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EFFECT OF MAGNESIUM, ZINC AND BORON FERTILIZERS ON YIELD, FRUIT QUALITY AND PROFITABILITY OF SPONGE GOURD (*LUFFA CYLINDRICA*)

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Abstract

An experiment was conducted at the research field of Soil and Water Management Section in Horticulture Research Centre, Bangladesh Agricultural Research Institute, during the summer seasons of 2020 and 2021. The study aimed to determine the influence of magnesium (Mg), zinc (Zn), and boron (B) fertilizers on the growth, yield, fruit quality, nutrient uptake and use efficiency and profitability of sponge gourd (*Luffa cylindrica L.*). The experiment followed a randomized complete block design with three replications. Nine treatment combinations were derived from three levels each of Mg (0, 4, and 8 kg ha^{-1}), Zn (0, 3, and 4 kg ha^{-1}), and B (0, 1.5, and 2 kg ha^{-1}). These were- T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-1.5 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B). Application of Mg-Zn-B at 8-4-2 kg ha^{-1} (T_9) led to the maximum fresh fruit yield (55.2 t ha^{-1}), which was 29.3% higher than the control (T_1). Treatment T_9 showed superior growth, yield attributes, and quality characteristics, recording the highest amounts of vitamin C (13.6 mg100 g^{-1}) and β-carotene (15.7 μg100 g^{-1}) and maximum uptake of Mg, Zn, and B. The apparent nutrient recovery efficiency of Mg showed inconsistent results, whereas the efficiency for Zn and B was most prominent in treatment T_9, followed by T_8. Application of Mg-Zn-B at 8-4-2 kg ha^{-1} significantly boosted profitability, leading to a maximum gross margin (BDT 962163 ha^{-1}) and the highest MRR of 920%. Results suggest that application of Mg-Zn-B at 8-4-2 kg ha^{-1} with a blanket dose of N-P-K-S at 100-30-80-20 kg ha^{-1} and 5 t ha^{-1} of cow dung could be adopted for sponge gourd cultivation in the Gazipur soil condition (AEZ-28).

Keywords: Economic return, fruit yield, growth, *Luffa cylindrica* L., nutrient uptake and use efficiency.

Introduction

Cucurbits are the common name for numerous vegetable crops in the Cucurbitaceae family. These sprawling plants are widely grown in dry and semi-

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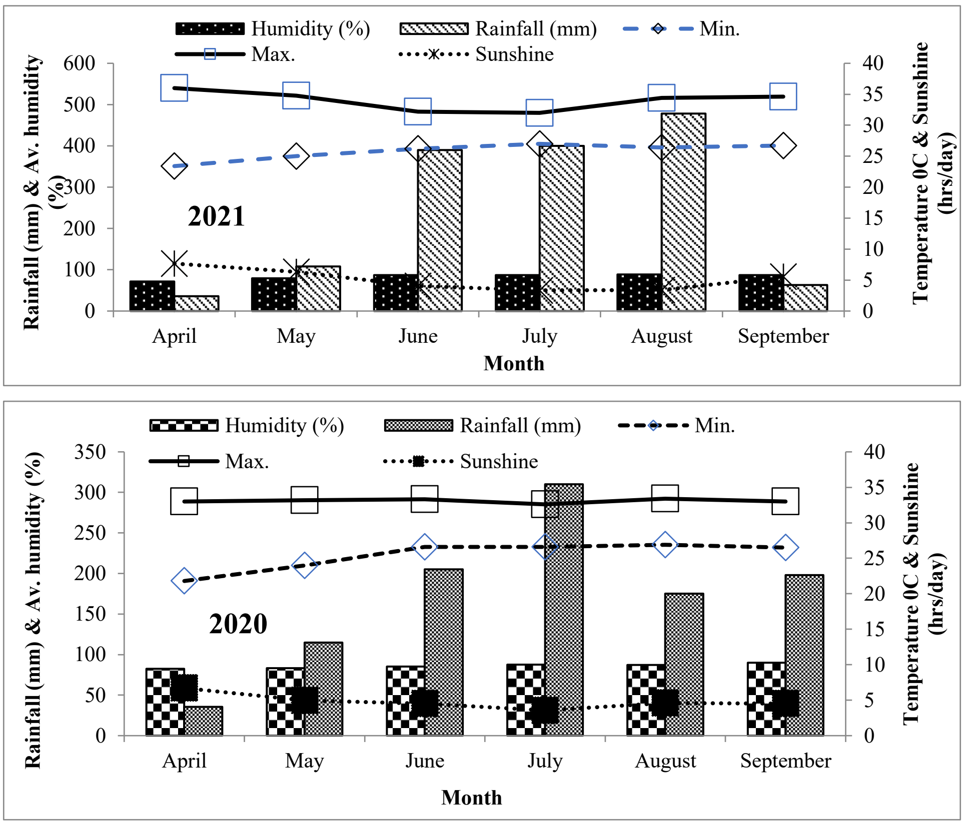
dry regions and represent a large portion of vegetables produced during the summer and rainy seasons. Sponge gourd (*Luffa cylindrica* L.), known locally as 'dhundul,' is a particularly valued and essential cucurbit whose cultivation is increasing day by day in Bangladesh. As a fresh fruit, it is considered a superfood for boosting immunity, as it is rich in protein, carbohydrates, and vitamin C (Zadge *et al.,* 2024; Sonavane *et al*., 2022). The fresh tender and immature fruits are harvested for culinary purposes. Matured and fibrous sponge gourds are used as bath sponges and in various industrial applications (Sheela and Anburani, 2024; Mashilo *et al.*, 2025). Experimental grey terrace soils are habitually characterized by their acidic nature, low organic matter content, poor water-holding capacity, and a tendency toward deficiencies of micronutrients like Zn and B, and medium or deficient levels of the secondary macronutrient like Mg due to high leaching and fixation (Ishfaq *et al.,* 2022; Wang *et al.,* 2022). Such conditions can severely limit the efficacy of nitrogen, phosphorus, and potassium (NPK) fertilization, leading to suboptimal plant growth and reduced marketable yield (Wang *et al.,* 2020). While nitrogen, phosphorus, and potassium (NPK) are fundamental, the role of micronutrients like zinc and boron, along with the secondary macronutrient magnesium, is increasingly recognized as a critical factor in enhancing sponge gourd growth, yield, quality, and nutrient use efficiency.

