Research Article:

EFFECT OF DIFFERENT DOSES OF NITROGEN AND BORON ON GROWTH, YIELD AND POST-HARVEST QUALITY OF BROCCOLI AT RAMPUR, CHITWAN

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ABSTRACT

A field experiment was conducted at Agriculture and Forestry University, Rampur, Chitwan from October 2022 to February 2023 to know the effect of nitrogen and boron on growth, yield, and quality of the Calabrese Variety of broccoli. Four doses of nitrogen as 100, 140, 180, and 220 kg/ha and three doses of boron 1, 1.5, and 2 kg/ha consisting of twelve treatments were applied in RCBD with three replications. Significantly the highest vegetative growth was recorded at 220 kg/ha nitrogen and 2 kg/ha boron dose which was statistically similar to 180 kg/ha nitrogen and 1.5 kg/ha boron dose respectively. The yield of Calabrese broccoli was significantly increased by the increasing rate of N and B application. The highest yield of 14.33 mt/ha was recorded at 220 kg/ha nitrogen which was statistically similar to 180 kg/ha nitrogen dose. Similarly, the highest yield (13.5 mt/ha) of Calabrese broccoli was recorded at 2 kg/ha boron which was statistically at par to 1.5 kg/ha boron dose. The quality parameters were also found significantly higher at higher doses of nitrogen and boron. The interaction effect of N and B on growth, yield, and quality was found non-significant under the different doses of nitrogen and boron. Nitrogen doses of 180 kg/ha and boron dose of 1.5 kg/ha is recommended for farmers' practice in the Chitwan conditions.

Keywords: Calabrese, head initiation, vegetative growth, vitamin C

INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica*), a Cole crop belonging to the family Brassicaceae, is globally valued for its exceptional nutritional and medicinal properties. It is rich in vitamins such as C, A, and B-complex, minerals, dietary fiber, and biologically active phytochemicals including sulforaphane, indoles, and isothiocyanates, which contribute to its antioxidant and chemo-preventive effects (Patel et al., 2019; Singh et al., 2017). Globally, China is the leading producer of broccoli, followed by India and the United States, while countries such as Spain, Mexico, and Italy also contribute significantly to global production (FAOSTAT, 2020). In Nepal, broccoli is a relatively new winter vegetable but is gaining popularity, particularly among urban consumers due to increasing health awareness. However, national productivity i.e. 20 mt/ha remains lower than its potential, indicating the need for improved agronomic and nutrient management practices (Bika et al., 2018; MoALD, 2024).

Despite its increasing demand, broccoli production in Nepal is constrained by several factors, among which imbalanced nutrient management is a major limitation. Nitrogen is a key macronutrient required for vegetative growth, protein synthesis, and chlorophyll formation, and broccoli is known to remove large quantities of nitrogen from the soil (Khanal, 2015). Similarly, boron is an essential micronutrient involved in cell wall development, carbohydrate

translocation, and reproductive growth, and its deficiency often leads to physiological disorders such as hollow stem, reduced head quality, and lower yield in broccoli (Giri et al., 2013; Sheokand et al., 2018). Although previous studies have reported the individual effects of nitrogen and boron on broccoli and other Cole crops, research on their interactive effects under Nepalese agro-ecological conditions, particularly in Chitwan, remains limited. The knowledge gap has resulted in non-specific fertilizer recommendations, contributing to yield instability and quality deterioration.

Optimizing the combined application of nitrogen and boron could therefore play a crucial role in improving broccoli growth, yield, and quality in a sustainable manner. Several studies have highlighted that balanced fertilization enhances nutrient use efficiency and minimizes physiological disorders while improving yield attributes (Hussain et al., 2012; Subedi et al., 2020). However, determining the appropriate doses and interaction effects of nitrogen and boron for local conditions is essential for formulating precise nutrient recommendations. Hence, the present study was undertaken to evaluate the effects of different levels of nitrogen and boron, both individually and in combination, on the growth, yield, and quality of Calabrese broccoli at Rampur, Chitwan. The findings of this research are expected to provide a scientific basis for optimized fertilizer management, thereby enhancing broccoli productivity and supporting sustainable vegetable production systems in Nepal.

