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SPECIALTY SECTION

This article was submitted to
Nutrition and Food Science Technology,
a section of the journal
Frontiers in Nutrition

RECEIVED 29 September 2022

ACCEPTED 08 March 2023

PUBLISHED 17 April 2023



CITATION

Tarafder SK, Biswas M, Sarker U, Ercisli S,
Okcu Z, Marc RA and Golokhvast KS (2023)
Influence of foliar spray and post-harvest
treatments on head yield, shelf-life, and
physicochemical qualities of broccoli.
Front. Nutr. 10:1057084.
doi: 10.3389/fnut.2023.1057084

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Influence of foliar spray and post-harvest treatments on head yield, shelf-life, and physicochemical qualities of broccoli

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Rapid senescence is the key factor in the deterioration of post-harvest shelf-life in broccoli heads. This study evaluates the head yield and its related traits, and physicochemical attributes of broccoli under four foliar sprays of mineral nutrients (B, Zn, Mo, and B + Zn + Mo) with control. The interaction effects of shelf-life and physicochemical attributes of broccoli for these five pre-harvest and five post-harvest storage treatments (LDP bag, HDP vacuum pack, 2% eggshell powder solution, 2% ascorbic acid, and control) both at cold storage and room temperature were evaluated with three replications. The significantly higher marketable head yield of 28.02 t ha⁻¹, maximum gross return [(Bangladesh Taka (BDT) 420300 ha⁻¹)], net return (BDT 30565 ha⁻¹), and maximum benefit–cost ratio (BCR) of 3.67 were obtained from the pre-harvest foliar application of B + Zn + Mo in broccoli. Pre-harvest foliar spray of combined nutrient B + Zn + Mo and post-harvest treatment high-density polyethylene (HDP, 15 μm) vacuum packaging efficiently improve post-harvest physicochemical attributes, viz., compactness, green color, texture, carbohydrates, fats, energy, antioxidants, vitamin C, and total phenols in broccoli head compared to the rest of the treatment combinations. In addition, this treatment combination also confirmed a maximum shelf-life of 24.55 days at cold storage [relative humidity (RH) 90–95% and 4°C] and 7.05 days at room temperature (RH 60–65% and 14–22°C) compared to the rest of the treatment combinations. Therefore, we recommend a pre-harvest foliar spray of combined nutrient elements B + Zn + Mo and an HDP (15 μm) vacuum post-harvest packaging for the maximum benefits for both farmers and consumers to get the best head yield, anticipated physicochemical attributes, and maximum shelf-life of broccoli.

KEYWORDS

pre-harvest foliar spray, texture, color, antioxidants, ascorbic acid, head yield, total phenol content, post-harvest packaging

Introduction

Vegetables are low-cost sources of essential minerals, proteins (1–3), vitamins, dietary fiber (4, 5), phenols, flavonoids (6, 7), colorants with strong antiradical potential (8–10) that contribute to human nutrition, palatability, constipation (11–13), and health promotion (14). Broccoli (*Brassica oleracea* var. *Italica*) has been referred to as a high-quality food. It is a high-value excellent commercial crop under the *Brassicaceae* family and contains glucobrassicin, glucoraphanin, neoglucobrassicin, progoitrin, glucoiberin, 4-methoxyglucobrassicin, glucoalyssin, and gluconasturtiin (15). An aliphatic glucosinolate, glucoraphanin is the most copious in heads of broccoli; nevertheless, 3-methylsulfinyl propyl glucosinolate (glucoiberin), glucoerucin, and glucobrassicin are also present in it (16). It is also a good source of vitamins (A, C, and K), isothiocyanates, folates, dietary phenolic compounds, fibers, and essential mineral nutrients. The bioactive compounds and nutritional values are beneficial for the inhibition of carcinogenic, obesity, and cardiovascular ailments (17). It possesses antioxidants that promote many aspects of health (18, 19). Broccoli is best known for its low glycemic index (GI = 10), a functional food that reduces hepatic glucose production and improves glucose control in patients with type-2 diabetes (20).

In the year 2019, the total production of broccoli in the world was 27 million tons. The majority (73%) of the world's broccoli was produced in China and India. Mexico, the USA, Spain, Turkey, Italy, Bangladesh, France, and Poland produced the rest (27%) of the world's broccoli (21). Advanced growers in Bangladesh are very enthusiastic about growing and spreading the farming area for broccoli due to its high nutritional value and high price.

Fertilizer management is crucial for high-quality head production in broccoli to achieve maximum return (22). The growers in Bangladesh are applying chemical fertilizers scattered to obtain a better head yield of broccoli without the utilization of necessary organic manures, which leads to soil health deterioration. As a result, it reduces the quality and shelf-life of broccoli (23). In Bangladesh, head yield and quality of broccoli are drastically decreased due to insufficient use of essential mineral nutrients, such as B, Zn, and Mo (24). Zn, Mo, and B spray in foliage meaningfully increases growth, yield, development, quality, and height, reducing hollow stem infestation in broccoli (25–27). Zn directly relates to photosynthesis, respiration, and carbon metabolism and stimulates tryptophan (precursor of IAA) synthesis, and increases growth, shoot production, and height. B significantly involves in the occurrence of cell division, ion absorption, fruit development, cell wall formation, translocation of sugars, carbohydrates transportation and metabolism, water relations, and hormone activation (26, 27). Hence, the meticulous application of these essential mineral nutrients helps to increase the growth, yield, development, and quality of broccoli (26, 28). It is assumed that the application of soil test-based chemical fertilizers along with the foliar spray of mineral nutrients in broccoli during cultivation enhances head yield.

Temperature management is the most important activity to extend the shelf-life and indirectly delay losses of quality parameters of broccoli during post-harvest storage. Yellowing and wilting of broccoli heads indicate deterioration which leads to

reduced market value owing to consumers' choice (29). Low-density polyethylene (LDP) and high-density polyethylene (HDP) are viable post-harvest treatment technologies to extend the shelf-life of broccoli which slow down the respiration rate and ethylene production, keep color intact, and maintain texture, flavor, and nutritive values (30). Polyethylene bag protects the color, compactness, and texture of broccoli due to the combined effect of the fluctuated atmosphere, high humidity, and low temperature (31). HDP vacuum pack in cold storage conditions (storage with 95% relative humidity (RH) at 4°C) is a fruitful technique to continue the shelf-life and quality of broccoli (32).

The literature has shown that individual foliar spray of Zn during pre-harvest displayed the highest stalk length, plant spread, root length, ascorbic acid, and B increased the TSS, head yield and carbohydrate content. However, Mo increased the reducing sugar (33). Thus, foliar application of each mineral nutrient may be a promising method for maximizing broccoli productivity and growth (25–27, 34). Similarly, polyethylene bags (HDP) enhance the efficiency in post-harvest quality and shelf-life of broccoli (29, 35), and eggshells can be used for the preservation of quality fresh vegetables and fruits (36). Post-harvest dipping of fruit in ascorbic acid solution may be used as a preferential method for improvement of shelf-life and increasing the keeping quality intact for a long time (37). It is hypothesized that Zn, Mo, and B spray in foliage and post-harvest treatments using low-cost technologies such as LDP (35 µm) bag, HDP vacuum pack (15 µm), 2% eggshell powder, and 2% ascorbic acid solution might be an effective way to maintain the quality and improve shelf-life of broccoli. Therefore, this study emphasizes using low-cost technologies such as LDP (35 µm) bag, HDP vacuum pack (15 µm), 2% ascorbic acid, and 2% eggshell powder solution in post-harvest stage and Zn, Mo, and B spray in foliage to improve physicochemical attributes and retain the shelf-life of broccoli. Although a few pre-harvest studies of some minerals on morphological traits are available, the pre-harvest effect of these elements on physicochemical traits is scarce. This is the first report regarding the in-depth study of broccoli on pre-harvest utilization of individual and combined Zn, Mo, and B in combination with post-harvest treatment materials under normal and cold storage facilities. Therefore, to fill the lacuna, the investigation was set up to take an elaborative study on the effects of combined mineral nutrients sprayed in foliage during pre-harvest and post-harvest application of different densities of 2% ascorbic acid solution, 2% eggshell powder, and polythene packaging, on the yield, shelf-life, and physicochemical attributes of broccoli.

Materials and methods

Location of the experimental site and duration

The study was carried out during the Rabi seasons (October to March) of 2020–2021 and 2021–2022 at a farmer's field in Palashi of Manirampur Upazila under Jashore district, Bangladesh. It is located at 23°1 0'N" latitude and 89° 14'0" E longitude. The altitude of the location is 9 m above the mean sea level. The experimental site is a medium-high land with loamy soil. Physical and chemical properties of the experimental plots of topsoil

in 0–15 cm depth were analyzed by the soil testing laboratory, Soil Resources Development Institute (SRDI), Jashore. Details are presented in [Supplementary Table S1](#).

