Optimizing Micronutrient Management for Improved Growth and Yield of Broccoli Varieties in Coastal Bangladesh

Abstract

Broccoli (Brassica oleracea var. italica L.) is a nutrient-dense vegetable, widely valued for its health-promoting properties, yet its cultivation in Bangladesh is hindered by nutrient deficiencies and limited adoption of effective fertilization practices. This study was conducted to evaluate the impact of boron (B) and zinc (Zn) application on the growth, yield, and quality of two broccoli varieties— 'Green Carpet' and 'Early You'—in the Gangetic Tidal Floodplain region, where soil deficiencies in these micronutrients are common. A two-factor Randomized Complete Block Design (RCBD) was employed, with treatments consisting of four B and Zn application levels: control (M0), 2 kg B + 4 kg Zn ha^{-1} (M1), 2.5 kg B + 4.5 kg Zn ha^{-1} (M2), and 3 kg B + 5 kg Zn ha^{-1} (M3). Growth parameters, curd characteristics, and yield were measured to determine the optimal nutrient application level and variety for local conditions.

The findings revealed that the combination of 2 kg B + 4 kg Zn ha^{-1} (M1) with the 'Early You' variety (V2) produced the most significant improvements in plant height, leaf growth, stem length and diameter, and primary curd size. The V2M1 treatment significantly reduced days to curd initiation and produced the highest yield per hectare (20.18 tons), outperforming the control treatment (13.01 tons). This combination also resulted in higher dry weight and greater nutritional density of the broccoli curds, emphasizing the critical role of B and Zn in promoting growth, structural robustness, and curd development. Both primary and secondary curd weights were notably enhanced under M1, particularly with 'Early You', highlighting the synergistic effect of variety-specific nutrient optimization.

These results underscore the potential of tailored boron and zinc applications to address soil nutrient deficiencies and optimize broccoli production under Bangladesh's unique agro-ecological conditions. By adopting the recommended M1 micronutrient treatment and prioritizing the 'Early You' variety, local farmers can achieve higher yields and improved broccoli quality, contributing to enhanced food security and economic sustainability in the region. This study provides a foundational framework for future research on nutrient management strategies in broccoli and serves as a model for other regions with similar soil nutrient constraints.

Comment [SB1]: Try to explain the treatment instead of writing in shortform in the abstract section. Avoid non standard abbreviations

Keywords: Boron (B), Zinc (Zn), Micronutrient management, Yield optimization, Growth parameters, Curd quality, Gangetic Tidal Floodplain, Sustainable agriculture, Nutrient deficiencies, Agroecological condition, Food security, Economic resilience, Curd initiation, Leaf and stem development

Comment [SB2]: Too many keywords, Have only 5-6

1. Introduction

Broccoli (*Brassica oleracea* var. *italica L.*), a member of the Brassicaceae family, is a cool-season vegetable valued globally for its high nutritional content and associated health benefits. Broccoli is recognized for its rich profile of vitamins, minerals, and bioactive compounds, such as vitamins A, C, and E, beta-carotene, and antioxidants, which contribute to immune function, skin health, and a reduced risk of chronic diseases, it is also high in glucosinolate (Mandingbam*et al.*, 2020; Singh *et al.*, 2019; Wu *et al.*, 2024). Broccoli cultivation has gained popularity in various regions, including Indonesia, where it has become an important horticultural crop since the 1970s (Fernandez, 2023). In recent years, broccoli has gained substantial popularity in Bangladesh, particularly in urban centers, where its culinary and health benefits are increasingly appreciated. Despite the rising demand and its significant nutritional value, broccoli production in Bangladesh remains relatively limited, with average yields below the global standard. Many farmers lack access to effective cultivation techniques, leading to suboptimal yields (Kayesh et al., 2019). Research shows that integrating organic and inorganic nutrient management can improve growth and yield, but many remain unaware of these methods (Tamang *et al.*, 2017).Feicheng, 2017 found thateffective nutrient management is essential for maximizing broccoli yield.

Effective nutrient management, especially using essential micronutrients, is crucial in addressing yield gaps in vegetable production (Tripathi *et al.*, 2015; Jatav *et al.*, 2020). Especially micronutrients such as Zinc, Iron, Boron, and Manganese are crucial for various physiological processes, including photosynthesis and enzymatic activities (A review on exploring the significance of micronutrients in crop production", 2023). Boron plays an essential role in cell wall formation, sugar transport, and hormone regulation, making it indispensable for root elongation and reproductive growth in plants (Ganie*et al.*, 2013; Arunkumar *et al.*, 2018). On the other hand,Zinc (Zn) is considered to be one of the essential micronutrients for the growth and development of cereals as well as vegetables (Nandal *et al.*, 2021). Zn is required in small but critical concentrations to allow several key plant physiological pathways like the synthesis of chlorophyll, proteins, and carbohydrates to function normally (Alloway, 2002; Mousavi *et al.*, 2011; Yosefi*et al.*, 2011).Studies indicate that both zinc and boron deficiencies are common in Bangladesh, affecting various agroecological zones, including the southern part (Akter *et al.*, 2023; Sarker *et al.*, 2018).

Research has demonstrated that applying boron and zinc in appropriate quantities can significantly enhance the yield and quality of cruciferous crops like broccoli by improving growth parameters, curd formation, and nutrient content (Kumar *et al.*, 2023; Yadav *et al.*, 2023). However, there is limited region-specific research on the optimal levels of boron and zinc for broccoli cultivation under Bangladesh's unique soil and climate conditions. This knowledge gap presents a challenge for farmers in the region, who are often uncertain of the appropriate levels of micronutrient application required to maximize crop productivity without risking toxicity or nutrient imbalance. In response to these challenges, this study was conducted to evaluate the effects of different boron and zinc application levels on the growth and yield of two broccoli varieties, "Green Carpet" and "Early You," under the agroecological conditions of Bangladesh's Gangetic Tidal Floodplain. These two varieties were chosen due to their adaptability and popularity among local growers, who aim to meet urban demand for high-quality broccoli. The study site, located in an area with moderately

Comment [SB3]: It is repeated on the objectives as well. Do not repeat the same sentences.

saline soils, offers a unique setting to assess how nutrient management can address soil constraints and enhance crop performance in similar agroecosystems across the country.

The primary objectives of this research were to (i) identify which variety among "Green Carpet" and "Early You" demonstrates superior growth and yield performance, (ii) investigate the individual and combined effects of boron and zinc on broccoli's growth metrics and yield components, and (iii) provide actionable recommendations for farmers to optimize boron and zinc applications, thereby contributing to sustainable broccoli production in the region. By addressing these objectives, this study aims to support farmers and agricultural extension services in making data-driven decisions that improve crop quality and yield while maintaining soil health.

2. Materials and Methods

2.1 Experimental Site and Period

The field experiment was conducted at the Field Laboratory of the Department of Horticulture, Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali, Bangladesh, from October 2018 to March 2019. The experimental site, located between 22°23′–22°30′ N latitude and 90°17′–90°27′ E longitude, lies in the Gangetic Tidal Floodplains (AEZ-13) at an elevation of 3 meters above mean sea level (Iftekhar & Islam, 2004).

