

Research Article

Varietal response of faba bean to foliar boron supplementation: Implications for yield and seed quality improvement

Md. Romanch Mahmud¹, Babli Rani Deb¹, Md. Shishir Ahamed², Shubroto Kumar Sarkar¹, F. M. Jamil Uddin¹, Md. Harun Rashid¹, Swapan Kumar Paul^{1*}

¹Department of Agronomy, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

²Department of Agribusiness and Marketing, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

(Received: September 20, 2025; Revised: February 04, 2026; Accepted: February 05, 2026; Published: February 20, 2026)

*Corresponding author: Swapan Kumar Paul, E-mail: skpaul@bau.edu.bd

Abstract

Faba bean (*Vicia faba* L.) is an important legume crop valued for its nutritional quality and ecological role in sustainable agriculture. Its productivity and seed composition can be influenced by micronutrient management, particularly boron (B), which plays a key role in reproductive development. The experiment comprised two faba bean varieties (black-seeded and brown-seeded) and five foliar B levels (0, 10, 20, 40, and 60 mg L⁻¹ applied at the pre-flowering and pod formation stages) in a randomized complete block design with three replications. The brown-seeded variety produced higher seed yield (2.32±0.04 t ha⁻¹) than the black-seeded variety (1.86±0.05 t ha⁻¹), while among B treatments, foliar application at 60 mg L⁻¹ produced the maximum seed yield (2.32±0.07 t ha⁻¹) and the control gave the lowest one (1.85±0.10 t ha⁻¹). Although vegetative growth parameters were not significantly affected by B, reproductive and yield traits were notably improved. The combination of brown-seeded faba bean with 60 mg L⁻¹ B produced the highest number of branches plant⁻¹ (3.80±0.25), pods plant⁻¹ (38.60±1.42), seeds pod⁻¹ (3.53±0.05), 1000-seed weight (228.17±3.48 g), seed yield (2.48±0.04 t ha⁻¹), stover yield (2.55±0.04 t ha⁻¹), and biological yield (5.03±0.08 t ha⁻¹). The highest seed protein content (22±0.26%) was recorded in the brown-seeded variety without B, whereas the black-seeded variety treated with 10 mg L⁻¹ B showed the highest seed fat content (2.40±0.14%). These results indicate that 60 mg L⁻¹ foliar boron application to brown-seeded faba bean effectively enhances yield traits and yield, while seed quality traits vary by genotype and boron level.

Keywords: *Vicia faba*, Micronutrient, Foliar spray, Productivity, Proximate components

Introduction

Faba bean (*Vicia faba* L.) stands out as a cold-hardy legume cultured extensively worldwide, valued for its remarkable nutrient content and significant ecological advantages (Salvador-Reyes *et al.*, 2023). It is a key member of the Fabaceae family, the third-largest group of flowering plants, and is the second most significant nutrient after grains (Poaceae) (Shehbal, 2021). It is an abundant supply of protein (25 - 40%), dietary fiber, slowly digested carbohydrate, and vital minerals like iron, magnesium, zinc, potassium, phosphorus, and zinc. It also includes bioactive substances that promote health, such as flavonoids and phenolics (Agrawal *et al.*, 2024). The faba bean provides a sustainable and reasonably priced plant-based protein alternative to the more expensive animal-based proteins (Paul *et al.*, 2021; Al-Yasari *et al.*, 2022). Faba beans are currently grown in over 66 countries and holds global significance as the fourth leading pulse crop, preceded only by chickpeas, dry beans, and dry peas (Paul & Gupta, 2021; Salvador-Reyes *et al.*, 2023; Deb & Paul, 2024). Through symbiotic nitrogen fixation, it increases soil fertility as a legume and lessens the demand for synthetic nitrogen fertilizers (Svanes *et al.*, 2022). Beyond its agronomic and nutritional benefits, faba bean serves as a natural source of levodopa (L-DOPA), the dopamine precursor employed in managing Parkinson's disease (Upadhyay *et al.*, 2014). Faba beans are grown mostly in the central and northern areas, during the rabi season. After transplanted *Aman* rice is harvested, local landraces like

Kalimotor, *Baklakalai*, and *Bhograkalai* are often grown as residual or relay crops, usually under minimal tillage conditions (Yasmin *et al.*, 2020; Paul *et al.*, 2022). However, despite its agronomic potential, yield instability remains a major constraint to widespread adoption. Targeted nutrient application through foliar feeding is considered one of the key strategies to improve yield stability and productivity, as it provides an efficient, rapid, and cost-effective supply of macro- and micronutrients during the critical growth phase (Ali *et al.*, 2014; Salem *et al.*, 2014). Boron is an essential micronutrient that plays a critical role in crop growth, development, productivity, and quality (Vera-Maldonado *et al.*, 2024). B deficiency in crops is more common than any other micronutrient deficiency (Gupta, 1993; Mohamed *et al.*, 2024). Managing micronutrients, particularly B, is vital to maximizing the growth and reproductive development of faba bean. Boron is essential for hormone regulation, nitrogen and potassium metabolism, sugar translocation, and reproductive processes such as seed production, pollen viability, and flower fertilization, yet due to fixation or leaching soils in many regions, including Bangladesh, are often deficient, making foliar application a practical strategy to meet plant needs at critical growth stages (Kadhim, 2022).

In addition to having a severe effect on vegetative growth, a lack of B can also have a major negative influence on floral fertility and seed development, which lowers the likelihood of successful reproduction. Because of its function in enzymatic activity, amino acid synthesis, and meristem activity, B is responsible for this (Al-Yasari

et al., 2022). A proper supply of B is especially important for fruit quality (Dordas *et al.*, 2007) and yield formation (pollination) in commercial plant production (Khayyat *et al.*, 2007). According to earlier research, foliar B application can improve seed quality, total production, branching, and plant height (Mosleh & Abdul Rasool, 2019; Elbatrawy *et al.*, 2023). Current boron recommendations remain uncertain because they are largely extrapolated from other crops and regions. In contrast, boron availability, cultivar-specific responses, and the effectiveness of foliar applications vary substantially across local agro-ecological conditions, highlighting the need for location-specific boron management guidelines for faba bean. Therefore, the present study aims to identify the optimal concentration of foliar-applied boron to enhance the growth, yield, and seed quality of faba bean varieties.