Magnesium (Mg), Zn and B elements, though required in relatively small quantities, are vital for a multitude of physiological and biochemical processes within the plant (Sidhu *et al.,* 2019). Zinc is a key cofactor for numerous enzymes, essential for carbohydrate metabolism and protein synthesis (Ahmed *et al.,* 2024), and is directly involved in the biosynthesis of auxins, the plant hormones that regulate growth and development (Pankaj *et al.,* 2018; Yadav *et al.,* 2023). Boron, on the other hand, plays a crucial structural role in maintaining cell wall integrity and membrane function (Jeevitha, 2018). It is also indispensable for pollen tube growth and sugar translocation processes that are fundamental to successful fruit set and development (Pandav *et al.,* 2016). Magnesium, as the central atom of the chlorophyll molecule, is directly tied to the efficiency of photosynthesis and energy transfer (Plant nutrition, Wikipedia, 2025). However, deficiencies of these nutrients are prevalent in many agricultural soils, particularly in regions with intensive cultivation, leading to stunted growth, reduced fruit quality, and diminished yields (Parvin *et al.,* 2024). However, a lack of zinc can result in "little-leaf" symptoms and poor fruit set, while boron deficiency can cause distorted fruit and premature flower shedding. A magnesium deficit manifests as interveinal chlorosis, severely impacting the plant's photosynthetic capacity (Jiao *et al.*, 2023). Therefore, a deeper understanding of the specific functions of magnesium, zinc, and boron, and their synergistic interactions is essential for developing effective and sustainable fertilization strategies. The experiment was, therefore, conducted to investigate the combined effects of these nutrients (Mg-Zn-B) on sponge gourd vegetative growth, fruit yield, fruit quality metrics, and the plant's ability to efficiently utilize available nutrients with economic return.

Materials and Methods

The experiment was conducted during the summer seasons of 2020 and 2021 at the research field of Soil and Water Management Section of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur (23°.59′ N and 90°.24′E). The experimental soil was clay loam. The average minimum and maximum temperatures ranged from 21.8°C to 36.0°C. The average relative humidity varied between 71.7% and 89.9%. Daily sunshine hours ranged from 3.35 to 7.67 hours. The rainfall during the trial period was recorded between 35.6 mm and 478 mm (Fig. 1). The temperatures and humidity both increased slightly in 2021 compared to 2020. Moreover, there was more rainfall in 2021, with the exception of the month of September.



Source: Meterological Station, Gazipur under the Ministry of Defence

Fig. 1. Monthly mean values for air temperature, average humidity, sunshine, and rainfall during the experimental period of 2020 and 2021.

Before experimentation, soil samples were collected from a depth of 0 to 15 cm using a standard procedure. The chemical properties of these samples were then analyzed using the standard methods outlined by Page *et al.* (1982), with the results presented in Table 1.

Table 1. Fertility status of soil in research field before experimentation

Soil	pH	OM%	Total N%	Ca	Mg	K	P	S	Zn	B
				meq 100 g^{-1}			µg g^{-1}			
Initial	6.2	1.20	0.061	4.63	1.11	0.11	11.8	12.4	0.84	0.17
Critical level	5.5-6.5	2-3	0.12	2.0	0.50	0.12	7	10	0.6	0.20
*Interpretation	Slightly acidic	Low	Very low	Optimum	Medium	Low	Medium	Low	Low	Low

*Source: Ahmed *et al.* (2018)

Healthy seeds of sponge gourd cv. 'BARI Dhundul-2' were sourced from Olericulture Division, HRC, BARI, Gazipur. The seeds were sown manually into 10 cm x 10 cm polythene bags containing fine clay loam soil on March 15, 2020, and March 16, 2021. Watering was done immediately after sowing, and the seedlings were irrigated twice a week. Seedlings were secured from insects and diseases using Autostin® 50 WDG (a.i. Carbendazim) fungicide and Sevin® WP 85 (a.i Carbaryl) insecticide. During the seedling growth period, the main plots were prepared using a tractor-driven chisel plow for four passes, followed by leveling with a rotavator. Remaining any weeds and debris were removed manually.

