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Research Article

Evaluation of Yield and Nitrogen Use Efficiency in Wheat as Influenced by Nitrogen Level and Variety

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ABSTRACT

The efficient management of nitrogen (N) is essential for improving wheat yield and nitrogen use efficiency (NUE), which may differ due to variation in growth duration and nitrogen dynamics in the soil. Therefore, a field experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, from November 2024 to March 2025 to evaluate the influence of wheat variety by different nitrogen levels on the yield and nitrogen use efficiency. Three wheat varieties, *viz.* BWMRI Gom-1, BWMRI Gom-2, BWMRI Gom-5 and four levels of nitrogen *viz.* i) 0 kg N ha^{-1}, ii) 45 kg N ha^{-1}, iii) 90 kg N ha^{-1}, iv) 135 kg N ha^{-1} were considered as treatments. Nitrogen was applied as per the treatments of the study. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Results revealed that the variety BWMRI Gom-2 produced the highest plant height (88.06 cm), grain yield (2.64 t ha^{-1}), straw yield (3.80 t ha^{-1}), biological yield (6.43 t ha^{-1}), harvest index (40.68%) and nitrogen use efficiency (43.45%). In case of nitrogen level, the highest plant height (90.32 cm), grain yield (3.30 t ha^{-1}), straw yield (4.61 t ha^{-1}), biological yield (7.90 t ha^{-1}), harvest index (41.79%) and nitrogen use efficiency (62.54%) were recorded from the treatment 90 kg N ha^{-1}. The yield-contributing characters and yield of wheat increased with increasing nitrogen levels up to 90 kg N ha^{-1}. Variety and nitrogen levels significantly influenced wheat yield. The results of the present study showed that the highest grain yield (3.44 t ha^{-1}) and nitrogen use efficiency (66.13%) were obtained from the variety BWMRI Gom-2 with an application of 90 kg N ha^{-1}. Grain yield and nitrogen use efficiency were the highest from the interaction between the variety BWMRI Gom-2 and 90 kg N ha^{-1}. Thus, the wheat variety BWMRI Gom-2 can be successfully cultivated with mentioned dose for higher yield and nitrogen use efficiency.

Introduction

Wheat (*Triticum aestivum* L.) is a cereal crop belonging to the genus *Triticum* and the family *Gramineae*. It is considered the first most important cereal crop throughout the world in terms of both area and production. It is the second most important cereal crop in Bangladesh, providing a significant portion of the population's daily caloric intake after rice. Wheat has some special advantages over rice in terms of food value and low cost of production. It contains carbohydrate (78.1%), protein (14.7%), minerals (2.1%), fat (2.1%) and a considerable proportion of vitamins (Mondal *et al.,* 2015). In the 2023-2024 fiscal year, wheat was cultivated on 0.312 million hectares (M ha) of land in Bangladesh, which produced at 1.17 million metric tons of wheat (BBS, 2024). It is cultivated in the winter season. This is because the optimal temperature for wheat growth is 10-20°C, when it is free from climatic hazards and diseases. In Bangladesh, the land is much more suitable for wheat production. It occupies some 4% of the total cropped area and 11% of the *Rabi* season cropped area, contributing 7% to the total output of food cereals. This indicates that wheat cultivation can help to a considerable extent in solving the food problem and saving a significant amount of foreign currency for the country. However, wheat yield in Bangladesh is not still satisfactory (Sarker *et al.,* 2023). The low wheat yield is due to various factors such as traditional practices, poor field management, late planting, unavailability of quality seed, use of local varieties, climatic hazards, intensive cropping, non-replenishment of soil nutrients, inadequate fertilizer use, irregular irrigation and poor fertilizer management (Alam *et al.,* 2024). On the other hand, the introduction of high-yielding varieties has a significant role in the

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yield response of wheat due to its differential genotypic characters, input requirement and life cycle. As a result, farmers of Bangladesh use diverse improved varieties with several yield-contributing characters differing from one variety to another. The growth process of wheat plants under a given agro-climatic condition also differs with variety (Rafii *et al.,* 2017).

Nitrogen (N) is the main component and a major constituent of plants, especially in living tissues formation. Every single indispensable process in the plant is related to protein, of which nitrogen is a fundamental constituent. Nitrogen is an integral part of proteins, phytochromes, compounds, coenzymes, chlorophyll and nucleic acids. All the biochemical processes occurring in plants are mainly governed by nitrogen and its associated compounds, which make it essential for the growth and development of wheat. Therefore, it is necessary to apply nitrogenous fertilizer in the soil to get bumper yields of wheat. The varieties which have high genetic yield potential require a high amount of nitrogen to produce their maximum production (Balamurugan *et al.,* 2021). To get the maximum yield of wheat, the application of nitrogen in adequate amount is considered a key to success. Application of nitrogen in splits does not have a considerable effect on economic yield; nevertheless, it reduces the crop lodging and increases 1000-grain weight. Increasing the amount of nitrogen application results in a greater number of spikes, increased grain yield and higher 1000-grain weight. However, inefficient nitrogen application can lead to environmental degradation and increased production costs (Ullah *et al.,* 2018). In Bangladesh, farmers often apply nitrogen fertilizers indiscriminately, leading to poor nitrogen use efficiency (NUE), environmental pollution and economic losses. Due to the fact that nitrogen is the most limiting nutrient for wheat production and the possible environmental problems related to its use, nitrogen use efficiency of crops plays a fundamental role in sustainable grain production (Asplund*.,* 2014). Nitrogen use efficiency is given by the ratio between grain yield (GY) and the amount of nutrient provided by the fertilizer. The variability among modern wheat varieties NUE has been attributed to nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE) (Barraclough *et al.,* 2010). Contributing of NUpE and NUtE to wheat genetic variation in NUE. Genetic variability in NUE under low N application rate due largely to differences in NUtE rather than NUpE. Studies indicate that the development and use of wheat cultivars with higher NUE can contribute to a reducing the amount of nitrogen to be applied without decreasing grain yield (Daba., 2017).

