YIELD AND AROMATIC QUALITY OF FRAGRANT RICE AS INFLUENCED BY NITROGEN AND SULPHUR FERTILIZERS

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CERTIFICATE

This is to certify that thesis entitled, **"YIELD AND AROMATIC QUALITY OF FRAGRANT RICE AS INFLUENCED BY NITROGEN AND SULPHUR FERTILIZAERS"** *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,*** *embodies the result of a piece of bona-fide research work carried out by* ***MD. HASAN MAHMUD****, Registration no.* ***13-05636*** *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.

Date:
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DEDICATED

TO

MY BELOVED PARENTS

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YIELD AND AROMATIC QUALITY OF FRAGRANT RICE AS INFLUENCED BY NITROGEN AND SULPHUR FERTILIZERS

ABSTRACT

The study was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during June to December 2018 to assess the yield and aromatic quality of fragrant rice influence of nitrogen and sulphur fertilizers. BRRI dhan34 was selected as variety for the experiment. The experiment consisted of two factors: Factor A: Levels of nitrogen (4 levels) as- N_1: 36.87 kg N ha^{-1}, N_2: 41.47 kg N ha^{-1}, N_3: 46.08 kg N ha^{-1}, N_4: 50.69 kg N ha^{-1} and Factor B: Levels of sulphur (4 levels) as- S_1: 6.4 kg S ha^{-1}, S_2: 7.2 kg S ha^{-1}, S_3: 8.0 kg S ha^{-1} and S_4: 8.8 kg S ha^{-1}. The experiment was laid out in split-plot design with three replications placing N levels in the main plot and sulphur in the sub-plot. Data were recorded on growth characters, yield and quality. Statistically significant variations were recorded for most of the characters due to different treatments. Nitrogen and/or sulphur levels had significant effect on effective tillers, filled grains, weight of 1000 grains, grain yield, milled rice, protein content, amylose content, proline content and grain 2-AP content. Maximum 1000 grain weight and grain yield were found from N_2 and S_1. Protein and Zn content showed as increasing trends with increasing N levels while amylose, proline and grain 2-AP content decreased with the same. Results of S levels revealed that protein and Zn contents decreased with increasing levels whereas, amylose, proline and grain 2-AP content increased with increasing S levels.. Among the treatment combinations, the highest 1000 grains weight (12.13-13.21 g) and yield (4.92-5.48 t ha^{-1}) significantly recorded from N_2S_1, N_2S_2, N_2S_3 and N_2S_4. The highest protein content (9.03%) was recorded from N_4S_2 and the lowest (7.40%) was in N_1S_4. The highest amylose content (27.0%) was recorded from N_1S_4 and the lowest (14.73%) was from N_4S_1. The maximum proline content (24.0 mg g^{-1} dry weight) was recorded from N_1S_2 while the lowest (16.67 mg g^{-1} dry weight) was in N_4S_3. The highest grain 2-AP content (0.980 µg g^{-1} dry weight) was recorded from N_1S_4 and the lowest (0.493 µg g^{-1} dry weight) was found from N_4S_1. The fertilizer levels 41.47 kg N ha^{-1} and 6.4 kg S ha^{-1} showed the best performance when considered yield and in case of amylose, proline and grain 2-AP content, 36.87 kg N ha^{-1} and 8.8 kg S ha^{-1} produced good aromatic quality of rice .

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
Anon.	Anonymous
SAU	Sher-e-Bangla Agricultural University
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BAU	Bangladesh Agricultural University
BRRI	Bangladesh Rice Research Institute
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAT	Days After Transplantating
eds.	Editors
et al.	et alii (And others)
FAO	Food and Agriculture Organization
L.	Linnaeus
LSD	Least Significance Difference
i.e.	id est (that is)
MoP	Muriate of Potash
BCSIR	Bangladesh Council of Scientific and Industrial Research
Sx	Standard Error for Comparision
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate
var.	Variety
viz.	Namely

CHAPTER 1
INTRODUCTION

Rice (*Oryza sativa)* is the 2nd world crop after wheat in the world. Bangladesh is 4th in rice production in the world. About 75 % area of Bangladesh is covered by rice in which 27% come from aromatic rice. In Bangladesh, it covers an area of about 1,13,85,953 ha and total production is about 5,25,90,000 metric tons (FAOSTAT, 2016). In Bangladesh, a number of fine rice cultivars are grown by farmers. Such common cultivars are BRRI dhan34, BRRI dhan37, BRRI dhan38, BRRI dhan80. Fragrant rice is globally appreciated among consumers and is in high demand because of its potent aromatic flavor and good quality (Hashemi *et al*., 2013). Despite a huge market demand at present area of aromatic rice cultivation is less than 2% of the national rice coverage of Bangladesh (Ashrafuzzaman *et al*., 2009). The production of fragrant rice in Bangladesh during 2013 is approximately 0.30 million tons from 0.16 million ha of land which is much below from the national average, and hence the yield needs to be increased by 53.3% (Mahamud *et al.,* 2013). Most of the well-off people preferred long, slender aromatic fine grain rice (Mannan *et al.,* 2012). The demand for aromatic grain rice has been increased due to economic development of the people of Bangladesh (Ali *et al*., 2016). On the contrary, the aromatic quality of all fragrant rice cultivars are not as per good enough compared to those of other rice growing varieties.

Selection of appropriate variety and application of integrated nutrient management, the yield can be increased. Nitrogen and sulphur are considered as the quality and quantity limiting factors for paddy. The influence of nitrogen is more pronounced as compared to sulphur and both these nutrients interact in increasing the grain yields of rice (Dikshit and Paliwal, 1989). Among the essential nutrients, nitrogen (N) is the main nutrient that determines rice yield, due to its role in the photosynthesis and dry matter accumulation in plant (Yoshida *et al*., 2006). Significant improvement in crop yields is attributed to the increase in fertilizer use, especially nitrogen fertilizer (Cassman *et al*., 2003). The levels of N fertilizer is usually greater than the recommendation for maximum crop growth and maximum yields (Fan *et al*., 2012).

An increase in yield of rice by 70-80% could be obtained by the application of nitrogen (IFC, 1982). N fertilizer increased significantly the plant height (Dahattonde,1992). The plant height significantly increased with increased N level (Maske *et al.,* 1997). The straw yield significantly affected by N level (Sahrawat *et al.,* 1999). Higher amount of nitrogen fertilizer applications produced taller plants (Bhuiyan *et al.*, 1990). The increasing rate of N from 40 to 160 kg ha^{-1} increased the productive tiller number $hill^{-1}$. The plant height, productive tiller number $hill^{-1}$ and grain yield increased with increasing the application of nitrogen fertilizer and were found the highest with 120 kg N ha^{-1} (Mondal *et al*., 1987). The significant linear increase in seed yield was recorded up to 80 kg N ha^{-1} and thereafter a marginal reduction in seed yield was found at 120 kg N ha^{-}.^{1} The highest level of N increased the straw yield. They recommended 98.5 kg N ha^{-1} (Neelam and Nisha, 2000).

N fertilizer has contributed an estimated 40% increase in per capita food production over the past 50 years (Brown, 1999 and Smil, 2002). Application of N is known to promote tillering in rice via increased photosynthetic activity. Balanced nitrogen fertilizer applied in soils is the most important variable that affects the quality and yields in rice (Wang *et al.,* 2008). About 80 kg ha^{-1} improved quality of grain and soil fertility (Sikdar *et al*., 2008). However, higher amount of nitrogen can lead to lodging in rice (Mahajan *et al.,* 2010). High aroma content in grains was associated to high total nitrogen in soil (Yang *et al.,* 2012) and 2-AP content in grains was increased with decreasing nitrogen application (Zhong and Tang, 2014).

Researchers have identified approximately 200 different compounds that contribute to rice aroma. 2-AP is considered to be the single most important votatile compound responsible for aroma in aromatic rice (Sriseadka *et al*., 2006). The 2-AP, popcorn like flavor compound was reported as a main active flavor component of aromatic rice (Buttery and Ling, 1982). Yoshihashi (2005) pointed out that, nitrogen fertilizer affects aroma formation in aromatic rice and showed a significant relationship with 2-AP biosynthesis. The 2-AP is produced in the rice grain while they are growing in the fields. So, it is quite important to preserve the content and maintain its flavor characteristics during production of aromatic rice through proper fertilizer management. Sulphur application also increased significantly the grain yield at a higher level.

Increase in rice yield due to S application could be ascribed to its important role in the synthesis of protein and methionine (Gupta *et al.,* 2004). Application of varying sulphur levels also increased significantly the straw and biological yield of rice. The direct effect of sulphur through single super phosphate on hybrid rice showed in a significant increase of 2l% in grain yield with an S use efficiency of 13 kg grain kg^{-1} (Babu *et al.*, 2001). The effect of S applied to rice significantly enhanced the growth and yield of rice . Different levels of S significantly increased growth attributes of rice i.e. number of tillers, number of leaves and dry matter production; yield trait such as harvest index of rice up to 45 kg ha^{-1} (Chandel *et al.*, 2003). The optimum doses of N and S fertilizer are crutial for enhanced productivity and nutrient uptake in aromatic rice. In the above mentioned perspective the present study was conducted with fulfilling the following objectives-

-To find out the optimum level of nitrogen and sulphur for maximizing growth and yield of BRRI dhan34.

-To find out the optimum nitrogen and sulphur for better grain quality of same variety.

CHAPTER 2
REVIEW OF LITERATURE

Rice has remarkable adaptability to different environmental conditions as is evident from its worldwi de distribution. Many researchers at home and abroad investigated various aspects of successful rice production. Nitrogen fertilizer is one of the major elements which greatly influence the vegetative growth and yield of rice. Judicious applications of both nitrogenous and sulphatic fertilizers are the main factors in rice based production system which can increase yield, quality and reduce production cost. BRRI, BINA and IRRI released different rice varieties of both aromatic and non- aromatic. Different researcher reported the effect of nitrogen and sulphur fertilization on yield attributes and quality of both aromatic and non-aromatic rice but the findings is not adequate and conclusive in agro-climatic condition of Bangladesh. An attempt was taken to review the available important and informative research findings that are related to nitrogen and sulphur fertilization on yield and quality of both aromatic and non-aromatic rice have been reviewed under the following headings:

2.1 Effect of nitrogen fertilization on growth, yield and quality of rice

Amin *et al.* (2006) found significant variation on growth, tillering and yield of three traditional rice varieties due to various doses of N fertilizer compared with that of a modern variety at BSMRAU, Salna, Gazipur. Sixty kg ha^{-1} N application produced more total dry matter and lesser ineffective tillers. Application of 30 kg ha^{-1} N had the maximum yield (4451 kg ha^{-1}).

Hossain *et al.* (2018) conducted an experiment in the field of Patuakhali Science and Technology University, Dumki, Patuakhali under AEZ-13 to maximize the yield with different levels of nitrogen for three aromatic rice varieties in Aman season. The experiment was conducted with three aromatic rice varieties viz., V_1 = BRRI dhan34, V_2 = BRRI dhan38 and V_3 = Sakkorkhora and four N fertilizer treatments viz., N_0 = 0 kg ha^{-1} nitrogen (Control), N_1 = 30 kg N ha^{-1}, N_2 = 45 kg N ha^{-1} and N_3 = 60 kg N ha^{-1}.

Result of effective tillers number hill^{-1} (12.00), 1000-grain weight (16.69 g), grain yield (3.44 t ha^{-1}), biological yield (8.05 t ha^{-1}), panicle length (29.44 cm) and harvest index (42.76%) were found highest with 45 kg N ha^{-1} but the maximum plant height (152.43 cm) and straw yield (4.64 t ha^{-1}) were found with 60 kg N ha^{-1} and control condition given the lowest value for all the characters.

Muhammad *et al.* (2005) observed that the highest plant height (116.55 cm), spikelets number panicle^{-1} (118.85) and yield of straw (11.00 t ha^{-1}) were resulted from 150 kg ha^{-1} urea.

Hossain *et al.* (2008) observed that different nitrogen rates also significantly influenced the aromatic rice cultivars. All the yield components were significantly enhanced up to 90 kg ha^{-1} N. The highest grain yield (3.62 t ha^{-1}) was found from 60 kg ha^{-1} N.

Dwivedi *et al*. (2006) carried out an field experiment on growth and yield of rice to assess the influence of N level. They observed that 184.07 kg ha$^{–1}$ N (urea) was the optimum rate for maximum rice yield.

Hossain *et al.* (2005) conducted an experiment to find out the effects of nitrogen (30, 60, 90 and 120 kg ha^{-1} N) and phosphorus on the growth and yield of rice and observed that application of nitrogen up to 90 kg ha^{-1} enhanced the growth and increased the yield of rice crop.

Manzoor *et al.* (2006) assessed the nine different nitrogen levels i.e. 0, 50, 75, 100, 125, 150, 175, 200 and 225 kg ha^{-1} in a field experiment to evaluate the performance of rice. Plant height, productive tillers hill^{-1}, length of panicle, grains panicle^{-1}, 1000 grain weight and paddy yield resulted increasing trend from 0 kg ha^{-1} N up to 175 kg ha^{-1} N. The yield contributing parameters including rice yield, grains panicle^{-1} and 1000 grain weight started decreasing at 200 kg N ha^{-1} level and above. Higher rice yield (4.24 t ha^{-1}) was found from 175 kg ha^{-1} nitrogen application treatment which also produced highest values of grains panicle^{-1} (130.2) along with a higher 1000 grain weight

(22.92 gm). The height of plant (139.8 cm) along with productive tillers hill^{-1} (23.42) and panicle length (29.75 cm) was the maximum at 225 kg N ha^{-1}.

Salahuddin *et al.* (2009) assessed gradual increase in panicle length (24.50 cm), grains panicle^{-1} (110) and grain yield (4.91 t ha^{-1}) due to the increase in nitrogen levels up to 150 kg ha^{-1} and declined thereafter.

Kandil *et al.* (2010) resulted that the increasing nitrogen fertilizer levels up to 80 kg ha^{-1} N resulted in marked increases in tiller number m^{-2}, panicle length, panicle weight, filled grains panicles$^{-1,}$ 1000 grain weight, grain and straw yields ha^{-1} and harvest index in both seasons. The addition of 144 or 192 kg ha^{-1} N recorded the tallest plants and the highest number of panicles m^{-2} without significant differences.

Khorshidi *et al.* (2011) studied that the influence of nitrogen fertilizer had no significant difference on 1000 seeds weight and number of grains panicle^{-1} but the application of 100 kg of nitrogen had the highest yield of 5733 kg ha^{-1}. Data also showed that panicle and harvest index had the highest positive correlation with yield.

Mohaddesi *et al.* (2011) found that different levels of nitrogen had not significant effects on traits except 1000 grain weight in both seasons. Increasing the levels of N up to 300 kg N ha^{-1} found in increases in plant height, grain yield, biological yield.

Salem *et al*. (2011) conducted that the number of tillers hill^{-1}, days from sowing up to panicle initiation, heading dates, leaf area index, leaf area ratio, chlorophyll content, 1000 grain weight, panicles length and grain yield (t ha^{-1}) were enhanced by increasing nitrogen levels up to 165 kg ha^{-1} N.

Sharma *et al.* (2012) conducted a field experiment and resulted that the application of 180 kg ha^{-1} N given the maximum grain yield of 70.60 q ha^{-1} and the lowest yield (44.12 q ha^{-1}) was found in the control plot.

Yoseftabar *et al.* (2012) showed that yield and yield components significantly enhanced with nitrogen fertilization. Interesting in comparison to 100 and 200 kg ha^{-1} level application of higher N fertilizer 300 kg ha^{-1} resulted a positive respond to application of higher nitrogen on hybrid variety.

Yoseftabar (2013) reported that N fertilizer is a main essential plant nutrient and vital input for in increasing crop yield. The application of 300 kg N ha^{-1} resulted highest number of panicle, maximum panicle length, more dry matter, highest number of primary branches, maximum total grain and grain yield.

Azarpour *et al*. (2014) studied on yield and physiological traits of three rice cultivars due to the effect of N fertilizer (0, 30, 60, and 90 Kg N ha^{-1}). Results showed that, increasing levels nitrogen fertilizer resulted the increment of growth indexes and yield of rice.