Materials and Methods

Experimental site and experimentation

The experiment was carried out at the Agronomy Field Laboratory (25°15' N, 90°5' E) of Bangladesh Agricultural University, Mymensingh, Bangladesh, from November 2023 to March 2024. The site lies within the Old Brahmaputra Floodplain (AEZ-9) and is characterized by non-calcareous dark grey soil (UNDP & FAO, 1988). The soil was characterized as siltyloam and pH value of 7.1, EC of 0.4 dS m⁻¹, organic carbon of 1.27%, total N of 0.11%, available P of 12.05 ppm, exchangeable K of 0.20 meq/100 g soil, available S of 18.10 ppm, and Zn of 1.5 ppm, the land classified as medium high. The site has a subtropical climate, marked by limited rainfall, low humidity, cooler temperatures, and shorter days during the period from November to March (Figure 1). The experiment was comprised two local varieties *viz.* black-seeded (V₁) and brown-seeded (V₂) faba bean and five B concentrations: 0 (B₀), 10 (B₁), 20 (B₂), 40 (B₃), and 60 (B₄) mg L⁻¹ applied at the pre-flowering and pod formation stage. The experiment conducted in a randomized completed block design with three replications.

Crop husbandry

The seeds were collected locally from Northern part (Gaibandha District) of Bangladesh and tested germination

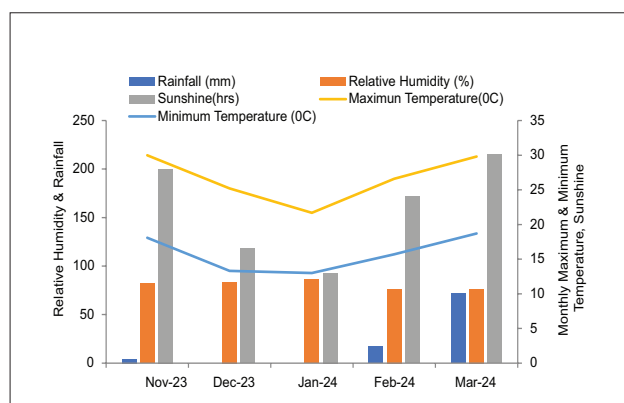


Figure 1: Meteorological data from November 2023 to March 2024

percent in the lab prior to field experimentation. Ploughing and cross ploughing were done to prepare the experimental field, and then a power tiller was used to ladder it. As sources of nitrogen, phosphorus, and sulfur, respectively, urea, triple super phosphate (TSP), muriate of potash (MoP), and gypsum were used. At final land preparation, N-P-K-S was applied @ 10-40-40-10 kg ha⁻¹ respectively in the form of urea, TSP, MoP, and gypsum (Paul *et al.*, 2021). Boron was applied as per treatment specification at two critical growth stages- at pre-flowering (25 days after emergence, DAE) and pod formation (60 DAE). Seeds were sown in furrows spaced 40 cm × 20 cm and immediately covered with soil. After sowing, the seeds were gently pressed into the pulverized soil by hand to ensure proper contact. Following seedling establishment, necessary intercultural operations were carried out to support healthy growth and development of the crop. At 15 DAE, when the plant reached a height of 8-10 cm, weeding and trimming were completed. When the plant reached a height of around 28 to 30 cm, the second weeding and thinning was carried out at 30 DAE.

Data collection

The crop was harvested when approximately 85% of the pods had turned brown. In order to collect data on crop characters and yield components five plants were chosen at random, omitting border rows. Manually the seeds of the pods were separated from the plants of 1.0 m² sampling area and were dried in the Sun to a constant weight. After that, the weight was recorded in an electrical balance, and the seed and straw yields were converted to t ha⁻¹. The following formula was used to get the harvest index (%).

$$\text{Harvest Index (\%)} = \frac{\text{Seed yield}}{\text{Seed yield} + \text{Stover yield}} \times 100$$

The Micro-Kjeldahl Method was used to estimate the protein (%) in faba bean seeds, and the Soxhlet apparatus was used to calculate the crude fat (%) (AOAC, 2000).

Data analysis

The collected data were subjected to statistical analysis using ANOVA in R software (version 4.4.2), and treatment means were compared using the Least Significant Difference (LSD) test, following the procedure described by Gomez and Gomez (1984).

Results

Plant height

Plant height was expressively affected by variety and foliar spray of B (Table 1). The brown-seeded variety exhibited greater height (73.53±1.87 cm) than the black-seeded variety (70.40±1.74 cm), likely due to inherent genetic differences between the cultivars. Among the B treatments, foliar application at 60 mg L⁻¹ resulted in the taller plants (75.92±2.42 cm), whereas the control group without B recorded the shorter height (68.04±2.47 cm).

Furthermore, a significant interaction effect was observed between variety and B level (Table 2). The combination of the V₂ variety with 40 mg L⁻¹ B foliar spray produced the taller plants (77.2±3.71 cm), while the V₁ variety without B application resulted shorter plants (66.29±1.99 cm).

Number of branches plant⁻¹

Branch development in faba bean was markedly influenced by varietal differences, as evidenced in Table 1, where the brown-seeded type produced significantly more branches per plant at harvest (3.28±0.13) compared to the black-seeded variety (3.10±0.14). Although the foliar application of B did not result in a statistically significant main effect, the highest branch number (3.63±0.17) was observed under B₄ (60 mg L⁻¹), while the lowest one (2.87±0.11) found in the control treatment (B₀). A significant interaction between variety and B concentration was also recorded (Table 2), with the brown-seeded variety under 60 mg L⁻¹ B (V₂B₄) yielding the greatest number of branches (3.80±0.25), whereas the black-seeded variety without B (V₁B₀) exhibited the fewest (2.67±0.05).

Number of pods plant⁻¹

Varietal differences notably influenced the number of pods plant⁻¹, with the brown-seeded faba bean producing a slightly higher pod count (32.91±0.99) than the black-seeded variety (32.84±1.02), as presented in Table 1. The foliar application of B also had a notable effect, where the highest number of pods (37.33±0.89) was recorded under the B₄ treatment (60 mg L⁻¹), and the lowest (29.63±1) was noticed in B₁ (10 mg L⁻¹), which was statistically similar to the control (B₀). A significant interaction between variety and B level was apparent (Table 2), with the maximum pod production plant⁻¹ (38.60±1.42) obtained from brown-seeded variety with 60 mg L⁻¹ B (V₂B₄). In contrast, the lowest number of pods (28.2±1.11) was found in V₂B₁ (brown-seeded × 10 mg L⁻¹ B), which did not differ significantly from V₁B₀ and V₂B₀.