One crucial requirement for the identification, selection and development of nitrogen-efficient germplasm is the availability of genetic diversity. Also, studies on wheat varieties with nitrogen inputs have reported that the genetic variation for nitrogen use efficiency and its component traits was available (Cormier *et al.,*2016; Nehe *et al.,* 2018). Thus, it is crucial to investigate genotypes with different nitrogen rates in particular soil and environmental conditions that enable farmers to enhance crop yields, curtail production expenses and ensure sustainable agricultural practices. The innovation and development of nitrogen-efficient wheat varieties can reduce nitrogen use without compromising the grain output. The nitrogen use efficiency of wheat has been estimated to be <60% (Duan *et al.,* 2014), suggesting that nitrogen is not optimally used for grain production. Several strategies have been employed to increase the nitrogen use efficiency in cereal crops, *viz.*, the use of slow-release nitrogen fertilizers, nitrification inhibitors, modified urea materials (including neem-coated urea), precise nitrogen management, leaf color charts, method, rate and time of nitrogen application, balanced fertilization and other techniques (Singh *et al*., 2023). In addition, the identification of nitrogen-efficient wheat varieties is another promising strategy to increase both yield and nitrogen use efficiency.

There are many studies of application of nitrogen for determining yield and nitrogen use efficiency of wheat. For example, depending on the varieties grown, the nitrogen input of N_{80} (80 kg ha^{-1}) to N_{120} (120 kg ha^{-1}) can result in a range of 28.8 to 40 kg of wheat grains with a nitrogen use efficiency of 1 kg of grain per kg of nitrogen applied (Mondal *et al.,* 2023). The accumulation of phytomass and the concentration of chlorophyll in leaves are intrinsically linked to the efficiency of nitrogen utilization, which enables them to serve as indirect selection markers for varieties that exhibit a high degree of nitrogen use efficiency (Rahman *et al.,* 2011). But the research related to nitrogen application and specific varieties of wheat is scarce in the context of Bangladesh. Thus, the judicious application of an optimal dosage of nitrogen fertilizer, tailored to the specific wheat varieties, can be perceived as the main strategy for maximizing economic yields, improving nitrogen uptake, and improving the effectiveness of nitrogen utilization in wheat. Despite advances in breeding techniques, there are instances where superior varieties are developed without considering their ability to sustain growth and productivity on soils with low- fertility. These varieties were specifically chosen for their ability to yield more under high-input fertilizer regimes. Therefore, to satisfy the growing global food demands of populations, it is crucial to constantly assess nitrogen-efficient varieties and choose breeds based on their genetic performance (Gawdiya *et al.,* 2023).

Therefore, the present experiment was conducted to evaluate yield and nitrogen use efficiency of wheat varieties under different nitrogen levels.

Materials and Methods

Description of the experimental site

The experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University (BAU), Mymensingh, from November 2024 to March 2025, to evaluate the influence of wheat variety under different nitrogen levels on yield and nitrogen use efficiency. The experimental site lies at 24 °43′13" N latitude and 90 °25′40" E longitude. The elevation of the experimental area is 18 meters above sea level. The experimental site belongs to the non-calcareous dark grey floodplain soil under the Old Brahmaputra Floodplain, Argo-Ecological Zone (AEZ-9) (UNDP and FAO, 1988). The soil at the experimental site exhibited a neutral pH of 6.80 and was categorized as moderately fertile, although it contained low organic matter content. The soil texture was silty loam and the topography of the area ranged from moderate to high elevation. Furthermore, the pH level of the soil was approximately 6.5, indicating a nearly neutral response with limited organic matter content. Physical and chemical properties of the experimental soil are shown in Table 1.

Table 1. Physical characteristics and chemical composition of the experimental soil

Properties	Results	Composition	Results
Sand (0.0 – 0.02 mm) %	21.95	Soil pH	6.80
Silt (0.02– 0.002 mm) %	66.75	Organic matter (%)	1.29
Clay (<0.002 mm) %	11.30	Total nitrogen (%)	0.101
Soil texture class	Silt loam	Available phosphorus (ppm)	26.00
Color	Dark gray	Exchangeable potassium (me / 100g soil)	0.13
Consistency	Granular	Available S (µgm/gm soil)	9.40
		Available B (µgm/gm soil)	0.13
		Available Zn (µgm/gm soil)	0.94

Source: Department of Soil Science, BAU

Experimental treatments and design

There are two sets of treatments in the experiment. The treatments were three varieties (BWMRI Gom-1, BWMRI Gom-2 and BWMRI Gom-5) and four nitrogen levels (0, 45, 90 and 135 kg ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times for each treatment. The experimental unit was divided into three blocks each of which representing a replication. So, there were altogether (4x3x3) = 36-unit plots, the size of each unit plot was (2.5m x 2m) = 5m^2. Inter-block and inter-plot spacing were 1 m and 0.5 m respectively**.**

Experimental material

Three wheat varieties *viz.* BWMRI Gom -1 (V_1), BWMRI Gom-2 (V_2) and BWMRI Gom-5 (V_3) were used for screening in relation to yield and nitrogen use efficiency. Certified varieties (seeds) were collected from the Regional Wheat Research Centre, Bangladesh Wheat and Maize Research Institute (BWMRI), Jamalpur.