Comment [SB4]: You have mentioned in later paragraph that seedlings were transplanted on greenhouse and later transplanted in the field. Write this clearly here.

2.2 Climate and Soil Characteristics

The climate of the experimental site is subtropical, with significant rainfall and abundant sunshine, especially from mid-October to mid-March, which is favorable for broccoli cultivation. The experimental field soil was classified as clay loam with a pH of 6.5 and an organic matter content of approximately 0.69%.

Comment [SB5]: If possible include average rainfall over the years or month

2.3 Planting Materials

Two hybrid varieties of broccoli, "Green Carpet" (produced by Asia Seed Co., LTD., South Korea) and "Early You" (produced by TAKII SEED, TAKII & CO., LTD., Kyoto, Japan), were used as planting materials.

2.4 Experimental Design and Layout

The experiment followed a two-factor design, with Factor A as the broccoli varieties (V1 = Green Carpet, V2 = Early You) and Factor B as the four micronutrient treatments (Boron and Zinc) including a control. A Randomized Complete Block Design (RCBD) with three replications was employed. The experimental area was divided into three blocks, each containing eight plots (two varieties × four treatments). Each unit plot measured 1.8 m × 1.6 m, with a spacing of 0.75 m between blocks and 0.5 m between plots. Row and plant spacing were 60 cm × 30 cm, respectively, resulting in a total of 288 plants across the experimental plots.

2.5 Treatments

List 1: The treatments consisted of four levels of Boron and Zinc applications

Treatments	Description
M0	Control (no micronutrients)
M1	2 kg B ha^{-1} + 4 kg Zn ha^{-1} (equivalent to 4 kg Solubor ha^{-1} + 11.2 kg Grozin ha^{-1} or 3 g Solubor and 3.25 g Grozin per plot)
M2	2.5 kg B ha^{-1} + 4.5 kg Zn ha^{-1} (5 kg Solubor ha^{-1} + 12.6 kg Grozin ha^{-1} or 4 g Solubor and 4 g Grozin per plot)
M3	3 kg B ha^{-1} + 5 kg Zn ha^{-1} (6 kg Solubor ha^{-1} + 14 kg Grozin ha^{-1} or 5 g Solubor and 4.5 g Grozin per plot)

Comment [SB6]: This term are just introduced and seems confusing. I think these are the sources for Boron and Zinc. Mention this in methodology earlier before writing in this table.

Comment [SB7]: Reason behind selection of these 2 2.5 3 B treatment and 4 4.5 5 Kg Zn treatment. How was the rate determined?

2.6 Raising of Seedlings

Seeds were sown in a permanent seedbed at the PSTU Horticultural Plant Nursery on November 1, 2018. Seedlings were covered with a polythene sheet to facilitate germination, which occurred within five days. Seedlings were maintained for 30 days under regular care, including watering, mulching, weed control, and pest management, before transplanting to the main field at a height of 12–15 cm.

2.7 Land Preparation

Land preparation commenced on November 10, 2018, involving multiple ploughings and laddering to create a fine tilth. Weed removal and soil clod crushing were conducted, and the field was treated with Diazinon 60 EC insecticide at 650 ml ha^{-1} to control pests. Beds were constructed to facilitate drainage.

2.8 Fertilizer and Manure Application

Each plot received well-decomposed cow dung at 15 tons ha^{-1}, incorporated during land preparation. Additional fertilizers included Urea at 250 kg ha^{-1}, applied in three stages: at land preparation, 30 days, and 45 days after transplanting. Muriate of Potash (MoP) at 200 kg ha^{-1}, applied in two doses: one at land preparation and the other split 15 and 30 days post-transplanting. Triple Super Phosphate (TSP) at 150 kg ha^{-1}, applied as a basal dose.Micronutrients were applied in a ring around the seedlings 15 days after transplanting, according to the specified treatments.

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2.9 Transplanting Procedure

Thirty-day-old seedlings were transplanted into the field on December 2, 2019, maintaining a spacing of 60 cm × 40 cm. Pre-transplant watering facilitated root health and minimized transplant shock. Transplanting was conducted in the afternoon with light post-transplant watering and shading for five days to promote establishment.

2.10Intercultural Operations

Intercultural practices included**Gap Filling,** replacement of dead or weak seedlings within seven days post-transplanting. ~~**Weeding,**~~Hand weeding was performed at 15, 18, and 35 days post-transplanting. **Earthing Up**~~,~~ wascarried out at 40 days to support plants using soil from row spaces. **Irrigation** was~~,~~conducted as needed based on soil moisture, using furrow irrigation.~~**Pest and Disease Management,**~~Agrifuran 5G was applied to manage pests, and Roval fungicide was used for fungal disease control.

Comment [SB9]: Do not highlight any part of the sentence in your entire manuscript. Follow this on other part of paper as I have only mentioned this once here.

2.11 Harvesting

Broccoli curds were harvested from February 2, 2019, to March 10, 2019. Harvesting maturity was determined by curd color and size, with primary curds harvested at compact formation. Secondary curds were harvested subsequently from axillary shoots. Data were collected from five randomly selected plants per plot.

2.12 Data Collection

Data were meticulously collected from five randomly selected plants in each plot, primarily focusing on various growth parameters and yield components to evaluate the effects of different treatments on broccoli growth. The specific traits and procedures are detailed below:

2.12.1 Plant Height

Plant height was measured at four intervals: 30, 45, 60, and 75 days after transplanting (DAT). The height was recorded from the base of the plant (ground level) to the tip of the tallest leaf, using a meter scale. Measurements were taken from five selected plants per plot, and the mean plant height for each plot was calculated and recorded in centimeters (cm).

2.12.2 Length of Largest Leaf

The length of the largest leaf per plant was measured at 30, 45, 60, and 75 DAT using a meter scale. The length was taken from the base to the tip of the leaf. This measurement was recorded for five plants in each plot, and the average length of the largest leaf was calculated for each plot and expressed in centimeters.

2.12.3 Leaf Breadth

The breadth of the largest leaf was measured at the same four time points: 30, 45, 60, and 75 DAT. Using a meter scale, the leaf breadth was recorded from the widest part of the leaf. Measurements were taken from five selected plants in each plot, and the average leaf breadth was recorded in centimeters.

2.12.4 Number of Leaves per Plant

The total number of leaves per plant was counted at the time of primary curd initiation. Leaves were counted for each of the five selected plants in every plot, and the mean number of leaves per plant was calculated and recorded.

2.12.5 Stem Length

Stem length was measured at the time of harvest from the base to the top of the stem. Using a meter scale, measurements were taken from the five selected plants per plot. The average stem length for each plot was then calculated and expressed in centimeters.

2.12.6 Stem Diameter

Stem diameter was measured at the time of harvest by taking measurements in three directions at the middle portion of the stem. Using a caliper, three diameter measurements were recorded for each selected plant, and the average diameter was calculated for each plant. The mean stem diameter per plot was then computed and recorded.