RESEARCH METHODS

Experimental site description

A field experiment was conducted at research farm under the department of Horticulture in Faculty of Agriculture under Agriculture and Forestry University, Rampur, Chitwan from October 2022 to February 2023. The experiment site was located at an altitude of about 228 m above mean sea level. It is geographically situated at 27˚ 40' north latitude and 84˚ 19' east longitude.

Agro-meteorological features of the experimental site

The study area lies in a tropical climate (Fig. 1). The maximum rainfall was recorded in October 2022 during the experiment period whereas November 2022 to February 2022 received no rainfall. The average maximum temperature was 26.5˚C and minimum temperature was 10.5˚C. The average relative humidity was 91.5 %. The total rainfall during the research period was 296.1 mm (National Maize Research Program, Chitwan, 2022/23).

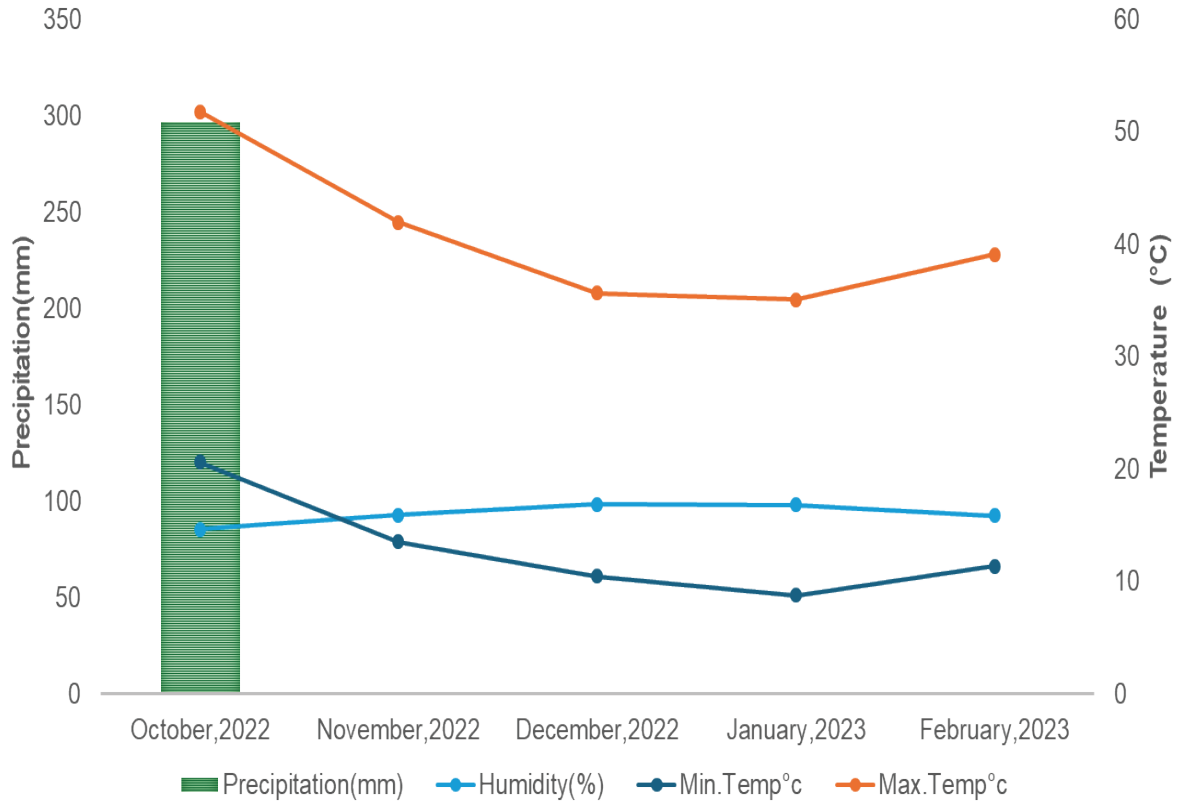

Fig. 1. Weather conditions during the broccoli growing period from October 2022 to February 2023 at Rampur, Chitwan, Nepal

Physiochemical properties of the soil at the experimental site

The soil samples from the experimental area were tested in n Soil and Fertilizer Testing Laboratory, Pokhara, Nepal. The soil of the experimental field was sandy loam having 3.3% organic matter, 0.13% total nitrogen, 71.5 kg/ha available P_2O_5, 277.8 kg/ha available K_2O with a pH value 5.6 and 0.11 ppm boron. The physicochemical properties of soils before the field experiment are presented in Table 1.