Crop husbandry

Repeated ploughing with a tractor was done on 10 November and the land was prepared finally on 12 November of 2024. Ploughing was followed by laddering in order to break clods as well as level the land. All weeds, stubbles and crop residues were removed from the experimental field. The layout of the experiment was done as per experimental design. The total amount of triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc oxide and boric acid were applied during final land preparation. The fertilizer dose was @ 140-100-120-12-7 kg ha^{-1} in the form of P_2O_5-K_2O-S-Zn-B, respectively. There were four levels of nitrogen (0, 45, 90 and 135 kg ha$^{-1)}$ which was applied from urea (46% N). Nitrogenous fertilizer (Urea) was used as per treatment specification. The recommended dose of urea was applied in two equal splits, during crown root initiation stage and panicle initiation stage at 25 and 50 days after sowing (DAS). Seeds were sown continuously in line on 13 November 2024 as per experimental treatment and the seed rate being at 120 kg ha^{-1}. The line-to-line distance was maintained 20 cm. After sowing, seed were covered the soil and slightly pressed by hand.

Intercultural operations

Intercultural operations were done in order to ensure and maintain the normal growth of the crops. Manual weeding was done thrice during the whole growing period at 22, 40 and 60 days after sowing (DAS). Three irrigations were applied, the first irrigation 25 days after sowing (DAS) at crown root initiation (CRI). the second after 50 days at heading stage and the third irrigation 75 days at grain filling stage. No infestation diseases were found. A guard was appointed to protect the wheat grain from birds especially tailorbird, parrot from mid-

February to harvest. The plots under experiment were frequently observed to notice any change in plant growth, other characters were noted down immediately to make necessary measures.

Sampling, harvesting and processing

The crop was harvested at maturity on 4 March, 2025. Variety BWMRI Gom-2 attained maturity a few days later than the other two varieties (BWMRI Gom-1 and BWMRI Gom-5). Samples were collected from different places of each plot leaving undisturbed 1 m^2 in the center. For collecting data on crop characters, the sample plants were selected at random and uprooted prior to harvesting, bundled, tagged and carefully carried to the agronomy research field laboratory. Samples of 1m^2 and rest crop was harvested separately plot-wise, bundled and tagged. The crop bundles were sun dried by spreading those on the threshing floor. Then the grains and straw were dried in the sun for five days. The grains and straw were recorded plot- wise weights at 14% moisture level and converted into t ha^{-1} basis.

Data measurements

The data recording procedure was systematically followed to measure yield components and nitrogen use efficiency in wheat. Firstly, grain yield (t ha^{-1}) was measured by harvesting mature wheat spikes from the net plot area at crop maturity. From each plot, five representative wheat hills (or clumps) were randomly selected. Grains from these hills were manually threshed, sun-dried to attain a uniform moisture level (typically 12–14%) and weighed. The grain weight was then converted into tons per hectare (t ha^{-1}) to standardize comparisons across treatments. Secondly, for determining straw yield (t ha^{-1}), the remaining above-ground non-grain biomass (stems and leaves) from the same plots was collected after threshing, dried thoroughly in the sun and weighed. The straw yield was also converted into t ha^{-1}. The biological yield of wheat was obtained by summing the grain and straw yields, which represents the total dry matter production of the crop. The harvest index (HI) was calculated using the formula: (Grain yield / Biological yield) × 100, indicating the proportion of total biomass allocated to grain. A higher harvest index reflects better partitioning efficiency towards economic yield. To estimate nitrogen uptake, grain and straw samples from each plot were analysed for nitrogen content using standard laboratory procedures such as the Kjeldahl method. Similarly, nitrogen uptake in grain (kg ha^{-1}) was determined by multiplying the nitrogen concentration by the grain dry weight and nitrogen uptake in straw (kg ha^{-1}) was calculated similarly. These two values were added to obtain total nitrogen uptake (kg ha^{-1}). Finally, nitrogen use efficiency was calculated by dividing the total nitrogen uptake by the amount of nitrogen fertilizer applied (kg ha^{-1}).

Nitrogen use efficiency (NUE) =

$$\frac{N\ uptake by\ plant\ with\ N\ application - N\ uptake\ by\ plant\ without\ N\ application}{The\ amount\ of\ N\ application}$$

Statistical Analysis

Data on yield and yield parameters were compiled, tabulated and subjected to statistical analysis. Analysis of variance was done with the help of computer package programmer R. The mean differences were adjudged by Duncan's Multiple Range Test (DMRT) following two-way ANOVA (Gomez and Gomez, 1984).

Results

Effect of variety on the yield contributing characters and harvest index (%) of wheat

The study also revealed high variability in both yield contributing characters influenced by varietal differences. The variety BWMRI Gom-2 produced the highest plant height (88.06 cm), number of total tillers per plant (4.33), number of effective tillers pr plant (3.89), spike length (9.49 cm), number of grains per spike (40.12), 1000-grain weight (44.42g) and harvest index (40.68%). Whereas, the lowest plant height (86.51 cm), number of total tillers per plant (4.63), number of effective tillers per plant (3.63), spike length (9.70 cm), number of grains per spike (41.40), 1000-grain weight (44.21g) was observed in BWMRI Gom-1 and lowest value also harvest index (40.68%) was obtained from BWMRI Gom-5 (Table 2).

Effect of nitrogen level on the yield contributing characters and harvest index of wheat varieties

The effect of nitrogen level on the highest plant height (90.32 cm), numbers of total tillers per plant (5.09), number of effective tillers per plant (4.18), spike length (10.20 cm), number of grains per spike (43.91), 1000-grain weight (44.58 g) and harvest index (41.79%) was observed from the treatment at 90 kg N ha^{-1}. Whereas, the lowest value for the plant height (81.93 cm), numbers of total tillers per plant (3.49), number of effective tillers per plant (3.13), spike length (8.46 cm), number of grains per spike (35.40),1000-grain weight (43.74 g) and harvest index (38.66%) was recorded from the treatment at 0 kg N ha^{-1} (Table 3).