Length of pod

Pod length was significantly affected by variety, with the brown-seeded faba bean producing longer pods (4.47±0.07 cm) compared to the black-seeded variety

Table 1: Effect of variety and foliar application of boron on yield attributes and yield on faba bean

Variety	Plant height (cm)	Branches plant ⁻¹ (no.)	Pods plant ⁻¹ (no.)	Length of pod (cm)	Unfilled pods plant ⁻¹ (no.)	Seeds pod ⁻¹ (no.)	1000-seed weight (g)	Biological yield (t ha ⁻¹)	Harvest index (%)
V ₁	70.4±1.74 ^b	3.1±0.14 ^b	32.84±1.02 ^b	4.13±0.12 ^b	2.48±0.19	3.2±0.06 ^b	185.76±0.75 ^b	3.83±0.08 ^b	48.45±0.31
V ₂	73.53±1.87 ^a	3.28±0.13 ^a	32.91±0.99 ^a	4.47±0.07 ^a	2.43±0.14	3.29±0.09 ^a	224±1.54 ^a	4.75±0.07 ^a	48.72±0.27
LSD ^(0.05)	2.28	0.07	0.01	0.31	0.35	0.01	4.22	0.09	0.62
Sig. level	**	**	**	**	NS	**	**	**	NS
CV%	4.13	3.10	3.99	9.51	19.11	2.42	2.69	2.82	2.68
Foliar application of boron									
B ₀	68.04±2.47 ^c	2.87±0.11	29.7±0.82 ^d	4.06±0.27	2.37±0.19	3.03±0.16 ^c	196.13±8.15 ^b	3.89±0.19 ^d	47.5±0.52 ^c
B ₁	69.13±3.24 ^{bc}	2.9±0.22	29.63±1 ^d	4.28±0.13	2.57±0.25	3.27±0.11 ^b	207.17±7.06 ^a	4.17±0.19 ^c	48.06±0.30 ^{bc}
B ₂	72.5±2.3 ^{ab}	3.35±0.23	32.6±1.33 ^c	4.39±0.16	2.17±0.2	3.23±0.07 ^b	207.39±7.98 ^a	4.34±0.22 ^b	48.91±0.11 ^{ab}
B ₃	74.24±2.74 ^a	3.2±0.15	35.13±0.9 ^b	4.26±0.04	2.5±0.27	3.23±0.06 ^b	205.79±8.19 ^a	4.38±0.21 ^b	48.99±0.1 ^{ab}
B ₄	75.92±2.42 ^a	3.63±0.17	37.33±0.89 ^a	4.5±0.07	2.67±0.34	3.46±0.04 ^a	207.91±8.67 ^a	4.7±0.14 ^a	49.45±0.12 ^a
LSD ^(0.05)	3.60	1.37	1.45	0.49	0.56	0.09	6.68	0.14	0.99
Sig. level	**	NS	**	NS	NS	**	*	**	**
CV%	4.13	3.10	3.99	9.51	19.11	2.42	2.69	2.82	2.68

Values in the same column with identical letters are statistically similar. ** = Significant at 1% level of probability, * = Significance at 5% level of probability, NS=Non-significant, Values are presented as mean±standard error. V₁=Black seeded faba bean, V₂=Brown seeded faba bean, B₀=0 mg L⁻¹, B₁=10 mg L⁻¹, B₂=20 mg L⁻¹, B₃=40 mg L⁻¹, B₄=60 mg L⁻¹

Table 2: Effect of interaction between variety and foliar application of boron on yield attributes and yields of faba bean

Variety×Foliar application of boron	Plant height (cm)	Branches plant ⁻¹ (no.)	Pods plant ⁻¹ (no.)	Length of pod (cm)	Unfilled pods plant ⁻¹ (no.)	Seeds pod ⁻¹ (no.)	1000-seed weight (g)	Biological yield (t ha ⁻¹)	Harvest index (%)
V ₁ B ₀	66.29±1.99 ^f	2.67±0.05 ^g	29.2±0.71 ^{fg}	3.81±0.49 ^b	2.27±0.05 ^{bc}	3.07±0.2 ^{de}	176.83±3.45 ^d	3.43±0.01 ^c	47.18±0.88 ^c
V ₁ B ₁	67.17±3.74 ^{ef}	2.87±0.38 ^f	31.07±1.19 ^{ef}	4.04±0.11 ^{ab}	2.6±0.43 ^{bc}	3.27±0.05 ^{bc}	190.19±2.2 ^c	3.69±0 ^d	47.74±0.48 ^{bc}
V ₁ B ₂	71.74±3.37 ^{b-c}	3.23±0.33 ^c	31.8±2.32 ^{de}	4.13±0.07 ^{ab}	2±0.34 ^c	3.2±0 ^{cd}	187.93±1.12 ^c	3.82±0.02 ^d	48.69±0.11 ^{ab}
V ₁ B ₃	71.28±3.22 ^{b-f}	3.27±0.22 ^c	33.93±1.12 ^{cd}	4.21±0.05 ^{ab}	2.07±0.29 ^c	3.2±0.09 ^{cd}	186.2±2.8 ^{cd}	3.88±0.03 ^d	48.97±0.11 ^{ab}
V ₁ B ₄	75.53±4.11 ^{abc}	3.47±0.2 ^b	36.07±0.28 ^{bc}	4.43±0.12 ^{ab}	3.47±0.05 ^a	3.4±0.05 ^{ab}	187.65±3.89 ^c	4.36±0.04 ^c	49.66±0.14 ^a
V ₂ B ₀	69.78±4.29 ^{def}	3.07±0.14 ^{de}	30.2±1.42 ^{efg}	4.31±0.05 ^{ab}	2.47±0.36 ^{bc}	3.0±0.25 ^c	215.42±2.35 ^b	4.35±0.04 ^c	47.82±0.47 ^{bc}
V ₂ B ₁	71.1±5.04 ^{cdef}	2.93±0.22 ^{ef}	28.2±1.11 ^g	4.51±0.12 ^{ab}	2.53±0.24 ^{bc}	3.27±0.22 ^{bc}	224.16±1.52 ^{ab}	4.64±0.01 ^b	48.38±0.27 ^{abc}
V ₂ B ₂	73.25±3.17 ^{a-d}	3.47±0.3 ^b	33.4±1.14 ^d	4.65±0.22 ^a	2.33±0.14 ^{bc}	3.27±0.14 ^{bc}	226.86±0.75 ^a	4.86±0.14 ^a	49.15±0.04 ^{ab}
V ₂ B ₃	77.2±3.71 ^a	3.13±0.2 ^{cd}	36.33±1.02 ^b	4.31±0.06 ^{ab}	2.93±0.27 ^{ab}	3.27±0.05 ^{bc}	225.39±2.18 ^a	4.88±0.05 ^a	49.02±0.17 ^{ab}
V ₂ B ₄	76.31±2.52 ^{ab}	3.8±0.25 ^a	38.6±1.42 ^a	4.56±0.07 ^a	1.86±0.14 ^c	3.53±0.05 ^a	228.17±3.48 ^a	5.03±0.08 ^a	49.24±0.1 ^a
LSD ^(0.05)	5.10	0.16	2.07	0.70	0.80	0.13	9.45	0.21	1.40
Sig. level	**	**	**	*	*	**	**	**	**
CV%	4.13	3.10	3.99	9.51	19.11	2.42	2.69	2.82	2.68