Details of treatments

The sources of mineral nutrients taken are boric acid (H_3BO_3) for B, Zn sulfate (ZnSO_4) for Zn, and ammonium heptamolybdate tetrahydrate $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}]$ for Mo with a single concentration of 0.40% each separately and combined along with control. The details of treatments are as follows: T_1 = control, T_2 = B, T_3 = Zn, T_4 = Mo and T_5 = B + Zn + Mo, 0.40%, respectively.

Preparation of mineral nutrients solutions and spraying

According to treatment, fresh solutions of mineral nutrients; boric acid (H_3BO_3) for B, Zn sulfate (ZnSO_4) for Zn, and ammonium heptamolybdate tetrahydrate $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}]$ for Mo were prepared meticulously just before spraying. To make a 1-L solution of 0.40% concentration of each mineral nutrient, 4 g amount of each mineral nutrient was taken, respectively and weighed carefully, and dissolved in 1 L of distilled water separately. The solution was thoroughly mixed until homogeneous. According to treatment, prepared fresh solutions of mineral nutrients were applied as a foliar spray to run off stage. The first spraying was done 15 days after transplanting, and subsequently, the second, third, and fourth spraying was done at 30, 45, and 60 days after transplanting. The spraying was done in the afternoon (~ 4.00 – 4.30 P.M.) with a manual knapsack sprayer to wet the whole leaf completely until runoff. The sprayer was washed with water properly before and after spraying every solution to avoid any kind of contamination. All necessary precautions were taken into account during the spraying of chemicals.

Design and layout of the experiment

Head yield and physicochemical attributes of broccoli were determined using a randomized complete block design (RCBD) with three replications and five treatments (T_1 = Control, T_2 = B, T_3 = Zn, T_4 = Mo, and T_5 = B + Zn + Mo, 0.40%, respectively). However, the shelf-life and physicochemical parameters of broccoli were also determined using a complete randomized design (CRD) in three replicates considering each of three factors; Factor 1: application of foliar mineral spray (T_1 = Control, T_2 = B, T_3 = Zn, T_4 = Mo and T_5 = B + Zn + Mo, 0.40%, respectively); Factor 2: post-harvest treatments at room temperature (i) LDP bag, (ii) HDP vacuum pack, (iii) 2% eggshell powder solution, (iv) 2% ascorbic acid solution, and v. control) and Factor 3: post-harvest treatments at cold storage condition (i) LDP bag, (ii) 2% eggshell powder solution, (iii) HDP vacuum pack, (iv) control, and (v) 2% ascorbic acid solution).

Sources of planting materials

Green Crown (hybrid) variety of broccoli was used for conducting the field experiment as planting material. The seeds were produced by Sakata Seed Corporation, Japan. The seeds were collected from East Bengal Seed Co. 174, Siddique Bazar, Dhaka-1000, Bangladesh. Green Crown (hybrid) is a medium-maturing, very uniform, large-headed, well-domed broccoli variety with small beads and with excellent texture. The large heads and almost dark green coloration make them very visually attractive. This variety has wide regional adaptability and offers very good uniformity of harvest.

Preparation of nursery bed and sowing of seeds

Two model seedbeds of size $3\text{ m} \times 1\text{ m} \times 0.15\text{ m}$ were prepared at the side of the experimental field. Well-decomposed farm yard manure (FYM) of 15 kg per square meter was applied to the prepared seedbed and mixed with the soil properly. The physical and chemical properties of FYM were analyzed by the soil testing laboratory, Soil Resources Development Institute (SRDI), Jashore, and the details are presented in [Supplementary Table S2](#). The soil of the seedbed was prepared to obtain good tilth to provide a suitable condition for the vigorous growth of young seedlings. Weeds, stubbles, and dried roots of previous crops were removed. Before sowing, Thiram 2.5 g per kg was used to treat the seeds. Seeds were sown on 26 October 2020 during the first year and 13 October 2021 during the second year, respectively in shallow furrows 10–15 cm apart by dropping the seeds at 1–2-cm depth. Regular light watering, hoeing, weeding, plant protection measures, etc. were done from time to time. The seedlings were transplanted 21 days after sowing.

Transplanting of seedlings

The healthy and 21 days age of uniform seedlings were transplanted to the experimental plots of size $3\text{ m} \times 2\text{ m}$, maintaining a spacing of $50\text{ cm} \times 40\text{ cm}$ as per layout on 16 November 2020 during the first year and on 3 November 2021 during the second year. The transplanting was done in the afternoon, followed by light irrigation.

Application of chemical fertilizers

The chemical fertilizer of broccoli recommended for the agro-ecological zone (AEZ-11) was used in all the treatments, including the control plot. Based on the soil test, inorganic fertilizers N, P_2O_5 , K_2O , and S at the rate of 118, 70, 95, and 2 kg/ha, respectively, were applied in the experimental plots. Urea, triple superphosphate (TSP), muriate of potash (MP), and gypsum were applied as a source of N, P, K, and S, respectively. A full dose of TSP and gypsum were used as basal doses. Urea and MP fertilizers were applied as three equal splits at 15, 30, and 45 days after transplanting as a ring

method under moist soil conditions and mixed well with the soil for better utilization (38).

Intercultural operations

Standard intercultural operations were followed in the entire research plot. Hoeing and weeding were done manually after 30 days of transplanting, followed by a second top dressing with urea and MP fertilizers. The second hoeing, weeding, and earthing up were carried out after 45 days of transplanting, followed by the third top dressing with urea and MP fertilizers. The crop was irrigated immediately after transplanting and then at an interval of 2–3 days until the establishment of seedlings. After this, the crop was irrigated at a regular interval of 7–8 days up to the maturity indices sign. Irrigation was provided with a buried pipe-lined water distribution system. In this system, pumped water is transmitted to the header tank where the pressure head of water is developed. Water then goes to the different points of the crop field through a pipeline laid under the ground surface with the help of outlets. In this system, water can be taken from a lower position to a higher position on the land. Generally, cement concrete (cc) or unplasticized polyvinyl chloride (uPVC) pipes are used to construct underground buried pipe lines. The main considerations for the choice of materials in an irrigation system are the ability of the materials (pipe) to withstand, especially the mechanical stress and temperature to which they may be subjected. Mechanical stress may be due to internal conditions such as water pressure, water acidity, and vacuum (NPI, 2005). To produce safe broccoli, the crop pests and diseases were meticulously managed by daily close observation using biological methods. Completely organic pesticides have been used in the experimental plots. Organic fungicide Dicoprime (750 g ha⁻¹) was used to prevent root rot and fusarium wilt of broccoli; 160 g of Dicoprime powder was mixed well with 1 L of water and left aside for at least 6–12 h. Later on, 50 L of water was added to the former solution and thoroughly mixed until homogeneous. The prepared solution was sprayed on the soil 3 days before planting. In the same way, the seedlings in experimental plots were sprayed two more times after the seedlings were planted at 30 days intervals. Under the management of broccoli back diamond, moth insects had been monitored regularly by setting up sex-pheromone using Spodo-O-Lure (Spodoptera Litura Pheromone Lure) (40 number ha⁻¹). A yellow sticky board was placed in the experimental plots to control white flies and aphid insects. In addition, Bionim plus (3 mL/L H₂O) and Neem oil (5 mL/L H₂O) were sprayed three times at 10–12 day intervals.

Harvesting

Broccoli heads were harvested in the morning before the soil warms up for the best flavor and when the buds of the head are firm and tight, just before the head's flower. Broccoli heads are cut with sharp scissors or a knife to avoid damaging the stem from the plant, taking at least 15 cm of stem attached to the sprouts. During the first year (2020–2021): five broccoli heads were randomly selected from each replication of all treatments and

TABLE 1 Description of numerical ratings for broccoli quality [According to a 1 to 5-point hedonic scale (39)].

Scale	Ranges of scores	Rating for quality attributes of broccoli		
		Color	Compactness	Texture
1	4.50–5.00	Dark green	Very compact	Highly crispy
2	3.50–4.49	Green	Compact	Crispy
3	2.50–3.49	Light green	Medium compact	Moderately crispy
4	1.50–2.49	Light yellow	Slightly loose	Soft
5	1.00–1.49	Very yellow	Loose	Very soft

harvested according to head maturity indices. The first harvesting of broccoli heads was done on 29 January 2020, and the last harvesting was on 3 February 2020 in the first year. Similarly, in the second year first harvesting of broccoli heads was done on 24 January 2021, and the last harvesting on 29 January 2021, respectively. A total of 60 broccoli heads were harvested during the first harvesting, and 40 broccoli heads were harvested during the second harvesting.

