARI Gom-20 (Gourab), BARI Gom-21 (Shatabdi), BARI Gom-22 (Sufi), BARI Gom-23 (Bijoy), BARI Gom-24 (Prodip), BARI Gom-25, BARI Gom-26, BARI Gom-27, BARI Gom-29, BARI Gom-30, and Sourov.

Experimental Design

The field experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. So, there were a total of 33 plots. The size of individual plot was (2 x 2) m^2 maintaining the plot to plot distance of 50 cm and replication to replication distance of 1 m.

Crop Management

The experimental field was prepared by the help of power tiller. All weeds and previous crop residues were removed from the experimental area. Recommended doses of fertilizers @ 80 kg N, 20 kg P, 40 kg K, 15 kg S and 5 kg Zn ha^{-1} were added in the form of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, and $ZnS0_4$ during final preparation. Treatments were randomly assigned to the plots. Seeds of the various wheat varieties were sown on December 06, 2017. Vitavax 200 @ 3 g kg^{-1} seed was used for treating the seeds 24 hours before sowing. Irrigated the experiment field three times, *viz*. at crown root initiation (25 DAS), booting (70 DAS) and grain filling (90 DAS) stages. All intercultural operations (weeding, irrigation, pesticide application) were completed properly and were kept similar in all the plots. The crop was harvested at maturity when 90% of the grains changed to golden yellow in color. The crop was harvested at 110 days after sowing (DAS).

Data Collection

Growth parameters

Crop growth parameters were attributed in plant height, tillers $plant^{-1}$ and dry matter $plant^{-1}$. Information relating these three traits was gathered over time started at 50 DAS and continued up to 100 DAS.

Plant height (cm)

For measuring plant height, 10 plants were randomly sampled from each plot. The plant height was measured from the ground level to the tip of the flag leaf at 10 days interval from 50 to 100 DAS. The recorded values were then averaged to note the plant height of each variety, and were expressed in cm.

Tillers $plant^{-1}$

Number of tillers was counted from 10 sampled plants from each plot. Then the average value was taken for tillers $plant^{-1}$. Finally, tiller number was converted to per square meter basis.

Dry matter (g $plant^{-1}$)

For recording dry matter, 5 sample plants were uprooted from each plot by destructive sampling method at 10 days interval from 50 to 100 DAS. The samples were dried in an oven at 70°C for 48 hours and the dry weights were taken using an electronic balance. The dry matter was expressed as g $plant^{-1}$ taking the average weight of the total. Later the dry matter was converted to unit area basis i.e. g m^{-2}.

Grain yield

Samples were taken from 1 m^2 area from the middle of each experimental unit by harvesting the crop near the soil level at maturity. The harvests were sun dried, beaten, cleansed and weights grain were noted. The grain yield were expressed in t ha^{-1}. Grain yield was adjusted to 14% moisture level.

Statistical Analyses

The collected data was analyzed by Statistical Tool for Agricultural Research (STAR) following analysis of variance (ANOVA) technique (R Core team, 2018). Variety means were separated by Duncan's New Multiple Range Test (DMRT) (Gomez and Gomez, 1984) at 5% level of significance. Functional relationships between wheat grain yield and yield parameters were established through correlation and regression analysis.

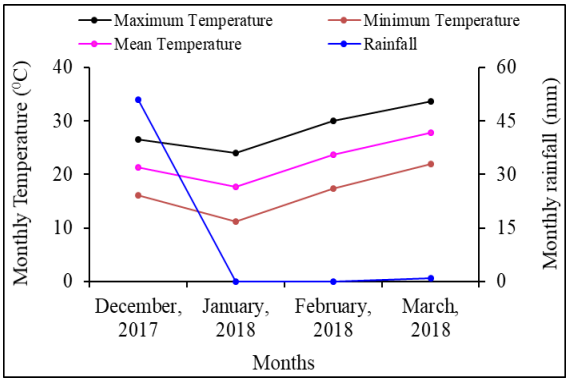

Fig. 1. Monthly temperatures (maximum, mean and minimum) and rainfall of Khulna during the study period.