2.12.7 Days to Curd Initiation

The number of days from transplanting to the visible initiation of curd formation was recorded for each plot. This parameter was observed daily, and the average number of days for curd initiation was calculated based on the data from the five selected plants in each plot.

2.12.8 Primary Curd Diameter

The diameter of the primary curd was measured at harvest. Using a meter scale, measurements were taken in multiple directions around the circumference of the curd to account for any irregular shape. The average of these measurements was calculated to obtain a mean curd diameter per plot, recorded.

2.12.9 Height of Primary Curd

The height of the primary curd was measured from the base of the curd (cutting point) to the top, immediately after harvesting. Measurements were recorded in cm from the five selected plants per plot, and the average height was calculated for each plot.

2.12.10 Weight of Primary Curd

The weight of the primary curd from each selected plant was measured using an electronic balance. The curd was weighed immediately after harvesting to ensure accuracy. The mean primary curd weight per plot was recorded in grams (g).

2.12.11 Weight of Secondary Curds per Plant

The weight of all secondary curds from the selected plants was measured using an electronic balance. Secondary curds, which developed after the primary curd harvest, were collected and weighed, and the mean secondary curd weight per plant was calculated for each plot in grams.

2.12.12 Dry Weight of Curd (%)

To determine the dry weight percentage of the curd, a 100 g sample from each plot was dried under direct sunlight for 72 hours, followed by oven drying at 70°C for three days until a constant weight was achieved. The final dry weight was recorded as a percentage of the initial fresh weight, calculated as follows:

$$\text{Dry Weight Percentage} = (\text{Dry Weight}/\text{Fresh Weight}) \times 100$$

2.13 Yield per Plot (kg)

The total yield per plot was calculated by summing the yield of all plants in each plot (12 plants per plot). This yield was recorded in kilograms (kg) per plot.

2.14 Yield per Hectare (ton)

The total yield per plot was calculated by summing the yield of all plants in each plot and then converted it into ton per hectare.

2.15 Statistical Analysis

Data analysis and graph preparation were conducted using R programming language (version 4.3.1) software following the principles of RCBD to identify treatment effects. Variance analysis was conducted, and means were compared using the Least Significant Difference (LSD) test at a 5% significance level (Gomez and Gomez, 1984).

3. Results

3.1 Plant Height

Plant height was observed across different days after transplanting (DAT) for broccoli varieties and varying micronutrient levels. The combined effect of varieties and micronutrients revealed a significant increase in plant height as days progressed. Variety V2 (Early You) treated with 2 kg boron ha^{-1} + 4 kg zinc ha^{-1} (M1) consistently showed the highest plant height at each measurement interval, reaching a peak of 56.5 cm at 75 DAT, while the lowest height was observed in V1 (Green Carpet) under control conditions (M0). Micronutrient application significantly influenced plant growth, with all treated plants displaying greater height compared to the control, underscoring the importance of boron and zinc in enhancing plant vigor. Further analysis by individual variety indicated that Early You consistently attained a slightly higher height than Green Carpet across all DAT, highlighting the varietal response to nutrient inputs (Figure 1).

Comment [SB10]: The graph does not clearly indicate whether there are significant differences between the treatments. To improve clarity, replace the line graph with a bar graph to represent the height under different varieties and micronutrient conditions. Include the results of the post hoc test by labeling groups with letters (e.g., a, b, c) to denote statistically significant differences. Additionally, add error bars (which is in first figure) to provide a complete view of the variation of the measurements.

You have done post hoc on figure 2 however not on the figure 1. Was there no any significnat difference or is it lacking on figure. Mnetion if there is no significant difference if So.

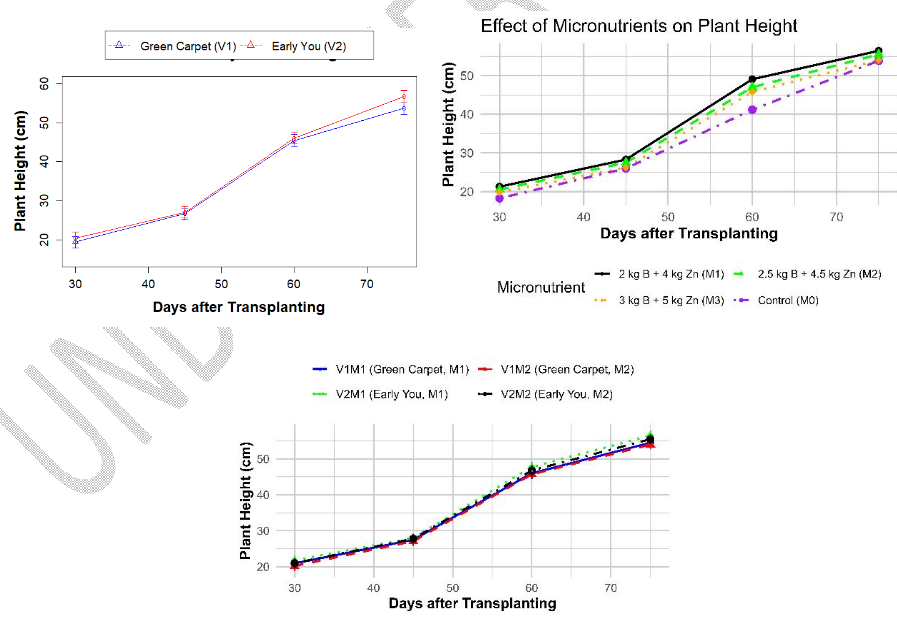

Figure 1: Plant height under Different Treatments and Treatment Combinations

3.2 Largest Leaf Length

It is observed that treatment combination V2M1 consistently produced the longest leaf length across all DATs. The shortest leaf length, on the other hand, was associated with the V1M0 (Green Carpet, Control) treatment combination. The differences between treatments were statistically significant, with letters denoting differences at each time point(Figure 2).

In terms of the effect of varying micronutrient levels, further confirms the significant influence of these micronutrients on leaf growth. Here, the highest leaf length was consistently observed under the M1 treatment (2 kg B + 4 kg Zn), followed by M2, M3, and M0, respectively, across all time points. The application of specific micronutrient levels, especially the combination of 2 kg B + 4 kg Zn, promotes maximum leaf growth in broccoli, particularly when paired with the Early You variety. This effect is apparent as early as 30 DAT and remains significant throughout the plant's development. The interaction between variety and micronutrient application highlights the potential for optimizing leaf growth through targeted treatment combinations(Figure 2).