Table 1. Physiochemical properties of soil at the experimental site at Rampur, Chitwan, 2022/23

Details	Observed variables	Rating	Test method
Texture	Sandy loam		Feel
pH	5.6	Moderately Acidic	Electrometric
Organic matter (%)	3.3	Medium	Walkey and Black (1934)
Total nitrogen (%)	0.13	Medium	Kjeldhal distillation method (1982)
Available phosphorus (kg/ha)	71.5	High	Modified Olsen's bicarbonate (1954)
Available potassium (kg/ha)	277.8	Medium	Flame-photometer (1993)
Boron (ppm)	0.11	Low	Atomic Absorption Spectrophotometer

Treatment details

The experiment was designed as two factorial experiments having two factors i.e. doses of nitrogen (with four levels) and doses of boron (with three levels) (Table 2). The treatment combinations consisting of different doses of nitrogen and boron has been illustrated in Table 3. The treatments were randomized thrice. There were twelve treatments in each three replications. So, there were altogether thirty-six plots for the experimental trial.

Table 2. Treatment details of the experiment at Rampur, Chitwan, 2022/23

Treatments	Symbol
Doses of nitrogen (Factor A)	
100 kg/ha	N_1
140 kg/ha	N_2
180 kg/ha	N_3
220 kg/ha	N_4
Doses of boron (Factor B)	
1 kg/ha	B_1
1.5 kg/ha	B_2
2 kg/ha	B_3

Treatment combinations

All possible combinations of nitrogen and boron doses were the treatments of the experiment (Table 3). There were four nitrogen doses and three boron doses used in the experiment. So, the total treatment combinations were twelve.

Table 3. Treatment combinations used in the experiment at Rampur, Chitwan, 2022/23

S.N.	Treatments combinations	Symbol
1	Nitrogen 100 kg/ha × Boron 1 kg/ha	N_1B_1
2	Nitrogen 100 kg/ha × Boron 1.5 kg/ha	N_1B_2
3	Nitrogen 100 kg/ha × Boron 2 kg/ha	N_1B_3
4	Nitrogen 140 kg/ha × Boron 1 kg/ha	N_2B_1
5	Nitrogen 140 kg/ha × Boron 1.5 kg/ha	N_2B_2
6	Nitrogen 140 kg/ha × Boron 2 kg/ha	N_2B_3
7	Nitrogen 180 kg/ha × Boron 1 kg/ha	N_3B_1
8	Nitrogen 180 kg/ha × Boron 1.5 kg/ha	N_3B_2
9	Nitrogen 180 kg/ha × Boron 2 kg/ha	N_3B_3
10	Nitrogen 220 kg/ha × Boron 1 kg/ha	N_4B_1
11	Nitrogen 220 kg/ha × Boron 1.5 kg/ha	N_4B_2
12	Nitrogen 220 kg/ha × Boron 2 kg/ha	N_4B_3

Experiment design

The experiment was laid out in a factor-randomized complete block design consisting of twelve treatments with three replications. The individual plot size was 3 m x 2.25 m. Seedlings were transplanted at the spacing of 60 cm × 45 cm. Each plot consists of five rows where each row contains five plants. Five plants out of twenty-five plants from each plot were taken as sample plants. The total experimental area was 498 m^2 while the net plot area was 324 m^2. The space between replication and plot was 1 m and 0.5 m respectively.

Detail of the field operations

The nursery for broccoli was raised on sterilized raised beds, where the soil was treated with Bavistin at 1 g L^{-1} of water to minimize soil-borne pathogens. Farmyard manure (FYM) at 5 kg m^{-2} along with a basal dose of urea, DAP, and potash at 5 g each square meter was applied uniformly for all varieties. Seeds were sown at a depth of 1.5–2.0 cm with 5 cm spacing. As a protection measures, SAAF (Carbendazim 12% + mancozeb 63% WP) at 1 g/ liter water; G-sunami (cypermethrin 5% EC + chlorpyriphos 50% EC) at 1 ml/liter of water and a micronutrient formulation of multiplex at 1 ml/water was applied during the growth and development of the broccoli. The experimental field was prepared by two ploughings followed by harrowing, and FYM was applied at 10 t ha^{-1}. Uniform, healthy 28-day-old seedlings with 3–4 true leaves were transplanted into the experimental field. Borax was applied as a basal dose at (1.0, 1.5, and 2.0 kg boron ha^{-1}) during field preparation as a source of boron (11.36% boron), while the recommended fertilizer dose of 120:80:60 kg NPK ha^{-1} was supplied through DAP, urea and MoP. Nitrogen was applied in two splits, half as a basal dose at transplanting and the remaining half at 45 days after transplanting (DAT). Cultural practices were maintained throughout the growth period, including two times weeding and one time earthing-up at 25 and 45 DAT. Similarly, the irrigation was applied for two times and two times application of insecticides and fungicides to ensure the healthy crop establishment and growth.