Values in the same column with identical letters are statistically similar. ** = Significant at 1% level of probability, * = Significance at 5% level of probability, NS=Non-significant, Values are presented as mean±standard error. V₁=Black seeded faba bean, V₂=Brown seeded faba bean, B₀=0 mg L⁻¹, B₁=10 mg L⁻¹, B₂=20 mg L⁻¹, B₃=40 mg L⁻¹, B₄=60 mg L⁻¹

(4.13±0.12 cm), as shown in Table 1. Although B application did not exert a statistically significant effect, numerically the longest pods (4.5±0.07 cm) were recorded under the B₄ treatment (60 mg L⁻¹), while the shortest pods (4.06±0.27 cm) were observed in the control (B₀). All treatment combinations except V₁B₀ were statistically identical, with the exception of the V₂B₂ treatment, which had the longest pod (4.65±0.22 cm). Pods in V₁B₀ were the shortest, measuring 3.81±0.49 cm (Table 2).

Number of unfilled pods plant⁻¹

Neither variety nor foliar application of B exerted a statistically significant effect on the number of unfilled pods plant⁻¹ (Table 1); however, numerically, the black-seeded faba bean produced slightly more unfilled pods (2.48±0.19) compared to the brown-seeded variety (2.43±0.14). The maximum number of unfilled pods plant⁻¹ (2.67±0.34) was recorded under the B₄ treatment (60 mg L⁻¹), while the lowest one (2.17±0.2) found in B₂ (20 mg L⁻¹). Despite the lack of individual effects, the interaction between variety and B application was notably significant at the 5% (Table 2). The uppermost number of unfilled pods plant⁻¹ (3.47±0.05) was noticed in the V₁B₄ treatment, which was statistically comparable to V₂B₃ and the lowest one (1.86±0.14) was noted in V₂B₄.

Number of seeds pod⁻¹

Variety had a substantial impact on the amount of seeds pod⁻¹; Table 1 shows that the brown-seeded faba bean produced more seeds pod⁻¹ (3.29±0.09), compared to the black-seeded variety (3.20±0.06). The use of B also had a notable impact; the B₄ treatment (60 mg L⁻¹) produced the most seeds pod⁻¹ (3.46±0.04), whereas the control (B₀) produced the fewest (3.03±0.16). Additionally, a noteworthy interplay between B level and variety was observed (Table 2). The V₂B₄ treatment (brown-seeded × 60 mg L⁻¹ B) had the maximum number of seeds pod⁻¹ (3.53±0.05), which showed no significant difference to V₁B₄. In contrast, the lowest seeds pod⁻¹ (3±0.25) was found in V₂B₀, which did not differ significantly in V₁B₀.

Weight of 1000 seeds

The 1000-seed weight was notably influenced by variety, with the brown-seeded faba bean producing heavier seeds (224±1.54 g) than the black-seeded variety (185.76±0.75 g), as presented in Table 1. Foliar application of B also had a notable impact on 1000-seed weight at the 5% level of significance. The highest seed weight (207.91±8.67 g) was observed in the B₄ treatment (60 mg L⁻¹), which was statistically comparable to B₁, B₂, and B₃, while the lowest weight (196.13±8.15 g) was recorded in the control (B₀). A significant interaction between variety and B application was also found (Table 2). The combination of the brown-seeded variety with 60 mg L⁻¹ B (V₂B₄) resulted in the highest 1000-seed weight (228.17±3.48 g), which showed no significant difference to V₂B₁, V₂B₂, and V₂B₃. In contrast, the lowest value (176.83±3.45 g) was recorded in V₁B₀, which was statistically similar to V₁B₃.

Seed yield

Seed yield was greatly influenced by faba bean variety. The brown-seeded variety exhibited a higher yield (2.32±0.04 t ha⁻¹) compared to the black-seeded variety (1.86±0.05 t ha⁻¹) (Figure 2a). Foliar supplementation of boron (B) also had a pronounced effect on the seed yield (Figure 2b). The highest yield (2.32±0.07 t ha⁻¹) was obtained under the B₄ treatment (60 mg L⁻¹), followed by B₃ and B₂ whereas the control (B₀) resulted in the lowest seed yield (1.85±0.10 t ha⁻¹). A significant interaction between variety and B application was found in seed yield (Figure 2c). The maximum seed yield (2.48±0.04 t ha⁻¹) was achieved under the V₂B₄ treatment, which was at par with V₂B₂ and V₂B₃. In contrast, the lowest yield (1.62±0.03 t ha⁻¹) was recorded in V₁B₀.

Stover yield

Stover yield also varied significantly between varieties. The brown-seeded faba bean resulted in the highest stover yield (2.44±0.03 t ha⁻¹), surpassing that of the black-seeded variety (1.98±0.03 t ha⁻¹) (Figure 3a). Foliar B application exerted a significant effect, with the maximum stover yield (2.38±0.08 t ha⁻¹) obtained under B₄ (60 mg L⁻¹), followed by B₃ (40 mg L⁻¹), which was statistically comparable to B₁ and B₂ (Figure 3b) while the control (B₀) resulted in the lowest stover yield (2.04±0.10 t ha⁻¹). Stover yield was significantly influenced by the interaction between variety and boron (Figure 3c). The highest stover yield (2.56±0.04 t ha⁻¹) was recorded under V₂B₄, which was statistically at par with V₂B₃ and V₂B₂. Conversely, the lowest yield (1.81±0.03 t ha⁻¹) found in V₁B₀, which was statistically similar to V₁B₁.