Table 2. Effect of variety on the yield contributing characters and harvest index of wheat

Variety	Plant height (cm)	No. of total tillers plant^{-1}	Number of effective tillers plant^{-1}	Spike length (cm)	No. of grains spike^{-1}	1000-grain weight (g)	Harvest index (%)
V_1	86.51b	4.33b	3.63b	9.49b	40.12c	44.21b	40.13b
V_2	88.06a	4.63a	3.89a	9.70a	41.40a	44.42a	40.68a
V_3	87.64a	4.58a	3.68b	9.55ab	40.80b	44.23b	40.08b
Level of significance	**	**	**	*	**	**	**
CV (%)	5.79	4.98	4.55	2.12	1.05	0.19	4.48

In a column, means with the same letters do not differ significantly as per DMRT, ** = Significant at 1% level of probability, * = Significant at 5% level of probability

V_1 = BWMRI Gom 1, V_2 = BWMRI Gom-2, V_3 = BWMRI Gom-5

Table 3. Effect of nitrogen level on the yield contributing characters and harvest index of wheat varieties

Nitrogen level	Plant height (cm)	No. of total tillers plant^{-1}	No. of effective tillers plant^{-1}	Spike length (cm)	No. of grains spike^{-1}	1000- grain weight (g)	Harvest index (%)
N_0	81.93d	3.49c	3.13c	8.46c	35.40c	43.74c	38.66d
N_1	87.80c	4.44b	3.58b	9.59b	40.02b	44.30b	39.18c
N_2	90.32a	5.09a	4.18a	10.20a	43.91a	44.58a	41.79a
N_3	89.56b	5.02a	4.06a	10.07a	43.77a	44.53a	41.56b
Level of significance	**	**	**	**	**	**	**
CV (%)	5.79	4.98	4.55	2.12	1.05	0.19	4.48

In a column, means with the same letters do not differ significantly as per DMRT, ** = Significant at 1% level of probability

N_0 = Control (0 kg N ha^{-1}), N_1 = 45 kg N ha^{-1}, N_2 = 90 kg N ha^{-1}, N_3 = 135 kg N ha^{-1}

Interaction effect of variety and nitrogen level on the yield contributing characters and harvest index of wheat varieties

Significant variations in wheat varieties were treated under interaction effect of variety and nitrogen level. The highest plant height (91.20 cm) was recorded from the treatment combination of BWMRI Gom-2 at 90 kg N ha^{-1} and the lowest plant height (81.60 cm) was recorded from the treatment combination of variety BWMRI Gom-1 at 0 kg N ha^{-1}. The highest harvest index (42.18%) was recorded from the variety BWMRI Gom-2 at 90 kg N ha^{-1} and the lowest harvest index (38.60%) was recorded from BWMRI Gom-5 at 0 kg N ha^{-1} (Table 4).

Table 4. Interaction effect of variety and nitrogen level on the yield contributing characters and harvest index of wheat varieties

Interaction	Plant height (cm)	No. of total tillers plant^{-1}	No. of effective tillers plant^{-1}	Spike length (cm)	No. of grains spike^{-1}	1000-grain weight (g)	Harvest index (%)
V_1N_0	81.60g	3.50e	3.07h	8.47e	34.20g	43.55g	38.61g
V_1N_1	86.23f	4.33d	3.47fg	9.57d	39.13e	44.28de	39.05f
V_1N_2	90.13bc	4.80bc	4.07bc	10.13a-c	43.93b	44.61ab	41.58c
V_1N_3	88.08e	4.67cd	3.80c-e	9.80cd	43.20c	44.39cd	41.27d
V_2N_0	82.28g	3.60e	3.13h	8.57e	36.20f	44.10f	38.78fg
V_2N_1	88.57de	4.40d	3.73d-f	9.62d	40.67d	44.36c-e	39.81e
V_2N_2	91.20a	5.33a	4.50a	10.43a	45.00a	44.75a	42.18a
V_2N_3	90.17bc	5.20a	4.20b	10.20ab	43.73bc	44.48bc	41.96ab
V_3N_0	81.92g	3.37e	3.20gh	8.33e	35.80f	43.58g	38.60g
V_3N_1	88.59de	4.60cd	3.53ef	9.60d	40.27d	44.25e	38.67g
V_3N_2	90.66ab	5.27a	4.27ab	10.27ab	44.05b	44.66a	41.82bc
V_3N_3	89.38cd	5.07ab	3.87cd	9.98bc	43.10c	44.45c	41.22d
Level of significance	**	*	*	*	**	**	**
CV (%)	5.79	4.98	4.55	2.12	1.05	0.19	4.48

In a column, means with the same letters do not differ significantly as per DMRT, ** = Significant at 1% level of probability, * = Significant at 5% level of probability

V_1= BWMRI Gom-1, V_2 = BWMRI Gom-2, V_3 = BWMRI Gom-5

N_0 = Control (0 kg N ha^{-1}), N_1 = 45 kg N ha^{-1}, N_2 = 90 kg N ha^{-1}, N_3 = 135 kg N ha^{-1}

Effect of variety on grain, straw and biological yield of wheat varieties

The effect of variety on grain, straw and biological yield of wheat varieties was statistically significant. The highest grain yield (2.64 t ha^{-1}), straw yield (3.80 t ha^{-1}) and biological yield (6.43 t ha^{-1}) was obtained from BWMRI Gom-2. Whereas, the lowest grain yield (2.47 t ha^{-1}), straw yield (3.65 t ha^{-1}) and biological yield (6.12 t ha^{-1}) was obtained from BWMRI Gom-1 (Figure 1).