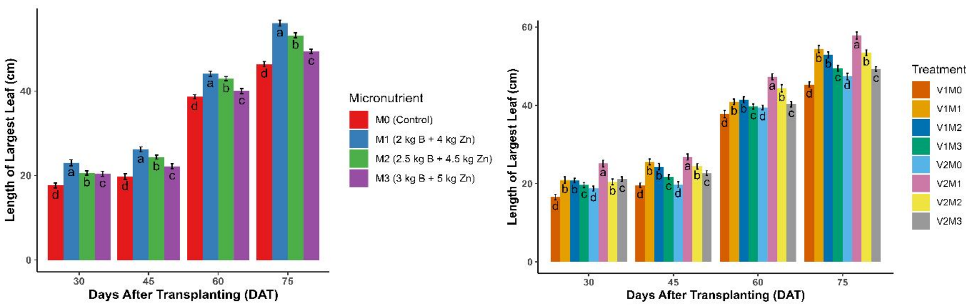

Figure 2: Largest leaf under Different Treatments and Treatment Combinations

3.3 Leaf breadth

The leaf breadth data across days after transplanting (DAT) under various treatments and micronutrient combinations displayed distinct patterns.In the combined treatment effects (first chart), leaf breadth increased consistently over time from 30 to 75 DAT, with notable variations among treatment combinations. The V2M1 treatment consistently produced the greatest leaf breadth across all DATs, reaching a maximum of 75 DAT. In contrast, the V1M0 treatmenthad the smallest leaf breadth values. Statistical significance denoted by letters above each bar indicates that the differences among treatments were substantial, with treatments like V2M1 and V1M1 significantly outperforming others in leaf breadth across all DATs(Figure 3).

For the effect of micronutrient levels alone, a similar increasing trend in leaf breadth over time was observed. The M1 treatment yielded the highest leaf breadth values consistently across DATs, especially evident at 75 DAT. The control (M0) consistently resulted in the lowest leaf breadth, reinforcing the positive impact of micronutrient application, particularly boron and zinc at optimal levels. The letters indicate significant differences, with M1 outperforming other micronutrient treatments at most time points.This analysis underscores the beneficial impact of specific treatment combinations, particularly V2M1, on enhancing leaf breadth, while also highlighting the critical role of optimal micronutrient application, especially with boron and zinc, in promoting leaf growth in broccoli(Figure 3).

Comment [SB11]: It might be better to have leaf size or a combined parameter for length and breadth. I believe brocoli are majorly grown for its curd. Try to highlight more of those things and combine these 3.2 and 3.3 in a single paragraph

Comment [SB12]: Try to use Figure 3 A or B . Do not use wording first chart

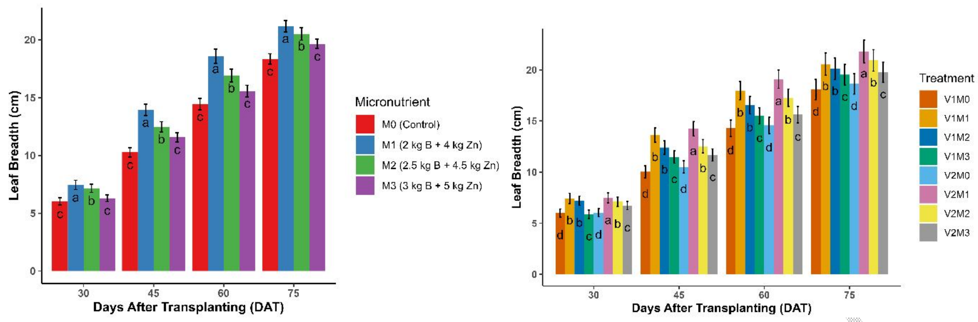

Figure 3: Leaf breadth under Different Treatments and Treatment Combinations

3.4 No. of leaves per plant

Treatment M1 led to the highest number of leaves per plant, significantly exceeding the leaf counts observed in the control (M0) and other micronutrient treatments. This suggests that the specific level of boron and zinc supplementation in M1 is highly effective in promoting leaf growth. In the combined treatment analysis, the combination V2M1yielded the highest leaf count, significantly outperforming all other combinations. This finding highlights the positive impact of pairing the "Early You" variety with the optimal micronutrient level in M1 to maximize leaf growth. Other combinations like V1M2 and V2M2 also showed relatively high leaf counts, although they were still significantly lower than V2M1. Conversely, combinations with the control treatment (e.g., V1M0 and V1M1) consistently resulted in fewer leaves (Figure 4).The results indicate that the specific micronutrient combination in M1 has a pronounced effect on leaf development, particularly when combined with the "Early You" variety. This data underscores the potential benefits of targeted boron and zinc supplementation to optimize leaf growth in broccoli.

Comment [SB13]: Figure 4.1 illustrates the leaf count per plant under four treatment levels (M0, M1, M2, M3) across both cultivars, V1 and V2. Measurements appear to have been taken separately for each cultivar. However, displaying V1 and V2 together in the same graph without clear differentiation between treatments where significant effects are observed—such as the lack of a notable difference in leaf count at the M1 treatment level—makes it challenging to interpret cultivar-specific responses. This will not fit with your methodology and This overlap in results suggests a need for clearer distinction or additional context to avoid misinterpretation. This goes on the remaining figure on the results too.

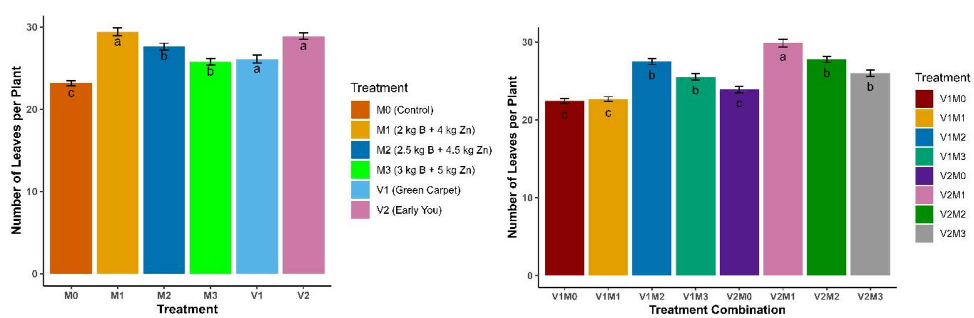

Figure 4: Number of leaves under Different Treatments and Treatment Combinations

3.5 Stem Length under Different Treatments and Treatment Combinations

The stem length of broccoli varied significantly across individual treatments and treatment combinations. In the individual treatment analysis, the highest stem length was observed with treatment M1, reaching 24.02 cm, followed by variety V2 with 20.98 cm. In contrast, the control treatment M0 resulted in the shortest stem length at 17.22 cm. These results demonstrate that both the variety and micronutrient levels significantly impact stem length, with M1 showing the most substantial effect among individual treatments (Figure 5).

In the combined treatment analysis, the treatment combination V2M1 resulted in the longest stem length at 25.37 cm, significantly outperforming other combinations. The combination V1M0yielded the shortest stem length at 17.00 cm. This suggests that the combination of variety V2 with M1 micronutrient level maximizes stem length, while the absence of micronutrient supplementation (M0) in variety V1 and V2 results in the shortest stems (Figure 5).