Biological yield

Biological yield was greatly influenced by variety, brown-seeded faba bean produced a higher biological yield (4.75±0.07 t ha⁻¹) than the black-seeded variety (3.83±0.08 t ha⁻¹), as shown in Table 1. Foliar supplementation of B also had a notable effect on biological yield. The maximum yield (4.70±0.14 t ha⁻¹) was recorded under the B₄ treatment (60 mg L⁻¹), followed by B₃ and B₂, while the control (B₀) had the minimum biological yield (3.89±0.19 t ha⁻¹). A significant interaction between variety and B application was observed in Table 2. The highest biological yield (5.03±0.08 t ha⁻¹) was noticed in the V₂B₄ treatment, which was statistically similar to V₂B₃, V₂B₂, and V₂B₁ while the lowest biological yield (3.43±0.01 t ha⁻¹) was recorded in V₁B₀ (Table 2).

Harvest index

Variety did not have a notable effect on the harvest index, although the brown-seeded faba bean exhibited a slightly higher value (48.72±0.27%) compared to the black-seeded variety (48.45±0.31%) as shown in Table 1. In contrast, foliar application of B greatly influenced the harvest index. The highest harvest index (49.45±0.12%) was observed under the B₄ treatment (60 mg L⁻¹), which was

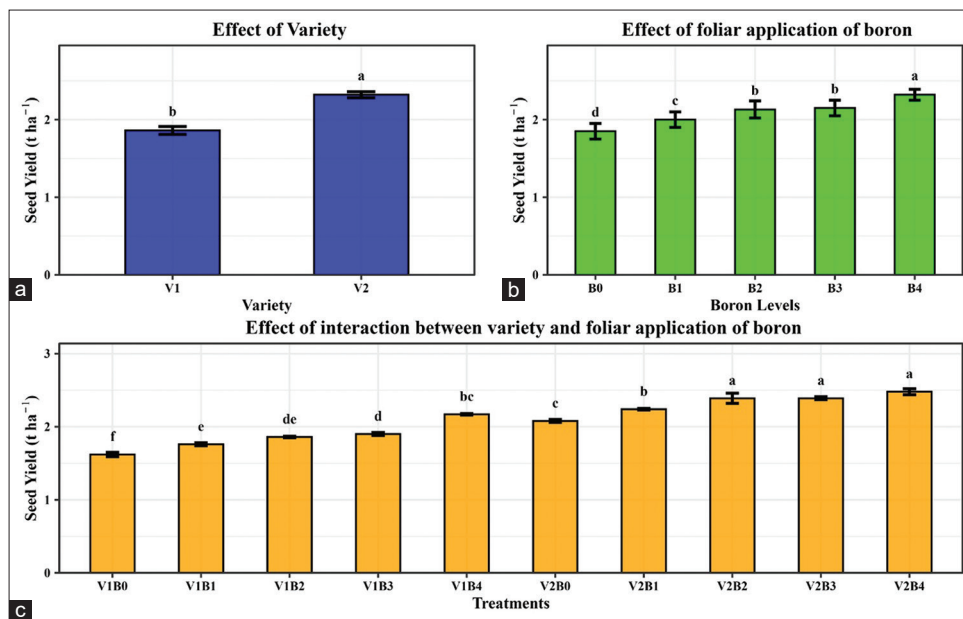


Figure 2: (a-c) Effect of faba bean variety, foliar application of boron, and their interaction on seed yield of faba bean

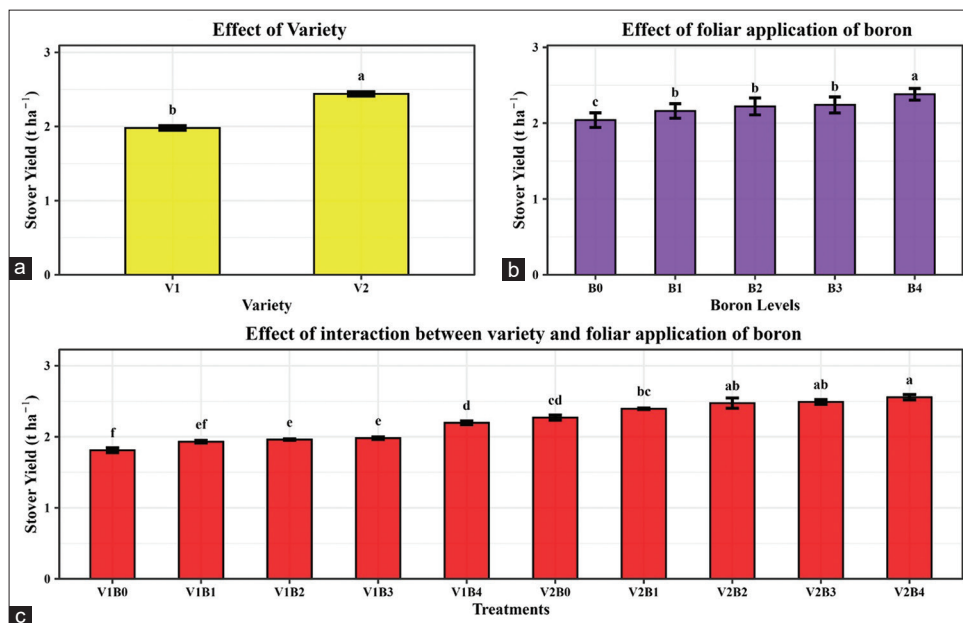


Figure 3: (a-c) Effect of faba bean variety, foliar application of boron, and their interaction on stover yield of faba bean

statistically comparable to B_3 and B_2 , while the lowest value ($47.50 \pm 0.52\%$) was observed in the control (B_0), similar to B_1 (Table 1). A significant interaction between variety and B application was also found in harvest index (Table 2). The highest harvest index ($49.66 \pm 0.14\%$) was recorded in V_1B_4 (black-seeded \times 60 mg L^{-1} B) where the lowest value ($47.18 \pm 0.88\%$) was found in V_1B_0 (black-seeded \times control).

Seed protein content (%)

Seed protein content was notably influenced by variety, with the brown-seeded faba bean having higher protein content ($17 \pm 0.85\%$) than the black-seeded variety ($16 \pm 0.37\%$) (Figure 4a). Foliar B application also significantly affected protein content; the control (B_0) showed the highest protein content ($19 \pm 1.23\%$), followed by B_4 (60 mg L^{-1}), while B_1 (10 mg L^{-1}) had the lowest

($15 \pm 1.24\%$) (Figure 4b). A significant interaction between variety and B was observed. The highest protein content ($22 \pm 0.26\%$) was recorded in V_2B_0 (brown-seeded \times control), followed by V_2B_2 , which showed no significant difference to V_1B_1 , V_2B_4 , and V_1B_4 , while the lowest value ($12 \pm 0.36\%$) found in V_2B_1 (brown-seeded \times 10 mg L^{-1}) (Figure 4c).