Haque *et al.* (2015) carried out an experiment to find the influence of five nitrogen levels viz. 0, 40, 80, 100 and 140 kg ha^{-1} N and he found the tallest plant, highest number of total, effective tillers $hill^{-1}$, grains $panicle^{-1}$, yield of grain and straw were found with 100 kg ha^{-1} N followed by 140 kg ha^{-1} N.

Zhaowen *et al.* (2018) experimented in the South China Agricultural University in Guangzhou, China with three N levels (N_0: 0 kg ha^{-1}, N_1: 30 kg ha^{-1}, and N_2: 60 kg ha^{-1}) were applied to a popular aromatic rice cv. Yungengyou 14 at the booting stage to find the accumulation pattern of 2-AP, proline. Among all other plant parts, the highest 2AP contents were found in ear axes and flag leaves, i.e., 17.04%-18.26% and 14.37%- 15.05% at 17 as well as 18.41%-22.74% and 14.38%-15.75% at 30 DAF under all N-levels. Interestingly, N application at the booting stage also maintained more proline and 2-AP contents in different plant tissues during the early grain filling stage.

Jee and Mahapatra (1989) reported that effective tillers m^{-2} were significantly lower with 90 kg N ha^{-1} as split urea application than deep placed USG.

Thakur (1991) noticed that yield attributes influenced significantly due to levels and sources of' nitrogen and through the highest panicle weight, grains number $panicle^{-1}$, 1000- grain weight was found at 60 kg N ha^{-1}.

Chopra and Chopra (2004) observed that yield attributes such as plant height, panicles $plant^{-1}$ and 1000-grain weight had influenced significantly due to levels of nitrogen. Yield attributing characters showed in significant increase in seed yield at

120 kg N ha^{-1} over 60 kg N ha^{-1} and the control. The relationship between nitrogen and seed yield was quadratic. The higher response was found at 60 kg N ha^{-1} and thereafter it decreases with increase in N rate.

Thakur (1993) observed that the increasing level of N up to 80 kg ha^{-1} was increased 1000-grains weight.

Sahrawat *et al*. (1999) reported that nitrogen level affected significantly plant height. Plant height enhanced significantly due to increasing levels of nitrogen up to 120 kg ha^{-1}.

Kim *et al*. (1999) treated that increases in tiller and panicle numbers were higher from increased N rate than greater plant density. Milled rice yield was highest and heavy panicle type rice was maximum at 165 kg N.

Sarker *et al*. (2001) assess the N responses of Japonica (Yumelvitachi) and an indica (Takanari) rice variety with different N levels viz. 0. 40, 80 and 120 kg N ha^{-1}. They noticed that grain and straw yields increased significantly but harvest index was not increased significantly with different N levels.

Castro and Saiter (2000) found that the effect of N application as basal (80, 60 and 45 kg ha^{-1}) and top dressing (10. 30 and 45 kg ha^{-1}) on the yield and yield components of Japonica rice and attained higher effective tillers, ripened grains percentage and higher grain yields from 45 kg N ha^{-1} (basal) and 45 kg N ha^{-1} (top dressing).

Singh *et al*. (2000) conducted that each preceding dose of N gave significantly lower grain and straw yields of rice over its incremental dose. Consequently more grain yield (2647 kg ha^{-1}) was found the with 100 kg N ha^{-1}.

Chopra and Chopra (2000) stated that the N application at the rate of 80 or 120 kg N ha^{-1} compared with control treatment increased all the yield attributes.

Singh *et al.* (1998) worked with an experiment which indicated that higher N application (150 kg ha^{-1}) given higher grain yields in hybrid rice.

Spanu and Pruneddu (1997) showed that rice yield increased with N levels ranging from 5.4 t ha^{-1} to 10.3 t ha^{-1}.

Chander and Pandey (1996) conducted that application of 120 kg ha^{-1} resulted maximum effective tiller m^{-2} compared to 60 kg N ha^{-1}.

Kumar *et al.* (1995) cited that total tiller numbers increased significantly with increasing N level from 80 kg to 120 kg ha^{-1}.

Hussain and Sharma (1991) observed that plant height was increased with the application of nitrogen up to 140 kg ha^{-1}. The lowest plant height was observed from the control condition and highest from 120 kg N ha^{-1}.

Ali (1994) reported that when 100 kg N ha^{-1} was added to the soil and found maximum weight of 1000-grains.

Dahattonde (1992) stated from a field trial on four rice cultivars with nitrogen doses from 0-120 kg N and yield increased significantly up to 100 kg N ha^{-1}.

Hussain and Sharma (1991) noticed that application of nitrogen increased number of grains $panicle^{-1}$ up to 80 kg ha^{-1}. At the rate of 120 kg ha^{-1} nitrogen application did not affect significantly the grains $panicle^{-1}$. 80 kg N ha^{-1} was given maximum number of grains $panicle^{-1}$ and the lowest was found by the control treatment.

Thakur (1991) showed that 1000-grain weight was increased with an increasing nitrogen levels upto 80 kg ha^{-1}.

Islam *et al*. (1990) cited 1000-grain weight was increased with an increasing nitrogen levels upto 80 kg ha^{-1}.

Idris and Matin (1990) noted that the grain yield gradually increased with an increase in N levels and was the highest at 120 kg N ha^{-1}.

BRRI (1990) carried out that N fertilizer application in transplant arnan rice at doses of 30, 60, 90 and 120 kg N had resulted the grain yield of 3.48, 4.41, 4.82 and 4.63 t ha^{-1}, respectively.

Biswas and Bhattacharya (1989) reported that the yield of rice from 0.5 to 5.0 t ha^{-1} increased with increasing nitrogen levels from 0 to 100 kg ha^{-1} increased in wet season and from 2.7 to 3.7 t ha^{-1} in dry season.

Reddy *et al.* (1986) conducted an experiment and showed more tiller number $hill^{-1}$ produced with nitrogen application from 0 to 120 kg ha^{-1} in three split dressings.

Kamal *et al*. (1988) reported that highest rate of nitrogen fertilizer given maximum tillers $hill^{-1}$, which was significantly greater than any of other treatments.

Kehinde and Fagande (1987) stated that lower and higher N level did not significantly decrease rice yield. Both the higher and lower levels of N fertilizer increased yield compared to the control.

Maskina and Singh (1987) evaluated the performances of three rice cultivars with 90, 120 or 150 kg N ha^{-1} and cited that yield and yield components of all the cultivars increased upto 150 kg N ha^{-1}.

2.2 Effect of sulphur fertilization on growth, yield and quality of rice

Mandal *et al*. (2000) worked out a greenhouse experiment to assess the effect of N and S fertilizer on nutrient content of rice grain (BRRI dhan28) at different growth stages (tillering, flowering and harvesting). Sulphur was applied as gypsum at 0, 5, 10 and 20 kg S ha^{-1} and nitrogen as urea. The straw and grain yield of rice increased significantly with combined application of urea and gypsum at different doses.

Peng *el al.* (2002) observed a field experiment where the available S content was average in these soil samples was 21.7 mg kg^{-1}. The soil with available S content was not higher than the critical value of 16 mg kg^{-1} accounted for 57.8%. Field experiments resulted that the application of S at the doses of 20-60 kg ha^{-1} was given yield-increasing efficiency to rice plant.

Sen *et al*. (2002) reported an extensive study on sulphur fertilizer application through single super phosphate in a sulphur deficient area of Murshidabad district, in India, in a rice-mustard cropping sequence. The yield of rice increased significantly with application of sulphur at 30 kg ha^{-1} and its residual effect on mustard was resulted. Application of sulphur not only helped to increase yield in both crops but also helped to control the movement and distribution of various cationic micronutrients in both the crops.

Singh and Singh (2002) observed a field experiment to find the effect of various nitrogen levels (50, 100 and 150 kg ha^{-1}) and S levels (0, 20 and 40 kg ha^{-1}) on rice cv. Swarna and PR-IOS in Varanasi, Uttar Pradesh. India. They stated that increasing levels of N and S up to 150 kg N ha^{-1} and 40 kg S ha^{-1} respectively significantly maximize plant height, tiller number m^{-2} row length, production of dry matter, length of panicle and grains $panicle^{-1}$. They also showed that total N uptake, grain, straw and grain protein yields improved significantly with the increasing level of N and S application being the highest at 150 kg N ha^{-1} and 40 kg S ha^{-1} respectively.

Biswas *et al*. (2004) noticed the effect of S in different region of India. The optimum S rate varied between 30-45 kg ha^{-1}. Rice yields enhanced from 5 to 51 %.

Mrinal and Sharma (2008) worked out a field trials during the rainy (kharif) season of 2002 and 2003 to evaluate the relative efficiency of different sources of sulphur (gypsum, elemental sulfur and cosavet) and different levels of sulfur (0, 10, 20, 30 and 40 kg S ha^{-1}) in rice. Sulfur application maximize the growth and yield contributing characters of rice. The increasing sulfur levels up to 30 kg S ha^{-1} was significantly enhanced grain and straw yields of rice.

Oo *et al.* (2007) was carried out a field experiment to assess the effect of N and S levels on the productivity and nutrient uptake of aromatic rice. They found that 100 kg N ha^{-1} and 20 kg S ha^{-1} for increased productivity of aromatic rice and uptake of N, P.

K and S under transplanted puddled conditions. Treatments attained: 4 N levels (0, 50, 100 and 150 kg ha^{-1}) and 4 S levels (0, 20,40 and 60kg ha^{-1}).

Nad *et al.* (2001) noticed that gypsum and ammonium sulfate as compared to elemental sulfur or pyrite, maintained sufficient N to S ratio in rice, resulting in decreasing in the unfilled grain percent, a vital consideration in rice yield.

Chandel *et al.* (2003) treated a field experiment to determine the effect of sulfur nutrition and S content on the growth of rice with 4 S levels (0, 15, 30 and 45 kg ha^{-1}). Leaf area index, number of tillers, dry matter production, harvest index increased significantly with increasing S levels up to 45 kg S ha^{-1}.

Bhuvaneswari *et al*. (2007) stated a field experiments during the 2001 kharif season, to find the effect of sulfur (5) at varying rates, i.e. 0, 20,40 and 60 kg ha^{-1}, with different organics, i.e. green manure, farmyard manure, sulfitation press mud and lignite fly ash, each applied at 12.5 t ha^{-1}, on yield, S use efficiency. The results observed that rice significantly showed to the S application and organics compared to the control. About 40 kg S ha^{-1} resulted the maximum grain (5065 kg ha^{-1}) and straw yields (7524 kg ha^{-1}).

Alamdari *et al.* (2007) treated a field experiments to evaluate the influence of sulfur (5) and sulfate fertilizers on zinc (Zn) and copper (Cu) by rice. The highest Cu content in the leaves was obtained when N, P, K, S and Cu sulfate were applied compared to the control. But, both Zn and Cu contents in the grain enhanced when N. P, K, S and Zn, Cu and Mn sulfate were applied together.

Islam *et al.* (2006) conducted an experiment in Bangladesh to find the effect of gypsum (100 kg ha^{-1}) applied before planting, and at 30 and 60 days after planting, on the nutrient content of transplanted Aus rice (BR-2) in the presence of basal doses of N, P. K fertilizers from May to September 1996. A control without gypsum application was included. Gypsum application at various dates increased progressively all the nutrients such as N, P. K, S, Ca and Mg. When the gypsum was applied at 30 days after planting resulted the maximum inerease of N, P, K, S. Ca and Mg. Protein synthesis was much higher due to gypsum application at 30 days after planting and accelerated with all the treatments of gypsum.

CHAPTER 3

MATERIALS AND METHODS

The experiment was conducted to find the influences of nitrogen and sulphur fertilization on yield and aromatic quality of fragrant rice. This chapter shows the materials and methods of the experiment with a short description on period of the experiment, location of the experiment, soil condition and climatic status of the experimental site, experimental treatment and design, growing of crops, collection of data and analysis procedure that followed for the conduction of this experiment and these have been showed below under the following headings and sub-headings:

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was carried out in the period from June to December 2018.

3.1.2 Location of the experiment

The experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The site is located at 23.740N latitude and 90.350E longitude with an altitude of 8.2 meter. Appendix I presented the location of the experiment.

3.1.3 Climatic status

The experimental site was under the sub-tropical climate and characterized by three particular seasons namely the monsoon or rainy season; the winter or dry season and the pre- monsoon period or hot seasonin Appendix III presented the information respect to monthly maximum and minimum temperature, rainfall, relative humidity and sunshine were collected during the period of study of the experimental site has been presented and these were collected from Bangladesh Meteorological Department, Agargaon.

3.1.4 Soil status

The experiment was done in a rice growing soil belonging to the "Madhupur Tract". Silty clay texture was found in top of the soil, red brown and olive–gray with fine to medium dark yellowish brown mottles. Soil pH was 5.6 and contained 0.45% organic carbon. The experimental land was well drained with good irrigation facilities and medium high land. It was above flood level. Sufficient sunshine was found during the period of experiment. The morphological characters of soil are as following - Soil series: Tejgaon, General soil: Non-calcareous dark grey (Appendix II). The physicochemical properties of the soil are presented in (Appendix II).

3.2 Details of the experiment

3.2.1 Planting material

Fragrant rice cultivar BRRI dhan34 was used as the variety in the experiment.

3.2.2 Treatments of the experiment

The experiment consisted of two factors:

Factor A: Levels of nitrogen (4 levels):

i. 36.87 kg   iii. 46.08 kg

ii. 41.47 kg (Recommended dose)   iv. 50.69 kg

Factor B: Levels of sulphur (4 levels):

i 6.4 kg (Recommended dose)   iii. 8.0 kg

ii. 7.2 kg   iv. 8.8 kg

Urea (46% N) was used as nitrogen source and gypsum (18.65% S) as sulphur source. There were total 16 (4×4) treatment combination as a whole and they are N_1S_1, N_1S_2, N_1S_3, N_1S_4, N_2S_1, N_2S_2, N_2S_3, N_2S_4, N_3S_1, N_3S_2, N_3S_3, N_3S_4, N_4S_1, N_4S_2, N_4S_3 and N_4S_4.

3.2.3 Experimental design and layout

The two factors experiment was laid out in split-plot design with three replications. An area of 280 m^2 (28 m × 10 m) was divided into 3 blocks. The four levels of N were assigned in the main plot and 4 levels of sulphur in the sub-plot. Each plot size was 2.5 m × 1.05 m. The space between two replication, main and in between two plots and sub plots were 0.9 m, 0.75 m and 0.5 m, respectively. Each plot and sub-plot were separated by raised border. The layout of the experiment presented in (Appendix IV).

3.3 Growing of crops

3.3.1 Seed collection and sprouting

Seed was collected from BRRI (Bangladesh Rice Research Institute), Gazipur, 20 days ahead of the sowing of seeds in seed bed. For cleaning, seeds were immersed in water in a bucket for 24 hours. The immersed seeds were taken out from water and kept in gunny bags. The seeds started sprouting after 48 hours. These seeds were suitable for sowing in the seed bed in 72 hours.

3.3.2 Raising of seedlings

The seed bed was made by puddling with 3-4 ploughing followed by laddering. The sprouted seeds were sown on the seedbed as uniformly as possible at 7th June, 2018. Irrigation was provided when needed. No fertilizer was used in the nursery bed.

3.3.3 Preparation of land

The plot selected for the experiment was opened in the 30th June 2018 with a power tiller, and left exposed to the sun for a week. For obtaining good puddle condition, the land was harrowed, ploughed and cross-ploughed several times after one week followed by laddering. Weeds and stubbles were removed from the field. The experimental plot was partitioned into unit plots in accordance with the experimental design at 6^{th} July, 2018.

3.3.4 Application of fertilizers and manure

The fertilizers P, K, Zn and B were applied in the form of TSP, MoP, zinc sulphate and borax @ 55, 60, 3.0 and 10 kg ha^{-1} respectively. Other manures and cowdung were applied at required amount in each plot. N and S fertilizers were applied in the form of urea and gypsum as per treatment. The total amount of cowdung and other manures, TSP, MoP, gypsum, zinc sulphate and borax were in the time of final land preparation. Urea was applied in three equal installments as top dressing at final land preparation and maximum tillering and panicle initiation stages.

3.3.5 Transplanting of seedling

Seedlings were uprooted carefully from the seed bed and transplanted on 8th July, 2018 in well puddled plot with spacing of 25 × 15 cm and 3 seedlings were transplanted in each hill. One week after transplanting all plots was checked for any missing hill, gap filling was done with extra seedlings which found from the seed bed.