Comment [SB14]: Similar comment as above for graph. Treatment combination graph is fine however there's no need to include V1 and V2 in graph as there's no significant difference

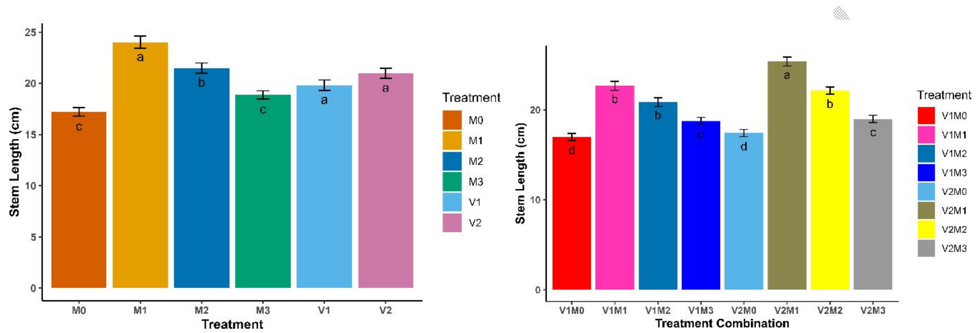

Figure 5: Stem length under Different Treatments and Treatment Combinations

3.6 Stem Diameter under Different Treatments and Treatment Combinations

Comment [SB15]: These results such as leaf length, breadth, no of leave per plant, stem length, setm diameter can also be presented in a table with post hoc analysis instead of individual graph for each. This measurement are less importance comapred to other measurements which are major for broccoli

The stem diameter of broccoli was significantly influenced by both individual treatments and combined treatment effects. In the individual treatment analysis, treatment M1 resulted in the largest stem diameter at 4.48 cm, followed by varieties V2 and V1 with stem diameters of 3.95 cm and 3.77 cm, respectively. The smallest stem diameter was observed in the control treatment M0 at 3.50 cm. This indicates that micronutrient application, particularly M1, has a considerable positive impact on stem diameter (Figure 6).

In the combined treatment analysis, the treatment combination V2M1 produced the largest stem diameter at 4.70 cm, significantly greater than other combinations. The smallest stem diameter was recorded with the V1M0 combination at 3.63 cm. These results suggest that the combination of variety V2 with M1 micronutrient level maximizes stem diameter, while the absence of micronutrient supplementation in V1 results in the smallest stem diameters (Figure 6).

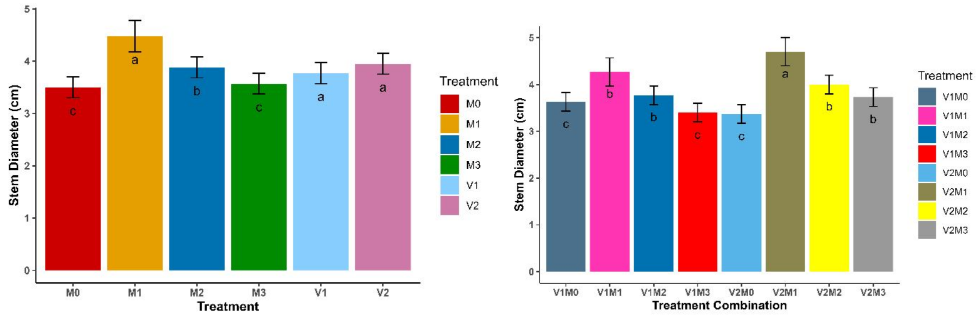

Figure 6: Stem diameter under Different Treatments and Treatment Combinations

3.7 Days to Curd Initiation

The combined effects of broccoli varieties and micronutrient treatments revealed significant variations in the timing of curd initiation. Treatments involving micronutrients (B and Zn) led to earlier curd initiation compared to the control (M0) treatment across both varieties. Specifically, the combination V1M1 resulted in the shortest time to curd initiation, demonstrating the positive impact of moderate B and Zn supplementation on promoting early curd formation. In contrast, the control combinations, V1M0 and V2M0, exhibited the longest times for curd initiation, indicating delayed reproductive development in the absence of micronutrient support(Figure 7).

The individual effects of each treatment level across the varieties. The control treatment (M0) consistently required the longest period for curd initiation, whereas treatments with B and Zn supplementation (M1, M2, and M3) significantly reduced this time. The M1 treatment achieved the earliest curd initiation across both varieties, suggesting that this combination optimally supports growth and curd development in broccoli. These findings underscore the importance of tailored micronutrient management to optimize broccoli growth and yield(Figure 7).

Comment [SB16]: Remove the same line in every your result section

Comment [SB17]: In the graph 7.2 V1M1 V1M2 seems to have significant difference visually however there's "a" for both of them. Double check your data

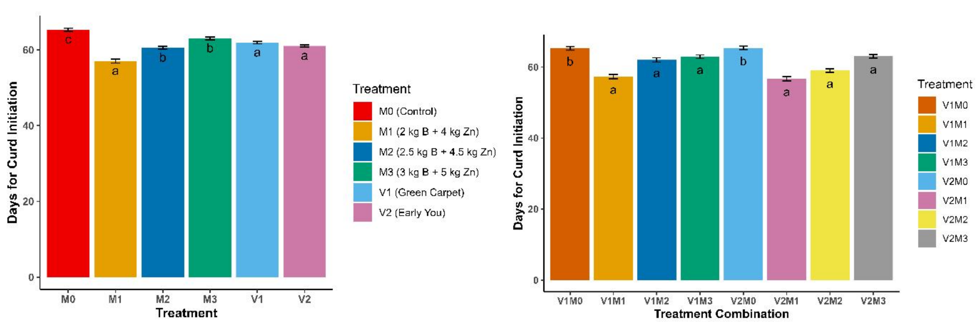

Figure 7: Days to curd initiation under Different Treatments and Treatment Combinations

3.8 Diameter of Primary Curd

The diameter of the primary curd in broccoli was significantly influenced by both individual treatments and their combinations. The treatment graph shows that the highest primary curd diameter was achieved with the M1 treatment reaching approximately 15 cm. The V2 treatment also exhibited a notable diameter, labeled demonstrating its effectiveness in enhancing curd growth. On the other hand, the M0 treatment (Control) exhibited the lowest diameter, around 10 cm, reflecting a reduced growth effect without added micronutrients (Figure 8).

In the combined treatment graph, the V2M1 combination significantly outperformed other combinations, recording the highest diameter. This indicates that combining the Early You variety with an optimal micronutrient level results in the most favorable curd development. Conversely, the V1M0 combination (Green Carpet variety without added micronutrients) had the smallest diameter.

This analysis highlights the importance of selecting suitable broccoli varieties and optimizing micronutrient applications for maximizing primary curd diameter, with the Early You variety and M1 nutrient level yielding the most substantial growth (Figure 8).

Comment [SB18]: No graph for the diameter of primary curd. Same figure is on Figure 7 and 8.