There were nine treatment combinations comprising three levels each of magnesium (0, 4 and 8 kg ha^{-1}), zinc (0, 3 and 4 kg ha^{-1}) and boron (0, 1.5 and 2 kg ha^{-1}). The experiment was laid out in a randomized complete block design with three replications. The nine treatment combinations were T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-1.5 kg ha^{-1} Mg-Zn-B), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B). The recommended dose of other fertilizers (Ahmed *et al.,* 2018) 100-30-80-20 kg ha^{-1} N-P-K-S, respectively along with decomposed cow dung 5 t ha^{-1} were used in all treatments. The unit plot size for sponge gourd was 2.8 m×1.5 m. Each plot consisted of two plants. The plant-to-plant distance within the plot was 1.4 m. Plots were separated by a 1.0 m space. Blocks were also separated by a 1.0 m distance. The effective row-to-row distance (which includes the inter-plot space) was 2.5 m. This 2.5 m distance is the sum of: 0.75 m (from the plot boundary to the row) + 1.0 m (plot separation space) + 0.75 m (from the next plot's boundary to the row) =2.5 m. The 1.0 m gap serves as a guard area to prevent competition between neighboring plots and blocks, which is vital for maintaining the integrity of the treatment effects. The sources of N, P, K, S, Mg, Zn and B were urea (46% N), triple super phosphate (20% P, 1.3% S, 14% Ca), muriate of potash (50% K), gypsum (18% S and 20% Ca), magnesium sulphate (12.5% S, 9.5% Mg), zinc sulphate heptahydrate (10.5% S, 21% Zn) and boric acid (17% B), respectively. The half amount of decomposed cow dung, full amount of TSP, gypsum, and half of MoP were applied manually at final plot preparation. Rest half amount of the decomposed cowdung, treatment wise magnesium sulphate, zinc sulphate and boric acid were applied in pit 5 days before planting, and all were manually mixed thoroughly with soil. Twenty-five days old seedlings were transplanted on 10 April 2020 and 11 April 2021. Only one plant was planted into a pit. One-third of urea was applied surrounding the plants after 15 days of transplanting. Half of MoP and second installment of 1/3 urea was top dressed during flower initiation to surrounding the plants. The remaining 1/3 urea was applied to the plants at fruiting stage. Irrigation, weeding, insect control, and other intercultural operations were done as and when required. Horizontal bamboo stakes were installed at the top joining of all other beds. The stakes support the climbing vines and lateral stems. Bamboo branches (kunchi) were used to secure adjoining stakes. Treatment wise young fruits of sponge gourd were harvested time to time starting from the 2nd week of June until last week of September in both years. Data on the yield and yield attributes of sponge gourd were collected. Fresh sponge gourd samples were collected from each experimental plot and brought to the Laboratory of Soil and Water Management Section, HRC, BARI and preserved the samples frozen at -30 °C. Sponge gourd fruit samples were removed from the freezer to estimate the amount of vitamin C and ß-carotene by standard method.

Plant samples analysis- Above-ground parts of sponge gourd plants were collected from each plot, sun-dried for five days, and then further dried in a digital convection oven (Human Lab Instrument Co., model Co-150, Hwaseong city, Korea) at 68°C for 48 hours. The samples were then ground to pass through a 1 mm sieve. Similarly, sponge gourd fruit samples from each treatment were washed, sliced into round or triangular shapes, and then dried and ground to pass through a 1 mm sieve. Each dry plant and fruit sample was then preserved in a polythene bag. Ground dry plant and fruit samples were digested with a di-acid mixture (HNO_3-$HClO_4$: 5:1 ratio) as described by Piper (2019) to determine their mineral content. Magnesium (Mg) was determined by atomic absorption spectrophotometry and boron (B) by spectrophotometry using the azomethine-H method. Zinc (Zn) content was directly measured from the digest using an Atomic Absorption Spectrophotometer (Varian, SpectrAA 55B, Sydney, Australia). The nutrient uptake by dry fruit and dry plant yield of sponge gourd was calculated by multiplying the nutrient content of plant part (fruit & plant) by its respective dry weight yield (Quddus *et al.,* 2023). The formula is as follow-

$$\textbf{Nutrient uptake}\ (\mathbf{kg\ ha^{-1}}) = \frac{\textbf{\textit{Nutrient content}}\ (\%)\times \textbf{\textit{Dry fruit yield or plant yield}}\ (\mathbf{kg\ ha^{-1}})}{\mathbf{100}} \text{ ----- } (1)$$

However, the total nutrient uptake of a sponge gourd was determined by the formula such as total nutrient uptake (kg ha^{-1}) = Nutrient uptake by fruit (kg ha^{-1}) + Nutrient uptake by dry plant (kg ha^{-1}).

Apparent nutrient recovery efficiency (ANR) was determined using the dry weight-based formula established by Baligar *et al.* (2001). This metric provides a clear understanding of how effectively the plant utilizes applied nutrients.

$$\text{ANR} = \frac{\textbf{Nutrient uptake}(\mathbf{kg\ ha^{-1}})-\textbf{ control value}}{\textbf{Applied nutrient}\ (\mathbf{kg\ ha^{-1}})} \times 100 \text{ ------------- } (2)$$

The data on growth, yield attributes, quality traits, yield, nutrient content & uptake and nutrient use efficiency of sponge gourd was statistically analyzed using a two-way analysis of variance (ANOVA) with Statistix 10 software. When significant differences were found, the means were compared using the least significant difference (LSD) test at a significance level of $P \leq 0.05$. Considering the experiment year/cultivation year as Factor A and nutrient treatment as Facor B, statistical analysis was done. So, the data presented under fertilizer/nutrient treatment in Tables and Figures are the average data of two years.