Observation measurement and analysis

Measurements were taken from the inner nine plants while the remaining sixteen plants were considered border plants. Out of the inner nine plants, five plants were selected randomly as sample plants. The growth parameters such as plant height (cm), number of leaves per plant (no.), canopy diameter (cm) were taken during the field experiment. Yield parameters like economic yield (mt/ha), biological yield (mt/ha) and dry matter (%) were also measured at the time of final harvest. Regarding the quality parameters, pH, total soluble solids, vitamin C and physiological loss in weight was measured after harvesting of the broccoli. Physiological loss in weight was measured based on the 50% acceptance by the consumer.

The parameters recorded throughout the experimental period were tabulated in Microsoft Excel and statistically analyzed by using R Studio (R version 4.3.1). The analysis of variance (ANOVA) was identified and means were compared using Duncan's Multiple Range Test (DMRT) at 1% or 5% levels of significance (Gomez & Gomez, 1984). The graph was constructed by using the MS Excel program.

RESULTS AND DISCUSSION

Plant height

The plant (cm) height differed significantly among the different doses of nitrogen and boron at 30 DAT, 45 DAT and 60 DAT (Table 4). A significantly higher plant height (74.77 cm) was observed at 60 DAT in the plants applied with 220 kg N/ha and similarly it was highest (69.08 cm) with the application of boron 2 kg/ha which was statistically similar to 1.5 kg/ha boron dose. No significant effect was seen on the interaction of nitrogen and boron doses in the plant

height of broccoli. Nitrogen doses at 220 kg/ha recorded maximum plant height statistically similar to 180 kg/ha nitrogen dose whereas 100 kg/ha nitrogen recorded minimum plant height at all growth stages. Higher doses of nitrogen lead to better vegetative growth that significantly leads the plant to achieve the highest plant height. An increase in plant height with increased in application of nitrogen as similar findings in line with Giri et al. (2013); El-Shikha et al. (2007); Moniruzzaman et al. (2007) and Nasreen & Islam (1992). It was observed that higher boron doses significantly increased the plant height while lower boron doses significantly decreased the plant height at all the growth stages of broccoli. Boron promotes the transfer of sugars and other carbohydrates within plants, which is essential for energy production and cell growth. This improves photosynthetic activity and leads to increased plant height (Adamczewska-Sowińska & Uklańska, 2009). The increase in plant height with an increase in boron doses is because boron promotes cell division and elongation and is especially required for actively growing regions of plant-like-apical meristems (Ahmad et al., 2009).

Table 4. Effect of nitrogen and boron doses on plant height of broccoli (*Brassica oleracea* var. *italica,* Plenck.) at Rampur, Chitwan, Nepal, 2022/23

Treatments	Plant height (cm)		
	30 DAT	45 DAT	60 DAT
Factor A - Nitrogen doses			
100 kg/ha	33.44^{b}	47.44^{c}	58.22^{c}
140 kg/ha	36.77^{a}	51.77^{b}	66.77^{b}
180 kg/ha	38.22^{a}	53.22^{ab}	68.22^{b}
220 kg/ha	38.55^{a}	55.22^{a}	74.77^{a}
SEm (±)	0.32	0.31	0.41
$LSD_{0.05}$	2.81	2.74	3.62
F-test	**	***	***
Factor B - Boron doses			
1.0 kg/ha	35.00^{b}	50.25^{b}	65.33^{b}
1.5 kg/ha	36.75^{ab}	52.08^{ab}	66.58^{ab}
2.0 kg/ha	38.50^{a}	53.41^{a}	69.08^{a}
SEm (±)	0.24	0.23	0.30
$LSD_{0.05}$	2.44	2.37	3.14
F-test	*	*	*
CV, %	7.84	5.40	5.53
Grand mean	36.75	51.91	67.00
A × B	ns	Ns	Ns