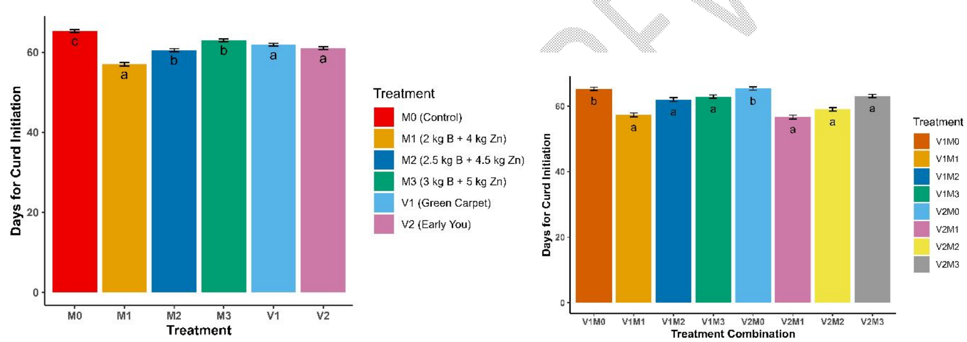

Figure 8: Diameter of primary curd under Different Treatments and Treatment Combinations

3.9 Primary Curd Length by Treatment

The analysis of primary curd length across different treatments (M0, M1, M2, M3, V1, V2) indicates that the micronutrient level significantly affects curd length. Treatment M1 showed the highest curd length with an average of approximately 15 cm, which was significantly greater than the control (M0) with a mean of around 11 cm. The treatment V2also demonstrated a high curd length, similar to M1, showcasing the beneficial effects of specific micronutrient levels on curd growth. The control (M0) had the lowest curd length, suggesting the absence of additional micronutrients impacts primary curd development. In combined treatment combinations (V1M0, V1M1, V1M2, V1M3, V2M0, V2M1, V2M2, V2M3), the highest curd length was recorded for treatment combination V2M1, reaching approximately 16 cm, significantly surpassing other combinations. V1M0 (Green Carpet, Control) presented the shortest curd length, averaging around 10 cm, highlighting the impact of variety and micronutrient combinations on curd development. The treatments with V1 and V2 varieties show varying responses to micronutrient levels, with V2M1 significantly outperforming all other combinations, which reinforces the advantage of specific nutrient combinations with the variety V2 for promoting curd growth (Figure 9).

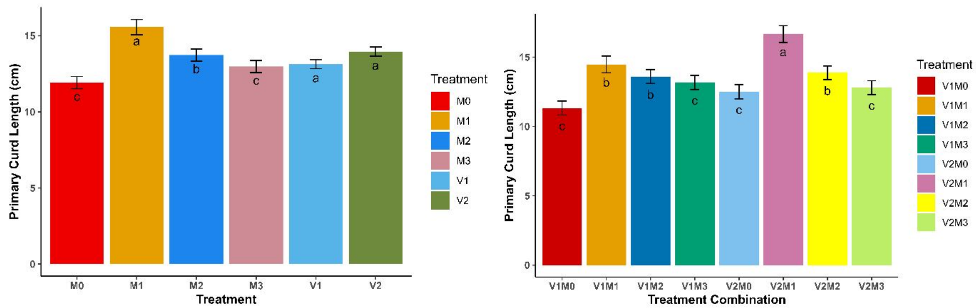

Figure 9: Primary curd length under Different Treatments and Treatment Combinations

3.10 Primary Curd Weight under Different Treatments and Treatment Combinations

The primary curd weight of broccoli was significantly influenced by both individual treatments and combined treatment effects. In the individual treatment analysis, the highest primary curd weight was observed with treatment M1, reaching 346.67 g, followed by variety V2 with 318.75 g. In contrast, the control treatment M0 resulted in the lowest primary curd weight at 235.00 g. These findings indicate that both variety and micronutrient levels play a role in affecting primary curd weight, with M1 demonstrating the highest individual impact (Figure 10).

In the combined treatment analysis, the treatment combination V2M1 yielded the highest primary curd weight at 385.67 g, significantly surpassing all other combinations. The combination V1M0 (Green Carpet, Control) yielded the lowest primary curd weight at 204.00 g. This combined analysis suggests that the combination of variety V2 and micronutrient level M1 produces the most substantial effect on primary curd weight (Figure 10).

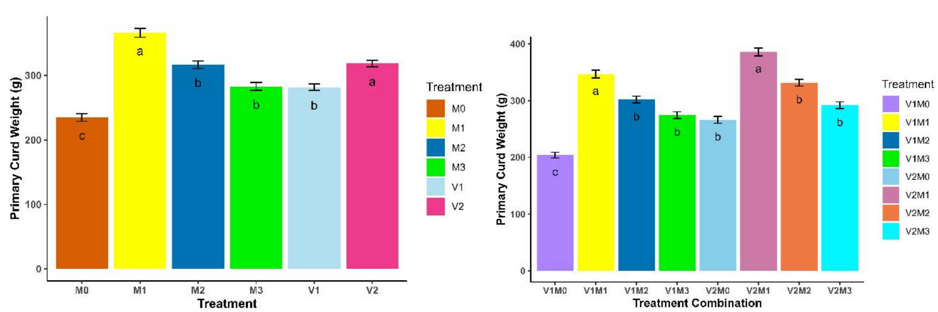

Figure 10: Primary curd weight under Different Treatments and Treatment Combinations

3.11 Secondary Curd Weight under Different Treatments and Treatment Combinations

The secondary curd weight of broccoli was influenced by both individual treatments and combined treatment effects. In the individual treatment analysis, the highest secondary curd weight was observed with treatment M1, reaching 99.30 g, followed by V2 with 96.63 g. In contrast, the control treatment M0 yielded the lowest secondary curd weight at 79.30 g. These results indicate that both variety and micronutrient levels impact secondary curd weight, with M1 producing the highest individual effect (Figure 11).

In the combined treatment analysis, the treatment combination V2M1 resulted in the highest secondary curd weight (107.23 g), significantly surpassing all other combinations. The combination V1M0 (Green Carpet, Control) produced the lowest secondary curd weight at 72.37 g. The combined results reinforce the observation that micronutrient level M1, particularly when paired with variety V2, has the most substantial impact on secondary curd weight (Figure 11).

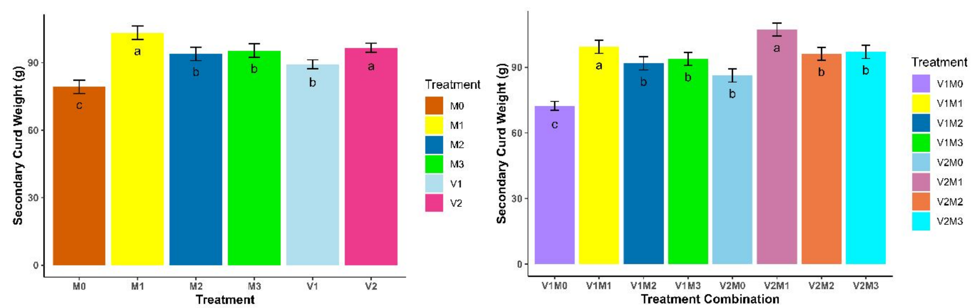

Figure 11: Secondary curd weight under Different Treatments and Treatment Combinations

3.12 Dry Weight of Curd

The dry weight of broccoli curd was significantly influenced by both individual treatments and the combined effect of variety and micronutrient levels. Treatment M1 resulted in the highest dry weight of curd among the individual treatments, significantly surpassing other treatments. The lowest dry weight was observed in the control treatment (M0), highlighting the critical role of micronutrient application in enhancing dry matter accumulation in broccoli curds. Furthermore, variety V2 consistently produced a higher dry weight of curd compared to variety V1, indicating a superior response to the applied treatments(Figure 12).