Yield attributing characteristics and head yield

The observation related to head production and its related traits (marketable head weight plant⁻¹ (g), diameter and length of heads, and marketable head yield t ha⁻¹) was calculated by selecting five plants randomly from each replication of all treatments between 2020 and 2021 and 2021 and 2022. The average was calculated and find out the pooled values for the head's length and diameter, marketable head weight [marketable weight of broccoli means the weight of head and leaves (pruned to at head level)], and marketable head yield.

Sensory evaluation of color, compactness, and texture

Compactness, sensory evaluation of color, and texture of broccoli were determined in fresh and stored conditions. The sensory evaluation of broccoli was performed using a test panel composed of five trained Sub-Assistant Agriculture Officer (SAAO) panelists. The numerical ratings sensory analyses, such as color, compactness, and texture of stored broccoli were determined and counted from hedonic scales (1 to 5-point) (39) (Table 1), at maximum shelf-life stage both room temperature and cold storage conditions within each level of storage materials separately and the mean values of rating score were calculated and marked the respective color of all treatments. The color, compactness, and texture were determined based on the treatment-wise results from the 2020–2021 and 2021–2022 periods.

Yellowing (%)

Yellowing was documented visually by cutting the whole green broccoli heads into four parts equally. The yellowing conditions were gradual yellowing and patchy color development.

Physiological loss in weight (%)

Physiological weight loss (PW) was expressed as % weight loss during storage from the initial weight before storage, and it was documented from the time periodical sampling during storage. The following formula was used for the determination of PLW:

$$PLW = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

Chemical analysis of fresh and stored broccoli

The treatment-wise samples were analyzed to determine the biochemicals of stored and fresh broccoli in the laboratory. The methods were briefly described chronologically. Carbohydrate content was determined following the AOAC method (40–43).

The following formula was used to determine carbohydrate content:

$$\text{Carbohydrate content (\%)} = 100 - (\% \text{ moisture} + \% \text{ ash} + \% \text{ protein} + \% \text{ fat} + \% \text{ fiber})$$

Fats of the respective broccoli samples were extracted using the Soxhlet apparatus with n-hexane as a solvent in triplicates (40–43). Approximately 10 g of dry sample of broccoli was extracted for 16 h at 70°C with 40 ml n-hexane using the Soxhlet apparatus. The extract was evaporated to dryness, and the residue was collected. The mean value of each replication under respective treatments was recorded.

The following formula was used to determine fat content:

$$\text{Fat content (\%)} = \{(W_3 - W_2)/(W_2 - W_1)\} \times 100$$

Where, W_1 = sample weight (g), W_2 = extraction thimble weight (g), and W_3 = extraction thimble weight with the dried crude fat (g).

The protein content was determined following the Micro Kjeldahl procedure (44–48) to determine nitrogen, and then crude protein was calculated by multiplying the nitrogen content by a conversion factor (6.25). The amount of nitrogen present in the sample was converted into ammonium sulfate with sulfuric acid in the presence of a catalyst mixture by digestion at 380°C. The liberated ammonia was distilled with sodium hydroxide solution to absorb by boric acid and then titrated and calculated nitrogen percentage using the following formula.

$$\text{Protein content (\%)} = \left\{ \frac{\{(V_1 - V_2) \times N \times 14.01 \times 100\}}{(W \times 1000)} \right\} \times 6.25$$

Where, V_1 = the amount of sulfuric acid that was used to neutralize the sample, V_2 = the amount of acid that was used to neutralize the blank, N = normality of the titrant (standard hydrochloric acid, 0.1 N); 14.01 = Molecular weight of nitrogen; 6.25 = total nitrogen to the protein conversion factor.

We pre-incubated the samples using dithiothreitol (DTT) for reducing dehydroascorbic acid to ascorbic acids. Then, ascorbic acids were measured with the reduction of ascorbic acids by 2, 2-dipyridyl (49, 50), which converted Fe^{3+} to Fe^{2+} complexes. The absorbance was taken using a spectrophotometer. Finally, results were expressed as mg/100 g of fresh weight (FW). Total phenol content (TPC) was estimated by the Folin-Ciocalteu reagent (51, 52). A spectrophotometer was used to read the absorbance at 760 nm. TPC was measured using gallic acid standard curves. Finally, results were expressed as mg/100 g FW. The antioxidant activity (AC) (DPPH) was estimated by the radical degradation by DPPH (53, 54). We measured the inhibition % of DPPH equivalent to the control using the equation:

$$AC (\%) = (Ab - AS/Ab) \times 100$$

Where, Ab represents the blank sample absorbance and AS is the absorbance of the samples.

Trolox was used as the reference standard, and finally, results were expressed as Trolox equivalent mg/100 g FW.

Energy calculation

We calculated the energy following the formula of AOAC (55):

$$\text{Energy (kcal/100 g)} = (\text{Protein} \times 4) + (\text{Fats} \times 9) + (\text{Carbohydrates} \times 4)$$

Shelf-life assessment of broccoli

According to treatment, the average shelf-life (days) was evaluated by taking five samples (452.7 g to 568.78 g for each sample) from each replication using five post-harvest treatments, viz., LDP (35 μ m) bag, HDP (15 μ m) vacuum pack, 2% eggshell powder solution, 2% ascorbic acid solution, and control condition both at room temperature and cold storage conditions in 2020–2021 and 2021–2022. At the room temperature condition, the storage temperature was 14–22°C with RH 60–65% and at the cold storage, the storage temperature was 4°C with RH 90–95%. The storage room was a one-storied building with a concrete roof and proper ventilation management. Sufficient lighting and ceiling fans were present there. Treatment-wise the broccoli heads were kept in the selective storage facilities and were placed on the table. Concerning cold storage conditions, we used cold storage, Muroley, Razarhat, and Jashore. We meticulously monitored the storage temperature of broccoli heads, both at cold storage and at room temperature conditions. At room temperature conditions, the temperature and relative humidity (RH) were observed by the operation manual for Temperature and Humidity Meter (HTC-2). The fixed temperature of 4°C and RH 90–95% were maintained in the cold storage throughout the storage periods. The shelf-life indicators, viz.,

deviation of existing color, compactness, texture, percent yellowing, and percent physiological loss in weight (PLW) of broccoli were observed meticulously. Visual and sensory qualities and PLW were observed daily at normal storage and five days intervals at cold storage, and collective results were documented from each replication under selected treatments. The shelf-life (days) had been determined based on the treatment-wise results of the 2020–2021 and 2021–2022 periods.

Treatments of broccoli

In this study, five post-harvest storage treatments were used, namely: LDP (35 μm) bag, HDP (15 μm) vacuum pack, 2% eggshell powder solution, 2% ascorbic acid solution, and control condition both at room temperature and cold storage conditions during the 2020–2021 and 2021–2022 study periods (Supplementary Figure S1). In the case of the LDP (35 μm) bag, the single sample of each replication was kept inside the package carefully and air-tied the bag as soon as possible. Similarly, in the case of the HDP (15 μm) vacuum pack, the single sample of each replication was kept inside the package carefully and locked in the bag as soon as possible. The dip treatment in 2% eggshell powder solution for 5 min to increase the shelf-life of broccoli heads was investigated. Similarly, the dip treatment in 2% ascorbic acid solution for 5 min to increase the shelf-life of broccoli heads was also investigated.

Determination of CO₂ and O₂ conditions and respiration rate inside the packages

We measured CO₂ and O₂ conditions inside the packages using the Q₂-Portable O₂/CO₂ analyzer (Shenzhen Empaer Technology Co. Ltd., Shenzhen, China). We also measured the respiration rate inside the packages using 3051H Fruit and Vegetable Breathing Tester (Zhejiang Top Cloud-Agri Technology Co. Ltd. China).

Economic performance

The cost of cultivation per hectare under different treatments was found based on expenditure incurred on different operations production of the crop separately under each treatment of both seasons. Gross return was found based on the market price of the product at the time when the product was ready for sale. The treatment-wise net return per hectare was found by deducting the cost of cultivation from the gross return per hectare. The benefit–cost ratio (BCR) for each treatment under investigation was calculated based on the present market prices of inputs and outputs to find out the maximum profitable treatment. The benefit–cost ratio (BCR) was found as follows:

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

Statistical analysis

The raw data were compiled by taking the means of all the plants taken for each treatment and replication for different traits. Then, mean data from both years (2020–2021 and 2021–2022) were pooled before statistical analysis. The recorded pooled data were analyzed using the Statistical Tool for Agricultural Research (STAR) program, and the pooled values were tested for significance using Tukey's test at 5 or 1% levels.