Note: Means with the same letter in the column are not significantly different at p = 0.05 by DMRT. *Significant at 5% (p< 0.05) and ns = not significantly different at 5% (p > 0.05). SEm = Standard error of the mean, LSD = Least significant difference, CV = Coefficient of variation

Number of leaves

The number of leaves differed significantly due to different doses of nitrogen at 30 DAT, 45 DAT and 60 DAT (Table 5). A significantly larger number of leaves (14) was found at 220 kg/ha nitrogen dose which was statistically similar to 180 kg/ha nitrogen dose at 60 DAT. The number of leaves differed significantly due to different doses of boron at 30 DAT, 45 DAT and 60 DAT. At 60 DAT, significantly more leaves (13.33) recorded at 2 kg/ha boron dose. No significant effect was seen on the interaction of nitrogen and boron doses in the number of leaves of broccoli. A higher number of leaves was found at 220 kg/ha nitrogen dose which is statistically similar to 180 kg/ha nitrogen dose while the lower number of leaves was found at 100 kg/ha nitrogen. A higher number of leaves at higher doses of nitrogen is due to quick and vigorous growth of shoot and root development (Vegetable and Floriculture Dept., 2016). The different doses of boron have a significant effect on the number of leaves at the growth stages of broccoli. It was observed that the maximum number of leaves was seen at higher boron doses while a minimum number of leaves was seen at the lower boron doses. Boron helps in the enhancement of nutrient uptake, photosynthesis, and higher metabolic activity in plants which might have resulted in more leaf numbers (Poudel et al., 2022).

Table 5. Effect of nitrogen and boron doses on the number of leaves of broccoli (*Brassica oleracea* var. *italica,* Plenck.) at Rampur, Chitwan, Nepal, 2022/23

Treatments	Number of leaves		
	30 DAT	45 DAT	60 DAT
Factor A - Nitrogen doses			
100 kg/ha	6.46^{c}	7.55^{b}	10.33^{c}
140 kg/ha	6.71^{b}	8.00^{b}	12.00^{b}
180 kg/ha	7.13^{a}	8.00^{b}	13.00^{ab}
220 kg/ha	7.30^{a}	10.00^{a}	14.00^{a}
SEm (±)	0.01	0.11	0.15
$LSD_{0.05}$	0.22	1.03	1.01
F-test	***	***	***
Factor B - Boron doses			
1.0 kg/ha	6.71^{b}	7.41^{c}	11.41^{b}
1.5 kg/ha	6.97^{a}	8.33^{b}	12.25^{b}
2.0 kg/ha	7.03^{a}	9.41^{a}	13.33^{a}
SEm (±)	0.02	0.09	0.08
$LSD_{0.05}$	0.19	0.90	0.87
F-test	**	***	***
CV, %	3.34	12.67	8.42
Grand mean	6.90	8.38	12.33
A × B	ns	Ns	Ns

Note: Means with the same letter in the column are not significantly different at p = 0.05 by DMRT. **significant at 1% (p< 0.01), *** significant at 0.1% (p <0.001) and ns: not significantly different at 5% (p > 0.05). SEm = Standard error of the mean, LSD = Least significant difference, CV = Coefficient of variation

Canopy diameter

The canopy diameter differed significantly at 30 DAT, 45 DAT and 60 DAT due to the effect of different doses of nitrogen (Table 6). At 60 DAT, significantly maximum canopy diameter of 74.77 cm was found at 220 kg/ha nitrogen dose. The canopy diameter differed significantly among the different doses of boron at 30 DAT, 45 DAT and 60 DAT. Maximum canopy diameter of 72 cm was observed at 60 DAT at 2 kg/ha boron dose which was statistically similar to 1.5 kg/ha boron dose. No significant effect was seen on the interaction of nitrogen and boron doses in the canopy diameter of broccoli. The canopy diameter of the broccoli significantly varies with different doses of nitrogen at all the growth stages of broccoli. The canopy diameter of the broccoli was found maximum at the higher doses of nitrogen while the minimum canopy diameter was found at the lower doses of nitrogen. Ullah et al. (2008) reported that the application of inorganic nitrogen fertilizer can solely affect the vegetative spread due to the increase in leaf length and breadth. The different doses of boron have a significant effect on the canopy diameter of the broccoli. Higher boron doses recorded the maximum canopy diameter while the lower boron doses recorded the minimum canopy diameter of the broccoli. A similar increase in growth parameters has been reported by Prasad & Yadav (2004) on cauliflower.