Gross margin of different fertilizer treatments was counted using fruit yield of sponge gourd from two year's mean data at average market price of 2020 and 2021 for the crops and nutrient (Mg, Zn & B fertilizers) inputs. Partial budget and marginal analyses were used to determine the most economically nutrient dose (Elias and Karim, 1984). Marginal rate of return (MRR) was calculated by the following equation:

$$\text{MRR} = \frac{\text{AdB}}{\text{AdC}}$$

Where, MRR = Marginal rate of return, AdB = Additional benefits between each pair of non-dominated treatments, AdC = Additional costs between each pair of non-dominated treatments.

Results and Discussion

Morphological growth and yield contributing characters of sponge gourd

Except individual fruit weight, sponge gourd growth and yield traits were remarkably affected by the year of cultivation (Table 2). Sponge gourd cultivated in the 2nd year exhibited superior growth and yield traits compared to those in the 1st year. The superior growth and yield of sponge gourds in the second year might be attributed to several factors. The residue of organic manure, along with residual Mg, Zn and B from the 1st year's application, likely enriched the soil. Additionally, the more favorable weather conditions during the 2nd year positively contributed to the higher sponge gourd performance. A similar result was corroborated by Quddus *et al.* (2025) in their study on bitter gourd. Sponge gourd growth and yield were significantly influenced by the application of Mg, Zn, and B. Vine length (1.1 m), root length (38.3 cm) and individual fruit weight (169 g) were found maximum from T_9 treatment closely followed by T_8 and their lowest values from T_1 treatment.The T_9 treatment gave the highest number of fruits per plant (71.4) and the control (T_1) treatment resulted in the lowest number of fruits per plant. Significantly, the increased fruit length (24.1 cm) was observed in T_9 treatment, while the decreased fruit length was found in T_1. Maximum fruit diameter was noted in T_9 treatment which was identical with most of the treatments except T_1 and T_3. These prominent advancements in sponge gourd parameters including vine and root elongation, the count of fruits per plant, fruit length, fruit diameter, and individual fruit weight are a consequence of the fundamental contributions of zinc, boron, and magnesium to plant physiology (Hamzah Saleem *et al.,* 2022). Zinc activates the various enzymes which are essential for metabolic reactions. It is directly involved in chlorophyll synthesis. Increased chlorophyll leads to more efficient energy production and, consequently, better plant growth. Zinc promotes auxin production responsible for cell elongation and division leading to the better length of plant and its roots (Hamzah Saleem *et al*., 2022). Boron is involved to maintain the structural integrity of plants like cell wall formation and carbohydrate metabolism, which are supported to contribute the impressive length of both the vines and the roots (Bolaños *et al.,* 2023). Magnesium is a central component of plant life, serving as a catalyst for numerous biological processes, such as chlorophyll synthesis, enzyme activation and carbohydrate transport (Hermans *et al.,* 2013). These ensure the fruits receive the necessary energy and nutrients for proper development, leading to an increased number of fruits per plant. In combination, the roles of these three nutrients synergistically support chlorophyll synthesis, carbohydrate metabolism, and various other biological activities, ultimately boosting the overall growth and yield attributes of sponge gourd plants (Yadav *et al.,* 2020). All are also critical for flower retention, improving nutrient uptake and fruit set, which directly impacts the number of fruits, fruit size and weight. This view is supported by the findings of Ashraf *et al.* (2020) and Sidhu *et al.* (2019).

Table 2. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on plant growth and yield attributes of sponge gourd

Year of cultivation (Y)	Vine length (m)	Root length (cm)	No. of fruits plant^{-1}	Fruit length (cm)	Fruit diameter (cm)	Individual fruit wt. (g)
2020	9.60b	34.4b	48.7b	20.9b	4.09b	151a
2021	11.6a	36.4a	78.7a	22.4a	4.84a	153a
CV (%)	5.24	4.51	3.19	2.61	4.88	4.47
Treatment (T)						
T_1	9.48e	29.7e	54.3e	17.7e	4.25c	144c
T_2	10.6cd	34.0d	60.5d	21.0d	4.41a-c	150bc
T_3	10.3d	33.7d	63.0c	20.9d	4.26bc	152bc
T_4	10.5d	34.7d	64.2c	22.1c	4.47a-c	145c
T_5	10.9a-c	36.6c	64.3c	21.8cd	4.51ab	145c
T_6	10.7b-d	37.3bc	63.4c	22.4bc	4.60a	146c
T_7	10.4d	36.4c	64.4c	21.8cd	4.54a	155b
T_8	11.0ab	38.0ab	67.9b	23.0b	4.55a	165a
T_9	11.1a	38.3a	71.4a	24.1a	4.61a	169a
CV (%)	5.24	4.51	3.19	2.61	4.88	4.47
Interaction(Y×T)	ns	ns	ns	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Marketable yield

The yields of fresh fruit, dry fruit and dry plant of sponge gourd were significantly influenced by both the years of cultivation. The yield performance of the second year was comparatively better than that of the first year (Table 3). The superior performance in the 2nd year was likely a result of two key factors: residual nutrients from the previous year's fertilizer application and more favorable weather conditions. The application of Mg, Zn, and B significantly impacted the yields of fresh fruit, dry fruit, and dry plant of sponge gourd (Table 3). The highest fresh fruit yield was recorded 55.2 t ha^{-1} in T_9 treatment (8-4-2 kg ha^{-1} Mg-Zn-B) which was statistically similar to T_8 treatment and the lowest yield was found in the control treatment (T_1). Similarly, the T_9 treatment also significantly gave maximum both the dry fruit yield (5.57 t ha^{-1}) and the dry plant yield (11.6 t ha^{-1}), closely followed by T_8 treatment. The lowest yields for both dry fruit and dry plant were observed in the control treatment (T_1). The combined application of Mg, Zn, and B registered maximum (29.3%) increase in fresh fruit yield followed by T_8