3.3.6 Intercultural operations

Intercultural operations were essential for growth and development of the crop. The following intercultural operations were done.

3.3.6.1 Irrigation and drainage

A constant level of standing water upto 6 cm was provided in the early stages of seedling establishment and then kept the amount throughout the total vegetative stages with wetting and drying system. In the reproductive and ripening phase, sufficient water was kept. At 15 days before harvesting, the plot was dried out.

3.3.6.2 Weeding

Some weeds infested the experimental plots. For ensuring better growth and development of the seedlings, weeds were cleaned by uprooting. The weeds were uprooted carefully by manual or mechanical means at 20 DAT (days after transplanting) and 40 DAT.

3.3.6.3 Plant protection

At 10 ml/ 10 ml of water, Diazinon and Ripcord were applied to control rice stem borer, leaf roller, rice bug in the plots. Net were given and own monitoring was done for controlling birds. Insecticide with dried fish was useful for controlling rats.

3.4 Harvesting, threshing and cleaning

At full maturity when 80-90% of the grains were turned into straw color, the crop was harvested. The harvested crop was separately tied up, properly tagged and brought to threshing floor. The grains were cleaned, dried and weighed for individual plot. The weight was adjusted to 12% moisture content. For each plot, rice grain and straw yield were recorded .

3.5 Data collection

3.5.1 Plant height

The height of the plant was recorded in centimeter (cm) from the ground level to the tip of the plant at 30, 45, 60, 75 DAT and at harvest. Data were listed as the average of 5 plants selected randomly from the inner rows of each plot.

3.5.2 Total tillers number

Total tiller number hill^{-1} was listed at 30, 45, 60, 75 DAT and at harvest as the average of randomly selected 5 plants from the inner rows of each plot.

3.5.3 Number of effective tillers

The number of total effective tillers hill^{-1} was counted as the number of panicle bearing tillers during harvesting. The average values were recorded from 5 selected hills and data on effective tillers hill^{-1} were listed.

3.5.4 Number of non-effective tillers

The number of total non-effective tillers hill^{-1} was counted as the number of non-panicle bearing tillers during harvesting. The average values were recorded from 5 selected hills and data on non-effective tillers hill^{-1} were listed.

3.5.5 Length of panicle

The length of panicle was assessed with a meter scale from 5 selected panicle and the average length as per panicle was recorded in cm.

3.5.6 Number of filled grains

The number of filled grains were counted randomly from selected 5 panicle of a plot on the basis of grain in the spikelet and recorded the average filled grain numbers panicle^{-1}.

3.5.7 Number of unfilled grains

The numbers of unfilled grains were counted randomly from selected 5 plants of a plot on the basis of not grain in the spikelet and recorded the average unfilled grain number panicle^{-1}.

3.5.8 Number of total grains

The total numbers of grains was found by the addition of filled and unfilled grain from selected 5 plants of the plot and calculated the average grains number panicle^{-1}.

3.5.9 Weight of 1000 grains

One thousand grains were counted randomly from the total cleaned grains and then measured in grams and listed.

3.5.10 Grain yield

Grains found from each unit plot were sun-dried and weighed carefully. Dry weigh of grains were measured from each plot and converted to ton hectare^{-1} (t ha^{-1}).

3.5.11 Straw yield

Straw attained from each unit plot were sun-dried and then weighed carefully. Dry weight of straw were measured from each plot and converted to ton hectare^{-1} (t ha^{-1}).

3.5.12 Biological yield

Biological yield calculated by the addition of grain yield and straw yield. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Straw yield.

3.5.13 Harvest index

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage.

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

3.5.14 Length of grain rice

Ten (10) milled grain rice was selected from the bulk sample after milling of each entry were measured for their length by slide calipers.

3.5.15 Breadth of grain rice

Ten (10) milled grain rice was selected from the bulk sample after milling of each entry were measured for their breadth by slide calipers.

3.5.16 Milled rice

After milling of 100 brown rice, the milled rice were counted and recorded in percent (%).

3.5.17 Broken rice

After milling of 100 brown rice, broken rice were counted and recorded in percent (%).

3.5.18 Husk

After milling of 100 grains brown rice and husk weight were taken and ratio of brown rice and husk was estimated.

3.5.19 Protein content

The protein content of rice grains was determined by the Micro-Kjeldahl method using automated nitrogen determination system (AOAC, 1990).

3.5.20 Zn content

The samples of rice grains were grounded for Zn analyses with milling machine and sieved. Thereafter, the samples were digested using a di-acid [perchloric acid ($HClO_4$) + nitric acid (HNO_3) in 3:10 ratio]. After digestion in the aliquot of samples, Zn content was estimated with the help of atomic absorption spectrophotometer (Perkin Elmer, Model-A, Analyst 100) as descrived by Prasad (2006).

3.5.21 Amylose content

The amylose content of the rice samples was found out by Juliano method (1971) with some modification. Hundred mg of the powdered rice sample was taken in a volumetric flask. One ml of 95% ethanol and 9 ml of 1 NaOH was added. For gelatinizing starch, it was heated in boiling water bath. Five ml of the starch extract was taken in 100 ml volumetric flask. One ml of 1N acetic acid and 2 ml iodide solution was added to the starch extract and the volume was made up to 100 ml. The solution was shaken and allowed to stand for 20 min. Then the absorbance was measured at 620 nm using Agilent Technologies Cary 60 UV-VIS spectrophotometer. Then the amylose content of the sample was determined with reference to the standard curve of rice amylose and expressed in per cent basis.

3.5.22 Proline content

According to the method established by Bates *et al.* (1973), the proline content of rice grains were measured. Almost 0.3 g grains were homogenized in a 4 ml solution of 3% sulfosalicylic acid. After boiling for 10 min, the solution was cooled. Samples were filtered and 2 ml of the filtrate was mixed with 3 ml ninhydrin reagent (2.5 g ninhydrin in 60 ml glacial acetic acid and 40 mL 6 M phosphoric acid) and 2 ml glacial acetic acid. The mixture was boiled for 30 min and 4 ml toluene was added to the cooled liquid for the extraction of proline. The extract was centrifuged at 4000 rpm for 5 min, and proline absorbance was detected at 520 nm and concentration expressed as μg g-1.

3.5.23 Grain-2AP content

The 2-AP content in grain was estimated using the method prior to analysis, grains were ground by mortar and pestle. Approximately 10 g grains were mixed homogeneously with 150 ml purified water into a 500 ml round-bottom flask attached to a continuous steam distillation extraction head. The mixture was boiled at 1500C in an oil pot. A 30 ml aliquot of dichloromethane was used as the extraction solvent and was added to a 500 ml round-bottom flask attached the other head of the continuous steam distillation apparatus, and this flask was boiled in a water pot at 530C. The continuous steam distillation extraction was linked with a cold water circulation machine in order to keep temperature at 100C. After approximately 35 min, the extraction was complete. Anhydrous sodium sulfite was added to the extract to absorb the water. The dried extract was filtered by organic needle filter and analyzed for 2-AP content by GCMS-QP 2010 Plus. High purity helium gas was used as the carrier gas at flow rate of 2 ml/min. The temperature gradient of the GC oven was as follows: 400C (1 min), increased at 20C min-1 to 650C and held at 650C for 1 min, and then increased to 2200C at 100C min-1, and held at 2200C for 10 min. The retention time of 2-AP was confirmed at 7.5 min. Each sample had three replicates, and 2-AP was expressed as μg g-1.

Protein, Zn, amylose, proline and 2-AP content were measured at Bangladesh Rice Research Institute (BRRI) and Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka.

3.6 Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among different treatments. The analysis of variance of all the recorded parameters were performed using STATISTIX-10 software. The difference of the means were separated by Duncun Multiple Range Test (DMRT) at 5% level of probability.

CHAPTER 4
RESULTS AND DISCUSSION

This chapter includes the presentation and discussion of the results found from the experiment. The results have been presented, discussed and possible interpretations were given in tabular and graphical forms. The results obtained from the experiment have been presented under separate headings and sub-headings as follows:

4.1 Growth and yield contributing characters of fragrant rice

4.1.1 Plant height

4.1.1.1 Effect of nitrogen on plant height

Plant height of BRRI dhan34 showed statistically significant variations due to different nitrogen levels, (Table 1). At 30, 45, 60, 75 DAT and harvest, the tallest plant (58.78, 83.33, 111.6, 125.03 and 177.32 cm, respectively) were observed from N_4 (50.69 kg N ha^{-1}) which was followed by (54.02, 80.29, 99,76,123.61 and 166.49 cm, respectively) in N_3 (46.08 kg N ha^{-1}). The plant heights (51.78, 79.72, 105.12,127.83 and 167.65 cm, respectively) of N_2 (41.47 kg N ha^{-1}) were statistically similar to N_3. The shortest plant (46.61, 76.34, 97.18, 117.55 and 157.85 cm, respectively) was found from N_1 (36.87 kg N ha^{-1}). Plant height were increased with increasing levels of nitrogen. Manzoor *et al.* (2006), Muhammad *et al.* (2005) and Mohaddesi *et al.* (2011) were observed similar result in their experiments.

4.1.1.2 Effect of sulphur on plant height

Plant height of BRRI dhan34 given statistically significant variations due to different sulphur levels, (Table 1). At 30, 45, 60, 75 DAT and harvest, the tallest plant (57, 86.33, 111.8, 137.92 and 182.47 cm, respectively) was observed from S_2 (7.2 kg S ha^{-1}). The shortest plant (52.8, 74.08, 91.33, 107.7 and 152.63 cm, respectively) were found from S_3 (8.0 kg S ha^{-1}). Mandal *et al.* (2000) reported that plant height significantly influenced by different levels of sulphur.

4.1.1.3 Combined effect of nitrogen and sulphur on plant height

Combined effect of nitrogen levels and sulphur levels showed significant differences for plant height of BRRI dhan34 (Table 2). At 30, 45, 60, 75 DAT and harvest, the tallest plant (58.52, 93.33, 138.0, 144.67 and 195.34 cm, respectively) was found from N_4S_2 (50.69 kg N ha^{-1} and 7.2 kg S ha^{-1}), while the shortest plant (45.99, 62.33, 73.67,86.0 and 132.33 cm, respectively) was recorded from N_1S_3 (36.87 kg N ha^{-1} and 8.0 kg S ha^{-1}) treatment combination.

Table 1. Effect of different levels of nitrogen and sulphur fertilization on plant height of BRRI dhan34 at different days after transplanting (DAT) and harvest

Treatments	Plant height (cm) at				
	30 DAT	45 DAT	60 DAT	75 DAT	Harvest
Levels of Nitrogen					
N_1	46.61 b	76.34 b	97.18 b	117.55 b	157.85 b
N_2	51.78 ab	79.72 ab	99.76 ab	123.61 ab	166.49 ab
N_3	54.02 ab	80.29 ab	105.12 ab	125.03 ab	167.65 ab
N_4	58.78 a	83.33 a	111.6 a	127.83 a	177.32 a
Sx	2.571	2.593	3.396	3.731	4.688
Level of significance	**	*	*	*	*
CV(%)	11.92	7.71	8.37	7.43	6.71
Levels of Sulphur					
S_1	48.5 c	80.04 ab	106.55 ab	124.17 b	166.84 b
S_2	57 a	86.33 a	111.8 a	137.92 a	182.47 a
S_3	52.8 b	74.08 b	91.33 c	107.70 c	152.63 c
S_4	52.94 b	79.23 b	103.96 b	124.23 b	167.38 b
Sx	1.820	3.071	2.553	3.724	4.302
Level of significance	**	**	**	**	**
CV(%)	8.44	9.19	6.24	7.41	6.47

N_1: 36.87 kg N ha^{-1}

N_2: 41.47 kg N ha^{-1}

N_3: 46.08 kg N ha^{-1}

N_4: 50.69 kg N ha^{-1}

S_1: 6.4 kg S ha^{-1}

S_2: 7.2 kg S ha^{-1}

S_3: 8.0 kg S ha^{-1}

S_4: 8.8 kg S ha^{-1}

Table 2. Combined effect of different levels of nitrogen and sulphur fertilization on plant height of BRRI dhan34 at different days after transplanting (DAT) and harvest

Treatments	Plant height (cm) at				
	30 DAT	45 DAT	60 DAT	75 DAT	Harvest
N_1S_1	55.01 a-d	81.03 ab	111.33 b	118.94 cde	168.73 bc
N_1S_2	47.11 de	83.33 ab	103.78 bc	133.33 abc	168.88 bc
N_1S_3	45.99 e	62.33 c	73.67 e	86.00 f	132.33 d
N_1S_4	557.56 ab	77.99 b	105.72 bc	124.84 cde	177.22 b
N_2S_1	49.67 b-e	77.21 b	106.81 b	129.62 a-d	163.77 bc
N_2S_2	51.89 a-e	85.67 ab	105.21 bc	141.00 ab	176.00 bc
N_2S_3	53.33 a-e	76.33 b	106.67 b	118.13 cde	163.19 bc
N_2S_4	50.89 a-e	79.66 b	101.78 bcd	122.59 cde	167.65 bc
N_3S_1	553.67 a-e	80.6 b	102.16 bcd	121.77 cde	165.19 bc
N_3S_2	51.78 a-e	83 ab	100.22 bcd	132.67 abc	178.67 b
N_3S_3	57.11 ab	76.67 b	93.67 cd	115.00 de	158.00 c
N_3S_4	52.22 a-e	80.89 ab	102.99 bcd	124.99 b-e	164.09 bc
N_4S_1	48.33 cde	81.3 ab	105.91 bc	126.34 b-e	169.66 bc
N_4S_2	58.52 a	93.33 a	138 a	144.67 a	195.34 a
N_4S_3	55.33 abc	81 ab	91.33 d	111.67 e	157.00 c
N_4S_4	47.89 cde	78.39 b	105.34 bc	124.52 cde	160.54 bc
Sx	2.939	6.142	5.106	7.448	8.603
Level of significance	*	*	**	*	*
CV(%)	8.44	9.19	6.24	7.41	6.47

4.1.2 Tillers number

4.1.2.1 Effect of nitrogen on tiller number

A significant variations in number of tillers hill^{-1} by different nitrogen levels were observed from BRRI dhan34 (Table 3). At 30 DAT, the highest number of tillers hill^{-1} (5.16) was found in N_3 (46.08 kg N ha^{-1}) which was followed by (4.08) with N_2 (41.47 kg N ha^{-1}), while the lowest number of tillers (3.17) was obtained in N_1 (36.87 kg N ha^{-1}). The highest number of tillers hill^{-1} (11.58) was found in N_3 which was statistically similar to N_4 and N_2 (10.75 and 10.58), whereas the lowest number (10.08) was found in N_1 at 45 DAT. At 60 DAT, the highest number of tillers hill^{-1} (17.67) was recorded in N_3 which was statistically similar to N_2, N_4 (16.83,16.67) and the lowest number (15.67) was observed in N_1. The highest number of tillers hill^{-1} (25.83) was found in N_2 which was statistically similar to N_3 and N_4 (24.75 and 24.33), whereas the lowest number (22.67) was found in N_1 at 75 DAT. At harvest, highest number of tillers hill^{-1} (23.17) was recorded in N_3 which was statistically similar to N_4 (21.92) and N_2 (21.41) whereas the lowest number (20.25) was found in N_1. Salem *et al*. (2011) and Kandil *et al.* (2010) reported that number of tillers hill^{-1} was influenced by different nitrogen levels.

4.1.2.2 Effect of sulphur on tiller number

A significant variations in number of tillers hill^{-1} by different sulphur levels were observed from BRRI dhan34 (Table 3). At 30 DAT, the highest number of tillers hill^{-1} (6.25) was found in S_1 (6.4 kg S ha^{-1}) which was followed by (4.17) with S_4 (8.8 kg S ha^{-1}), while the lowest number of tillers (1.83) was obtained in S_2 (7.2 kg S ha^{-1}). The highest number of tillers hill^{-1} (13.25) was found in S_1 which was followed by S_2 (10.92), whereas the lowest number (8.17) was found in S_4 at 45 DAT. At 60 DAT, the highest number of tillers hill^{-1} (18.50) was recorded in S_1 which was statistically similar to S_2 (17.25) and the lowest number (14.08) was observed in S_4. The highest number of tillers hill^{-1} (26.33) was found in S_1 which was statistically similar to S_3 and S_2 (24.67 and 24.25), whereas the lowest number (22.33) was found in S_4 at 75 DAT. At harvest, highest number of tillers hill^{-1} (23.16) was recorded in S_1 which was statistically similar to S_3 (21.92) and S_2 (21.75) whereas the lowest number (19.92) was found in S_4. Chandel *et al.* (2003) showed that number of tillers hill^{-1} was affected by different levels of sulphur.