Table 6. Effect of nitrogen and boron doses on canopy diameter of broccoli (*Brassica oleracea* var. *italica,* Plenck.) at Rampur, Chitwan, Nepal, 2022/23

Treatments	Canopy diameter (cm)		
	30 DAT	45 DAT	60 DAT
Factor A - Nitrogen doses			
100 kg/ha	34.11^{b}	54.88^{b}	59.00^{c}
140 kg/ha	36.44^{b}	57.55^{b}	68.00^{b}
180 kg/ha	38.33^{ab}	58.33^{b}	69.22^{b}
220 kg/ha	43.11^{a}	65.33^{a}	74.77^{a}
SEm (±)	0.54	0.57	0.58
$LSD_{0.05}$	4.81	5.01	5.16
F-test	**	**	***
Factor B - Boron doses			
1.0 kg/ha	35.16^{b}	55.08^{b}	63.66^{b}
1.5 kg/ha	37.91^{ab}	59.5^{a}	67.58^{ab}
2.0 kg/ha	40.91^{a}	62.5^{a}	72.00^{a}
SEm (±)	0.41	0.42	0.43
$LSD_{0.05}$	4.16	4.34	4.46
F-test	*	**	**
CV, %	12.94	8.69	7.79
Grand mean	38.00	59.02	67.75
A × B	ns	Ns	Ns

Note: Means with the same letter in the column are not significantly different at p = 0.05 by DMRT. *Significant at 5% (p< 0.05), ** significant at 1% (p <0.01), *** significant at 0.1% (p <0.001), and ns = not significantly different at 5% (p > 0.05). SEm = Standard error of the mean, LSD = Least significant difference, CV = Coefficient of variation

Yield parameters

The results showed significant differences regarding economic yield and biologicalyield among the different doses of nitrogen (Table 7). Significantly maximum biological yield (58.16 mt/ha) and economic yield (14.33 mt/ha) was obtained at 220 kg/ha nitrogen which was statistically similar to 180 kg/ha nitrogen. A significant difference was seen in the dry matter of Calabrese broccoli at different nitrogen doses. The highest dry matter (10.82 %) was observed in the plants applied with 220 kg N/ha. The effect of different doses of boron was found significant on biological yield. The maximum biological yield (47.83 mt/ha) was observed at 2 kg boron/ha. A significant difference was seen in the economic yield and dry matter of Calabrese broccoli at different boron doses. The highest economic yield of 13.5 mt/ha was recorded at the 2 kg/ha boron dose which was statistically similar to the 1.5 kg/ha boron dose. Similarly, the highest dry matter of 10.7 % was recorded at the 2 kg/ha boron dose which was statistically similar to the 1.5 kg/ha boron. The interaction effect of nitrogen and boron doses are found non-significant on the biological yield, economic yield, and dry matter of broccoli.

Higher biological yield is associated with a higher dose of nitrogen while lower biological yield is associated with the low dose in the broccoli. Boron also has a significant effect on the biological yield of broccoli concerning the different doses of boron. Higher boron doses result in a higher biological yield while lower boron doses result in a lower biological yield of broccoli due to more vegetative growth. Higher doses of nitrogen result in a higher economic yield. Nitrogen promotes chlorophyll synthesis and amino acid composition in proteins, which are essential for plant growth and yield. Wider leaf areas have high light harvesting increasing the photosynthetic activity that ultimately increases the yield of broccoli. These results correspond with the results of Ghobadi et al. (2010). Higher boron doses result in a higher economic yield while lower boron doses result in a lower economic yield of broccoli. Boron increases nutrient transfer within plants, hence increasing the growth. Boron has a pivotal role in the cell differentiation, development, translocation of photosynthates, and growth regulators from source to sink. A similar result has been obtained by Farooq et al. (2018). Higher dry matter is associated with a higher dose of nitrogen and boron while lower dry matter is associated with a low dose in the broccoli.