Seed fat content (%)

Variety had no significant effect on seed fat content, though the black-seeded faba bean showed a slightly higher fat percentage ($1.92 \pm 0.09\%$) than the brown-seeded variety ($1.90 \pm 0.11\%$) (Figure 4a). Foliar B application significantly affected fat content, with the highest value observed in B_1 ($2.25 \pm 0.11\%$), which was as good as B_2 , while the lowest fat content ($1.50 \pm 0.09\%$) was found in the control (B_0) (Figure 4b). A significant interaction between variety

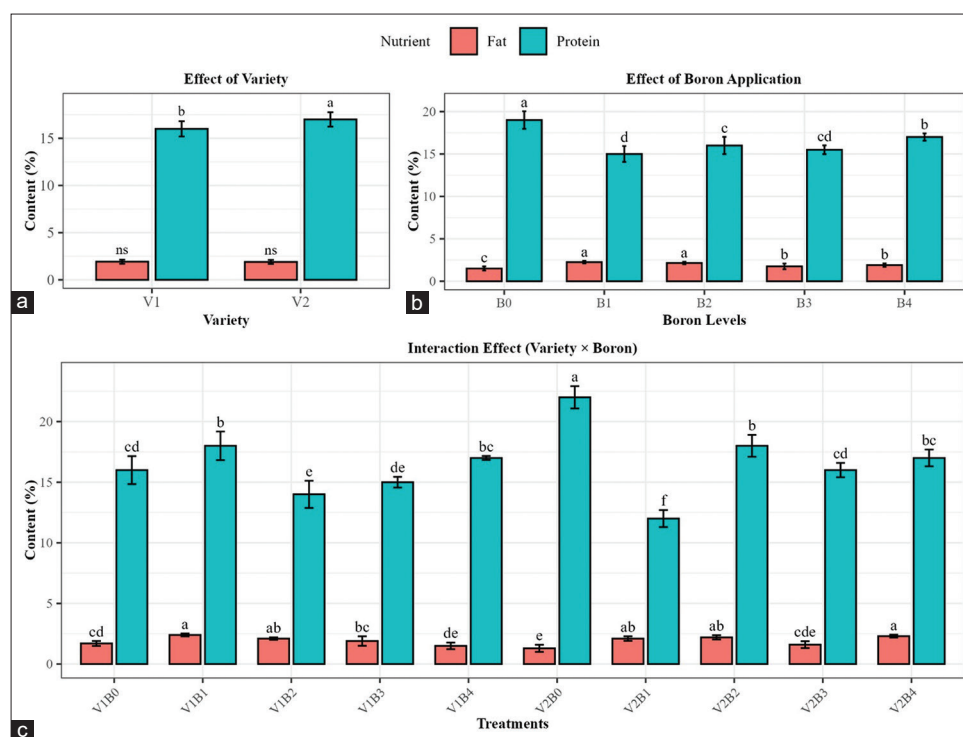


Figure 4: (a-c) Effects of faba bean variety, foliar boron application, and their interaction on seed protein and fat contents. Values are presented as mean \pm standard error. V_1 = Black seeded faba bean, V_2 = Brown seeded faba bean, B_0 = 0 mg L⁻¹, B_1 = 10 mg L⁻¹, B_2 = 20 mg L⁻¹, B_3 = 40 mg L⁻¹, B_4 = 60 mg L⁻¹

and B was recorded in V_1B_1 (black-seeded \times 10 mg L⁻¹ B) produced the highest fat content (2.4 \pm 0.14%) which was at par with V_2B_4 , V_2B_2 , V_2B_1 , and V_1B_2 , whereas the lowest (1.30 \pm 0.07%) was recorded in V_2B_0 (brown-seeded \times control), statistically similar to V_1B_4 and V_2B_3 (Figure 4c).

Discussion

Foliar supplementation of boron (B) significantly influenced faba bean growth, yield, and seed quality, with marked differences observed between the brown- and black-seeded varieties. The brown-seeded variety consistently outperformed the black-seeded variety in plant height, branch number, pod number, pod length, seeds pod⁻¹, 1000-seed weight, and both seed and biological yield, highlighting the importance of genetic factors in shaping varietal responses to micronutrient supplementation. The increase in plant height recorded at higher B concentrations, particularly at 60 mg L⁻¹, is attributable to boron's crucial role in carbohydrate translocation, regulation and mobilization of indole-3-acetic acid (IAA), and stimulation of cell division and expansion in meristematic tissues (Shelp *et al.*, 2006; Assi *et al.*, 2019; Hassan, 2019; Kadhim, 2022). Branch development was also enhanced under B application, especially in the brown-seeded variety, reflecting boron's influence on lateral growth through improved photosynthate allocation and hormonal regulation (Sharaf *et al.*, 2009; Al-Amiri, 2014). Pod number and length increased with foliar B, indicating its involvement in reproductive processes such as pollen tube growth, fertilization, and pod set (Reda *et al.*, 2014; Kadhim, 2022; Dey *et al.*, 2023). The number of seeds pod⁻¹ and 1000-seed weight were notably improved with boron application, likely due to optimized source-sink

relationships and enhanced assimilate translocation toward developing seeds (Barker & Pilbeam, 2006; Sharaf *et al.*, 2009; Kadhim, 2022; Khuong *et al.*, 2022). Seed yield and stover yield also increased under higher B levels, reflecting improved vegetative growth, flowering, and assimilate partitioning (Kumar *et al.*, 1988; El-Kabbany, 2000; Kassab, 2005). Biological yield showed a similar trend, with maximum values recorded in the brown seeded faba bean with 60 mg L⁻¹, combination, suggesting that boron enhances overall biomass accumulation by promoting chlorophyll synthesis, enzymatic activity, and structural development (Gharib & Hegazi, 2010). Harvest index was moderately improved under B application, indicating more efficient allocation of dry matter toward economic yield (Daoud, 1999).