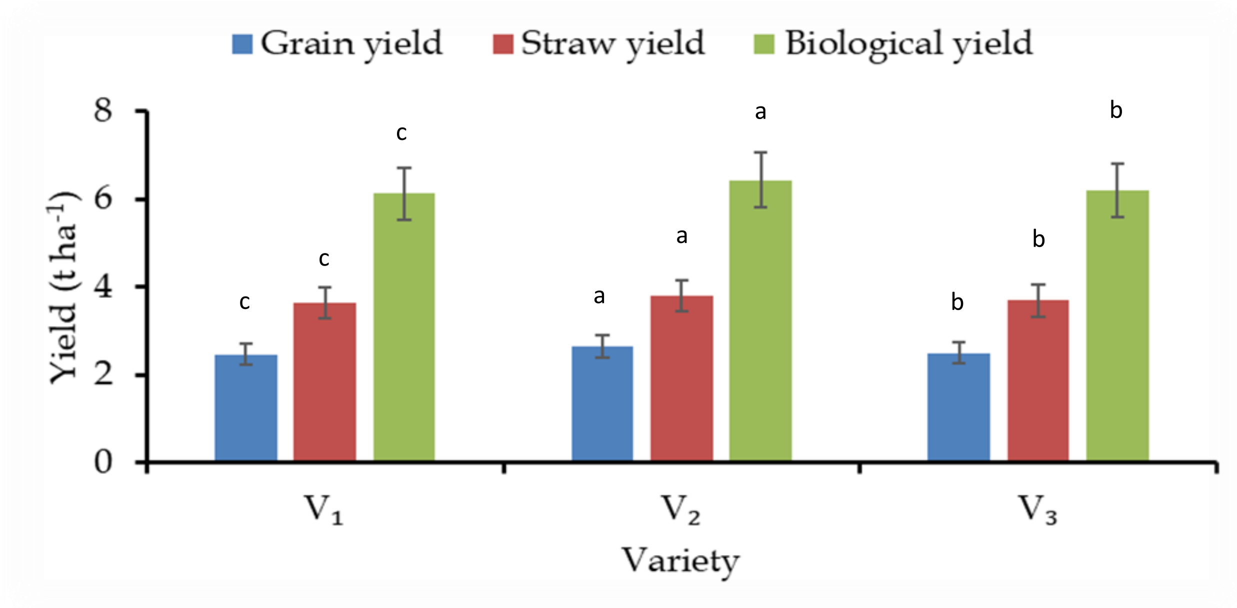

Figure 1. Effect of variety on grain, straw and biological yield of wheat varieties
Here,
V_1 = BWMRI Gom-1, V_2 = BWMRI Gom-2, V_3 = BWMRI Gom-5

Effect of nitrogen (N) levels on grain, straw and biological yield of wheat varieties

From the analysis of variance, the effect of nitrogen level on grain, straw and biological yield were statistically significant. The highest grain yield (3.30 t ha^{-1}), straw yield (4.61 t ha^{-1}) and biological yield (7.90 t ha^{-1}) was obtained from 90 kg N ha^{-1}. Whereas, the lowest grain yield (1.34 t ha^{-1}), straw yield (2.13 t ha^{-1}) and biological yield (3.47 t ha^{-1}) was obtained from the treatment at 0 kg N ha^{-1} (Figure 2).

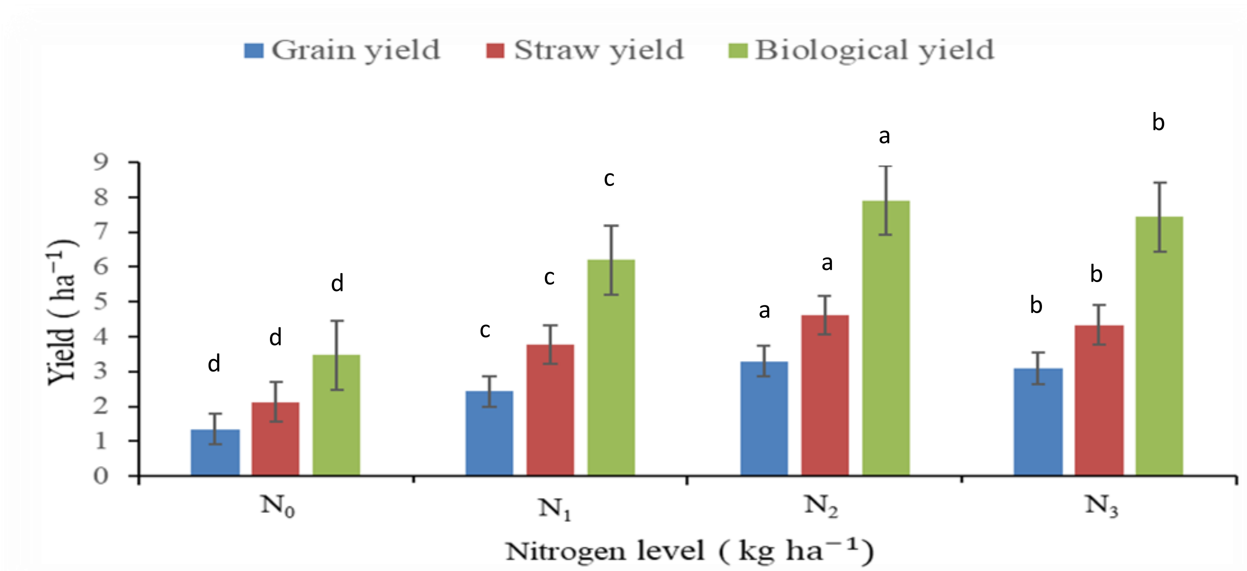

Figure 2. Effect of nitrogen (N) levels on grain, straw and biological yield of wheat varieties
Here,
N_0 = Control (0 kg N ha^{-1}), N_1 = 45 kg N $ha^{-1,}$ N_2 = 90 kg N ha^{-1}, N_3 = 135 kg N ha^{-1}

Interaction effect of variety and nitrogen level on grain, straw and biological yield of wheat varieties

From the analysis of variance, the interaction effect of variety and nitrogen treatment on grain, straw and biological yield were statistically significant. The highest grain yield (3.44 t ha^{-1}), straw yield (4.71 t ha^{-1}) and biological yield (8.15 t ha^{-1}) was obtained from the treatment combination of variety BWMRI Gom-2 at 90 kg N ha^{-1}. Whereas, the lowest grain yield (1.33 t ha^{-1}), straw yield (2.12 t ha^{-1}) and biological yield (3.45 t ha^{-1}) was obtained from the treatment combination of variety BWMRI Gom-1 at 0 kg N ha^{-1} (Figure 3).