Results and discussions

Yield attributing characteristics and head yield

Figures 1–4 revealed that foliar spray of mineral significantly ($p \leq 0.05$) increased the head length and diameter, marketable head weight, and marketable head yield of broccoli. Among the treatments, the highest head length (19.25 cm) and head diameter (20.87 cm) were documented in B + Zn + Mo, followed by B with a head length of 18.44 cm, head diameter of 18.9 cm and Zn with a head length of 17.29 cm and head diameter of 18.39 cm (Figure 1). At a 5% level of significance, the maximum pooled value of marketable head weight plant⁻¹ (560.33 g) was recorded in B + Zn + Mo followed by B (530.94 g) and Zn (521.92 g) (Figure 2). There was no statistical difference between B and Zn treated plots for marketable head weight plant⁻¹. The maximum pooled value of marketable head yield (28.02 t ha⁻¹) was recorded in B + Zn + Mo followed by B (26.55 t ha⁻¹) and Zn (26.1 t ha⁻¹) (Figure 3). The marketable head yield had no statistical difference between B and Zn treated plots. Whereas, in the control treatment, the minimum head length, head diameter, marketable head weight plant⁻¹, and marketable head yield were 14.39 cm, 15.63 cm, 452.7 g, and 22.64 t ha⁻¹, respectively.

Maximum head length and diameter were obtained from the spraying of combined B, Zn, and Mo. The supply of sufficient essential elements may be the reason for more vegetative growth. The results were corroborative of the results of Singh et al. (56) in broccoli and Bairwa et al. (57) in cauliflower. The synergistic action of these elements increased carbohydrate accumulation and photosynthesis rate in the head and enhanced diameter and length. Chowdhury and Sikder (34) found similar increments in the diameter and length of broccoli. The application of treatment B + Zn + Mo increased the marketable head yield by 19.20% compared to the control. Physiological activities in broccoli, viz., protein, and chlorophyll synthesis, cell elongation and division, carbohydrate metabolism, amino acid formation, sugar translocation, and various enzymatic reactions, were accelerating due to foliar spray of Zn, B, and Mo, which leads to more carbohydrate accumulation in broccoli heads. This might be due to the combined foliar application of the advanced and subsequently increased the broccoli yield. These results conform with the results on broccoli (34). Singh et al. (56) observed that the application of B + Mn + Zn produced a significant maximum yield contributing traits like head diameter, length, and marketable head yield of broccoli. In broccoli, application from zero to 1.5 kg/ha B significantly enhanced leaves per plant, plant height, leaf length and width, plant

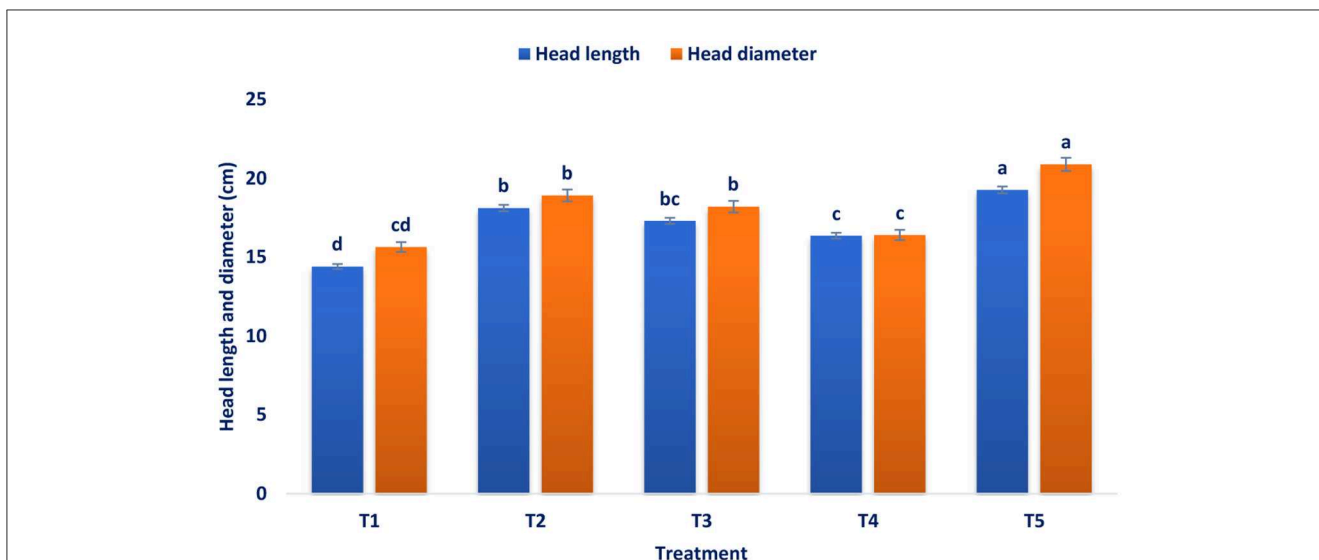


FIGURE 1 Influence of pre-harvest foliar application of mineral nutrients on the head length and diameter of broccoli at the marketable stage. T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively.

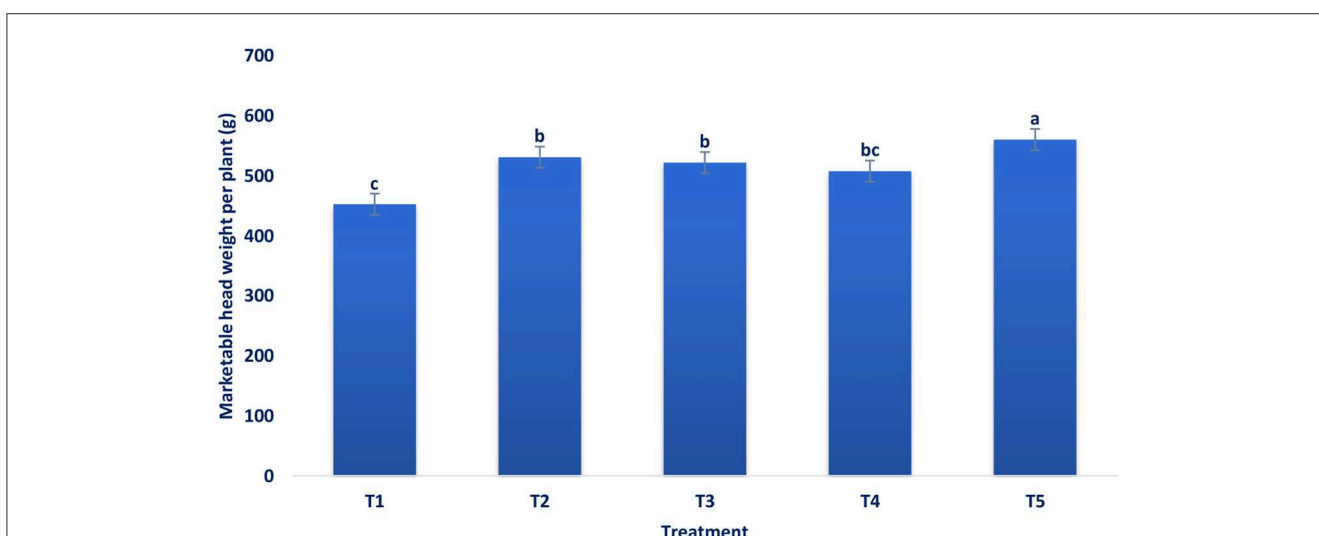


FIGURE 2 Influence of pre-harvest foliar application of mineral nutrients on marketable head weight plant⁻¹ (g) of broccoli at the marketable stage. T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively.

spread, main head weight, and head yield (24). Xaxa et al. (58) showed that the head yield of broccoli was significantly influenced by the different treatment combinations of micronutrients. Patel et al. (25) observed that the combined fertilization of B (2.5 kg/ha), Mo (0.5 kg/ha), manganese (3 kg/ha), and Zn (2 kg/ha) had the highest head yield. Patel et al. (25) also investigated that compared to RDF, the combined application of B and Mo was more effective than their sole application. Application of RDF + borax (1.5%) + ammonium molybdate (2.5%) was found as the best combination for the maximum head yield of broccoli. Similar findings were also recorded by Bairwa et al. (57) in cauliflower, who showed that application of 2 kg ha⁻¹ ammonium molybdate + 25 kg ha⁻¹ ZnSO₄ + RDF (100%) and 20 kg ha⁻¹ borax

displayed most substantial effect on yield and yield attributing characteristics of cauliflower compared to control (100% RDF). It revealed from the current study that different treatments spray increased the head yield, and combined micronutrients B, Mo, and Zn demonstrated the highest values. Micronutrient spray promotes food material production, translocation, transformation, and distribution from leaves to the sink tissue in the broccoli heads. The higher head yield might be attributed due to the application of that mixture of micronutrients contributed to head yield because of the improved availability of vital elements at optimum stages of growth, which ultimately promotes the rate of metabolism in plants (25). Augmented activities of metabolic caused greater assimilation of carbohydrates and proteins that additionally led to greater