treatment. This synergistic effect of these three elements not only improves soil health but also enhances the plant's ability to absorb other essential nutrients for optimal growth and development, ultimately leading to higher yields (Ashraf *et al.*, 2020). The T_9 treatment resulted in a higher sponge gourd yield is mainly due to an increased number of fruits plant^{-1} and an increase in individual fruit weight. This improvement in yield is likely due to the significant roles of Mg, Zn, and B in key physiological processes. Such as Mg is involved in photosynthesis, Zn is crucial for carbohydrate metabolism, and B plays a vital role in pollen tube growth and fruit set. These physiological activities collectively contribute to greater biomass production, more fruit per plant, and ultimately, a significant increase in yield. This is consistent with the findings of Ahmed *et al.* (2024) in tomato, who also demonstrated the positive impact of these nutrients on crop yield.

Table 3. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on yields of sponge gourd

Cultivation year (Y)	Fresh fruit yield (t ha^{-1})	Dry fruit yield (t ha^{-1})	Dry plant yield (t ha^{-1})	% Fresh fruit yield increase over control
2020	48.4b	4.91b	10.0b	-
2021	51.7a	5.12a	10.7a	-
CV (%)	3.17	5.39	7.06	-
Treatment (T)				
T_1	42.7d	4.23d	8.39d	-
T_2	50.4bc	5.03bc	10.4bc	18.0
T_3	49.3c	4.93c	10.2c	15.5
T_4	48.8c	4.92c	10.1c	14.3
T_5	50.5bc	5.10bc	10.6bc	18.3
T_6	49.0c	4.96c	10.2c	14.8
T_7	51.5b	5.11bc	10.7bc	20.6
T_8	53.4a	5.33ab	11.1ab	25.1
T_9	55.2a	5.57a	11.6a	29.3
CV (%)	3.17	5.39	7.06	-
Interaction(Y×T)	ns	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Quality traits of sponge gourd

The vitamin C and ß-carotene content of sponge gourd were significantly influenced by the years of cultivation. Sponge gourd in the second cultivation year had a higher content of both vitamin C and ß-carotene compared to the first year's (data not presented). Combined applications of Mg, Zn and B significantly affected vitamin C and ß -carotene content of sponge gourd fruit (Fig. 2a, and 2b). The highest vitamin C content (13.6 mg/100g) was found in T_9 treatment and the control treatment (T_1) had the lowest vitamin C content (Fig. 2a). Similarly, the T_9 treatment also produced the highest ß-carotene content (15.7 µg/100g), closely followed by the T_8 treatment (15.4 µg/100g). The control treatment (T_1) had the lowest ß-carotene content (Fig.2b). The application of Mg-Zn-B at 8-4-2 kg ha^{-1}) in the T_9 treatment resulted in a 17.2% increase in vitamin C content of sponge gourd fruit compared to the control treatment where Mg-Zn-B was not applied. This suggests a synergistic effect among these three nutrients. The result is in line with the results of Singh *et al.* (2022), who also found that foliar application of micronutrients can increase vitamin C levels in fruit vegetable. While these findings partially support the work of Thriveni *et al.* (2015) on the benefits of combined fertilizer application, the specific roles of Mg, Zn, and B in this enhancement require further investigation. Similarly, the application of these three nutrients led to an observed increase in ß-carotene content in the fruit of sponge gourd. This could be due to the known involvement of Mg and micronutrients viz. Zn and B in various physiological and biochemical processes within the fruit, as noted by Sultana *et al.* (2017). The exact mechanisms by which these nutrients influence ß-carotene production are not yet fully understood, although the results are partially supported by Mashilo *et al.* (2025).

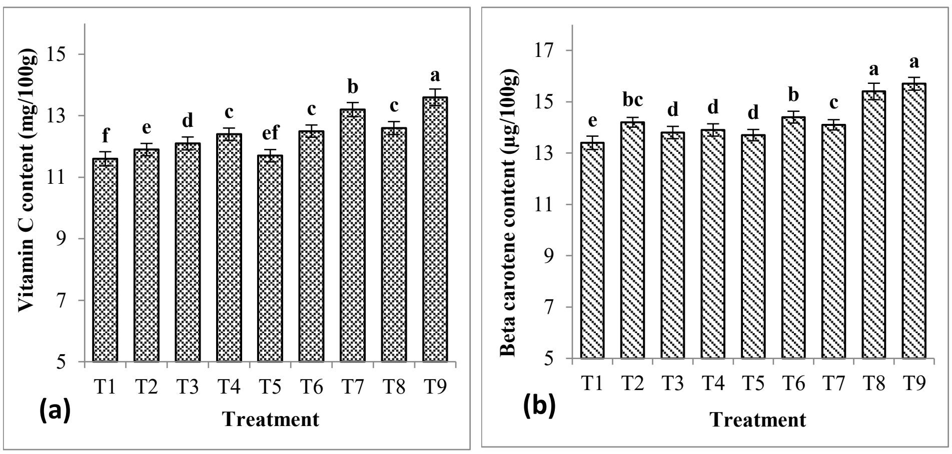


Fig. 2. Effect of Mg, Zn, and B on vitamin C content (a) and beta carotene content of sponge gourd fruit (b). The error bars represent the ± standard error of the mean (n=3). The mean values indicated by the uncommon letters in the bars are significantly different at the 5% level by the LSD test.