Seed quality traits, including protein and fat content, displayed variable responses to foliar B. Higher protein content in certain treatments, particularly in the control and some B combinations, may reflect interactions between boron and nitrogen metabolism, with excessive or imbalanced B potentially reducing protein synthesis (Ziolek & Ziolek, 1988; Jasim & Obaid, 2014; Elbatrawy *et al.*, 2023). Conversely, moderate B application (10-60 mg L⁻¹) enhanced seed fat content, likely through increased phloem sugar mobility, particularly sucrose, which serves as a carbon source for fatty acid synthesis, and through the activation of key enzymes such as fatty acid synthase and acetyl-CoA carboxylase (Bellaloui, 2011; Bellaloui *et al.*, 2013). The consistent significance of variety and B interactions across most traits highlights the importance of cultivar-specific B management for optimizing both yield and seed quality. Overall, these

findings confirm that foliar boron application, particularly at 60 mg L⁻¹ during pre-flowering and pod formation, substantially enhances vegetative growth, reproductive development, yield components, and selected quality parameters in faba bean.

Conclusion

This study demonstrated that foliar boron supplementation significantly enhanced the growth, yield, and seed quality of faba bean under field conditions. Among the tested varieties, the brown-seeded type consistently outperformed the black-seeded type in key agronomic traits and yield attributes. Foliar application of boron at 60 mg L⁻¹, applied twice at pre-flowering and pod formation stages, proved to be the most effective treatment. This combination maximized seed yield, biomass production, and important yield components such as pods plants⁻¹, seed weight, and seeds pod⁻¹. The findings highlight that brown-seeded faba bean is particularly responsive to boron nutrition, especially when supplied at critical developmental stages namely at the pre-flowering and pod formation stages. Therefore, integrating foliar boron application into existing cultivation practices can substantially improve faba bean productivity in similar agro-ecological zones.

Author contributions

Md. Romanch Mahmud: Writing – original draft, Methodology, Data curation, Formal analysis. Babli Rani Deb: Writing – original draft, Data curation, Formal analysis. Md. Shishir Ahamed: Software, Formal analysis, Visualization, Validation, Shubroto Kumar Sarkar: Methodology, Writing – original draft. F M Jamil Uddin: Methodology, Data Curation, Investigation. Md. Harun Rashid: Conceptualization, Supervision, Formal analysis. SKP: Conceptualization, Supervision, Data curation, Formal analysis, Writing– original draft, Review and editing, Visualization, Validation, Funding acquisition.

Acknowledgements

We are thankful to Ministry of Science and Technology, Government of the People's Republic of Bangladesh for financial support [Project No: SRG-231127 (2023/31/MoST)] to conduct the study.

References

Agrawal, S., Panigrahi, C., & Eri, R. (2024). An elaborative discussion on the potentiality, functional characteristics, curative effects, antinutritional factors, processing, and industrial applications of faba beans (*Vicia faba* L.) as a versatile legume. *International Journal of Food Science and Technology*, 59(1), 30-57. <https://doi.org/10.1111/ijfs.16803>

Al-Amiri, A. S. U. (2014). *Influence of foliar fertilizers in growth and yield of leguminous crops Vicia faba L.* Master's thesis, University of Baghdad.

Ali, N. S., Rahi, H. S., & Shaker, A. A. (2014). *Soil fertility*. Scientific Book House.

Al-Yasari, M. N. H., Al-Mosawi, A. N. A., & Al-Karhi, M. A. J. (2022). Response of three faba bean cultivars to boron. *Biochemical and Cellular Archives*, 22(2), 3899-3904. <https://doi.org/10.51470/bca.2022.22.2.3899>

AOAC. (2000). *Official methods of the association of official analytical chemists*. The Association of Official Analytical Chemists.

Assi, S. L., Tarkhan, M., & Abdul-Ameer, H. K. (2019). Influence of foliar application of boron and seed scarification on some vegetative growth and yield of broad bean (*Vicia faba* L.) local var. *Journal of University of Babylon for Pure and Applied Sciences*, 27(5), 75-87.

Barker, A. V., & Pilbeam, D. J. (2006). *Handbook of plant nutrition*. CRC Press. <https://doi.org/10.1201/b18458>

Bellaloui, N. (2011). Effect of water stress and foliar boron application on seed protein, oil, fatty acids and nitrogen metabolism in soybean. *American Journal of Plant Sciences*, 2(5), 692-701. <https://doi.org/10.4236/ajps.2011.25084>

Bellaloui, N., Hu, Y., Mengistu, A., Kassem, M. A., & Abel, C. A. (2013). Effects of foliar boron application on seed composition, cell wall boron, and seed $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ isotopes in water-stressed soybean plants. *Frontiers in Plant Science*, 4, 270. <https://doi.org/10.3389/fpls.2013.00270>

Daoud, W. M. (1999). *Effect of nitrogen and seed quantities on the growth, yield and quality of grains of five cultivars of bread wheat*. Doctoral Dissertation, University of Baghdad.

Deb, B. R., & Paul, S. K. (2024). Agronomic management of faba bean (*Vicia faba* L.): A review. *Turkish Journal of Agriculture-Food Science and Technology*, 12(S1), 2166-2179. <https://doi.org/10.24925/turjaf.v12is1.2166-2179.7102>

Dey, A., Begum, M., Kobiraj, M.S., Rashid, M.H. & Paul S. K. (2023). Influence of foliar application of boron on the growth, yield and quality of sesame (cv. BARI Til-4). *Turkish Journal of Agriculture-Food Science and Technology*, 11(12), 2356-2364. <https://doi.org/10.24925/turjaf.v11i12.2355-2363.6364>

Dordas, C., Apostolides, G. E., & Goundra, O. (2007). Boron application affects seed yield and seed quality of sugar beets. *The Journal of Agricultural Science*, 145(4), 377-384. <https://doi.org/10.1017/S0021859607006879>

Elbatrawy, W. S. W. S., Yousif, E. E., & Ghannam, H. A. (2023). Effect of sorbitol and boron on the growth and seed quality of faba bean (*Vicia faba* L.). *Egyptian Journal of Agricultural Research*, 101(2), 538-551. <https://doi.org/10.21608/ejar.2023.191974.1337>

El-Kabbany, E. (2000). Effect of foliar spray with zinc and boron on yield and some chemical constituents of faba bean. *Journal of Soil Science and Agricultural Engineering*, 25(3), 1873-1882. <https://doi.org/10.21608/jssac.2000.258769>

Gharib, F. A., & Hegazi, A. Z. (2010). Salicylic acid ameliorates germination, seedling growth, phytohormones and enzyme activity in bean (*Phaseolus vulgaris* L.) under cold stress. *Journal of the American Science*, 6(10), 675-683.

Gupta, U. C. (1993). Boron and its role in crop production. CRC Press.

Hassan, R. K. (2019). *Influence of the concentrations and dates of leaf fertilization in the growth and yield of two varieties of broad bean*. Master's thesis, Al-Furat Al-Awsat Technical University.