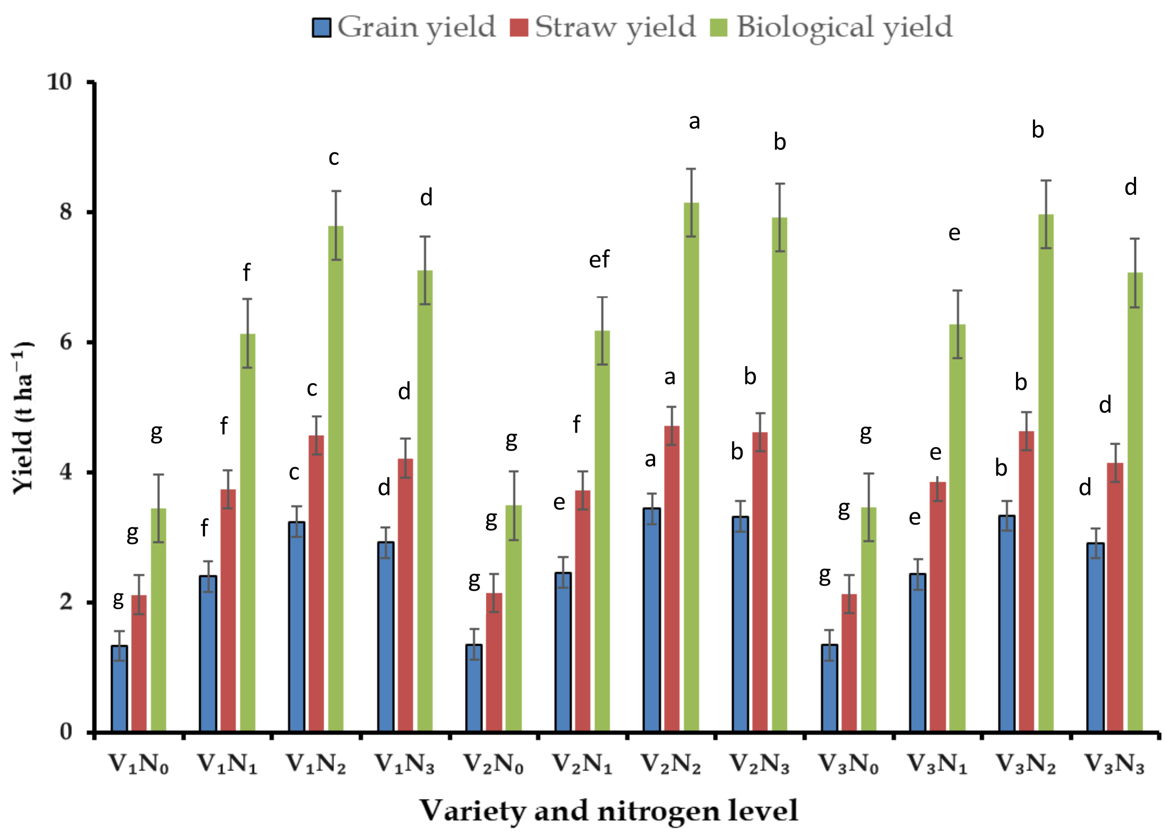

Figure 3. Interaction effect of variety and nitrogen level on grain, straw and biological yield of wheat varieties
Here,
V_1= BWMRI Gom-1, V_2 = BWMRI Gom-2, V_3 = BWMRI Gom-5
N_0 - Control (0 kg N ha^{-1}), N_1 - 45 kg N ha^{-1}, N_2 - 90 kg N ha^{-1}, N_3 - 135 kg N ha^{-1}

Effect of variety on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties

From the analysis of variance, the effects of variety on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties were statistically significant in different variety. The highest N content (%) in grains (1.51), N content (%) in straw (0.71), total N uptake in plant (67.17 kg N ha^{-1}) and nitrogen use efficiency (43.45%) were obtained from BWMRI Gom-2. Whereas, the lowest N content (%) in grains (1.48), N content (%) in straw (0.67), total N uptake in plant (62.64 kg N ha^{-1}) and nitrogen use efficiency (39.34%) were obtained from BWMRI Gom-1 (Table 5).

Table 5. Effect of variety on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties

Variety	% N content in grain	N uptake in grain (kg ha^{-1})	%N content in straw	N uptake in straw (kg ha^{-1})	Total N uptake in plant (kg ha^{-1})	Nitrogen use efficiency (%)
V_1	1.48	37.50b	0.67	25.04b	62.54c	39.34b
V_2	1.51	40.41a	0.71	26.78a	67.17a	43.45a
V_3	1.49	38.23b	0.68	25.87ab	64.10b	40.10b
Level of significance	**	**	**	**	**	**
CV (%)	2.09	2.73	3.99	4.77	2.71	4.68

In a column, means with the same letters or without letters do not differ significantly as per DMRT,
**= Significant at 1% level of probability, NS = Not significant
V_1 = BWMRI Gom-1, V_2 = BWMRI Gom-2, V_3 = BWMRI Gom-5

Effect of nitrogen level on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties

From the analysis of variance, the effect of nitrogen level on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties was statistically significant. The highest N content (%) in grains (1.66), N content (%) in straw (0.77), total N uptake in plant (90.49 kg N ha^{-1}) and nitrogen use efficiency (62.54%) were obtained from the treatment at 90 kg N ha^{-1}. Whereas, the lowest N content (%) in grains (1.32), N content (%) in straw (0.56), total N uptake in plant (29.70kg N ha^{-1}) and nitrogen use efficiency (0.00%) were obtained from the treatment at 0 kg N ha^{-1} (Table 6).