T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Nutrient content in dry fruit and dry plant of sponge gourd

Except for Mg content in dry fruit, the cultivation year significantly affected the contens of Mg in the dry plant, and Zn and B in both the dry fruit and plant of sponge gourd (Table 4). The concentrations of Mg, Zn and B in the dry fruit and dry plant of sponge gourd were higher in the 2nd year cultivation than in those of the 1st year. This improvement in nutrient concentration during the 2nd year might be attributed to the residual benefits of the nutrients applied in the 1st year. Moreover, a more favorable weather condition in the 2nd year may have also contributed to the plant's uptake of Mg, Zn, and B. These findings are corroborated by the findings of Quddus *et al.* (2025) on bitter gourd. The application of Mg, Zn, and B fertilizers led to a significant increase in the concentration of these nutrients in both the dry fruit and dry plant of sponge gourd (Table 4). The T_9 treatment consistently resulted in the highest nutrient accumulation. It produced the highest Mg content (7.75 g kg^{-1} in dry fruit and 11.6 g kg^{-1} in dry plant), which was statistically similar to T_8, T_7, and T_6 treatments. The maximum Mg accumulation in the T_9 treatment was likely associated with the combined application of Mg, Zn and B. This combination enhanced Mg uptake in the sponge gourd plants.

Table 4. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on nutrient content in sponge gourd

Cultivation year (Y)	Magnesium content (g kg^{-1})		Zinc content (g kg^{-1})		Boron content (g kg^{-1})	
	Dry fruit	Dry plant	Dry fruit	Dry plant	Dry fruit	Dry plant
2020	7.28a	10.8b	0.0543b	0.0673b	0.0723b	0.0652b
2021	7.38a	11.5a	0.0549a	0.0724a	0.0729a	0.0701a
CV (%)	4.42	3.29	1.63	6.49	1.00	6.25
Treatment (T)						
T_1	6.58d	10.3d	0.0476g	0.0622e	0.0648f	0.0634c
T_2	7.00c	10.9c	0.0529f	0.0677cd	0.0701e	0.0657bc
T_3	7.17c	11.1bc	0.0539ef	0.0665de	0.0728c	0.0676a-c
T_4	7.29bc	11.1bc	0.0546de	0.0685cd	0.0716d	0.0665a-c
T_5	7.37bc	11.2a-c	0.0554cd	0.0695cd	0.0734c	0.0685ab
T_6	7.56ab	11.3ab	0.0567ab	0.0705b-d	0.0746b	0.0675a-c
T_7	7.67ab	11.4ab	0.0571ab	0.0725a-c	0.0751b	0.0686ab
T_8	7.61ab	11.5ab	0.0562bc	0.0755ab	0.0752b	0.0695ab
T_9	7.75a	11.6a	0.0574a	0.0765a	0.0761a	0.0708a
CV (%)	4.42	3.29	1.63	6.49	1.00	6.25
Interaction(Y×T)	ns	ns	ns	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Increased Mg fertilization directly boosts the plant's Mg content, which can help mitigate aluminum (Al) toxicity in soils, as reported by Cakmak (2015). Similarly, the highest Zn content (0.0574 g kg^{-1} in dry fruit and 0.0765 g kg^{-1} in dry plant) was also found in T_9, followed by T_8 in the case of dry plant, with the lowest content recorded in the control treatment (T_1). The T_9 treatment also produced the maximum B content (0.0761 g kg^{-1} in dry fruit and 0.0708 g kg^{-1} in dry plant. The lowest B content was observed in the control treatment (T_1). Combined application of 8-4-2 kg ha^{-1} MG-Zn-B significantly enhanced the content of Zn and B in sponge gourd plants. Previous studies by Ashraf *et al*. (2020) and Sultana *et al*. (2017) have confirmed the positive influence of Mg, Zn, and B application on Zn and B accumulation in plants. While the specific role of Mg on Zn and B concentration in sponge gourd remains less understood, Quddus *et al*. (2022) reported that application of 12 kg Mg ha^{-1} to the soil facilitated the maximization of Zn and B concentrations in tomato plants.

Table 5. Effect of cultivation year and the use of zinc, boron and magnesium fertilizers on total uptake of Mg, Zn and B by sponge gourd

Cultivation year (Y)	Total Mg uptake (kg ha^{-1})	Total Zn uptake (kg ha^{-1})	Total B uptake (kg ha^{-1})
2020	126b	0.946b	1.01b
2021	143a	1.063a	1.13a
CV (%)	8.44	7.92	7.29
Treatment (T)			
T_1	101d	0.724e	0.806e
T_2	132c	0.975d	1.04cd
T_3	130c	0.942d	1.05cd
T_4	131c	0.964d	1.03d
T_5	137bc	1.02cd	1.10b-d
T_6	135bc	1.00cd	1.06cd
T_7	142bc	1.07bc	1.12bc
T_8	148ab	1.14ab	1.16ab
T_9	156a	1.21a	1.25a
CV (%)	8.44	7.92	7.29
Interaction(Y×T)	ns	ns	ns

The means that a column that includes the same letters is not statistically different at the 5% level using LSD test. CV = Coefficient of variation, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Total uptake of Mg, Zn and B (fruit + dry plant) by sponge gourd