The combined effect of variety and micronutrient levels, depicted in the second graph, showed that the treatment combination V2M1 achieved the maximum dry weight of curd. In contrast, the combination V1M0 resulted in the lowest dry weight of curd, underscoring the necessity of micronutrient supplementation, especially for the Green Carpet (V1) variety. Significant differences were evident among the treatment combinations, with V2M1 producing a notably higher dry weight than other combinations, suggesting that the Early You (V2) variety performs optimally under specific boron and zinc levels(Figure 12).

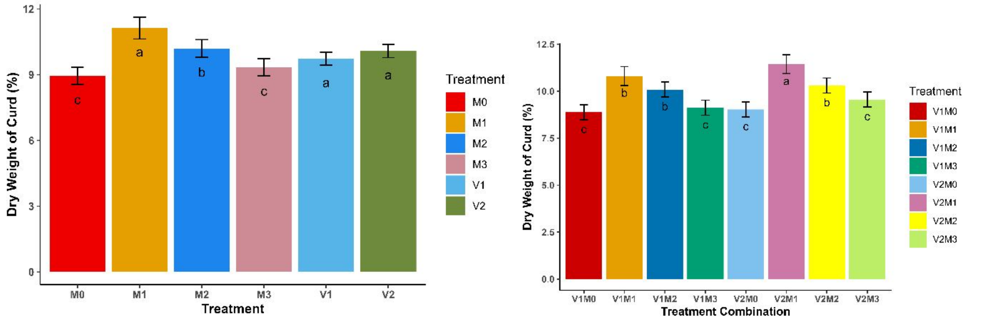

Figure 12: Dry weight of curd under Different Treatments and Treatment Combinations

3.13 Yield per Plot under Different Treatments

Both individual treatments and combined treatment effects influenced the yield per plot of broccoli. The highest yield was observed with treatment M1 (5.40 kg), followed by V2 (4.95 kg) and M2 (4.97 kg). In contrast, the control treatment M0 yielded the lowest at 3.92 kg. The yield differences between varieties V1 and V2 were moderate, with V2 generally producing a higher yield (Figure 13).

In the combined treatment analysis, the treatment combination V2M1 resulted in the highest yield per plot (5.78 kg), followed by V1M1 (5.01 kg). The control combinations, V1M0 and V2M0, produced the lowest yields at 3.57 kg and 4.28 kg, respectively. These results indicate that the M1 micronutrient level had the most substantial effect on yield enhancement, particularly in combination with the V2 variety (Figure 13).

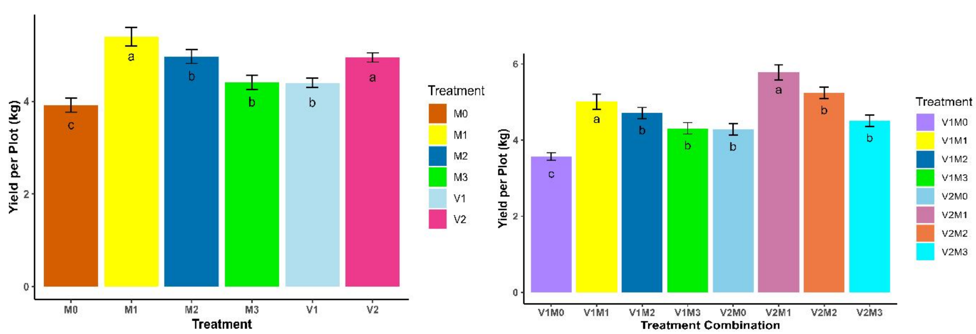

Figure 13: Yield per plot under Different Treatments and Treatment Combinations

3.14 Yield per Plot (ton per hectare)

The yield per hectare of broccoli was significantly influenced by both the varieties and micronutrient treatments, as demonstrated in Figure 14. Variety V2 achieved a higher yield of 17.13 tons per hectare compared to V1, which yielded 15.88 tons per hectare. This represents the higher-yielding variety V2 (Figure 14).

Micronutrient treatments also had a pronounced effect on yield. The M1 treatment resulted in the highest yield of 19.38 tons per hectare, significantly outperforming the other micronutrient levels, including the control (M0), which yielded only 13.76 tons per hectare (Figure 14). The combined effects of variety and micronutrient levels revealed that the treatment combination V2M1 produced the highest yield at 20.18 tons per hectare. V1M0 yielded the lowest at 13.01 tons per hectare (Figure 14).

Comment [SB19]: Try to follow similar pattern of the combined treatment graph. Legend is repeated in the graph keep only one