Jasim, A. H., & Obaid, A. S. (2014). Effect of foliar fertilizers spray, boron and their interaction on broad bean (*Vicia faba* L.) yield. *Scientific Papers Series B, Horticulture*, 58, 271-276.

Kadhim, J. J. (2022). Influence of foliar nutrition through boron on growth and yield components of some field bean (*Vicia faba* L.) varieties. *Journal of Plant Production*, 13(8), 559-563. <https://doi.org/10.21608/jpp.2022.149719.1143>

Kassab, O. M. (2005). Soil moisture stress and micronutrients foliar application effects on the growth and yield of mung bean plants. *Journal of Plant Production*, 30(1), 247-256.

- <https://doi.org/10.21608/jpp.2005.237098>
- Khayyat, M., Tafazoli, E., Eshghi, S., & Rajaei, S. (2007). Effect of nitrogen, boron, potassium and zinc sprays on yield and fruit quality of date palm. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 2(3), 289-296.
- Khuong, N. Q., Thuc, L. V., Tran, N. T. B., Huu, T. N., & Sakagami, J.-I. (2022). Foliar application of boron positively affects the growth, yield, and oil content of sesame (*Sesamum indicum* L.). *Open Agriculture*, 7(1), 30-38. <https://doi.org/10.1515/opag-2022-0067>
- Kumar, K., Arvind, K., Vidyasagar, R., & Rao, K. V. N. (1988). Studies on growth and activity of photosynthetic enzymes in *Sorghum bicolor* (L.) as influenced by micronutrients. *Proceedings of Indian National Science Academy Part B Biological Sciences*, 54(1), 57-80.
- Mohamed, A. A., Eissa, M. A., & Bakheit, B. R. (2024). Algal and nanoparticles of silicon and boron foliar application efficiency for maximizing yield and quality traits of two faba bean varieties. *Egyptian Journal of Agronomy*, 46(1), 213-227. <https://doi.org/10.21608/agro.2024.284735.1425>
- Mosleh, M. F., & Abdul Rasool, I. J. (2019). Role of spraying boron and sugar alcohols on growth, yield and seed production of pepper. *Iraqi Journal of Agricultural Science*, 50(2), 646-652.
- Paul, S. K., & Gupta, D. R. (2021). Faba bean (*Vicia faba* L.), a promising grain legume crop of Bangladesh: A review. *Agricultural Reviews*, 42(3), 292-299. <https://doi.org/10.18805/ag.R-203>
- Paul, S. K., Gupta, D. R., Mahmud, N. U., Muzahid, A. N. M., & Islam, M. T. (2022). First report of collar and root rot of faba bean caused by *Rhizoctonia solani* AG-2-2 IIIB in Bangladesh. *Plant Disease*, 106(3), 1072-1079. <https://doi.org/10.1094/PDIS-08-21-1603-PDN>
- Paul, S. K., Mondal, M., Sarker, U. K., & Sarker, S. K. (2021). Response of yield and seed quality of faba bean (*Vicia faba*) to irrigation and nutrient management. *Research on Crops*, 22(2), 256-264. <https://doi.org/10.31830/2348-7542.2021.066>
- Reda, F., Magdi, T. A., & El-Lethy, S. R. (2014). The role of Zn and B for improving (*Vicia faba* L.) tolerance to salinity stress. *Middle East Journal of Agriculture Research*, 3(4), 707-714.
- Salem, A. E. K., El-Harty, E., Ammar, M. H., & Alghamdi, S. S. (2014). Evaluation of faba bean (*Vicia faba* L.) performance under various micronutrient foliar applications and plant spacing. *Life Science Journal*, 11(10), 1298-1304.
- Salvador-Reyes, R., Campigli Furlan, L., Martínez-Villaluenga, C., Dala-Paula, B. M., & Pedrosa Silva Clerici, M. T. (2023). From ancient crop to modern superfood: Exploring the history, diversity, characteristics, technological applications, and culinary uses of Peruvian fava beans. *Food Research International*, 173(Part 2), 113394. <https://doi.org/10.1016/j.foodres.2023.113394>
- Sharaf, A. E. M., Farghal, I. I., & Sofy, M. R. (2009). Response of broad bean and lupin plants to foliar treatment with boron and zinc. *Australian Journal of Basic and Applied Sciences*, 3(3), 2226-2231.
- Sheh Бала, E. S. (2021). Molecular phylogeny of the genus *Vicia* L. (Fabaceae) based on ITS2 and Cox1 housekeeping genes. *Genus*, 30.
- Shelp, B. J., Marentes, E., Kitheka, A. M., & Vivekanandan, P. (2006). Boron mobility in plants. *Physiologia Plantarum*, 94(2), 356-361. <https://doi.org/10.1111/j.1399-3054.1995.tb05323.x>
- Svanes, E., Waalen, W., & Uhlen, A. K. (2022). Environmental impacts of field peas and faba beans grown in Norway and derived products, compared to other food protein sources. *Sustainable Production and Consumption*, 33, 756-766. <https://doi.org/10.1016/j.spc.2022.07.020>
- UNDP, & FAO. (1988). Land resources appraisal of Bangladesh for agricultural development. Report 2. *Agro-ecological regions of Bangladesh* (pp. 212-221). Bangladesh Agricultural Research Council.
- Upadhyay, V. S., Muntean, B. S., Kathem, S. H., Hwang, J. J., AbouAlaiwi, W. A., & Nauli, S. M. (2014). Roles of dopamine receptor on chemosensory and mechanosensory primary cilia in renal epithelial cells. *Frontiers in Physiology*, 5, 72. <https://doi.org/10.3389/fphys.2014.00072>
- Vera-Maldonado, P., Aquea, F., Reyes-Díaz, M., Ca'rcamo-Fincheira, P., Soto-Cerda, B., Nunes-Nesi A., & Inostroza-Blancheteau, C. (2024). Role of boron and its interaction with other elements in plants. *Frontiers in Plant Science*, 15, 1332459. <https://doi.org/10.3389/fpls.2024.1332459>
- Yasmin, W., Paul, S. K., & Anwar, M. P. (2020). Growth, yield and quality of faba bean (*Vicia faba* L.) in response to sowing date and phosphorus fertilization. *Archives of Agriculture and Environmental Science*, 5(1), 11-17. <https://doi.org/10.26832/24566632.2020.050102>
- Ziolek, E., & Ziolek, W. (1988). Effect of foliar fertilization by microelements on the yields of horse beans depending on row spacing and plants. *Agraria*, 27, 167-179.