Table 7. Effect of nitrogen and boron doses on yield, and dry matter of broccoli (*Brassica oleracea* var. *italica,* Plenck.) at Rampur, Chitwan, Nepal, 2022/23

Treatments	Biological yield (mt/ha)	Economic yield (mt/ha)	Dry matter (%)
Factor A - Nitrogen doses			
100 kg/ha	31.72^{d}	10.45^{c}	10.30^{c}
140 kg/ha	39.77^{c}	12.66^{b}	10.56^{b}
180 kg/ha	47.66^{b}	13.22^{ab}	10.56^{b}
220 kg/ha	58.16^{a}	14.33^{a}	10.82^{a}
SEm (±)	0.47	0.12	0.01
$LSD_{0.05}$	4.16	1.43	0.22
F-test	***	***	**
Factor B - Boron doses			
1.0 kg/ha	41.45^{b}	11.85^{b}	10.42^{b}
1.5 kg/ha	43.7^{b}	12.65^{ab}	10.55^{ab}
2.0 kg/ha	47.83^{a}	13.5^{a}	10.70^{a}
SEm (±)	0.35	0.12	0.02
$LSD_{0.05}$	3.60	1.24	0.19
F-test	**	*	*
CV, %	9.60	11.57	2.19
Grand mean	44.33	12.66	10.56
A × B	ns	ns	ns

Note: Means with the same letter in the column are not significantly different at p = 0.05 by DMRT. *significant at 5% (p< 0.05), ** significant at 1% (p <0.01), *** significant at 0.1% (p <0.001), and ns = not significantly different at 5% (p > 0.05). SEm = Standard error of the mean, LSD = Least significant difference, CV = Coefficient of variation

Quality parameters

Quality parameters like pH, TSS (^{o}brix), Vitamin C (mg/100 g), and Physiological loss in weight (%) were calculated, analyzed and depicted in the table under the special headings (Table 8). No significant difference was found in the pH content of broccoli among the different doses of nitrogen and boron. Similarly, the result showed a significant difference in the TSS of the broccoli at different doses of nitrogen (Table 8). The highest TSS (8.36 ^{0}brix) was observed at 220 kg/ha nitrogen dose which was statistically similar to 180 kg/ha nitrogen dose. A significant difference in TSS of broccoli was observed at different doses of boron at all growth stages. Significantly the highest TSS (8.31 ^{0}brix) at 2 kg/ha boron dose which was statistically similar to 1.5 kg/ha boron dose. No significant difference was found in the interaction of nitrogen and boron doses in the TSS of the Calabrese variety of broccoli.

The result showed a significant difference in the Vitamin C of the broccoli at different doses of nitrogen. Significantly highest vitamin C was observed at 220 kg/ha nitrogen (79.33 mg/100 g) which was statistically similar to 180 kg/ha nitrogen dose while the lowest vitamin C (77 mg/100 g) was observed at 100 kg/ha nitrogen dose. A significant difference in Vitamin C content in broccoli was observed at different doses of boron. The highest Vitamin C content (78.83 mg/100 g) was observed at 2 kg/ha boron dose which was statistically similar to 1.5 kg/ha boron dose. No significant difference was found for the interaction of nitrogen and boron doses in the Vitamin C content of the Calabrese variety of broccoli (Table 8).

TSS and Vitamin C are significantly affected by the different doses of nitrogen. The highest TSS and Vitamin C content were recorded at a higher dose of nitrogen while the lowest TSS and Vitamin C content were recorded at a lower dose of nitrogen. Nitrogen and boron regulate the function of enzymes like invertase and sucrose synthase which ultimately increases the TSS content of broccoli (Sardar et al., 2022). These results are in close with the findings of Muhammad et al. (2024). Similarly, TSS and Vitamin C content are also significantly affected by the different doses of boron. Higher boron dose results in higher TSS and Vitamin C content while lower boron dose results in lower TSS and Vitamin C content of the Calabrese variety of broccoli. Increased concentration of nutrients under boron fertilization might be the reason for it. Nutrient uptake by plants depends mainly on boron accumulation. Boron aids the function of enzymes such as L - galactono-1, 4 - lactone dehydrogenase that helps in the synthesis of Vitamin C content in broccoli (Bankar, 2019). These results are in close conformity with the findings of Saha et al. (2010) in broccoli.