4.1.2.3 Combined effect of nitrogen and sulphur on tiller number

Combined effect of nitrogen levels and sulphur levels showed significant differences for number of tillers hill^{-1} of BRRI dhan34 (Table 4). At 30 DAT, the highest number of tillers hill^{-1} (7.33) was recorded in the treatment combination of N_4S_1 (50.69 kg N ha^{-1} and 6.4 kg S ha^{-1}), which was statistically similar to N_3S_4 (46.08 kg N ha^{-1} and 8.8 kg S ha^{-1}) while the lowest number (1.33) was obtained in the treatment combination of N_1S_4 (36.87 kg N ha^{-1} and 8.8 kg S ha^{-1}). The highest number of tillers hill^{-1} (14.67) was found in the treatment combination of N_4S_1 and the lowest number (6.67) was found in the treatment combination of N_1S_4 at 45 DAT. The highest number of tillers hill^{-1} (19.67) was obtained in the treatment combination of N_3S_1, whereas the lowest number (12.33) was recorded in the treatment combination of N_1S_4 at 60 DAT. At 75 DAT, the highest number of tillers hill^{-1} (29.33) was observed in the treatment combination of N_2S_1 whereas the lowest number (18.00) was found in the treatment combination of N_1S_4. At harvest, the highest number of tillers hill^{-1} (25.00) was observed in the treatment combination of N_3S_3 which was statistically similar to N_4S_1 (25.00) whereas the lowest number (17.67) was found in the treatment combination of N_1S_4.

Table 3. Effect of different levels of nitrogen and sulphur fertilization on number of tillers hill^{-1} of BRRI dhan34 at different days after transplanting (DAT) and harvest

Treatments	Tillers hill^{-1} (No.) at				
	30 DAT	45 DAT	60 DAT	75 DAT	Harvest
<u>Levels of Nitrogen</u>					
N_1	3.17 c	10.08 b	15.67 b	22.67 b	20.25 b
N_2	4.08 b	10.58 ab	16.83 ab	25.83 a	21.41 ab
N_3	5.16 a	11.58 a	17.67 a	24.75 ab	23.17 a
N_4	3.92 b	10.75 ab	16.67 ab	24.33 ab	21.92 ab
Sx	0.270	0.456	0.574	0.918	0.819
Level of significance	**	*	*	*	*
CV(%)	16.20	10.40	8.42	9.22	9.25
<u>Levels of Sulphur</u>					
S_1	6.25 a	13.25 a	18.50 a	26.33 a	23.16 a
S_2	1.83 c	10.92 b	17.25 ab	24.25 ab	21.75 ab
S_3	4.08 b	10.67 b	17.00 b	24.67 ab	21.92 ab
S_4	4.17 b	8.17 c	14.08 c	22.33 b	19.92 b
Sx	0.552	0.758	0.696	1.131	1.205
Level of significance	**	**	**	**	*
CV(%)	13.10	17.26	10.20	11.35	13.61

Table 4. Combined effect of different levels of nitrogen and suphur fertilization on number of tillers hill^{-1} of BRRI dhan34 at different days after transplanting (DAT) and harvest

Treatments	Tillers hill^{-1} (No.) at				
	30 DAT	45 DAT	60 DAT	75 DAT	Harvest
N_1S_1	6.33 ab	13.33 ab	17.67 abc	24.00 bc	21.00 abc
N_1S_2	1.67 ef	11.33 b-e	16.67 bcd	25.33 abc	21.67 abc
N_1S_3	3.33 def	9.00 e-g	16.00 cd	23.33 bc	20.67 abc
N_1S_4	1.33 f	6.67 g	12.33 e	18.00 d	17.67 c
N_2S_1	5.67 abc	12.33 a-d	17.67 abc	29.33 a	22.00 abc
N_2S_2	2.33 ef	10.33 c-f	17.33 abc	23.33 bc	20.67 abc
N_2S_3	3.67 cde	10.33 c-f	17.00 a-d	25.67 abc	22.00 abc
N_2S_4	4.67 bcd	9.33 d-g	15.33 cd	25.00 abc	21.00 abc
N_3S_1	5.67 abc	12.67 abc	19.67 a	24.33 bc	24.67 ab
N_3S_2	1.67 ef	11.67 b-e	17.67 abc	24.33 bc	22.33 abc
N_3S_3	6.00 ab	13.33 ab	19.00 ab	27.00 abc	25.00 a
N_3S_4	7.33 a	8.67 efg	14.33 de	23.33 bc	20.67 abc
N_4S_1	7.33 a	14.67 a	19.00 ab	27.67 ab	25.00 a
N_4S_2	1.67 ef	10.33 c-f	17.33 abc	24.00 bc	22.33 abc
N_4S_3	3.33 def	10.00 c-f	16.00 cd	22.67 c	20.00 bc
N_4S_4	3.33 d-f	8.00 fg	14.33 de	23.00 bc	20.33 a-c
Sx	1.103	1.515	1.391	2.261	2.409
Level of significance	**	*	*	*	*
CV(%)	13.10	17.26	10.20	11.35	13.61

4.1.3 Number of effective tillers

4.1.3.1 Effect of nitrogen on effective tillers

Effective tillers $hill^{-1}$ of fragrant rice variety BRRI dhan34 resulted statistically significant variations due to different levels of nitrogen (Table 5). The highest number of effective tillers $hill^{-1}$ (18.92) was found from N_2 which was statistically similar (18.58 and 17.5) by N_4 and N_3, whereas the lowest number (14.83) was recorded from N_1. Haque *et al.* (2015) and Manzoor *et al.* (2006) recorded the highest number of effective $tiller^{-1}$ was found with different nitrogen levels.

4.1.3.2 Effect of sulphur on effective tillers

Statistically significant variation was recorded due to different sulphur levels for effective tillers $hill^{-1}$ of aromatic rice (Table 5). The highest number of effective tillers $hill^{-1}$ (19.25) was resulted from S_1 which was statistically similar (17.67) to S_3, while the lowest number (16.25) was found from S_4.

4.1.3.3 Combined effect of nitrogen and sulphur on effective tillers

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for effective tillers $hill^{-1}$ of scented rice (Table 6). The highest number of effective tillers $hill^{-1}$ (21.33) was found from N_2S_1, while the lowest number (11.66) was recorded from N_4S_4 treatment combination.

4.1.4 Number of non-effective tillers

4.1.4.1 Effect of nitrogen on non-effective tillers

Non-effective tillers $hill^{-1}$ of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 5). The highest number of non-effective tillers $hill^{-1}$ (5.33) was found from N_1, whereas the lowest number (3.33) was resulted from N_4. Amin *et al.* (2006) found that lesser non-effective tillers developed due to application of 60 kg ha^{-1} N.

4.1.4.2 Effect of sulphur on non-effective tillers

Statistically significant variation was found due to different sulphur in terms of the number of non-effective tillers $hill^{-1}$ of fragrant rice (Table 5). The highest number of non-effective tillers $hill^{-1}$ (5.08) was recorded from S_2, while the lowest number (3.58) was found from S_4 which was statistically similar to (3.92) from S_1 .

4.1.4.3 Combined effect of nitrogen and sulphur on non-effective tillers

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation in terms of number of non-effective tillers $hill^{-1}$ of fragrant rice (Table 6). The highest number of non-effective tillers $hill^{-1}$ (6.33) was found from N_4S_4, whereas the lowest number (2.66) was recorded from N_4S_1 treatment combination.

4.1.5 Length of panicle

4.1.5.1 Effect of nitrogen on panicle length

Panicle length of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 5). The longest panicle (26.81) was found from N_4 which was statistically similar (26.00 and 25.89) by N_3 and N_2, whereas the shortest panicle (24.79) was recorded from N_1. Panicle length was increased due to different levels of nitrogen. Manzoor *et al.* (2006), Salahuddin *et al.* (2009) and Kandil *et al.* (2010) conducted similar results in their experiment.

4.1.5.2 Effect of sulphur on panicle length

Statistically significant variation was recorded due to different sulphur levels for panicle lenght of aromatic rice (Table 5). The longest panicle (28.48) was resulted from S_1, while the shortest panicle (23.06) was found from S_4.

4.1.5.3 Combined effect of nitrogen and sulphur on panicle length

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for panicle length of scented rice (Table 6). The longest panicle (30.73) was found from N_4S_1, while the lowest number (20.90) was recorded from N_4S_4 treatment combination.

4.1.6 Number of filled grains

4.1.6.1 Effect of nitrogen on filled grains

Filled grains panicle^{-1} of fragrant rice variety BRRI dhan34 resulted statistically significant variations due to different levels of nitrogen (Table). The highest number of filled grains panicle^{-1} (233.58) was found from N_2 which was statistically similar (220.17 and 219.83) by N_3 and N_1, whereas the lowest number (218.17) was recorded from N_4. Kandil *et al.* (2010) and Manzoor *et al.* (2006) reported that N influenced filled grains at different levels of nitrogen.

4.1.6.2 Effect of sulphur on filled grains

Statistically significant variation was recorded due to different sulphur levels for filled grains panicle^{-1} of aromatic rice (Table 5). The highest number of filled grains panicle^{-1} (260.42) was resulted from S_1, while the lowest number (178.58) was found from S_4. Singh and Singh (2002) observed that filled grains panicle^{-1} was significant with increasing levels of S up to 40 kg S ha^{-1}.

4.1.6.3 Combined effect of nitrogen and sulphur on filled grains

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for filled grains panicle^{-1} of scented rice (Table 6). The highest number of filled grains panicle^{-1} (268.33) was found from N_2S_1, while the lowest number (170.67) was recorded from N_4S_4 treatment combination.

4.1.7 Number of unfilled grains

4.1.7.1 Effect of nitrogen on unfilled grains

Unfilled grains panicle^{-1} of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 5). The highest number of unfilled grains panicle^{-1} (28.00) was found from N_3 which was statistically similar (25.83) by N_2, whereas the lowest number (22.33) was recorded from N_1.

4.1.7.2 Effect of sulphur on unfilled grains

Statistically significant variation was recorded due to different sulphur levels for unfilled grains panicle^{-1} of aromatic rice (Table 5). The highest number of unfilled grains panicle^{-1} (33.5) was resulted from S_3, while the lowest number (20.0) was found from S_4. Nad *et al.* (2001) noticed that unfilled grains were influenced by different sulphur levels.

4.1.7.3 Combined effect of nitrogen and sulphur on unfilled grains

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for unfilled grains panicle^{-1} of scented rice (Table 6). The highest number of unfilled grains panicle^{-1} (41.0) was found from N_4S_4, while the lowest number (12.67) was recorded from N_4S_1 treatment combination.

4.1.8 Number of total grains

4.1.8.1 Effect of nitrogen on total grains

Total grains panicle^{-1} of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 5). The highest number of total grains panicle^{-1} (261.67) was found from N_3 which was statistically similar (254.83 and 248.67) by N_4 and N_2, whereas the lowest number (235.17) was recorded from N_1. Yoseftabar (2013) and Haque *et al.* (2015) found the highest grains panicle^{-1} was found with 100 kg ha^{-1} N followed by 140 kg ha^{-1} N.

4.1.8.2 Effect of sulphur on total grains

Statistically significant variation was recorded due to different sulphur levels for total grains panicle^{-1} of aromatic rice (Table 5). The highest number of total grains panicle^{-1} (302.33) was resulted from S_1, while the lowest number (204.92) was found from S_4.

4.1.8.3 Combined effect of nitrogen and sulphur on total grains

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for total grains panicle^{-1} of scented rice (Table 6). The highest number of total grains panicle^{-1} (328.33) was found from N_4S_1, while the lowest number (187.33) was recorded from N_4S_4 treatment combination.

Table 5. Effect of different levels of nitrogen and sulphur fertilization on effective, non-effective tillers hills^{-1}, panicle length, filled, unfilled and total grains panicle^{-1} of BRRI dhan34

Treatments	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains panicle^{-1} (No.)
Levels of Nitrogen						
N_1	14.83 b	5.33 a	24.79 b	219.83 ab	22.33 c	235.17 b
N_2	18.92 a	3.92 b	25.89 ab	233.58 a	25.83 ab	248.67 ab
N_3	17.50 a	4.25 b	26.00 ab	220.17 ab	28.00 a	261.67 a
N_4	18.58 a	3.33 c	26.81 a	218.17 b	24.92 bc	254.83 ab
Sx	2.497	0.226	0.744	5.98	1.142	8.486
Level of significance	*	**	*	*	**	*
CV(%)	12.96	13.14	7.05	6.98	10.29	8.31
Levels of Sulphur						
S_1	19.25 a	3.92 bc	28.48 a	260.42 a	23.50 bc	302.33 a
S_2	16.67 b	5.08 a	25.90 b	227.33 b	24.08 b	246.75 b
S_3	17.67 ab	4.25 b	26.06 b	225.42 b	33.50 a	246.33 b
S_4	16.25 b	3.58 c	23.06 c	178.58 c	20.00 c	204.92 c
Sx	2.357	0.272	0.909	14.58	1.850	15.360
Level of significance	*	**	**	**	**	**
CV(%)	17.52	15.84	8.61	16.18	18.37	15.04

Table 6. Combined effect of different levels of nitrogen and sulphur fertilization on effective, non-effective tillers hills^{-1}, panicle length, filled, unfilled and total grains panicle^{-1} of BRRI dhan34

Treatments	Effective tillers hill^{-1} (No.)	Non-effective tillers hill^{-1} (No.)	Panicle length (cm)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains panicle^{-1} (No.)
N_1S_1	17.33 ab	3.67 cd	24.42 bcd	255.33 ab	18.00 de	286.00 abc
N_1S_2	16.00 abc	5.67 ab	26.04 bc	216.67 a-d	26.33 bc	234.00 c-f
N_1S_3	14.33 bcd	3.67 cd	27.80 ab	221.00 a-d	32.33 b	233.33 c-f
N_1S_4	17.67 ab	5.67 ab	223.52 cd	186.33 cd	27.67 bc	202.67 ef
N_2S_1	21.33 a	4.67 bc	25.68 bc	268.33 a	24.67 cd	289.33 abc
N_2S_2	16.00 bc	4.67 bc	25.73 bc	225.33 abc	22.33 cd	251.67 b-e
N_2S_3	18.33 ab	3.67 cd	27.93 ab	224.67 a-d	33.00 b	245.33 c-f
N_2S_4	18.33 ab	2.66 d	24.23 bcd	179.33 cd	23.33 cd	208.33 ef
N_3S_1	21.00 a	3.67 cd	26.99 abc	266.67 ab	23.67 cd	305.67 ab
N_3S_2	16.00 bc	6.33 a	25.93 bc	243.00 ab	24.33 cd	252.67 b-e
N_3S_3	17.33 ab	3.67 cd	27.15 abc	245.00 ab	21.00 cd	267.0 bcd
N_3S_4	17.33 ab	3.33 d	23.60 cd	178.00 cd	23.00 cd	221.33 def
N_4S_1	21.33 a	2.66 d	30.73 a	251.33 ab	12.67 e	328.33 a
N_4S_2	118.67 ab	3.67 cd	25.90 bc	224.33 a-d	23.33 cd	248.67 b-e
N_4S_3	16.67 abc	3.33 d	27.43 ab	211.00 bcd	27.67 bc	239.67 c-f
N_4S_4	11.66 d	6.33 a	20.90 d	170.67 d	41.00 a	187.33 f
Sx	2.351	0.544	1.818	25.95	3.401	4.318
Level of significance	*	**	*	*	*	*
CV(%)	17.52	15.84	8.61	16.18	18.07	15.04

4.1.9 Weight of 1000-grains

4.1.9.1 Effect of nitrogen on 1000-grains weight

Weight of 1000-grains of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 7). The maximum weight (12.97 g) was found from N_2, whereas the minimum weight (11.65 g) was recorded from N_4. Weight of 1000-grains was influenced with various levels of nitrogen. Salem *et al*. (2011), Kandil *et al.* (2010) and Manzoor *et al.* (2006) found the similar results in their experiment.