The total uptake of Mg, Zn, and B by sponge gourd varied significantly by the cultivation year (Table 5). Particularly, sponge gourd plants demonstrated a significant increase in the total uptake of these three nutrients in 2021 compared to the previous year (Table 5). Combined application of Mg, Zn and B fertilizers significantly affected the total uptake of Mg, Zn and B nutrients by sponge gourd (Table 5). The highest total Mg uptake, 156 kg ha^{-1}, was observed in the treatment T_9, which was identical with T_8, while the lowest was noticed in the control treatment. Similarly, T_9 also led to a significant increase in the total uptake of Zn (1.21 kg ha^{-1}) and B (1.25 kg ha^{-1}), closely followed by T_8. Both Zn and B uptake were found lowest in the control (T_1). The combined application of Mg, Zn and B might have synergistically enhanced the total uptake of these nutrients by sponge gourd plants. When applied at the right time, in the right amount, and in the right way, these three nutrients can significantly build up nutrient availability in the soil. This allows for easier plant uptake, leading to better growth and proper accumulation within the plant body, which ultimately increases the uptake values of Mg, Zn, and B. This view is supported by the findings of Gerendás and Führs (2013).

Apparent recovery efficiency of Mg, Zn and B of sponge gourd

The year of cultivation had a significant effect on the apparent recovery efficiency of Mg, Zn, and B in sponge gourd (data not presented). As shown in Figures 3a-c, the combined application of Mg, Zn, and B fertilizers significantly influenced the apparent nutrient recovery (ANR) efficiencies of these elements in the sponge gourd plant. The T_5 treatment showed the highest apparent magnesium recovery efficiency at an impressive 911%, which was statistically similar to most other treatments except T_6, T_7 and T_8 treatments (Fig. 3a). This higher recovery efficiency of Mg might be attributed to variations in Mg application rate specially a lower dose of Mg in the T_5 treatment. Lower dose of Mg fertilizer is converted into vigorous plant growth and less hamper to the environment. Higher doses of magnesium fertilizer can lead to greater loss through leaching, especially since Mg is a highly mobile nutrient in soils, consequently reducing overall recovery efficiency. Furthermore, in acidic soils, high levels of competing cations like aluminum (Al), iron (Fe), manganese (Mn), and hydrogen ions (H^+) can antagonistically inhibit Mg uptake by roots (Dash *et al.,* 2023). A lower or balanced dose of Mg minimizes this competition, while a very high rate could worsen ionic imbalances. Therefore, lower Mg doses generally represent a more optimal and efficient use of the nutrient relative to crop needs, whereas higher doses result in diminishing Mg use efficiency and increased nutrient losses (Wang *et al.,* 2025). Govindasamy *et al.* (2023) reported that the degree of nutrient use efficiency (NUE) is affected by the crop yield potential, crop type, inherent soil fertility, and amount of applied fertilizer and precise crop management practices. In our study, T_9 treatment achieved the greatest apparent zinc recovery efficiency at 12.1%, with treatments T_8, T_7, and T_6 showing statistically similar results (Fig. 3b). Furthermore, the treatment T_8 attained the highest apparent boron recovery efficiency at 23.9%, with T_9 showing statistically similar results (Fig. 3c). These findings are in line with the previous studies by Quddus *et al.* (2022) in tomato. By understanding the aforesaid conditions like application timing, rate, and method of fertilizer application, we can improve the fertilizer management strategies to enhance both crop yield and nutrient use efficiency.