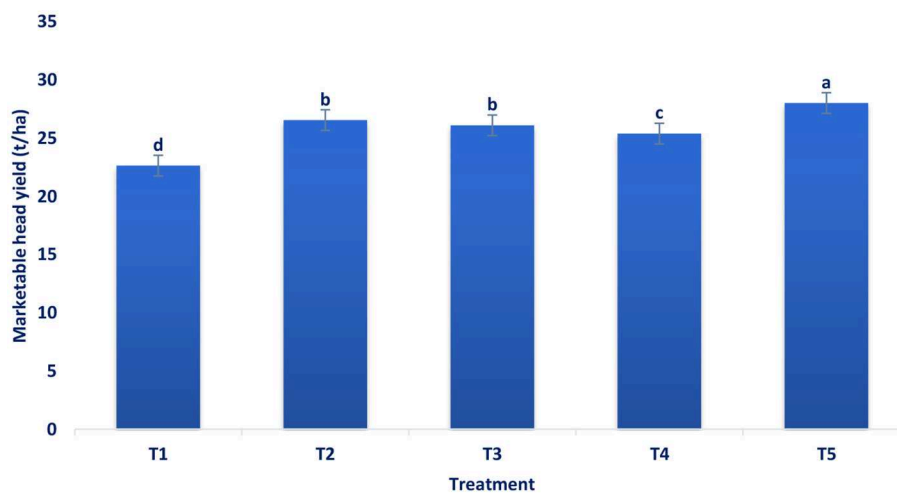


FIGURE 3

Influence of pre-harvest foliar application of mineral nutrients on the marketable head yield $t\ ha^{-1}$ of broccoli. T_1 = control, T_2 = B, T_3 = Zn, T_4 = Mo, and T_5 = B + Zn + Mo, 0.40%, respectively.

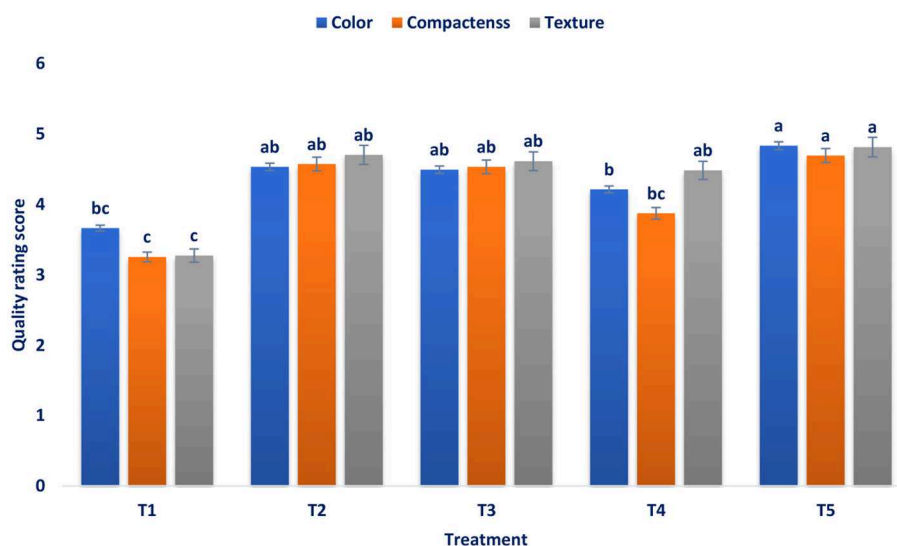


FIGURE 4

Influence of pre-harvest foliar application of mineral nutrients on quality indices of fresh broccoli. T_1 = control, T_1 = control, T_2 = B, T_3 = Zn, T_4 = Mo, and T_5 = B + Zn + Mo, 0.40%, respectively.

nutrient uptake and yields. Furthermore, micronutrients spray accumulated more photosynthates and increased other metabolic activity for the biosynthesis of numerous primary and secondary metabolites for cell elongation and division, which improved head yield and its related characters (59). Mo promotes plant weight and leaf characteristics and may be a noteworthy consequence of the augmentation of head yield and its related characteristics. Moreover, Mo spray stimulates the augmentation of the metabolic pools essential for the amalgamation of saccharides, in addition to enhancing the capacity of photosynthetic (60). Phosphorous and B in the plant resulted from the synergistic interaction effect of greater head yield (61). Zn and the P application may create the synergetic effect that serves as an energy source for

auxin synthesis. Moniruzzaman et al. (24) reported enhanced photosynthetic reactions in broccoli with the application of Zn and B.

Physico-chemical analysis of fresh broccoli

Sensory evaluation of color, compactness, and texture

The dark green color and very compact and highly crispy broccoli heads are the most important quality attributes which determine its marketability and market value. From the experimental results shown in Figure 4, it was found that

pre-harvest foliar application of B, Zn, B + Zn + Mo, and significantly ($p \leq 0.01$) increased the quality attributes, viz., texture, compactness, and color of broccoli. According to the 1–5-point hedonic scale of Ranganna (39), the maximum pooled value of texture (4.81), compactness (4.69), and color (4.83) were determined in B + Zn + Mo followed by B with compactness (4.57), texture (4.70), and color (4.53) and Zn with the compactness (4.53), color (4.49), and texture (4.61). Whereas, the minimum compactness (3.25), color (3.66), and texture (3.27) were observed in control. It may be owing to the effects of the foliar spray of B, Zn, and Mo that influenced the length of the duration of the post-harvest life of broccoli through increased nutrient uptake by the plants during the growing period. It also developed water-conducting tissue for maintaining the quality attributes, including compactness, color, and texture of broccoli, which is in accordance with the previous study of Mohamed et al. (62) in broccoli. The application of foliar mineral nutrients, particularly B, Zn, and Mo, has a beneficial role in improving the quality of broccoli due to their involvement as a catalyst of various enzymes and other physiologically active molecules (63). Pre-harvest application of Zn plays an important role in the photosynthesis process (64), which increases color density. Zn increases the net photosynthetic rate, and chlorophyll content is probably responsible for the green color of broccoli heads (65). Mo presumably maintains cell firmness and its structure of walls and helps in retarding weight loss of broccoli (66). Duffy (67) stated that Zn improved turgidity and efficiency of water use in tissues and helps to maintain greater moisture levels inside the tissues of broccoli heads. B increases the synthesis of secondary metabolites for the biosynthesis of lignin (68). Thus, a rise in lignin as a result of spraying higher doses of B in broccoli tissue may minimize water loss.

Chemical analysis of fresh broccoli heads

Protein

From Table 2, it was found that foliar spray of nutrients significantly ($p \leq 0.01$) augmented protein content in broccoli heads. Among the treatments, the maximum protein (3.55%) was recorded in Mo, followed by B + Zn + Mo (3.33%) and Zn (3.31%). Whereas, the minimum protein (2.5%) was observed in the control. Mo may involve in the absorption of nitrogen and nitrogen metabolism, which leads to higher protein content in broccoli heads (69). B plays a pivotal role in nitrogen (N) metabolism as it enhances nitrate levels and reduces nitrate reductase activity under limited B conditions (70, 71).

Fat

It was revealed from Table 2 that foliar spray of nutrients increased the fat content significantly ($p \leq 0.01$) in broccoli heads. Among the treatments, the maximum fat (0.4375%) was recorded in B + Zn + Mo and Zn (0.4362%) and followed by B (0.4331%). Whereas, the minimum fats of 0.3821% were noted in the control.

Carbohydrates

According to experimental results in Table 2, it was found that foliar spray of nutrients significantly ($p \leq 0.01$) increased the carbohydrate content in broccoli heads. Among the treatments, the maximum carbohydrates (5.25%) were recorded in B + Zn + Mo followed by Zn (4.47%) and B (4.18%), which were statistically similar. Whereas, the minimum carbohydrates (2.82%) were noted in the control. It is owing to greater vegetative growth and metabolic activities for accumulation of more carbohydrates in broccoli heads deferential as a result of nutrient spray. Sharma (33) and Singh et al. (28) also found the results in broccoli to support our present findings. The literature has shown that foliar spray of Zn during pre-harvest displayed the highest carbohydrate; however, Mo increased the reducing sugar (33).