4.1.9.2 Effect of sulphur on 1000-grains weight

Statistically significant variation was recorded due to different sulphur levels for the weight of 1000-grains of aromatic rice (Table 7). The maximum weight (13.27 g) was resulted from S_1, while the minimum weight (11.48 g) was found from S_4.

4.1.9.3 Combined effect of nitrogen and sulphur on 1000-grains weight

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the weight of 1000-grains of scented rice (Table 8). The maximum weight (13.21 g) was found from N_2S_1 which were statistically similar with N_2S_2, N_2S_3 and N_2S_4, while the minimum weight (10.13 g) was recorded from N_4S_4 treatment combination.

4.1.10 Grain yield

4.1.10.1 Effect of nitrogen on grain yield

Grain yield of fragrant rice variety BRRI dhan34 resulted statistically significant variations due to different levels of nitrogen (Table 7). The maximum grain yield (5.19 t ha^{-1}) was found from N_2 which was statistically similar (4.78 and 4.54) by N_1 and N_3, whereas the minimum grain yield (3.71 t ha^{-1}) was recorded from N_4.

4.1.10.2 Effect of sulphur on grain yield

Statistically significant variation was recorded due to different sulphur levels for the grain yield of aromatic rice (Table 7). The maximum grain yield (4.82 t ha^{-1}) was found from S_1 which was statistically similar (4.56 and 4.49) by S_2 and S_3, whereas the minimum grain yield (4.35 t ha^{-1}) was recorded from S_4. Biswas *et al*. (2004) and Mandal *et al*. (2000) assessed that grain yield affected due to different sulphur levels.

4.1.10.3 Combined effect of nitrogen and sulphur on grain yield

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the grain yield of scented rice (Table 8). The maximum grain yield (5.48 t ha^{-1}) was found from N_2S_1 which were statistically similar with $N_2S_{2,}$ N_2S_3 and $N_2S_{4,}$ while the minimum grain yield (3.29 t ha^{-1}) was recorded from N_4S_4 treatment combination.

4.1.11 Straw yield

4.1.11.1 Effect of nitrogen on straw yield

Straw yield of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 7). The maximum straw yield (5.74 t ha^{-1}) was found from N_4 which was statistically similar (5.66) by N_3, whereas the minimum straw yield (5.24 t ha^{-1}) was recorded from N_1. Kandil *et al.* (2010) and Muhammad *et al.* (2005) showed that different nitrogen levels increased straw yield.

4.1.11.2 Effect of sulphur on straw yield

Statistically significant variation was recorded due to different sulphur levels for the straw yield of aromatic rice (Table 7). The maximum straw yield (6.16 t ha^{-1}) was found from S_1, whereas the minimum straw yield (4.89 t ha^{-1}) was recorded from S_3. Mandal *et al*. (2000) found that different doses of S influenced significantly the straw yield.

4.1.11.3 Combined effect of nitrogen and sulphur on straw yield

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the straw yield of scented rice (Table 8). The maximum straw yield (6.63 t ha^{-1}) was found from N_4S_1, while the minimum straw yield (4.67 t ha^{-1}) was recorded from N_1S_4 treatment combination.

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

4.1.12.1 Effect of nitrogen on biological yield

Biological yield of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 7). The maximum biological yield (10.68 t ha^{-1}) was found from N_2 which was statistically similar (10.21 and 10.02) by N_3 and N_1, whereas the minimum biological yield (9.44 t ha^{-1}) was recorded from N_4. Mohaddesi *et al.* (2011) found that increasing N fertilizer levels up to 300 kg N ha^{-1} found in increases in biological yield.

4.1.12.2 Effect of sulphur on biological yield

Statistically significant variation was recorded due to different sulphur levels for the biological yield of aromatic rice (Table 7). The maximum biological yield (10.98 t ha^{-1}) was found from S_1 which was statistically similar (10.09) by S_2, whereas the minimum biological yield (9.38 t ha^{-1}) was recorded from S_3.

4.1.12.3 Combined effect of nitrogen and sulphur on biological yield

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the biological yield of scented rice (Table 8). The maximum biological yield (11.65 t ha^{-1}) was found from N_2S_3, while the minimum biological yield (8.77 t ha^{-1}) was recorded from N_4S_3 treatment combination.

4.1.13 Harvest index(%)

4.1.13.1 Effect of nitrogen on harvest index

Harvest index of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 7). The highest harvest index (48.59) was found from N_2 and the lowest harvest index (39.25) was recorded from N_4. Khorshidi *et al.* (2011) showed that different nitrogen levels had positive relation with harvest index.

4.1.13.2 Effect of sulphur on harvest index

Statistically significant variation was recorded due to different sulphur levels for the harvest index of aromatic rice (Table 7). The highest harvest index (47.86) was found from S_3 which was statistically similar (45.19) by S_2, whereas the lowest harvest index (43.89) was recorded from S_1. Chandel *et al.* (2003) assessed that harvest index was influenced by various sulphur levels.

4.1.13.3 Combined effect of nitrogen and sulphur on harvest index

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the harvest index of scented rice (Table 8). The highest harvest index (52.44) was found from N_2S_1, while the lowest harvest index (36.23) was recorded from N_4S_4 treatment combination.

Table 7. Effect of different levels of nitrogen and sulphur fertilization on weight of 1000-grains, grain, straw, biological yield and harvest index of BRRI dhan34

Treatments	Weight of 1000-grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Levels of Nitrogen					
N_1	12.39 ab	4.78 ab	5.24 c	10.02 ab	47.7 ab
N_2	12.97 a	5.19 a	5.49 b	10.68 a	48.59 a
N_3	12.25 ab	4.55 ab	5.66 ab	10.21 ab	44.56 b
N_4	11.65 b	3.71 b	5.74 a	9.45 b	39.25 c
Sx	0.131	0.199	0.090	0.440	0.098
Level of significance	**	*	**	**	*
CV(%)	3.02	10.70	3.99	4.32	8.10
Levels of Sulphur					
S_1	13.27 a	4.82 a	6.16 a	10.98 a	43.89 b
S_2	12.00 b	4.56 ab	5.53 b	10.09 ab	45.19 ab
S_3	12.26 b	4.49 ab	4.89 c	9.38 b	47.86 a
S_4	11.48 c	4.35 b	5.55 b	9.9 ab	43.93 b
Sx	0.639	0.249	0.279	0.970	1.099
Level of significance	**	*	**	*	**
CV(%)	10.69	13.40	12.35	11.30	5.96

Table 8. Combined effect of different levels of nitrogen and sulphur fretilization on weight of 1000-grains, grain, straw, biological yield and harvest index of BRRI dhan34

Treatments	Weight of 1000-grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
N_1S_1	11.28 bcd	4.89 bc	4.82 de	9.71 bcd	50.36 ab
N_1S_2	10.96 cd	4.76 bcd	5.70 a-d	10.46 abc	45.5 bc
N_1S_3	11.58 bcd	4.75 bcd	5.14 de	9.79 bcd	48.02 abc
N_1S_4	10.82 cd	4.71 bcd	4.67 e	9.38 cd	50.21 ab
N_2S_1	13.21 a	5.48 a	4.97 de	10.45 abc	52.44 a
N_2S_2	12.36 ab	5.21 ab	5.53 b-e	10.74 ab	48.51 abc
N_2S_3	12.13 abc	5.15 ab	6.50 ab	11.65 a	44.21 bcd
N_2S_4	12.36 ab	4.92 abc	5.65 a-e	10.57 ab	46.54 bc
N_3S_1	10.87 cd	4.63 cd	5.24 de	9.87 bcd	46.9 bc
N_3S_2	12.40 abc	4.54 cde	5.55 b-e	10.09 bc	45.00 bcd
N_3S_3	11.35 bcd	4.53 cde	6.27 abc	10.8 ab	41.9 cd
N_3S_4	12.15 bc	4.49 cde	5.51 b-e	10.0 bc	44.9 bcd
N_4S_1	10.76 cd	4.27 de	6.63 a	10.9 ab	39.17 cde
N_4S_2	12.30 bc	3.73 def	5.35 cde	9.08 de	41.07 cd
N_4S_3	12.05 bc	3.54 def	5.23 de	8.77 e	40.36 cde
N_4S_4	10.13 d	3.29 f	5.79 a-d	9.08 de	36.23 e
Sx	1.074	0.498	0.558	1.940	2.197
Level of significance	*	**	*	*	**
CV(%)	10.69	13.40	12.35	11.30	5.96

4.2 Quality contributing characters of fragrant rice

4.2.1 Length of grain rice

4.2.1.1 Effect of nitrogen on grain length

Grain length of fragrant rice resulted non-significant variations due to different levels of nitrogen (Figure 1). The highest grain length (5.1) was found from N_3 and the lowest grain length (4.93) was recorded from N_4.

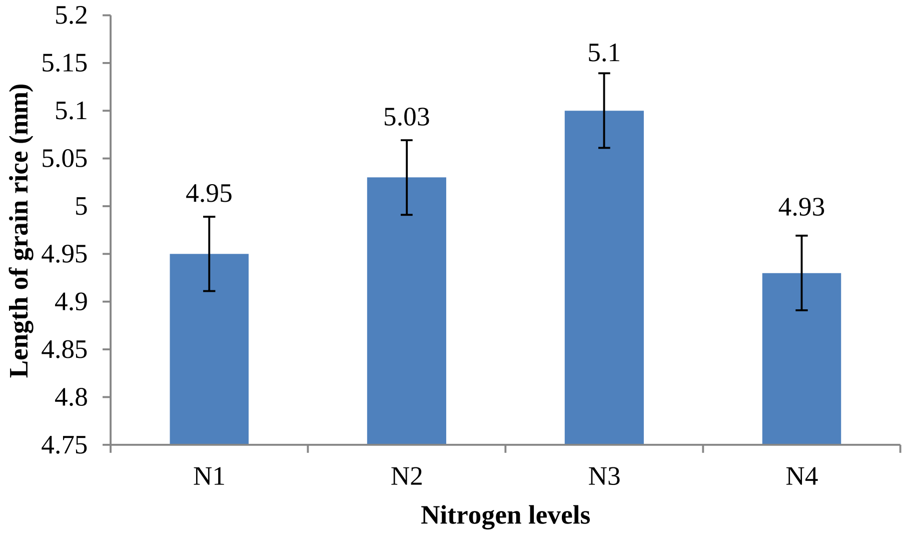

Figure 1. Effect of different levels of N on grain length (mm) of BRRI dhan34

4.2.1.2 Effect of sulphur on grain length

Statistically non-significant variation was recorded due to different sulphur levels for the grain length of aromatic rice (Figure 2). The highest grain length (5.11) was found from S_3, whereas the lowest grain length (5.05) was recorded from S_1.

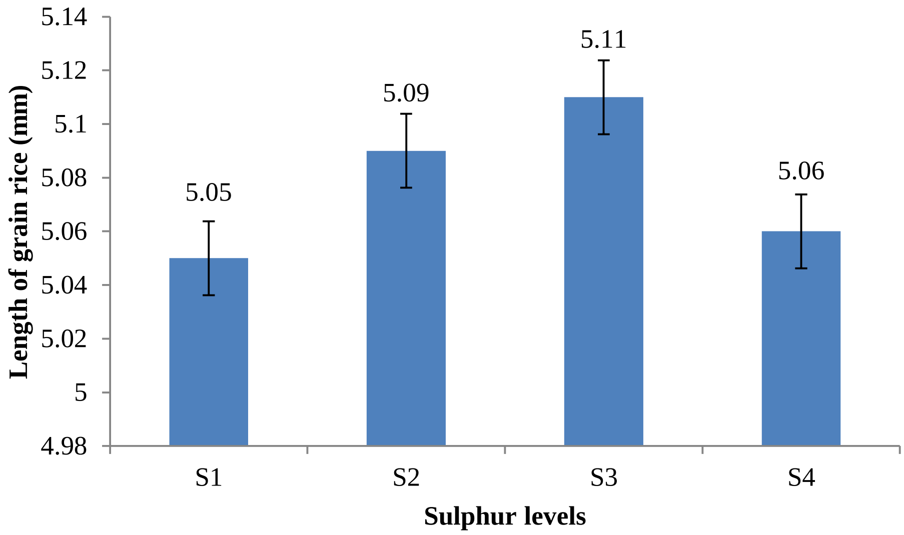

Figure 2. Effect of different levels of S on grain length (mm) of BRRI dhan34

4.2.1.3 Combined effect of nitrogen and sulphur on grain length

Combined effect of different levels of nitrogen and sulphur showed statistically non-significant variation for the grain length of scented rice (Table 9). The highest grain length (5.18) was found from N_3S_4, while the lowest grain length (4.98) was recorded from N_4S_3 treatment combination.

4.2.2 Breadth of grain rice

4.2.2.1 Effect of nitrogen on grain breadth

Grain breadth of fragrant rice resulted statistically non-significant variations due to different levels of nitrogen (Figure 3). The highest grain breadth (2.18) was found from N_3 and the lowest grain breadth (2.13) was recorded from N_4.

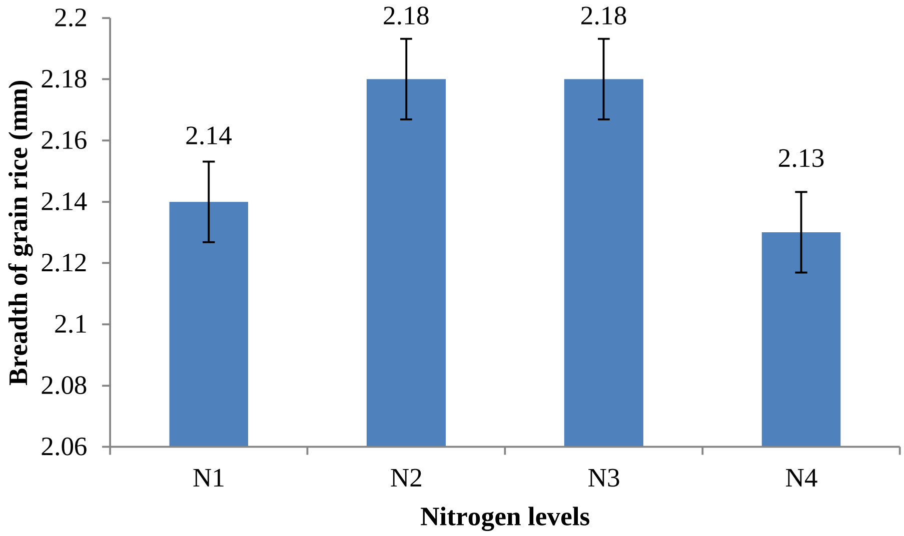

Figure 3. Effect of different levels of N on grain breadth (mm) of BRRI dhan34

4.2.2.2 Effect of sulphur on grain breadth

Statistically non-significant variation was recorded due to different sulphur levels for the grain breadth of aromatic rice (Figure 4). The highest grain breadth (2.18) was found from S_3 whereas the lowest grain breadth (2.13) was recorded from S_2.

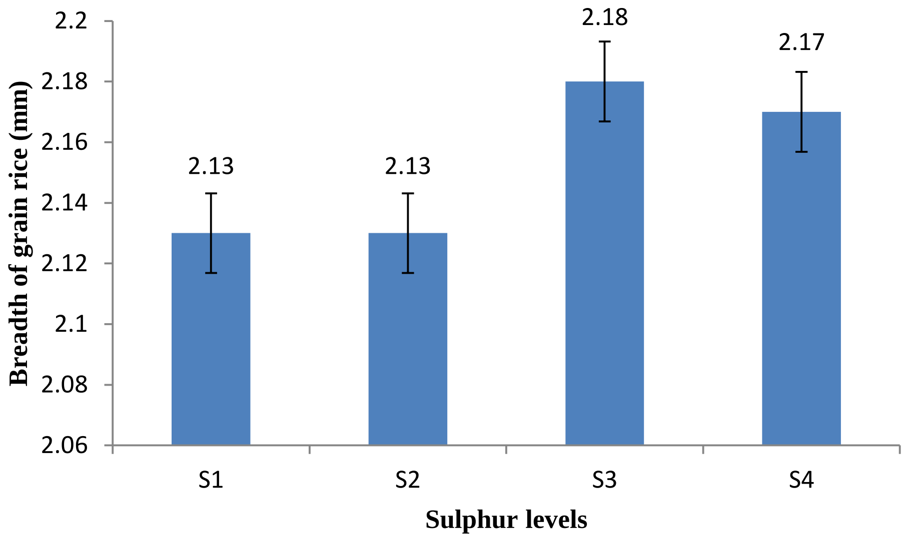

Figure 4. Effect of different levels of S on grain breadth (mm) of BRRI dhan34

4.2.2.3 Combined effect of nitrogen and sulphur on grain breadth

Combined effect of different levels of nitrogen and sulphur showed statistically non-significant variation for the grain breadth of scented rice (Table 9). The highest grain breadth (2.20) was found from N_2S_1, while the lowest grain breadth (2.07) was recorded from N_1S_1 treatment combination.