RESULTS AND DISCUSSION

Plant height (cm)

In our study significant variation in height ($p \leq 0.01$) was detected amongst the eleven wheat varieties tried. Height of plants increased steadily over time reaching the peak at 100 DAS (Table 1). BARI Gom-21 (Shatabdi) yielded the longest plants in all the sampling dates except at 100 DAS when BARI Gom-24 (Prodip) produced the tallest plants but plant heights of both the varieties were statistically alike to BARI Gom-20 (Gourab) and BARI Gom-26. On the contrary, BARI Gom-30 provided the shortest plants (Table 1) irrespective of different sampling period. The results of our study are well supported by the findings of Hossain et al., (2021).

They also found the tallest plants in BARI Gom-21 and relatively dwarf stature in BARI Gom-30. Variation obtained in plant height in the present investigation might be controlled by the genetic makeup of these varieties. The reduction in plant height in all the varieties compared to the optimum might be due to shortening of growth and photosynthetic period enforced by heat stress in a late sown environment (Mishra et al., 2000; Ubaidullah et al., 2006).

Table 1. Plant height of wheat varieties at different days after sowing (DAS)

Variety	Plant height (cm) at different DAS					
	50	60	70	80	90	100
BARI Gom-20 (Gourab)	29.23 abc	44.97 abc	55.57 bcd	66.97 c	80.93 a	87.93 ab
BARI Gom-21 (Shatabdi)	32.23 a	48.73 a	60.97 a	72.53 a	81.37 a	92.20 a
BARI Gom-22 (Sufi)	27.23 abc	41.77 bcd	56.80 b	69.73 abc	76.87 cdef	85.13 bc
BARI Gom-23 (Bijoy)	27.20 abc	42.37 bcd	55.70 bcd	67.07 bc	76.13 def	86.30 bc
BARI Gom-24 (Prodip)	30.40 ab	48.13 a	59.13 ab	72.37 a	81.00 abc	92.63 a
BARI Gom-25	30.10 ab	45.53 ab	57.17 b	71.03 ab	77.50 bcde	83.90 bcd
BARI Gom-26	28.77 abc	44.07 abc	55.87 bcd	70.43 abc	79.37 abcd	88.10 ab
BARI Gom-27	28.67 abc	42.10 bcd	55.77 bcd	66.60 c	75.80 def	82.90 cd
BARI Gom-29	26.57 bc	40.40 cd	53.07 cd	68.03 bc	73.67 ef	80.03 d
BARI Gom-30	24.47 c	38.83 d	52.37 d	65.60 abc	72.57 f	79.57 d
Sourov	27.13 abc	41.73 bcd	56.57 bc	69.37 abc	76.90 cde	83.57 bcd
p-level	0.01	0.01	0.01	0.01	0.01	0.01
CV (%)	6.16	3.98	2.22	2.97	2.89	2.95

In the same column, means with same letter are statistically similar but means with different letter are statistically dissimilar at 5% probability level.

Dry matter (g plant^{-1})

The influence of cultivar on above ground biomass production was found substantial ($p < 0.01$) in eleven wheat varieties examined (Table 2). The acquisition of dry matter plant^{-1} amplified parallel to time reaching the maximum at 100 DAS. BARI Gom-24 (Prodip) gained the highest dry matter from 50 to 90 DAS which is statistically identical to dry

matter gathered by BARI Gom-21 (Shatabdi). However, at 100 DAS BARI Gom-21 (Shatabdi) possessed the greatest dry matter which was also statistically similar to BARI Gom-24 (Prodip). Like plant height, BARI Gom-27 displayed the lowermost dry biomass plant^{-1} in the entire growth duration (Table 2). This dissimilarity in dry weight might be due to the hereditary deviation, microclimate and soil factors that may arise in natural contexts. The postulation of the current inquiry agrees to the conclusions of Malik et al., (2013) and Hossain et al., (2021). The reduction in dry weight of wheat under high temperature stress in late sown conditions was attributed due to the inferior grain and straw yield (Hasan et al., 2007).