Energy

Table 2 revealed that the foliar spray of nutrients displayed significant ($p \leq 0.01$) effects on the energy produced in the broccoli heads. Among the treatments, the maximum energy (38.26 kcal/100 g) was recorded in B + Zn + Mo, followed by Zn (35.25 kcal/100 g) and B (32.03 kcal/100 g). Whereas, the minimum energy (24.72 kcal/100 g) was recorded in the control. This might be due to the accumulation of fats in the broccoli heads from the combined foliar application of mineral nutrients. Beta-oxidation of fats produces more adenosine triphosphate (ATP) compared to carbohydrates and proteins. These high energy-rich compounds ATPs release energy in the broccoli heads by breaking into ADP and inorganic phosphate. We know that energy is released from fat, protein, and carbohydrate. In our study, a combined spray of B + Zn + Mo increased fat, protein, and carbohydrate content in broccoli heads, and the increment of these compounds may result in the augmentation of energy heads.

Vitamin C

Vitamin C content differed significantly ($p \leq 0.01$) in the broccoli heads with the application of nutrients in foliage (Table 2). Among the treatments, the maximum vitamin C (87.75 mg/100 g) was recorded in B + Zn + Mo followed by Zn (85.99 mg/100 g) and B (84.95 mg/100 g). Whereas, the minimum vitamin C was observed (70.3 mg/100 g) in the control. B, Zn, and Mo meet up need-based essential nutrients to plants and may create the synergistic effects to enhance the photosynthetic rate for greater development and growth of broccoli which finally mobilize the ascorbic acid biosynthesis to accumulate vitamin C in broccoli heads. These results are consistent with the results of broccoli (25, 34, 56).

Antioxidants

The application of foliar nutrients significantly ($p \leq 0.01$) influenced the antioxidant content in broccoli heads (Table 2). Among the treatments, the maximum antioxidants (72.45 mg/100 g) were observed in B + Zn + Mo followed by Zn (70.62 mg/100 g) and B (68.45 mg/100 g), which were statistically similar. The minimum antioxidants (55.71 mg/100 g) were recorded in the control. The previous literature (72) has shown that application

TABLE 2 Pre-harvest foliar application effect of mineral nutrient sources on nutrient content in fresh broccoli heads.

Treatment	Nutrient contents in fresh broccoli head						
	Protein (%)	Fat (%)	Carbohydrates (%)	Energy (kcal/100 g)	Vitamin C (mg/100 g)	Antioxidants (mg/100 g)	Phenols (mg/100 g)
T ₁	2.50 ± 0.01c	0.3821 ± 0.02c	2.82 ± 0.2c	24.72 ± 0.1d	70.3 ± 0.02d	55.71 ± 0.1d	26.96 ± 0.1d
T ₂	2.86 ± 0.3b	0.4331 ± 0.1ab	4.18 ± 0.3bc	32.03 ± 0.2bc	84.95 ± 0.03ab	68.45 ± 0.3b	38.42 ± 0.3b
T ₃	3.31 ± 0.03abc	0.4362 ± 0.01a	4.47 ± 0.1ab	35.25 ± 0.4b	85.99 ± 0.4ab	70.62 ± 0.04ab	40.24 ± 0.05ab
T ₄	3.55 ± 0.04a	0.4155 ± 0.3b	3.43 ± 0.1b	31.64 ± 0.01c	81.31 ± 0.04abc	65.13 ± 0.1bc	34.71 ± 0.02bc
T ₅	3.33 ± 0.5ab	0.4375 ± 0.01a	5.25 ± 0.2a	38.26 ± 0.1a	87.75 ± 0.01a	72.45 ± 0.2a	41.03 ± 0.01a
Level of Significance	**	**	**	**	**	**	**

T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively. **Significant level at 1% level of significance, in a column means having a similar letter(s) are not significantly different.

of minerals stimulates polyphenolic biosynthesis and antioxidant activity in plants. As high polyphenols content highly correlates with high antioxidant potential (73, 74), broccoli heads showed high antioxidant potential.

Total phenol content

Nutrient spray in foliage responded significantly ($p \leq 0.01$) to the total phenol content in broccoli heads (Table 2). Among the treatments, the maximum phenols (41.03 mg/100 g) were observed in B + Zn + Mo, followed by Zn (40.24 mg/100 g) and B (38.42 mg/100 g), which were statistically similar. Whereas, the minimum phenol (26.96 mg/100 g) was noted in the control. The antioxidant activity of phenols is mainly due to their redox properties, which allow them to act as antioxidants (75). Phenolics have numerous groups of simple phenols and phenolic acids, including hydroxybenzoic acids and hydroxycinnamic acids (76, 77). Flavonoids such as flavonols, flavanols, flavones, flavanones, isoflavones, and anthocyanins (78), which detoxify the reactive oxygen species (ROS) (79, 80), protect against many degenerative diseases like cancer and cardiovascular disorders (9). The previous literature (72) has shown that application of minerals stimulates polyphenolic biosynthesis in plants which correlates to our current results. Glucosinolates are abundant phenolic compounds in broccoli. Foliar zinc application significantly increased the sulforaphane content in broccoli heads (81). Sulfur and boron application increased glucosinolate concentration in rapeseeds (82). From the literature, we found that phenolic compounds in broccoli were increased, which supports the augmentation of total polyphenols in our current study.

Shelf-life

Shelf-life is always dependent on the type of vegetables and the conditions in which they are stored. At room temperature conditions (14–22°C with RH 60–65%), the samples were stored for 1.75–7.25 days, LDP (35 μm) bag packaging samples were stored for 3.29–5.53 days, HDP (15 μm) vacuum packaging samples were stored for 3.85–7.25 days, 2% eggshell powder solution-treated broccoli heads were stored for 2.33–3.73 days, 2% ascorbic acid

solution-treated broccoli heads samples were stored for 2.25–3.69 days, and control conditioned broccoli heads were stored for 1.75–3.25 days. In the cold storage (RH 90–95% and 4°C), the samples were stored for 11.04–24.73 days. LDP (35 μm) bag packaging samples were stored for 15.04 to 22.52 days, HDP (15 μm) vacuum packaging samples were stored for 16.89–24.73 days, 2% eggshell powder solution-treated broccoli heads were stored for 12.39–15.37 days, 2% ascorbic acid solution-treated broccoli heads samples were stored for 12.31 to 15.25 days, and control conditioned broccoli heads were stored for 11.04–13.35 days. Evident from the experimental results revealed that foliar spray of minerals and post-harvest packaging and chemical treatments significantly ($p \leq 0.01$) influenced the shelf-life of broccoli (Table 3). At a 1% level of significance, the treatment combination of T₅ × HDP confirmed a maximum shelf-life of 7.05 days at room temperature (RH 60–65% and 14–22°C) which was statistically different from others. The treatment combination of T₂ × HDP gave the second maximum shelf-life of 6.13 days at room temperature, followed by T₃ × HDP with 5.75 days and T₅ × LDP with 5.49 days which were statistically different. While the treatment combination of T₁ × con. showed a minimum shelf-life of 1.75 days at room temperature conditions. Similarly, at a 1% level of significance, the treatment combination of T₅ × HDP confirmed a maximum shelf-life of 24.55 days at cold storage (90–95% RH and 4°C) conditions which were statistically different from others. The treatment combination of T₂ × HDP gave the second maximum shelf-life of 23.35 days at cold storage, followed by T₃ × HDP with 22.69 days, T₅ × LDP with 21.75 days, T₂ × LDP with 21.36 days, and T₃ × LDP with 20.53 days, which were statistically similar. While the treatment combination of T₁ × con. showed a minimum shelf-life of 11.04 days under cold storage conditions. At the temperature of 14°C, the oxygen and carbon dioxide conditions inside the LDP packages were 45% O₂ + 55% CO₂, and inside the HDP packages were 48% O₂ + 52% CO₂ (Table 4). At the temperature of 22°C, the oxygen and carbon dioxide conditions inside the LDP packages were 33% O₂ + 67% CO₂, and inside the HDP packages were 36% O₂ + 64% CO₂. On the other hand, in cold storage, the O₂ and CO₂ conditions inside the LDP packages were 60% O₂ + 40% CO₂, and inside the HDP packages, were 65% O₂ + 35% CO₂ (Table 4). Similarly, at the temperature of 14°C, the respiration rate inside the LDP packages was 80–90 mg CO₂

TABLE 3 Influence of pre-harvest foliar application of mineral nutrients and post-harvest packaging and chemical treatments on shelf-life of broccoli under different storage temperatures.