4.2.3 Milled rice

4.2.3.1 Effect of nitrogen on milled rice

Milled rice of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Figure 5). The maximum milled rice (74.82) was found from N_4 which was statistically similar (72.01 and 71.37) by N_2 and N_3 and the minimum milled rice (69.27) was recorded from N_1.

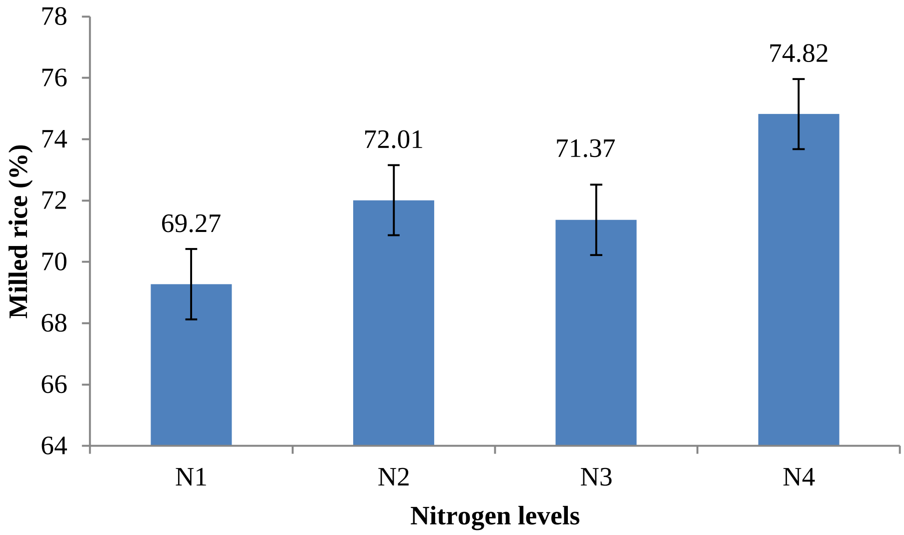

Figure 5. Effect of different levels of N on milled rice (%) of BRRI dhan34

4.2.3.2 Effect of sulphur on milled rice

Statistically significant variation was recorded due to different sulphur levels for the milled rice of aromatic rice (Figure 6). The maximum milled rice(76.16) was found from S_2, whereas the minimum milled rice (67.72) was recorded from S_3.

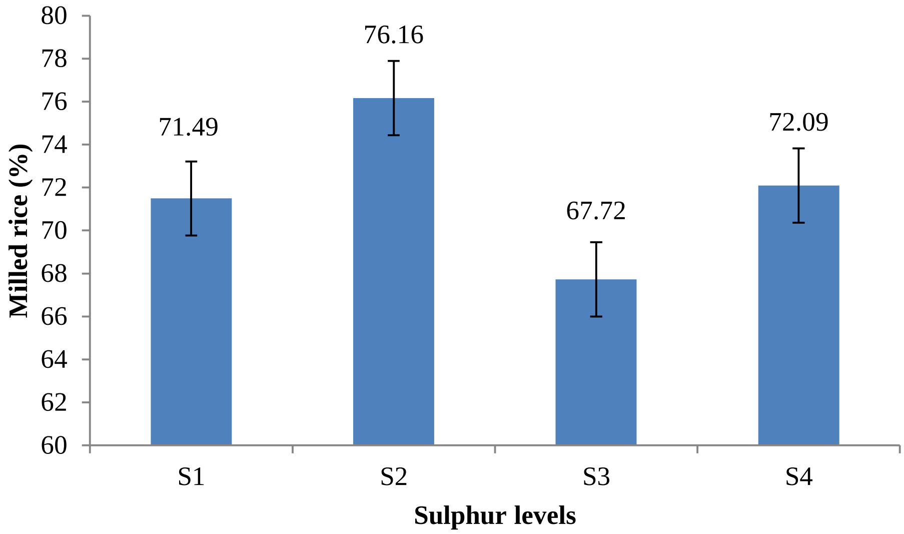

Figure 6. Effect of different levels of S on milled rice (%) of BRRI dhan34

4.2.3.3 Combined effect of nitrogen and sulphur on milled rice

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the milled rice of scented rice (Table 9). The maximum milled rice (77.50) was found from N_4S_1, while the minimum milled rice (65.67) was recorded from N_1S_1 treatment combination.

4.2.4 Broken rice

4.2.4.1 Effect of nitrogen on broken rice

Broken rice of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Figure 7). The maximum broken rice (3.89) was found from N_1 which was statistically similar (3.62) by N_4 and the minimum broken rice (3.36) was recorded from N_3 which was statistically similar (3.57) by N_2 .

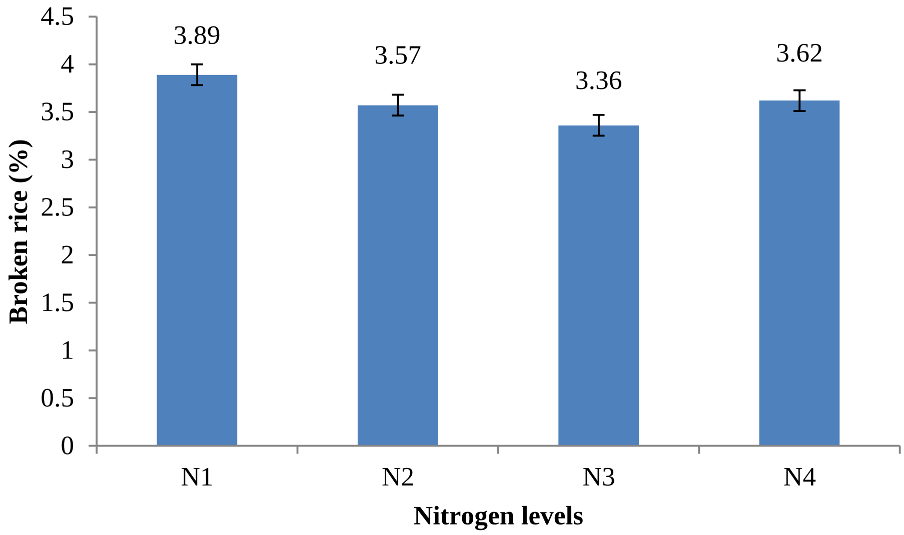

Figure 7. Effect of different levels of N on broken rice (%) of BRRI dhan34

4.2.4.2 Effect of sulphur on broken rice

Statistically significant variation was recorded due to different sulphur levels for the broken rice of aromatic rice (Figure 8). The maximum broken rice(4.06) was found from S_4, whereas the minimum broken rice (3.09) was recorded from S_1.

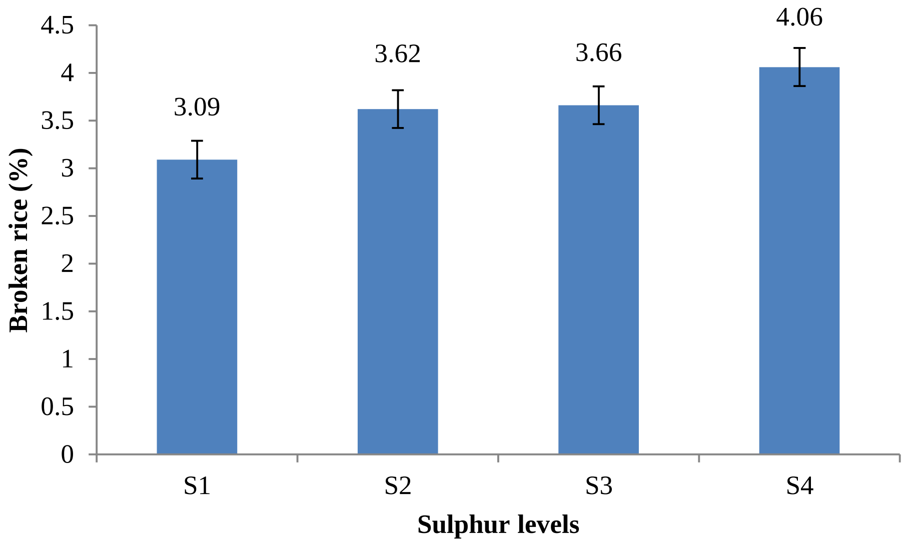

Figure 8. Effect of different levels of S on broken rice (%) of BRRI dhan34

4.2.4.3 Combined effect of nitrogen and sulphur on broken rice

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the broken rice of scented rice (Table 9). The maximum broken rice (4.17) was found from N_1S_4, while the minimum broken rice (2.87) was recorded from N_2S_1 treatment combination.

4.2.5 Husk

4.2.5.1 Effect of nitrogen on husk

Husk of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Figure 9). The maximum husk (26.13) was found from N_2 which was statistically similar (24.81 and 24.43) by N_4 and N_3 and the minimum husk (23.22) was recorded from N_1 .

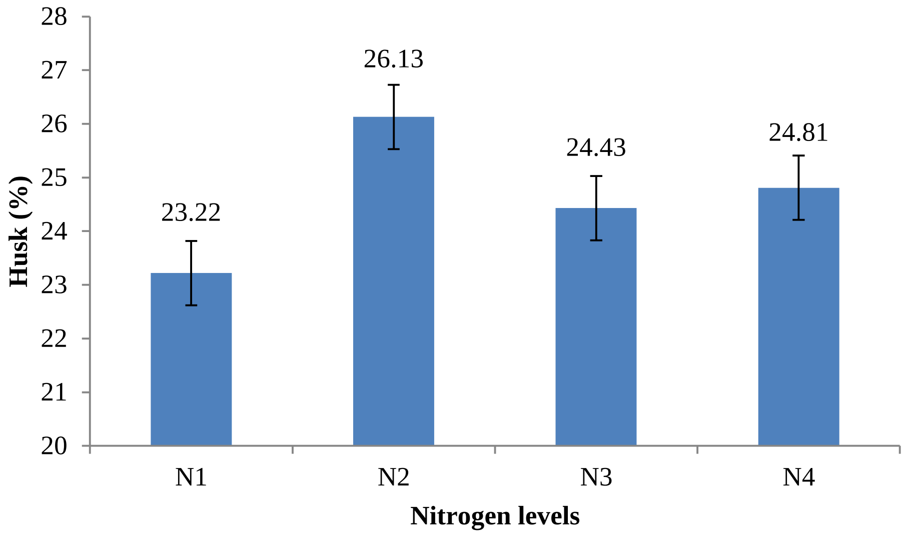

Figure 9. Effect of different levels of N on husk (%) of BRRI dhan34

4.2.5.2 Effect of sulphur on husk

Statistically significant variation was recorded due to different sulphur levels for the husk of aromatic rice (Figure 9). The maximum husk (29.33) was found from S_2, whereas the minimum husk (19.63) was recorded from S_4.

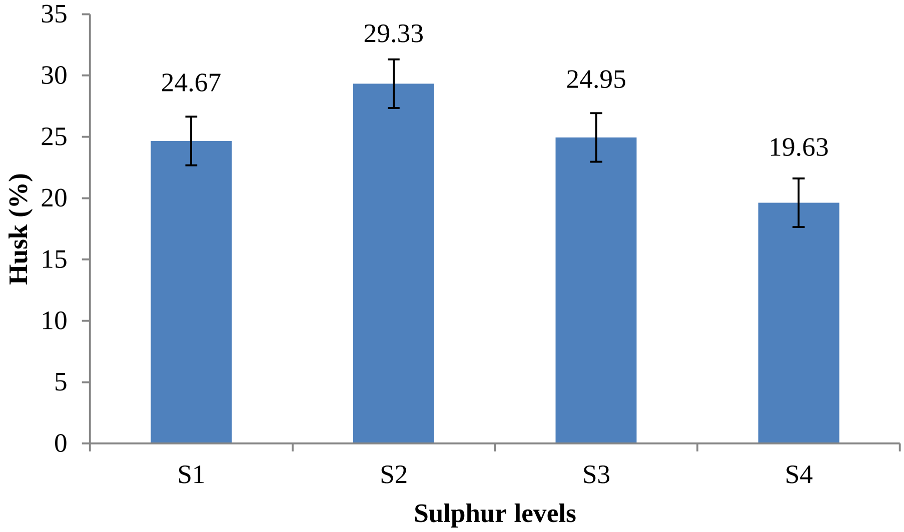

Figure 10. Effect of different levels of S on husk (%) of BRRI dhan34

4.2.5.3 Combined effect of nitrogen and sulphur on husk

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the husk of scented rice (Table 9). The maximum husk (30.00) was found from N_3S_2, while the minimum husk (17.00) was recorded from N_3S_4 treatment combination.

Table 9. Combined effect of different levels of nitrogen and sulphur fertilization on length, breadth, milled, broken and hush of BRRI dhan34

Treatments	Length of grain rice (mm)	Breadth of grain rice (mm)	Milled rice (%)	Broken rice (%)	Husk (%)
N_1S_1	5.05	2.13	65.67 d	3.10 de	21.84 def
N_1S_2	5.02	2.07	74.65 abc	4.13 ab	29.00 ab
N_1S_3	5.04	2.20	67.79 cd	4.13 ab	23.04 c-f
N_1S_4	5.03	2.17	68.97 bcd	4.17 a	19.00 fg
N_2S_1	5.06	2.20	71.22a-d	2.87 e	26.85 abc
N_2S_2	5.00	2.20	76.73 a	3.62 a-d	29.33 ab
N_2S_3	5.03	2.17	68.57 bcd	3.72 abc	27.02 abc
N_2S_4	5.07	2.13	71.52 a-d	4.07 ab	21.33 ef
N_3S_1	5.06	2.10	71.58 a-d	3.18 cde	24.35 cde
N_3S_2	5.12	2.17	76.17 ab	3.16 cde	30.00 a
N_3S_3	5.1	2.20	67.08 cd	3.13 de	26.36 abc
N_3S_4	5.18	2.23	70.64 a-d	3.97 ab	17.00 g
N_4S_1	4.99	2.10	77.50 a	3.24 cde	25.66 bcd
N_4S_2	5.08	2.10	77.07 a	3.57 bcd	29.00 ab
N_4S_3	4.98	2.17	67.45 cd	3.64 a-d	23.39 cde
N_4S_4	5.06	2.17	77.25 a	4.04 ab	21.19 efg
Sx	---	---	3.548	0.269	1.948
Level of significance	NS	NS	*	*	*
CV(%)	7.41	6.84	6.21	9.40	9.48

4.2.6 Protein content

4.2.6.1 Effect of nitrogen on protein content

Protein content of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 10). The highest protein content (8.39) was found from N_4 which was statistically similar (8.38 and 8.20) by N_3 and N_2 and the lowest protein content (7.93) was recorded from N_1.

4.2.6.2 Effect of sulphur on protein content

Statistically significant variation was recorded due to different sulphur levels for the protein content of aromatic rice (Table 10). The highest protein content (8.84) was found from S_2, which was statistically similar (8.19 and 8.19) by S_1 and S_3, whereas the lowest protein content (7.68) was recorded from S_4. Islam *et al.* (2006) and Singh and Singh (2002) conducted that protein synthesis influenced by different levels of sulphur.

4.2.6.3 Combined effect of nitrogen and sulphur on protein content

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the protein content of scented rice (Table 11). The highest protein content (9.03) was found from N_4S_2, while the lowest protein content (7.40) was recorded from N_1S_4 treatment combination.

4.2.7 Zn content (mg g^{-1}) on dry weight basis

4.2.7.1 Effect of nitrogen on Zn content

Zn content of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 10). The highest Zn content (0.147) was found from N_1 which was statistically similar (0.140 and 0.139) by N_4 and N_2 and the lowest Zn content (0.131) was recorded from N_3 .