Correlation Analysis

It is apparent from Table 3 that highly significant relationships ($p < 0.001$) were estimated between the grain yield and plant height (Panday et al., 2020). In the plant height, lower values of correlation were found in the first three sampling dates, conversely, the dry matter showed upper values of correlation coefficients with grain yield in the later stage of growth.

Grain yield showed a positive and significant ($p < 0.001$) correlation with plant height under water stress from tillering to crop maturity, which suggests that under stressed condition the yield depends on the achievement of better vegetative development and larger stem reserve mobilization (Khan et al., 2010). This result is in agreement with the report of Aydin et al. (2010) that indicated plant height had the greatest direct effect on grain yield and suggested that plant height and test weight are primary selection criteria for improving grain yield in wheat. Gulmezoglu et al. (2010) revealed that grain yield of wheat depended on plant height, length of spike and spike weight. Similar relationship was also reported in rice by Zhao et al., (2020) in China. Positive and momentous associations were estimated between aboveground dry matter and grain yield also (Table 3). This sort of significant relationship between grain yield and dry matter is anticipated under late sowing conditions since assimilates contribute to the grain formation via dry matter re-allocation (Shakhatreh et al., 2001). Rind et al., (2023) reported significant correlation between grain yield and dry matter in various bread wheat genotypes in Pakistan. As considerably greater correlation coefficients for the relationships to grain yield were achieved with dry matter, it is likely to conclude that the yield estimation by the above-ground dry weight offers high consistency. The findings of the present study are well supported by the findings of earlier researches (Pouri et al., 2019; Habibpour et al., 2012; Zarei et al., 2013). They also described noteworthy correlation between grain yield and plant height, tillers number and plant biomass in wheat.

Table 2. Dry matter of eleven wheat genotypes from Bangladesh over time

Variety	Dry matter plant^{-1} (g) at different DAS					
	50	60	70	80	90	100
BARI Gom-20 (Gourab)	7.55 bcd	10.94 b	13.77 b	17.57 b	20.14 bcd	24.22 abc
BARI Gom-21 (Shatabdi)	9.06 ab	13.78 a	16.86 a	19.93 a	23.00 ab	26.41 a
BARI Gom-22 (Sufi)	6.52 cdef	10.25 bc	13.11 bc	16.47 bc	20.47 bc	24.13 abcd
BARI Gom-23 (Bijoy)	7.21 bcde	10.76 bc	13.37 b	16.23 bc	19.53 cde	23.40 bcd
BARI Gom-24 (Prodip)	10.55 a	14.01 a	17.28 a	21.32 a	23.54 a	26.28 a
BARI Gom-25	4.84 ef	8.24 cd	11.64 bcd	15.38 cd	17.40 def	22.13 cd
BARI Gom-26	8.47 abc	10.42 bc	13.65 b	16.77 bc	21.33 abc	25.05 ab
BARI Gom-27	5.36 def	8.46 bcd	11.65 bcd	14.92 cd	16.71 ef	22.79 bcd
BARI Gom-29	4.52 f	7.63 d	10.89 cd	13.35 de	15.58 f	21.79 cd
BARI Gom-30	4.29 f	6.45 d	9.73 d	12.60 e	15.51 f	21.40 d

Variety	Dry matter plant^{-1} (g) at different DAS					
	50	60	70	80	90	100
Sourov	5.49 def	8.92 bcd	13.02 bc	16.14 bc	18.90 cde	23.35 bcd
p-level	0.01	0.01	0.01	0.01	0.01	0.01
CV (%))	12.34	8.77	6.36	4.51	5.20	4.02

In the same column, means with same letter are statistically similar but means with different letter are statistically dissimilar at 5% probability level.