Treatment combination	Shelf-life (days)	
	At room temperature condition (14–22°C with RH 60–65%)	In cold storage condition (4°C with RH 90–95%)
T ₁ × LDP	3.29 ± 0.02gh	15.04 ± 0.01cd
T ₂ × LDP	5.33 ± 0.03de	21.36 ± 0.01b
T ₃ × LDP	4.85 ± 0.05e	20.53 ± 0.04bc
T ₄ × LDP	4.37 ± 0.01f	18.12 ± 0.05bc
T ₅ × LDP	5.49 ± 0.01d	21.75 ± 0.03b
T ₁ × HDP	3.85 ± 0.05e	16.89 ± 0.1c
T ₂ × HDP	6.13 ± 0.04b	23.35 ± 0.02b
T ₃ × HDP	5.75 ± 0.01c	22.69 ± 0.04b
T ₄ × HDP	5.23 ± 0.03de	21.65 ± 0.03b
T ₅ × HDP	7.05 ± 0.01a	24.55 ± 0.1a
T ₁ × ESP	2.33 ± 0.03ij	12.39 ± 0.05de
T ₂ × ESP	3.45 ± 0.01g	14.52 ± 0.02cd
T ₃ × ESP	3.25 ± 0.02gh	14.25 ± 0.1cd
T ₄ × ESP	2.75 ± 0.01hi	13.74 ± 0.03d
T ₅ × ESP	3.69 ± 0.01e	15.25 ± 0.04c
T ₁ × AA	2.25 ± 0.02ij	12.31 ± 0.01de
T ₂ × AA	3.33 ± 0.04gh	14.11 ± 0.05cd
T ₃ × AA	3.13 ± 0.03hi	13.94 ± 0.02cd
T ₄ × AA	2.45 ± 0.01i	13.31 ± 0.03de
T ₅ × AA	3.63 ± 0.05e	15.05 ± 0.04c
T ₁ × Con	1.75 ± 0.04j	11.04 ± 0.01f
T ₂ × Con	3.05 ± 0.02hi	12.55 ± 0.02de
T ₃ × Con	2.55 ± 0.05i	12.33 ± 0.04de
T ₄ × Con	1.93 ± 0.02ij	12.04 ± 0.05e
T ₅ × Con	3.15 ± 0.01gh	13.25 ± 0.03de
Level of significance	**	**

T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively. LDP = low-density polyethylene (35 μm) bag, HDP = high-density polyethylene (15 μm) vacuum pack, ESP = 2% eggshell powder solution, AA = 2% ascorbic acid solution, and Con = control condition. **Significant level at 1%, level of significance, in a column, means having a similar letter(s) are not significantly different.

kg⁻¹ h⁻¹; inside the HDP packages was 78–80 mg CO₂ kg⁻¹ h⁻¹. At the temperature of 22°C, the respiration rate inside the LDP packages was 204–307 mg CO₂ kg⁻¹ h⁻¹, and inside the HDP packages was 190–255 mg CO₂ kg⁻¹ h⁻¹. On the other hand, in cold storage, the respiration rate inside the LDP packages was 15–20, and inside the HDP packages was 10–11 mg CO₂ kg⁻¹ h⁻¹ (Table 4). The treatment combination of T₅ × HDP significantly gave the maximum shelf-life both at room temperature (RH 60–65% and 14–22°C) and in cold storage (RH 90–95% and 4°C).

Foliar application of B, Zn, and Mo might be improved nutrients uptake and greater development of water-conducting tissue in plants during the growth period and ultimately increased the length of the duration of post-harvest life, compactness, color, and texture of broccoli by the plants. These findings are supported by Mohamed et al. (62) in broccoli. A previous study showed that polyethylene bags (HDP) enhance the efficiency of the post-harvest shelf-life of broccoli which is corroborative to the current study (29, 35). The application of foliar mineral nutrients, particularly B, Zn, and Mo has a beneficial role in improving the quality of broccoli due to their involvement as a catalyst of various enzymes and other physiologically active molecules (62). Foliar minerals minimized the respiration rate, strengthened the cell wall, and protected available moisture in broccoli heads which prevented yellowing and weight loss and subsequently preserved shelf-life during storage (83). The majority of the interaction effects of post-harvest treatments, such as eggshells (2%) and ascorbic acids (2%) and pre-harvest nutrients sprays like Mo, B, Zn, and Mo + B + Zn demonstrated medium to low shelf-life. Some researchers also dipped fruit in ascorbic acid and eggshell powder solutions and found suitable post-harvest treatments for extending shelf-life and increasing the keeping quality intact for a long-time quality of fresh vegetables and fruits (36, 37).

The reason for the highest shelf-life in the HDP vacuum pack (15 μm) may be its sophisticated techniques which delayed the physiological deterioration of broccoli heads. In HDP vacuum (15 μm) packaging, control gas exchange around air and CO₂ and O₂ levels decelerated the alteration of starch to sugars. Cold storage prevented decaying, rotting, and chilling injury in broccoli heads and maintained a more green color. Furthermore, low temperatures during storage reduced respiration rate and delayed the senescence of broccoli heads. A foliar spray of nutrients in broccoli and a storage HDP vacuum pack (15 μm) protected the degradation of chlorophyll and production of ethylene. This combination might control the yellowing of broccoli. These results of shelf-life corroborated the results of broccoli (32).

This study also observed that broccoli heads, when kept in control (without using storage materials) at room temperature conditions, the shelf-life of broccoli deteriorated because of the higher respiratory rate, moisture loss, and physiological changes that occurred very faster rate compared to other post-harvest storage treatments. These findings are in accordance with the previous findings of Ferdousi et al. (83) and Roni et al. (84) on broccoli.

Physico-chemicals at maximum shelf-life of storage broccoli

Sensory evaluation of color, compactness, and texture

Changes in color, compactness, and texture values are important factors affecting visual qualities during the post-storage period (Table 5). Foliar spray of nutrients and packaging and chemical treatments during storage significantly ($p \leq 0.01$) influenced the color, compactness, and texture of broccoli. Among the treatments, the maximum color (rating 3.75), compactness

TABLE 4 CO₂ and O₂ conditions and respiration rate inside the packages.

Parameters	Temperature					
	In cold storage condition		At room temperature condition			
	4°C		14°C		22°C	
	LDP	HDP	LDP	HDP	LDP	HDP
Respiration rate (mg CO ₂ kg ⁻¹ h ⁻¹)	15–20	10–11	80–90	78–80	204–307	190–255
Oxygen condition (%)	60	65	45	48	33	36
Carbon dioxide condition (%)	40	35	55	52	67	64

LDP, low-density polyethylene; HDL, high-density polyethylene.

(rating 3.81), and texture (rating 3.71) were documented in T₅ × HDP at cold storage (RH 90–95% and 4°C) after 24 days of storage periods. Whereas, the minimum color (rating 1.94), compactness (rating 2.08), and texture (rating 1.95) were observed in T₁ × con. under cold storage after 11 days. Similarly, storage broccoli heads at room temperature (RH 60–65% and 14–22°C) demonstrated the maximum color (3.65), compactness (3.73), and texture (3.66) in the treatment combination of T₅ × HDP after 7 days. Whereas, the minimum color (1.89), compactness (2.17), and texture (1.42) were observed in T₁ × con. at room temperature (RH 60–65% and 14–22°C) condition after 2 days. All the interaction effects of post-harvest treatments [eggshells (2%) and ascorbic acids (2%)] and pre-harvest nutrients spray (Mo, B, Zn, and Mo + B + Zn) resulted in medium to low color, compactness, and texture. In the previous study, some workers also dipped fruit in ascorbic acid and eggshell powder solutions and found suitable post-harvest treatments to preserve the quality of fresh vegetables and fruits (36, 37).

Among the treatment combinations, the maximum green color was retained intact in T₅ × HDP at the end of the storage period at both room temperature and cold storage conditions. The yellowing was more in the broccoli without any packaging or treatment. It was evident that the minimum yellow color of broccoli was recorded in both the storage conditions using an HDP vacuum pack (15 μm) might be due to its sophisticated techniques, which delayed and protected the physiological deterioration of the broccoli heads. In the HDP vacuum pack (15 μm), gas exchange was more controlled in the surrounding air, and CO₂ and O₂ levels were declined to stored broccoli heads that ultimately converted the starch to sugars. Moreover, low-temperature storage of broccoli heads reduced the respiration rate and delayed senescence. This might have restricted the yellowing of broccoli. The findings of the present investigation corroborate the findings of Chingtham and Banik (29) on broccoli. These results agreed with the results of De Beer and Crouch (35), who displayed a greater yellowing % from 7 days of storage at 0 °C. Exactly 25% yellowing was found in control-treated broccoli heads after 21 days of storage which had reached unsaleable. Packed broccoli confirmed color scores of <15–20% for long storage. The increasing trend of the yellowing of broccoli during the study period was also supported by Eason et al. (85), who detected that control condition broccoli heads beginning the senescence and yellowing after 2 days. They also observed that the senescence of broccoli heads was delayed with

a shelf-life of 30 and 24 days when it was stored at 0°C and 5°C, respectively.