4.2.7.2 Effect of sulphur on Zn content

Statistically significant variation was recorded due to different sulphur levels for the Zn content of aromatic rice (Table 10). The highest Zn content (0.144) was found from S_1, which was statistically similar (0.139 and 0.138) by S_4 and S_2, whereas the lowest Zn content (0.136) was recorded from S_3. Alamdari *et al.* (2007) showed that different levels of sulphur influenced Zn content.

4.2.7.3 Combined effect of nitrogen and sulphur on Zn content

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the Zn content of scented rice (Table 11). The highest Zn content (0.154) was found from N_2S_1, while the lowest Zn content (0.119) was recorded from N_3S_3 treatment combination.

4.2.8 Amylose content

4.2.8.1 Effect of nitrogen on amylose content

Amylose content of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 10). The highest amylose content (24.79) was found from N_1 which was statistically similar (23.67 and 22.99) by N_2 and N_3 and the lowest amylose content (20.08) was recorded from $N_{4.}$

4.2.8.2 Effect of sulphur on amylose content

Statistically significant variation was recorded due to different sulphur levels for the amylose content of aromatic rice (Table 10). The highest amylose content (25.67) was found from S_4, which was statistically similar (23.20) by S_2, whereas the lowest amylose content (20.92) was recorded from S_3.

4.2.8.3 Combined effect of nitrogen and sulphur on amylose content

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the amylose content of scented rice (Table 11). The highest amylose content (27.00) was found from N_1S_4, while the lowest amylose content (14.73) was recorded from N_4S_1 treatment combination.

4.2.9 Proline content on dry weight basis

4.2.9.1 Effect of nitrogen on proline content

Proline content of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 10). The highest proline content (21.83) was found from N_1 and the lowest proline content (18.48) was recorded from N_4. Zhaowen *et al.* (2018) found that proline contents influenced by different nitrogen levels.

4.2.9.2 Effect of sulphur on proline content

Statistically significant variation was recorded due to different sulphur levels for the proline content of aromatic rice (Table 10). The highest proline content (22.00) was found from S_3, which was statistically similar (20.92) to S_4, whereas, the lowest proline content (17.50) was recorded from S_1.

4.2.9.3 Combined effect of nitrogen and sulphur on proline content

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the proline content of scented rice (Table 11). The highest proline content (24.00) was found from N_1S_2, while the lowest proline content (14.73) was recorded from N_4S_3 treatment combination.

4.2.10 Grain-2AP on dry weight basis

4.2.10.1 Effect of nitrogen on grain 2-AP content

Grain-2AP of fragrant rice resulted statistically significant variations due to different levels of nitrogen (Table 10). The maximum Grain-2AP content (0.823) was found from N_1 which was statistically similar (0.751) by N_2 and the minimum Grain-2AP (0.724) was recorded from N_4. Zhaowen *et al.* (2018) found that grain-2AP contents influenced by different nitrogen levels.

4.2.10.2 Effect of sulphur on grain 2-AP content

Statistically significant variation was recorded due to different sulphur levels for the Grain-2AP of aromatic rice (Table 10). The maximum Grain-2AP (0.959) was found from S_4, whereas the minimum Grain-2AP (0.507) was recorded from S_1.

4.2.10.3 Combined effect of nitrogen and sulphur on grain 2-AP content

Combined effect of different levels of nitrogen and sulphur showed statistically significant variation for the Grain-2AP of scented rice (Table 11). The maximum Grain-2AP (0.980) was found from N_1S_4, while the minimum Grain-2AP (0.493) was recorded from N_4S_1 treatment combination.

Table 10. Effect of different levels of nitrogen and sulphur fertilization on protein, Zn, amylose, proline and grain-2AP content in BRRI dhan34

Treatments	Protein content (%)	Zn content (mg g^{-1}) on dry weight basis	Amylose content (%)	Proline content (mg g^{-1}) on dry weight basis	Grain-2AP (μg g^{-1}) on dry weight basis
Levels of Nitrogen					
N_1	7.93b	0.147 a	24.79 a	21.83 a	0.823 a
N_2	8.20 ab	0.139 ab	23.67 ab	20.43 b	0.751 ab
N_3	8.38 a	0.131 b	22.99 ab	19.92 b	0.728 b
N_4	8.39 a	0.140 a	20.08 b	18.48 c	0.724 b
Sx	0.181	3.80	1.468	0.394	0.031
Level of significance	**	*	*	**	*
CV(%)	5.39	6.69	15.71	4.79	10.28
Levels of Sulphur					
S_1	8.19 ab	0.144 a	21.75 b	17.50 c	0.507 c
S_2	8.84 a	0.138 ab	23.20 ab	20.24 b	0.775 b
S_3	8.19 ab	0.136 b	20.92 b	22.00 a	0.784 b
S_4	7.68 b	0.139 ab	25.67 a	20.92 ab	0.959 a
Sx	0.319	3.98	1.275	0.666	0.028
Level of significance	**	*	**	**	**
CV(%)	9.50	7.01	13.65	8.09	9.26

Table 11. Combined effect of different levels of nitrogen and sulphur fertilization on protein, zn, amylose, proline and grain-2AP content in BRRI dhan34

Treatments	Protein content (%)	Zn content (mg g^{-1}) on dry weight basis	Amylose content (%)	Proline content (mg g^{-1}) on dry weight basis	Grain-2AP (µg g^{-1}) on dry weight basis
N_1S_1	8.35 a-d	0.153 ab	23.47 abc	22.33 ab	0.670 d
N_1S_2	9.00 a	0.140 a-e	23.53 abc	24.00 a	0.967 a
N_1S_3	8.25 a-d	0.151 abc	21.33 abc	19.00 cde	0.967 a
N_1S_4	7.40 d	0.145 a-d	27.00 a	22.00 ab	0.980 a
N_2S_1	7.54 bcd	0.154 a	25.50 ab	17.67 e	0.710 cd
N_2S_2	8.84 ab	0.138 b-e	21.60 abc	21.67 ab	0.520 e
N_2S_3	7.94 a-d	0.133 def	19.33 cd	17.33 e	0.933 ab
N_2S_4	7.98 a-d	0.129 def	24.68 abc	17.91de	0.747 cd
N_3S_1	8.26 a-d	0.124 ef	23.29 abc	20.50 bc	0.790 cd
N_3S_2	8.50 a-d	0.139 a-e	22.99 abc	23.00 ab	0.500 e
N_3S_3	8.02 a-d	0.119 f	21.00 bc	17.00 e	0.957 ab
N_3S_4	7.50 cd	0.141 a-d	24.67 abc	21.33 bc	0.757 cd
N_4S_1	8.63 abc	0.146 a-d	14.73 d	20.46 bcd	0.493 e
N_4S_2	9.03 a	0.135 c-f	24.69 abc	21.33 bc	0.513 e
N_4S_3	8.54 a-d	0.141 a-e	22.00 abc	16.67 e	0.767 cd
N_4S_4	7.83 a-d	0.140 a-e	26.33 ab	20.54 bc	0.830 bc
Sx	0.638	0.016	2.549	1.219	0.059
Level of significance	**	*	*	*	*
CV(%)	9.50	7.01	13.65	8.09	9.26

CHAPTER 5
SUMMARY AND CONCLUSION

The study was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during the period from June to December 2018 to assess the yield and aromatic quality of fragrant rice as influenced by nitrogen and sulphur fertilization. The variety BRRI dhan34 was used for this experiment. The experiment consisted of two factors: Factor A: Levels of nitrogen (4 levels) as- 36.87 kg, 41.47 kg , 46.08 kg, 50.69 kg and Factor B: Levels of sulphur (4 levels) as- 6.4 kg, 7.2 kg, 8.0 kg, 8.8 kg. The two factors experiment was carried out in split-plot design with three replications. The four levels of N were assigned in the main plot and 4 levels of sulphur in the sub-plot. Data were recorded on growth contributing characters, yield and quality of BRRI dhan34 and statistically significant variation was assessed for most of the studied characters for different treatments.

For different levels of nitrogen, the tallest plant (58.78, 83.33, 111.6, 127.83 and 177.32 cm respectively) was observed from N_4, while the shortest plant (46.61, 76.34, 97.18, 117.55 and 157.85 cm respectively) was found from N_1. At 30, 45, 60 DAT and harvest, the maximum number of tillers hill^{-1} (5.16, 11.58, 17.67 and 23.17, respectively) was recorded from N_3 except 25.83 from N_2 at 75 DAT , while the minimum number (3.17, 10.08, 15.67, 22.67 and 20.25 respectively) was observed from N_1 at 30, 45, 60, 75 DAT and harvest. The highest number of effective tillers hill^{-1} (18.92) was found from N_2, while the lowest number (14.83) was observed from N_1. The highest number of non-effective tillers hill^{-1} (5.33) was observed from N_1, whereas the lowest number (3.33) was recorded from N_4. The longest panicle (26.81 cm) was observed from N_4, while the shortest panicle (24.79 cm) was found from N_1. The highest number of filled grains panicle^{-1} (233.58) was found from N_2, while the lowest number (218.17) was recorded from N_4. The highest number of unfilled grains panicle^{-1} (28.00) was observed from N_3 and the lowest number (22.33) was found from N_1. The highest number of total grains panicle^{-1} (261.67) was recorded from N_3, while the lowest number (235.17) was observed from N_1. The highest weight of 1000-grains (12.97 g) was observed from N_2 and the lowest weight (11.65 g) was recorded from N_4. The highest grain yield (5.19 t ha^{-1}) was found from N_2, while the lowest grain yield (3.71 t ha^{-1}) was observed from N_4. The highest straw yield (5.74 t ha^{-1}) was observed from N_4, whereas the lowest straw yield (5.24 t ha^{-1}) was recorded from N_1. The highest biological yield (10.68 t ha^{-1}) was found from N_2, while the lowest biological yield (9.44 t ha^{-1}) from N_4. The highest harvest index (48.59 %) was found from N_2 and the lowest harvest index (39.25 %) was recorded from N_4.

The highest length of grain (5.1 mm) was recorded from N_3, while the lowest length (4.93 mm) was found from N_4. The highest breadth of grain rice (2.18 mm) was observed from N_3, whereas the lowest breadth (2.13 mm) was found from N_4. The maximum milled rice (74.82%) was found from N_4, while the minimum (69.27%) was recorded from N_1. The maximum broken rice (3.89%) was observed from N_1, whereas the minimum (3.36%) was found from N_3. The maximum husk (26.13%) was found from N_2, while the minimum (23.22%) was recorded from N_1. The highest protein content (8.39%) was found from N_4, while the lowest (7.93%) was observed from N_1. The highest Zn content (0.147 mg g^{-1}) was observed from N_1, while the lowest (0.131 mg g^{-1}) from $N_{3.}$ The highest amylose content (24.79%) was found from N_1, whereas the lowest (20.08 %) was recorded from N_4. The highest proline content (21.83 mg g^{-1}) was observed from N_1, while the lowest (18.48 mg g^{-1}) from N_4. The highest grain 2-AP content (0.823 µg g^{-1}) was recorded from N_1, whereas the lowest (0.724 µg g^{-1}) was observed from N_4.

In case of different levels of sulphur, the tallest plant (57, 86.33, 111.8, 137.92 and 182.47 cm respectively) was observed from S_3 for 30 DAT and S_2 for others, while the shortest plant (48.5, 74.08, 91.33, 107.70 and 152.63 cm respectively) was found from S_1 for 30 DAT and S_3 for others. At 30, 45, 60 DAT and harvest, the maximum number of tillers $hill^{-1}$ (6.25, 13.25, 18.50, 26.33 and 23.16 respectively) was recorded from S_1 , while the minimum number (8.17, 14.08, 22.33 and 19.92 respectively) was observed from S_4 at 45, 60, 75 DAT and harvest except (1.83) at 30 DAT from S_2. The highest number of effective tillers $hill^{-1}$ (19.25) was found from S_1, while the lowest number (16.26) was observed from S_1.

The highest number of non-effective tillers hill^{-1} (5.08) was observed from S_2, whereas the lowest number (3.58) was recorded from S_4. The longest panicle (28.48 cm) was observed from S_1, while the shortest panicle (23.06 cm) was found from S_4. The highest number of filled grains panicle^{-1} (260.42) was found from S_1, while the lowest number (178.58) was recorded from S_4. The highest number of unfilled grains panicle^{-1} (33.50) was observed from S_3 and the lowest number (20.00) was found from S_4. The highest number of total grains panicle^{-1} (302.33) was recorded from S_1, while the lowest number (204.92) was observed from S_4. The highest weight of 1000-grains (13.27 g) was observed from S_1 and the lowest weight (11.48 g) was recorded from S_4. The highest grain yield (4.82 t ha^{-1}) was found from S_1, while the lowest grain yield (4.35 t ha^{-1}) was observed from S_4. The highest straw yield (6.16 t ha^{-1}) was observed from S_1, whereas the lowest straw yield (4.89 t ha^{-1}) was recorded from S_3. The highest biological yield (10.98 t ha^{-1}) was found from S_1, while the lowest biological yield (9.38 t ha^{-1}) from S_3. The highest harvest index (47.86 %) was found from S_3 and the lowest harvest index (43.89 %) was recorded from S_1.

The highest length of grain (5.11 mm) was recorded from S_3, while the lowest length (5.05 mm) was found from S_1. The highest breadth of grain rice (2.18 mm) was observed from S_3, whereas the lowest breadth (2.13 mm) was found from S_1. The maximum milled rice (76.16%) was found from S_2, while the minimum (67.72%) was recorded from S_3. The maximum broken rice (4.06%) was observed from S_4, whereas the minimum (3.09%) was found from S_1. The maximum husk (29.33%) was found from S_2, while the minimum (19.63%) was recorded from S_4. The highest protein content (8.84%) was found from S_2, while the lowest (7.68%) was observed from S_4. The highest Zn content (0.144 mg g^{-1}) was observed from S_1, while the lowest (0.136 mg g^{-1}) from $S_{3.}$ The highest amylose content (25.67%) was found from S_4, whereas the lowest (20.92%) was recorded from S_3. The highest proline content (22.00 mg g^{-1}) was observed from S_3, while the lowest (17.50 mg g^{-1}) from S_1. The highest grain 2-AP content (0.959 µg g^{-1}) was recorded from S_4, whereas the lowest (0.507 µg g^{-1}) was observed from S_1.

Due to the combined effect of different levels of nitrogen and sulphur, the tallest plant (58.52, 93.33, 138, 144.67 and 195.34 cm respectively) was observed from N_4S_2, while the shortest plant (45.99, 62.33, 73.67, 86.0 and 132.33 cm respectively) was found from N_1S_3. At 30, 45, 60 DAT and harvest, the maximum number of tillers hill^{-1} (7.33, 14.67, 19.67, 29.33 and 25.0 respectively) was recorded from N_3S_4, N_4S_1, N_3S_1, N_2S_1 and N_3S_3 respectively , while the minimum number (1.33, 6.67, 12.33, 18.0 and 17.67 respectively) was observed from N_1S_4 at 30, 45, 60, 75 DAT and harvest. The highest number of effective tillers hill^{-1} (21.33) was found from N_2S_1, while the lowest number (11.66) was observed from N_4S_4. The highest number of non-effective tillers hill^{-1} (6.33) was observed from N_4S_4, whereas the lowest number (2.66) was recorded from N_4S_1. The longest panicle (30.73 cm) was observed from N_4S_1, while the shortest panicle (20.90 cm) was found from N_4S_4. The highest number of filled grains panicle^{-1} (268.33) was found from N_2S_1, while the lowest number (170.67) was recorded from N_4S_4. The highest number of unfilled grains panicle^{-1} (41.00) was observed from N_4S_4 and the lowest number (12.67) was found from N_4S_1. The highest number of total grains panicle^{-1} (328.33) was recorded from N_4S_1, while the lowest number (187.33) was observed from N_4S_4 . The highest weight of 1000-grains (13.21 g) was observed from N_2S_1 and the lowest weight (10.13 g) was recorded from N_4S_4. The highest grain yield (5.48 t ha^{-1}) was found from N_2S_1, while the lowest grain yield (3.29 t ha^{-1}) was observed from N_4S_4. The highest straw yield (6.63 t ha^{-1}) was observed from N_4S_1, whereas the lowest straw yield (4.67 t ha^{-1}) was recorded from N_1S_4. The highest biological yield (11.65 t ha^{-1}) was found from N_2S_3, while the lowest biological yield (8.77 t ha^{-1}) from N_4S_3. The highest harvest index (52.44 %) was found from N_2S_1 and the lowest harvest index (36.23 %) was recorded from N_4S_4.