Table 8. Effect of nitrogen and boron doses on quality attributes of broccoli (*Brassica oleracea* var. *italica,* Plenck.) at Rampur, Chitwan, Nepal, Nepal, 2022/23

Treatments	pH	TSS (^{0}brix)	Vitamin C (mg/100 g)
Factor A - Nitrogen doses			
100 kg/ha	6.60	8.06^{c}	77.00^{c}
140 kg/ha	6.54	8.20^{bc}	77.66^{bc}
180 kg/ha	6.65	8.27^{ab}	78.22^{ab}
220 kg/ha	6.57	8.36^{a}	79.33^{a}
SEm (±)	0.02	0.01	0.09
$LSD_{0.05}$	-	0.14	1.14
F-test	ns	**	**
Factor B - Boron doses			
1.0 kg/ha	6.57	8.13^{b}	77.33^{b}
1.5 kg/ha	6.61	8.23^{ab}	78.00^{ab}
2.0 kg/ha	6.59	8.31^{a}	78.83^{a}
SEm (±)	0.01	0.01	0.13
$LSD_{0.05}$	-	0.12	0.99
F-test	ns	*	*
CV, %	2.95	1.80	1.50
Grand mean	6.59	8.22	78.05
A × B	ns	ns	ns

Note: Means with the same letter in the column are not significantly different at p = 0.05 by DMRT. *significant at 5% (p< 0.05), ** significant at 1% (p <0.01), and ns = not significantly different at 5% (p > 0.05). SEm = Standard error of the mean, LSD = Least significant difference, CV = Coefficient of variation

The result showed a significant difference in the physiological loss in weight of the broccoli at different doses of nitrogen two days after storage (Table 9). Significantly higher physiological loss in weight (9.71%) was observed at 220 kg/ha nitrogen dose which was statistically similar to 140 kg/ha and 180 kg/ha nitrogen dose. At 4 days after storage, significantly higher physiological loss in weight (15.85%) was observed at 220 kg/ha nitrogen which was statistically similar to 180 kg/ha nitrogen dose. No significant effect was observed in the physiological loss in weight of broccoli under the different doses of boron at two and four days of the storage. The higher the nitrogen dose, the higher the physiological loss in weight of broccoli while the lowest physiological loss in weight was observed at a lower dose of broccoli. Miwa et al., (2009) reported that plants receiving too much nitrogen often have higher water content in their tissues which causes more physiological loss in the weight of broccoli at higher nitrogen doses.

Table 9. Effect of nitrogen and boron doses on physiological loss in weight of broccoli (*Brassica oleracea* var. *italica,* Plenck.) at Rampur, Chitwan, Nepal, 2022/23

Treatments	Physiological loss in weight (%)	
	2 DAS	4 DAS
Factor A - Nitrogen doses		
100 kg/ha	8.86^{b}	14.13^{c}
140 kg/ha	9.31^{ab}	15.10^{b}
180 kg/ha	9.68^{a}	15.24^{b}
220 kg/ha	9.71^{a}	15.85^{a}
SEm (±)	0.05	0.06
LSD0.05	0.50	0.60
F-test	**	***
Factor B - Boron doses		
1.0 kg/ha	9.38	14.76
1.5 kg/ha	9.28	15.18
2.0 kg/ha	9.51	15.30
SEm (±)	0.04	0.05
$LSD_{0.05}$	-	-
F-test	ns	ns
CV, %	5.45	4.10
Grand mean	9.39	15.08
A × B	ns	ns

Note: Means with the same letter in the column are not significantly different at p = 0.05 by DMRT. **significant at 1% (p< 0.01), *** significant at 0.1% (p <0.001), and ns = not significantly different at 5% (p > 0.05). SEm = Standard error of the mean, LSD = Least significant difference, CV = Coefficient of variation, DAS = Days after storage

CONCLUSION

Based on the result of the study, higher growth, yield, and better postharvest quality of Calabrese broccoli were obtained by increasing the dose of nitrogen dose 180 kg/ha to 220 kg/ha and boron dose 1.5 kg/ha to 2 kg/ha. No combined effect was observed due to the interaction of nitrogen and boron doses. From this research, it was concluded that 180 kg/ha nitrogen dose and 1.5 kg/ha boron dose is recommended dose for better growth, higher yield, and better post-harvest quality of Calabrese broccoli in Terai conditions of Nepal.

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AUTHOR CONTRIBUTIONS

BB: Conceptualization, Investigation, Data curation, Formal analysis, Writing – original draft; **HNG:** Conceptualization, Writing – review & editing, Supervision; **AKS:** Investigation, Writing – review & editing; **KMT:** Investigation, Writing – review & editing.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL APPROVAL AND PERMITS

Not applicable.

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