Table 6. Effect of nitrogen level on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties

Nitrogen level	% N content in grain	N uptake in grain (kg ha^{-1})	% N content in straw	N uptake in straw (kg ha^{-1})	Total N uptake in plant (kg ha^{-1})	Nitrogen use efficiency (%)
N_0	1.32d	17.73d	0.56d	11.93d	29.70d	0.00d
N_1	1.40c	33.86c	0.63c	23.90c	57.85c	56.29b
N_2	1.66a	54.93a	0.77a	35.56a	90.49a	62.54a
N_3	1.56b	48.32b	0.74b	32.20b	80.36b	45.02c
Level of significance	**	**	**	**	**	**
CV (%)	2.09	2.73	3.99	4.77	2.71	4.68

In a column, means with the same letters do not differ significantly as per DMRT, ** = Significant at 1% level of probability

N_0 = Control (0 kg N ha^{-1}), N_1 = 45 kg N ha^{-1}, N_2 = 90 kg N ha^{-1}, N_3 = 135 kg N ha^{-1}

Interaction effect of variety and nitrogen level on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties

From the analysis of variance, the interaction effects of variety and nitrogen level on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties were statistically significant. The highest N content (%) in grains (1.67), N content (%) in straw (0.79), total N uptake in plant (92.03 kg N ha^{-1}) and nitrogen use efficiency (66.13%) were obtained from the treatment combination of variety BWMRI Gom-2 at 90 kg N ha^{-1}). Whereas, the lowest N content (%) in grains (1.31), N content (%) in straw (0.55), total N uptake in plant (29.16 kg N ha^{-1}) and nitrogen use efficiency (0.00%) were obtained from the treatment combination of variety BWMRI Gom-1 at 0 kg N ha^{-1} (Table 7).

Table 7. Interaction effect of variety and nitrogen level on nitrogen content, nitrogen uptake and nitrogen use efficiency (%) in wheat varieties

Interaction	% N content in grains	N uptake in grains (kg ha^{-1})	% N content in straw	N uptake in straw (kg ha^{-1})	Total N uptake in plant (kg ha^{-1})	N use Efficiency (%)
V_1N_0	1.31d	17.47d	0.55e	11.69e	29.16e	0.00e
V_1N_1	1.39c	33.31c	0.63d	23.82d	57.13d	62.16b
V_1N_2	1.54b	44.93b	0.73c	30.22c	75.15c	51.10c
V_1N_3	1.66a	54.28a	0.75a-c	34.44b	88.72b	44.12d
V_2N_0	1.33d	18.05d	0.56e	11.90e	30.07e	0.00e
V_2N_1	1.39c	34.15c	0.64d	23.87d	58.30d	62.74b
V_2N_2	1.67a	55.49a	0.79a	36.53a	92.03a	66.13a
V_2N_3	1.65a	55.01a	0.77ab	35.71ab	90.71ab	44.92d
V_3N_0	1.32d	17.69d	0.57e	12.20e	29.89e	0.00e
V_3N_1	1.40c	34.10c	0.62d	24.02d	58.12d	62.73b
V_3N_2	1.57b	45.63b	0.74bc	30.73c	76.35c	51.63c
V_3N_3	1.58b	54.42a	0.76a-c	35.65ab	89.59ab	46.03d
Level of significance	*	**	*	**	**	**
CV (%)	2.09	2.73	3.99	4.77	2.71	4.68

In a column, means with the same letters do not differ significantly as per DMRT, ** = Significant at 1% level of probability

V_1= BWMRI Gom-1, V_2 = BWMRI Gom-2, V_3 = BWMRI Gom-5

N_0 = Control (0 kg N ha^{-1}), N_1 = 45 kg N ha^{-1}, N_2 = 90 kg N ha^{-1}, N_3 = 135 kg N ha^{-1}

Discussion

The experiment was conducted to evaluate the effect of different nitrogen levels and wheat varieties on yield-contributing characters, yield and nitrogen use efficiency. Plant height of wheat was significantly influenced by nitrogen levels and variety, with the maximum height recorded at 90 kg N ha^{-1}. After that, at 135 kg N ha^{-1} plant height also decreased, indicating that 90 kg N ha^{-1} was the optimum for maximizing vegetative growth. Among the varieties, BWMRI Gom-2 produced the tallest plants, reflecting its efficient response to nitrogen. Adequate nitrogen availability promotes cell division and elongation, contributing to greater plant height. Similar results were reported by Hnizil *et al.* (2024), who also observed that plant height of wheat increased significantly with optimal nitrogen application.

Nitrogen application had a significant effect on total tillers production. The number of tillers increased with a nitrogen rate of 90 kg N ha^{-1}. Beyond this level, total tillers number showed little improvement, indicating a saturation point. BWMRI Gom-2 variety produced the highest number of total tillers, suggesting a stronger tillering ability under optimal doses. Zhou *et al.* (2020) reported a similar finding that optimal nitrogen promotes effective tiller formation more than excessive doses (i.e., beyond 90 kg N ha^{-1}). The numbers of effective tillers, which directly contributes to grain yield, also absorb at 90 kg N ha^{-1}. The increase in effective tillers with nitrogen may be attributed to improved nutrient availability from the soil conditions. Again, BWMRI Gom-2 produced the most effective tillers, indicating higher reproductive success. (Alam *et al.*,2023; Hawksford., 2017) also reported that the availability of nitrogen fertilizer enhances the survival and fertility of tillers across varieties.