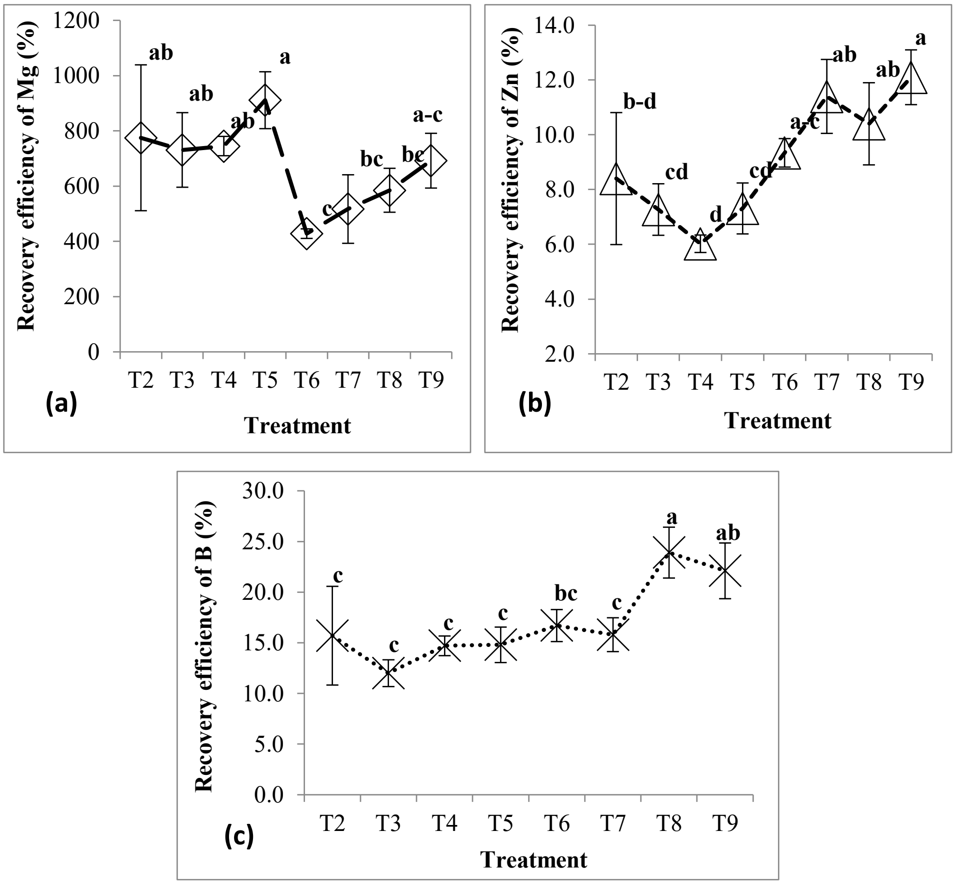


Fig. 3. Effect of Mg, Zn, and B on recovery efficiency of magnesium (a), recovery efficiency of zinc (b) and recovery efficiency of boron in sponge gourd (c). The error bars represent the ± standard error of the mean (n=3).

The mean values indicated by the uncommon letters on the bars are significantly different at the 5% level according to the LSD test, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Economic analysis

A partial budget analysis was performed as part of the economic evaluation to calculate the total variable costs and the gross margin for each fertilizer treatment. The highest gross return (BDT 1104000 ha^{-1}) and the maximum gross margin (BDT 962163 ha^{-1}) were achieved in the treatment T_9 (8−4−2 kg ha^{-1} Mg-Zn-B). Conversely, the lowest gross margin observed was BDT 854000 ha^{-1}. For the dominance analysis, the treatments (T_1 to T_9) were initially arranged in descending order of total variable costs (which, in this context, refers to nutrient or fertilizer cost). Table 7 of the analysis indicated that treatments T_3, T_4, T_5, T_6, and T_7 were cost dominated (CD), while T_1, T_2, T_8, and T_9 were determined to be cost undominated (CUD). The marginal rate of return (MRR) for changing from T_9 to T_8 was 920% (Table 7). This means, if farmers invest BDT 141837, he could recover BDT 3529, plus an additional amount of Tk 32471. In this way, other MRRs found from T_2 to T_1 treatment and T_8 to T_2 treatment were 89.85% and 4.91%, respectively. Here the highest MRR was observed from T_9 to T_8 treatment (920%) every BDT 100 of additional investment BDT 920 was returned. Application of 8-4-2 kg ha^{-1} Mg-Zn-B (T_9) plus the blanket dose of 100-30-80-20 NPKS appeared as the best treatment combination for cultivation of sponge gourd from economic poit of view when MRR was considered.

Table 6. Cost and return analysis of sponge gourd cultivation as influence by MgZnB fertilizers

Treatment	Gross return (BDT ha^{-1})	Nutrient cost (BDT ha^{-1})	Gross margin (BDT ha^{-1})	Remarks
T_1	854000	0	854000	CUD
T_2	1008000	81115	926885	CUD
T_3	986000	84644	901356	CD
T_4	976000	87781	888219	CD
T_5	1010000	91311	918689	CD
T_6	980000	131641	848359	CD
T_7	1030000	135170	894830	CD
T_8	1068000	138308	929692	CUD
T_9	1104000	141837	962163	CUD

Input price: Zinc sulfate (lab grade) = BDT 1400 kg^{-1}, Magnesium sulphate=(lab grade)= BDT 1200 kg^{-1}, Boric acid (lab grade)= BDT 1200 kg^{-1}, Average output price of cabbage: BDT 20 kg^{-1}

T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_3 (4-3-2 kg ha^{-1} Mg-Zn-B), T_4 (4-4-1.5 kg ha^{-1} Mg-Zn-B), T_5 (4-4-2 kg ha^{-1} Mg-Zn-B), T_6 (8-3-15 Mg-Zn-B kg ha^{-1}), T_7 (8-3-2 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Table 7. Marginal analysis of cost undominated treatments applied in sponge gourd cultivation

CUD treatment	Nutrient cost (Tk ha^{-1})	Marginal increase in nutrient cost (BDT ha^{-1})	Gross margin (BDT ha^{-1})	Marginal increase in gross margin (BDT ha^{-1})	MRR (%)
T_1	0	-	-	-	-
T_2	81115	81115	926885	72885	89.9
T_8	138308	57193	929692	2807	4.91
T_9	141837	3529	962163	32471	920

CUD = Cost undominated, CD = Cost dominated, T_1 (0-0-0 kg ha^{-1} Mg-Zn-B), T_2 (4-3-1.5 kg ha^{-1} Mg-Zn-B), T_8 (8-4-1.5 kg ha^{-1} Mg-Zn-B) and T_9 (8-4-2 kg ha^{-1} Mg-Zn-B).

Conclusion

The results of this study revealed that, application of Mg-Zn-B at 8-4-2 kg ha^{-1} fertilizer (T_9) to the soil significantly improved sponge gourd fruit yield and quality as this treatment recorded better plant growth, a greater number of fruits, heavier and larger fruits. The highest uptake of Mg, Zn, and B by the sponge gourd plants also occurred in the same treatment. The apparent recovery efficiency was high for zinc in T_9 and for boron in T_8 treatment, but the results for magnesium were inconsistent. The T_9 treatment was also the most economically viable, as indicated by its high gross margin and maximum MRR. Results suggest that the application of Mg-Zn-B at 8-4-2 kg ha^{-1} fertilizer can significantly enhance the growth, yield, fruit quality, and profitability of sponge gourd cultivation. These findings are particularly relevant for regions where imbalanced fertilization is a common practice. However, further research is needed to validate these results across different agroecological zones.

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