The highest length of grain rice (5.18 mm) was recorded from N_3S_4, while the lowest length (4.98 mm) was found from N_4S_3. The highest breadth of grain rice (2.23 mm) was observed from N_3S_4, whereas the lowest breadth (2.07 mm) was found from N_1S_2. The maximum milled rice (77.5%) was found from N_4S_1, while the minimum (65.67%) was recorded from N_1S_1. The maximum broken rice (4.17%) was observed from N_1S_4, whereas the minimum (2.87%) was found from N_2S_1. The maximum husk (30.00%) was found from N_3S_2, while the minimum (17.0%) was recorded from N_3S_4. The highest protein content (9.03%) was found from N_4S_2, while the lowest (7.40%) was observed from N_1S_4. The highest Zn content (0.154 mg g^{-1}) was observed from N_2S_1, while the lowest (0.119 mg g^{-1}) from N_3S_3. The highest amylose content (27.00%) was found from N_1S_4, whereas the lowest (14.73 %) was recorded from N_4S_1. The highest proline content (24.00 mg g^{-1}) was observed from N_1S_2, while the lowest (16.67 mg g^{-1}) from N_4S_3. The highest grain 2-AP content (0.967 µg g^{-1}) was recorded from N_1S_4, whereas the lowest (0.493 µg g^{-1}) was observed from N_4S_1.

From the above results, it may be concluded that N_2S_1(41.47 kg N ha^{-1} and 6.4 kg S ha^{-1}) may be recommended for producing maximum yield. When we considered quality of grain such as amylose, proline and grain 2-AP, the combination of N_1S_4(36.87 kg N ha^{-1} and 8.8 kg S ha^{-1}) may be used for the production of good aromatic quality of rice.

Considering the results of the present experiment, further studies in the following areas may be suggested:

1. This kind of study if repeated in different agro-ecological zones (AEZ) of Bangladesh, this would tune the regional adaptability of the variety and will confirm the results more precisely.

2. Other combination of organic manures and chemical fertilizers may be used for more information on quality of fragrant rice especially BRRI dhan34.

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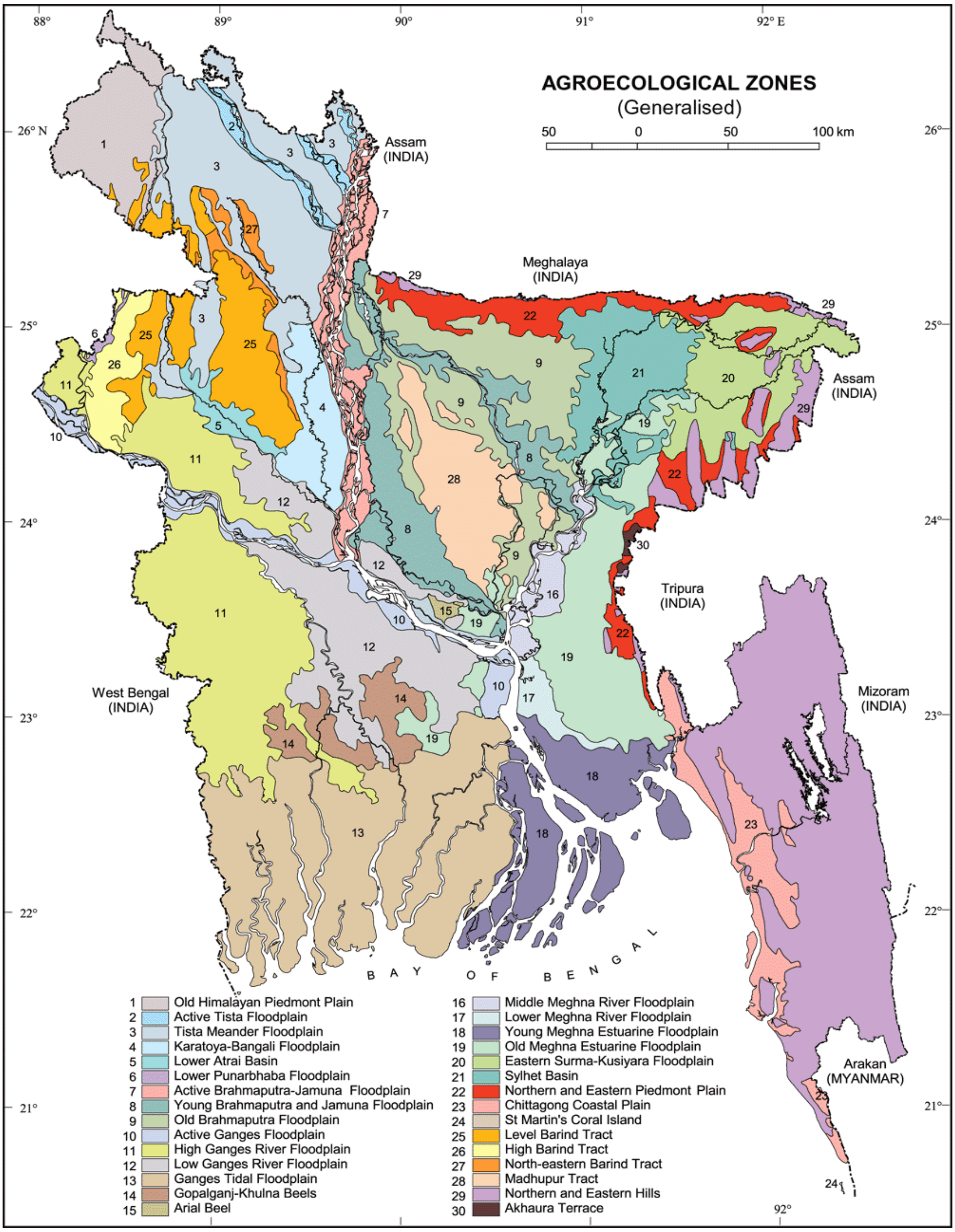
APPENDICES

Appendix I. Map showing the experimental sites under study



☆ = The experimental site under study

Appendix II. Physical characteristics of field soil

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Agronomy 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	28
% Silt	46
% clay	27
Textural class	Silty-clay
P^H	5.6
Organic carbon (%)	0.47
Organic matter (%)	0.78
Total N (%)	0.02
Available P (ppm)	19.07
Exchangeable K (me/100 g soil)	0.13
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI)

Appendix III: Monthly average of temperature, relative humidity, total rainfall and sunshine hour of the experiment site during the period from June 2018 to November 2018

Month (2018)	Air temperature (^0c)		Relative humidity(%)	Rainfall (mm)	Sunshine (hr)
	Maximum	Minimum			
June	35.9	22.2	79	317	5.3
July	36.4	23.8	82	573	5.2
August	35.0	22.9	80	324	5.3
September	34.7	24.7	79	284	4.3
October	26.3	19.5	82	23	6.8
November	25.6	16.7	77	00	6.7

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

S

E W

N

Plot size = 2.5 m × 1.05 m

Sub-plot to Sub-plot: 0.5 m

Plot to plot: 0.75 m

Replication to replication: 0.9 m

Factor A: Levels of nitrogen (4 levels) as

N_1: 80 kg N ha^{-1}

N_2: 90 kg N ha^{-1}

N_3: 100 kg N ha^{-1}

N_4: 110 kg N ha^{-1}

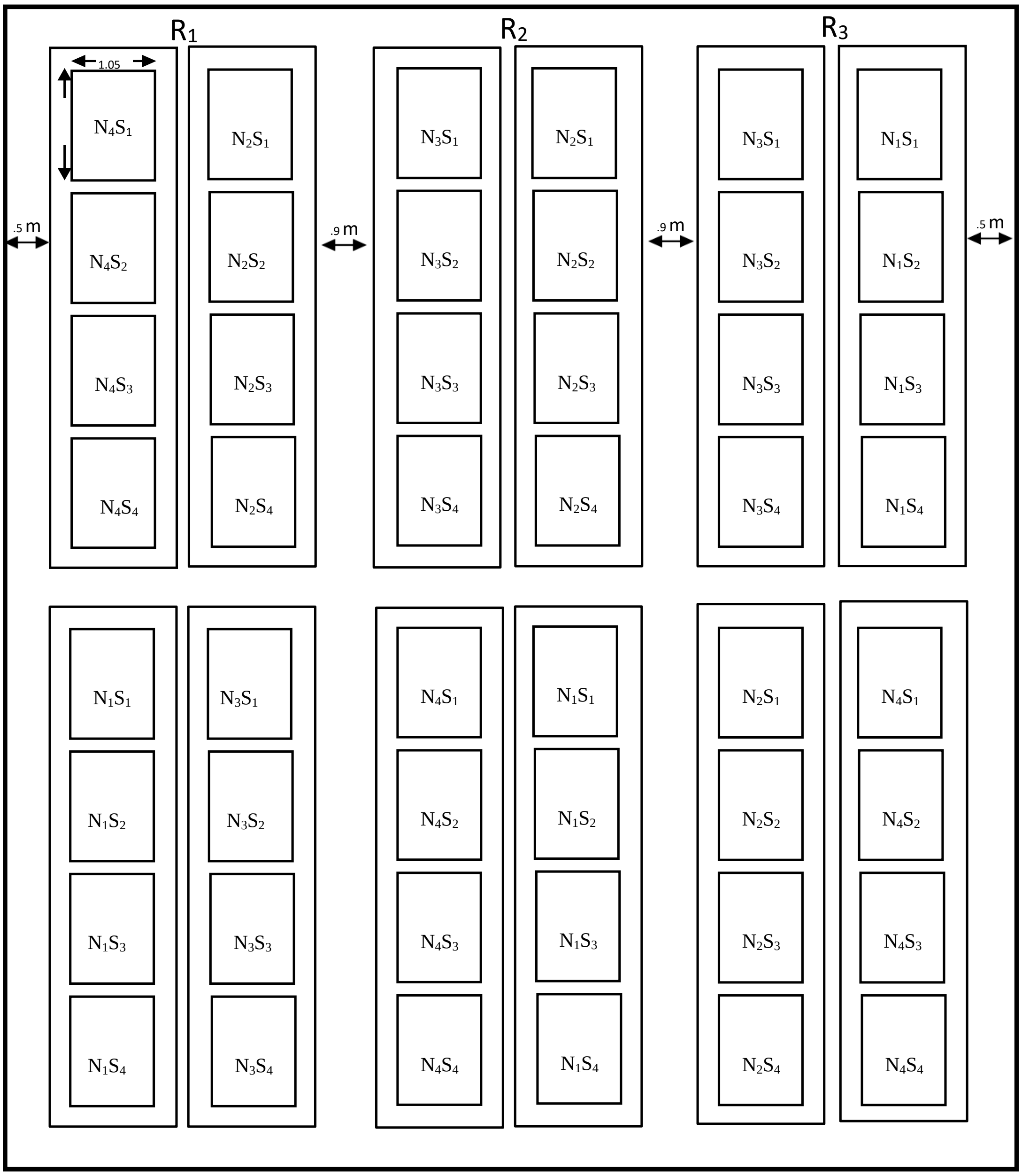
Factor B: Levels of sulphur (4 levels) as

S_1: 40 kg S ha^{-1}

S_2: 45 kg S ha^{-1}

S_3: 50 kg S ha^{-1}

S_4: 55 kg S ha^{-1}



Appendix IV. Layout of the experimental design

Appendix V. Summary of analysis of variance for plant height of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values of plant height at different DAT				
		30	45	60	75	at harvest
Replication	2	63.49	129.92	112.91	101.24	333.07
Levels of nitrogen(A)	3	306.9**	108.59*	532.26*	225.48*	698.69*
Error-1	6	39.66	37.85	74.59	84.12	126.34
Levels of sulphur (B)	3	144.6**	285.98**	988.42**	1833.49**	1889.03**
A X B	9	24.03 *	61.34 *	376.07**	199.3*	258.8*
Error-2	24	19.88	53.8	41.42	83.74	117.56

Appendix VI. Summary of analysis of variance for no. of tillers hill^{-1} of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values of plant height at different DAT				
		30	45	60	75	at harvest
Replication	2	0.77	3.25	27.9	49.08	54.44
Levels of nitrogen(A)	3	8.178**	4.67*	8.08*	20.74*	17.52*
Error-1	6	0.438	1.25	1.98	5.06	4.02
Levels of sulphur (B)	3	39.06**	51.83**	41.92**	32.41**	21.52*
A X B	9	6.0**	4.76*	2.06*	13.71*	5.91*
Error-2	24	1.83	3.44	2.9	7.67	8.71

Appendix VII. Summary of analysis of variance for effective tillers hill^{-1}, non-effective tillers hill^{-1}, panicle length and filled grains panicle^{-1} of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values at harvest			
		Effective tillers hill^{-1}	Non-effective tillers hill^{-1}	Panicle length	Filled grains panicle^{-1}
Replication	2	54.64	1.08	4.05	189.8
Levels of nitrogen (A)	3	6.63*	8.47**	8.29*	685.6*
Error-1	6	2.42	0.31	3.32	241.4
Levels of sulphur (B)	3	7.24*	4.97**	58.8**	14189.5**
A X B	9	5.74*	2.77**	3.38*	256.9*
Error-2	24	6.95	0.44	4.96	1296.7

Appendix VIII. Summary of analysis of variance for unfilled grains panicle^{-1} , total grains panicle^{-1}, 1000-grain weight and filled grains grain yield of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values at harvest			
		Unfilled grains panicle^{-1}	Total grains panicle^{-1}	1000-grain weight	Grain yield
Replication	2	21.65	171.1	1.76	0.174
Levels of nitrogen (A)	3	78.58**	1525*	3.53**	0.79*
Error-1	6	6.7	432.1	0.138	0.24
Levels of sulphur (B)	3	422.02**	19181**	92.19**	1.34*
A X B	9	59.43*	353.4*	0.422*	1.07**
Error-2	24	21.33	1415.5	1.73	0.37

Appendix IX. Summary of analysis of variance for unfilled straw yield, biological yield, harvest index of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values at harvest		
		Straw yield	Biological yield	Harvest index
Replication	2	0.052	0.168	1.78
Levels of nitrogen (A)	3	0.581**	4.367**	15.38^{NS}
Error-1	6	0.049	0.193	13.39
Levels of sulphur (B)	3	3.181**	2.784*	41.14**
A X B	9	0.328*	2.175*	26.48**
Error-2	24	0.467	1.319	7.24

Appendix X. Summary of analysis of variance for grain length (mm), grain breadth (mm), milled rice (%), broken rice (%) and husk (%) of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values of plant height at different DAT				
		Grain length	Grain breadth	Milled rice	Broken rice	Husk
Replication	2	0.019	0.0006	15.75	0.04	4.17
Levels of nitrogen (A)	3	0.757*	0.009^{NS}	62.82*	0.56*	17.25*
Error-1	6	0.272	0.004	15.83	0.09	4.41
Levels of sulphur (B)	3	0.48^{NS}	0.031^{NS}	143.1**	1.87**	204.59**
A X B	9	0.34^{NS}	0.01^{NS}	16.89*	0.18*	6.42*
Error-2	24	0.136	0.008	19.91	0.12	5.42

Appendix XI. Summary of analysis of variance for protein content (%), Zn content (mg g^{-1}) on dry weight basis, Amylose content (%), Proline content (mg g^{-1}) and Grain-2AP(µg g^{-1}) on dry weight basis of BRRI dhan34

Sources of variation	Degrees of freedom	Mean square values of plant height at different DAT				
		Protein content	**Zn content**	**Amylose content**	**Proline content**	**Grain-2AP**
Replication	2	0.77	0.00005	6.7	4.56	0.002
Levels of nitrogen (A)	3	8.178**	0.00005*	48.49*	23.05**	0.025*
Error-1	6	0.438	0.000008	12.93	0.93	0.006
Levels of sulphur (B)	3	39.06**	0.00001*	52.02**	44.15**	0.418**
A X B	9	6.0**	0.00002*	11.04*	3.87*	0.011*
Error-2	24	1.83	0.000009	9.74	2.66	0.005