Spike length improved with increased nitrogen, with the longest spike at 90 kg N ha^{-1} , as adequate nitrogen supports spikelet development and elongation, while excessive nitrogen might not enhance this genotype significantly. Among varieties, BWMRI Gom-2 recorded the longest spikes, likely due to better nitrogen assimilation. Govindasamy *et al.* (2023) also indicated that optimal nitrogen enhances reproductive development. The 1000-grain weight was maximum at 90 kg N ha^{-1}, which uptakes better grain filling and nutrient translocation. Similar results were reported by Congreves *et al.* (2021), who found that nitrogen availability improves assimilate supply to developing grains. Again, BWMRI Gom-2 recorded the highest grain weight, suggesting better grain filling, possibly due to soil, environmental conditions and efficient photosynthate translocation. In contrast, varieties like BWMRI Gom-1 exhibited relatively lower grain weight. (Zahid *et al.,* 2025; Hossain *et al.*, 2018) emphasized that genotypes with higher grain weight perform better in terms of yield.

In the present study, the highest grain yield was observed at 90 kg N ha^{-1}, which was significantly higher than that of the other varieties. On the other hand, 135 kg N ha^{-1} level did not significantly improve yield, possibly due to nutrient imbalance or nitrogen loss. BWMRI Gom-2 recorded the highest grain yield among the varieties. Tripathi *et al.* (2023) reported that variety-specific differences in physiological and genotypic traits result in different yield levels. Straw yield followed a trend similar to grain yield, with the highest values obtained at 90 kg N ha^{-1}. Increased vegetative growth due to adequate nitrogen availability contributed to more biological yield accumulation. However, further nitrogen application at 135 kg N ha^{-1} did not significantly increase straw yield. Again, BWMRI Gom-2 produced the highest straw yield, likely due to greater plant height and biomass production. According to Naz *et al.* (2016), balanced nitrogen application improves straw biomass while supporting grain yield. Biological yield, representing the total above-ground biomass, was significantly influenced by nitrogen levels and variety. Maximum biological yield was observed at 90 kg N ha^{-1}. This suggests an improved source-sink relationship under optimum nitrogen conditions. The variety BWMRI Gom-2 produced the highest biological yield, likely due to its better vegetative and reproductive performance. Cai *et al.* (2021) reported that appropriate nitrogen improves total biomass accumulation without increasing the risk of lodging.

The harvest index increased with nitrogen level, reaching its highest value at 90 kg N ha^{-1}, indicating efficient partitioning of biomass to economic yield. Excess nitrogen at 135 kg N ha^{-1} did not significantly increase harvest index. BWMRI Gom-2 showed the highest harvest index (%), confirming its superior efficiency in resource partitioning. Similar observations were made by Ali *et al.* (2020), suggesting that optimal nitrogen enhances harvest index in modern wheat varieties. Nitrogen use efficiency was significantly influenced by nitrogen levels and variety. The highest nitrogen use efficiency was observed at 90 kg N ha^{-1}, indicating optimal uptake and conversation of nitrogen into yield. At 135 kg N ha^{-1}, nitrogen use efficiency declined due to diminishing returns and potential nitrogen loss. BWMRI Gom-2 demonstrated higher nitrogen use efficiency, suggesting genotypic variation plays a role in nitrogen response and cropping systems. Liu *et al.* (2022) observed that excessive nitrogen input reduces nitrogen use efficiency and increases losses through leaching or volatilization.

Overall, lower nitrogen dose (45 kg N ha^{-1}) was inadequate for optimum growth, resulting in lower biomass and yield. In contrast, higher nitrogen (135 kg N ha^{-1}) did not further improve performance and sometimes even reduced efficiency due to nutrient imbalances, leaching losses, or lodging. Excess nitrogen also decreased nitrogen use efficiency due to diminishing returns. 90 kg N ha^{-1} proved to be the most effective nitrogen level for improving wheat yield and efficiency. BWMRI Gom-2 had a balanced combination of high tillering ability, efficient nitrogen use, and better grain characteristics, which helped it outperform Gom-1 and Gom-5 in terms of grain yield, straw yield, biological yield, and harvest index. Among varieties, BWMRI Gom-2 consistently outperformed others across all traits. The findings highlight the importance of balanced nitrogen management and selecting responsive genotypes to enhance productivity and nitrogen efficiency in wheat cultivation.

Conclusion

The study has demonstrated that variety BWMRI Gom 2 along with N 90 kg ha^{-1} exhibited the highest plant height, number of total tillers per plant, grain yield, straw yield, biological yield, harvest index, nitrogen uptake in grain, nitrogen uptake in straw, total nitrogen uptake in plant and nitrogen use efficiency. The results also indicated that all the treatments combinations compared to give over control treatment combination. As a result, the present study helped to identify the most efficient varieties that can be strongly recommended to wheat farmers in different region. Furthermore, wheat varieties have a lot of genetic-heterogeneity in terms of grain yield, straw yield, harvest index and nitrogen use efficiency which is very useful in breeding activities. Therefore, the current study also suggests that these varieties can be used in wheat breeding programs to produce genetically enhanced in different wheat varieties.

Authors contribution

PCR and MRU developed the concept and designed the experiments. PCR collected the data and wrote the manuscript. MRU evaluated the result, analyzed data statistically and contributed to writing the manuscript. MRU, and UKS contributed to revising manuscript critically for important intellectual content. All authors read the article and approved the final version to be published.

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Competing interests

The authors have declared that no competing interests exist.

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