Table 3. Correlations between plant height (cm) and dry matter (g plant^{-1}) and grain yield in wheat

		Days after sowing (DAS)					
		50	60	70	80	90	100
Grain yield	Plant height	0.783***	0.883***	0.848***	0.732***	0.933***	0.967***
	Dry matter	0.935***	0.945***	0.975***	0.982***	0.949***	0.955***

Regression Analysis

Grain yield among tested wheat varieties varied widely ($p \leq 0.01$) (Fig. 2 and Fig. 3). The array of grain yield was 1.44-3.01 t ha^{-1} (Jahan et al., 2025). Comprehensive regression analysis of relationships between the numbers of tillers and grain yield of wheat disclosed that the association has an asymptotic character (Fig. 2). For this we used a non-linear regression (sigmoidal function $y = a/ (1 + \exp (-(x - x_0)/b)$; where a, b and x_0 - parameters of function; y - yield; x - number of tillers) for establishing of the linkage. This clues to better significance of the association compared to linear regression (Křen et al., 2014). On the contrary, dry matter exhibited a linear relationship ($y = a + bx$; where a and b - parameters of function; y - yield; x - dry matter) with grain yield as shown in Fig. 3. The regression equation obtained for tiller m^{-2} was, $y = -1E\text{-}05x^2 + 0.016x - 1.8443$. In case of dry matter m^{-2}, the regression equivalence estimated was, $y = 0.0022x - 0.6527$. However, in both the cases we found positive relationships. Our results are in line with the findings of several other researchers (Bogale and Tesfaye, 2016; Borkhatariya et al., 2025, Maurya et al., 2023; Shar et al., 2024). The values of coefficient of determination put forward that more than 65% ($R^2 = 0.665$) of the variation in grain yield is attributed due to difference in tiller m^{-2}, while more than 85% ($R^2 = 0.875$) is explained by dry matter m^{-2}.

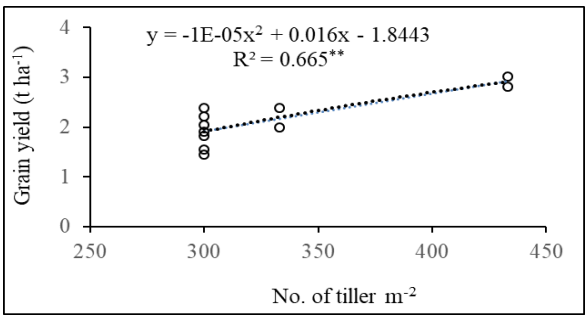

Fig. 2. Functional relationship between tiller m^{-2} and grain yield in wheat varieties.

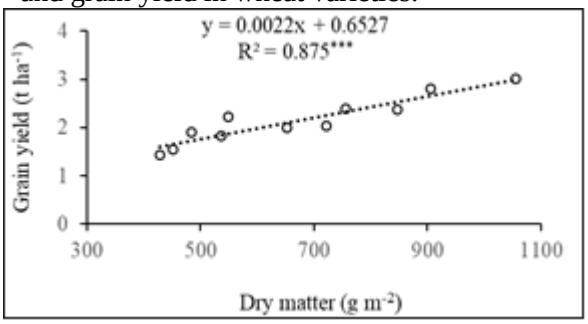

Fig. 3. Functional relationship between dry matter m^{-2} and grain yield in wheat varieties.

CONCLUSION

The present research well assessed the correlation and regression analysis in wheat. Scrutinizing the relations between the various traits that mark up the yield is part of exploring the assemblage of yield. Thus, the overall results obtained conclude that number of tillers per plant, good plant height and biomass yield are the central traits to be highlighted during selection in the breeding plans for enhancing grain yield in wheat. The correlation study revealed that positive and significant relationship of grain yield with different attributes showed that increase in grain yield

per plant related to increase plant height and biological yield. Regression analysis recommended that no. of tillers m^{-2} and dry matter m^{-2} may be used for further advance in grain yield in wheat varieties.

Acknowledgement

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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