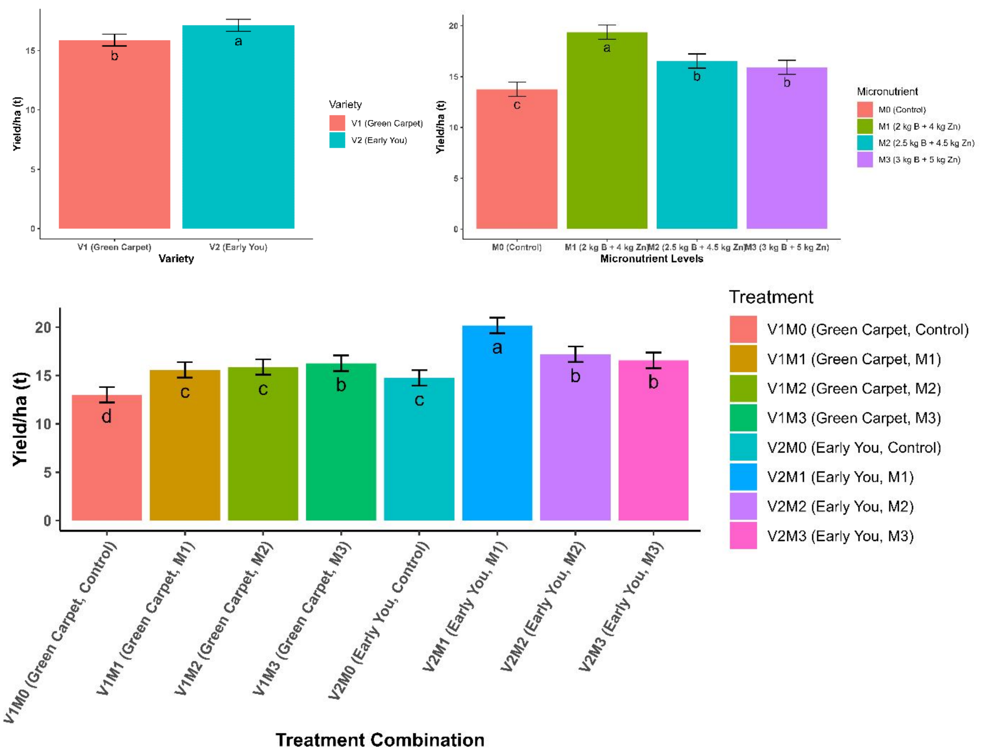

Figure 14: Yield per plot under Different Treatments and Treatment Combinations

4. Discussion

The findings of this study indicate that the application of specific levels of boron (B) and zinc (Zn), particularly at 2 kg boron ha^{-1} + 4 kg zinc ha^{-1} (M1), significantly enhances broccoli growth and yield characteristics across various parameters, including curd weight, stem dimensions, leaf count, and dry weight. These effects were particularly pronounced in the variety "Early You" (V2), which consistently demonstrated superior performance when paired with the M1 treatment. This suggests a synergistic interaction between the selected variety and micronutrient levels, resulting in optimized growth and yield, which is consistent with previous findings that emphasize the role of balanced micronutrient applications in crop productivity and soil health improvement (Tropik*et al.*, 2024; Nandi *et al.*, 2024).

4.1 Yield and Curd Weight

The yield per plot and primary curd weight were highest under the M1 treatment, with the "Early You" variety outperforming "Green Carpet." This outcome aligns with studies that highlight boron's role in enhancing cell wall integrity and facilitating nutrient transport, and its presence is particularly significant during the reproductive phase, as it enhances pollen germination and tube growth, which are critical for successful fertilization and fruit set, all of which are critical for curd formation in broccoli (Thakur *et al.*, 2023; Day *et al.*, 2020). Zinc's contribution to enzyme activation and protein synthesis further supports enhanced plant vigor and curd size, which are essential yield components (Ashikuzzaman*et al.*, 2024; Mousavi *et al.*, 2013). The higher yields observed in the V2M1 combination reinforce the importance of selecting appropriate variety-micronutrient combinations to maximize yield outcomes under local agroecological conditions.

Comment [SB20]: Explain the reason for why it performed better on the 2 rather than 2.5 and 3. Do not put vague words. Boron facilitates nutrient transport - so with high application it should have yielded higher yield and curd weight. However results do not show such things. Mention the reasons for that being specific.

4.2 Secondary Curd and Stem Attributes

Secondary curd and stem traits, including weight, length, and diameter, were significantly improved by the M1 treatment, especially when combined with the "Early You" variety. These improvements are indicative of the roles of boron and zinc in enhancing structural plant components, likely due to their involvement in lignin synthesis and stem fortification (Dong *et al.*, 2022; Long & Peng, 2023). The observed increase in stem length and diameter under the M1 treatment is supported by findings that suggest zinc's role in promoting stem elongation and strength through increased internodal growth (Klein *et al.*, 1962) and enhanced chlorophyll production, which are essential for photosynthetic efficiency and biomass accumulation.

4.3 Leaf Growth and Broccoli Curd Development

The application of boron and zinc at optimal levels was found to promote leaf growth in both breadth and length, with a significant increase under the M1 treatment. The increased leaf area could contribute to greater photosynthetic capacity, which in turn supports curd development by supplying essential carbohydrates and nutrients during critical growth stages. Micronutrients are important for plant nutrition because they affect the growth, development, and quality of horticultural crops by improving photosynthesis (Ahmed *et al.,* 2024). The substantial leaf growth observed in the "Early You" variety, particularly under M1, suggests that this variety is well-suited for micronutrient-rich conditions, likely due to its genetic predisposition for higher nutrient uptake and utilization efficiency.

4.4 Influence of Combined Treatments on Dry Weight of Curd

The dry weight of broccoli curd, a critical measure of curd quality, was significantly higher under the M1 treatment, particularly with the V2M1 combination. This result aligns with previous studies indicating that boron and zinc applications enhance dry matter accumulation, which is critical for marketable yield and nutritional quality in broccoli (Moniruzzaman*et al.,* 2007; Islam *et al.,* 2015; Hussain*et al.,* 2012). Higher dry weights in the curd suggest enhanced nutrient density, likely a result of boron's role in carbohydrate metabolism and zinc's contribution to protein synthesis, both of which are essential for forming denser, nutrient-rich curds (Sarker *et al.,* 2021). This trend underscores the value of targeted micronutrient applications to improve both yield quantity and quality.

4.5 Implications and Recommendations

The findings of this study underscore the importance of precise nutrient management strategies for optimizing broccoli production in Bangladesh's coastal and floodplain soils. Given the documented deficiencies of boron and zinc in these soils, the results support the use of specific micronutrient levels (e.g., M1: 2 kg B + 4 kg Zn per hectare) to enhance yield and quality traits in broccoli. The superior performance of the "Early You" variety suggests that variety selection should be prioritized alongside nutrient management, as the interaction between genotype and nutrient availability plays a substantial role in determining crop outcomes.

Comment [SB21]: The discussion are very poor. Mention all the specific as similar to earlier comment.

5. Conclusion

This study demonstrates the significant impact of targeted boron and zinc applications on improving broccoli growth, yield, and quality under the specific agroecological conditions of Bangladesh's Gangetic Tidal Floodplain. The findings reveal that the combination of 2 kg boron ha^{-1} and 4 kg zinc ha^{-1} (M1 treatment) yields optimal results, particularly when paired with the "Early You" variety, which consistently outperformed the "Green Carpet" variety across multiple growth parameters. The superior performance of "Early You" under M1 treatment highlights the importance of selecting varieties that are genetically compatible with specific micronutrient regimes, ultimately maximizing both growth efficiency and yield.

Furthermore, the study underscores the critical role of micronutrients in enhancing structural components such as curd size, leaf area, and stem diameter, all of which contribute to a robust crop with greater marketable value. By promoting photosynthesis and nutrient transport, these micronutrients foster accelerated growth, improved curd initiation, and increased dry weight, thereby enriching the nutritional profile of the harvested broccoli. The notable increase in both primary and secondary curd weights indicates enhanced productivity, supporting previous research on the essential functions of boron and zinc in crop physiology.

These findings are particularly valuable for broccoli growers in Bangladesh, where boron and zinc deficiencies are prevalent. This study not only provides actionable guidance for optimizing fertilizer strategies but also emphasizes the role of sustainable nutrient management in addressing yield gaps in vegetable production. By adopting the recommended nutrient levels and variety-specific treatments, local farmers can potentially enhance both the yield and quality of their broccoli crops, contributing to increased food security and economic resilience. Overall, this research lays the groundwork for future studies on nutrient-optimized horticultural practices and serves as a model for other regions facing similar soil nutrient challenges.

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