Maximum compactness and texture scores decreased with the advancement of the period of storage. These findings conform with that of Chingtham and Banik (29) in broccoli. Beer and Crouch (35) showed that HDP (15 μm) bags, in terms of yellowing percentage, extended storability by more than 14 days, compared to controls which reached a cut-off point of 25% yellowing at 21 days. A previous study showed that polyethylene bags (HDP) enhance the efficiency of the post-harvest quality of broccoli (29, 35). Toivonen (86) stated that broccoli heads with wrapped packaging contributed to the best retention of firmness and the minimum loss of water independent of storage temperature.

Phytochemicals

Tables 6, 7 revealed that chemically treated materials had a significant effect on nutrient retention which kept the phytochemicals intact in broccoli heads during the storage period. Among the treatment combinations, the maximum and appreciable amount of nutrients, viz., protein (3.17%), fat (0.4371%), carbohydrates (5.15%), vitamin C (81.75 mg/100 g), antioxidants (71.75 mg/100 g), and total phenols (39.85 mg/100 g) were retained intact in T₅ × HDP up to 24 days which were 4.80, 0.091, 1.90, 6.84, 0.97, and 2.88%, respectively lower than the fresh broccoli heads (Table 2). Whereas the minimum amount of protein (1.87%), fat (0.3671%), carbohydrates (2.46%), vitamin C (53.01 mg/100 g), antioxidants (45.31 mg/100 g), and phenols (20.31 mg/100 g) were retained in T₁ × con. Broccoli heads under control treatment at 11 days of storage duration, contents of these phytochemicals deteriorated by 44.35, 16.36, 53.6, 40.11, 38.39, and 50.6%, respectively, compared to the fresh ones (Table 2).

Similarly, when broccoli heads were stored at room temperature (14–22°C with RH 60–65%), the various nutrients, viz., protein (2.92%), fats (0.4315%), carbohydrates (4.69%), vitamin C (77.63 mg/100 g), antioxidants (66.49 mg/100 g), and total phenols (37.33 mg/100 g) retained intact up to 7 days in T₅ × HDP which were 12.31%, 1.37%, 10.67%, 11.53%, 8.23%, and 9.02%, respectively lower than compared to the fresh broccoli heads (Tables 2, 6, 7). Hasan et al. (87) reported a decline in ascorbic acid of fresh pointed gourd under cold storage up to

TABLE 5 Effects of pre-harvest foliar application of mineral nutrient sources and post-harvest packaging and chemical treatments on quality attributes in storage broccoli heads under different storage temperatures at the maximum shelf-life stage.

Treatment combination	Color		Compactness		Texture	
	At room temperature condition (14–22°C)	In cold storage condition (4°C)	At room temperature condition (14–22°C)	In cold storage condition (4°C)	At room temperature condition (14–22°C)	In cold storage condition (4°C)
T ₁ × LDP	2.31 ± 0.2c	2.27 ± 0.03d	2.40 ± 0.09c	2.38 ± 0.4c	2.46 ± 0.08c	2.31 ± 0.02c
T ₂ × LDP	3.43 ± 0.5ab	3.30 ± 0.07ab	3.68 ± 0.04a	3.70 ± 0.01ab	3.36 ± 0.04ab	3.21 ± 0.01ab
T ₃ × LDP	3.27 ± 0.1ab	3.15 ± 0.04abc	3.42 ± 0.02ab	3.47 ± 0.07ab	3.16 ± 0.01abc	3.15 ± 0.03ab
T ₄ × LDP	3.10 ± 0.3ab	3.16 ± 0.01ab	3.18 ± 0.1abc	3.27 ± 0.01ab	2.93 ± 0.03abc	2.90 ± 0.02abc
T ₅ × LDP	3.57 ± 0.4a	3.71 ± 0.06a	3.75 ± 0.03a	3.76 ± 0.06a	3.55 ± 0.06a	3.67 ± 0.01a
T ₁ × HDP	2.39 ± 0.01c	2.43 ± 0.01c	2.46 ± 0.02c	2.42 ± 0.09c	2.48 ± 0.02c	2.38 ± 0.08c
T ₂ × HDP	3.57 ± 0.5ab	3.41 ± 0.6ab	3.70 ± 0.01a	3.85 ± 0.07a	3.43 ± 0.08ab	3.25 ± 0.01ab
T ₃ × HDP	3.35 ± 0.4ab	3.21 ± 0.2abc	3.56 ± 0.08ab	3.68 ± 0.03a	3.26 ± 0.03ab	3.29 ± 0.05ab
T ₄ × HDP	3.19 ± 0.02bc	3.25 ± 0.01ab	3.29 ± 0.07ab	3.52 ± 0.02ab	3.11 ± 0.07abc	3.16 ± 0.08ab
T ₅ × HDP	3.65 ± 0.7a	3.75 ± 0.07a	3.73 ± 0.5a	3.81 ± 0.01a	3.66 ± 0.8a	3.71 ± 0.08a
T ₁ × ESP	2.07 ± 0.9d	2.11 ± 0.01c	2.37 ± 0.4c	2.17 ± 0.07d	2.31 ± 0.6c	2.27 ± 0.08c
T ₂ × ESP	3.29 ± 0.6ab	3.21 ± 0.06a	3.42 ± 0.8a	3.45 ± 0.01ab	3.23 ± 0.07abc	3.10 ± 0.09ab
T ₃ × ESP	3.05 ± abc	3.07 ± 0.03ab	3.21 ± 0.6ab	3.22 ± 0.08ab	3.08 ± 0.01abc	3.02 ± 0.01abc
T ₄ × ESP	2.89 ± 0.04abc	3.05 ± 0.04ab	2.91 ± 0.04abc	3.09 ± 0.07abc	2.72 ± 0.07abc	2.62 ± 0.01bc
T ₅ × ESP	3.51 ± 0.8a	3.57 ± 0.02a	3.45 ± 0.06a	3.69 ± 0.03a	3.43 ± 0.09a	3.591 ± 0.5a
T ₁ × AA	2.01 ± 0.01d	2.05 ± 0.04d	2.34 ± 0.07c	2.08 ± 0.2d	2.27 ± 0.8c	1.95 ± 0.7c
T ₂ × AA	3.30 ± 0.09ab	3.07 ± 0.09ab	3.40 ± 0.01a	3.37 ± 0.01ab	3.28 ± 0.02ab	3.04 ± 0.05ab
T ₃ × AA	2.95 ± 0.07abc	2.85 ± 0.03abc	3.17 ± 0.1ab	3.10 ± 0.5ab	3.03 ± 0.06abc	2.90 ± 0.4ab
T ₄ × AA	12.80 ± 0.05abc	2.91 ± 0.06ab	2.87 ± 0.3bc	2.89 ± 0.4bc	2.75 ± 0.02abc	2.59 ± 0.1bc
T ₅ × AA	3.45 ± 0.02a	3.47 ± 0.01a	3.41 ± 0.08a	3.63 ± 0.3a	3.36 ± 0.7a	3.45 ± 0.4a
T ₁ × Con	1.72 ± 0.08c	1.94 ± 0.02d	2.17 ± 0.01c	2.08 ± 0.2d	1.42 ± 0.09c	1.95 ± 0.3c
T ₂ × Con	2.6 ± 0.06ab	3.08 ± 0.07ab	3.38 ± 0.07a	3.38 ± 0.4ab	2.89 ± 0.07ab	2.99 ± 0.1ab
T ₃ × Con	2.37 ± 0.03abc	2.77 ± 0.01abc	3.09 ± 0.3ab	3.09 ± 0.4ab	2.72 ± 0.01ab	2.89 ± 0.3ab
T ₄ × Con	2.18 ± 0.7abc	2.83 ± 0.02ab	2.66 ± 0.04abc	2.81 ± 0.7bc	2.54 ± 0.9ab	2.53 ± 0.4bc
T ₅ × Con	2.81 ± 0.04a	3.45 ± 0.01a	3.36 ± 0.01a	3.65 ± 0.2a	3.25 ± 0.1a	3.41 ± 0.3a
Level of significance	**	**	**	**	**	**

T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively. LDP = Low-density polyethylene (35 μm) bag, HDP = High-density polyethylene (15 μm) vacuum pack, ESP = 2% eggshell powder solution, AA = 2% ascorbic acid solution, and Con = control condition. **Significant level at 1%, level of significance, in a column, means having a similar letter(s) are not significantly different.

shelf-life. Whereas, the minimum amount of nutrients, viz., protein (2.11%), fats (0.3667%), carbohydrates (2.21%), vitamin C (46.83 mg/100 g), antioxidants (37.26 mg/100 g), and total phenols (15.41 mg/100 g) were retained intact in T₁ × con. at room temperature for up to 2 days, which were 37.2%, 16.45%, 8.38%, 47.09%, 49.33%, and 62.52%, respectively lower than fresh broccoli heads (Tables 2, 6, 7). It was evident from the results in Tables 6, 7 that the HDP vacuum pack (15 μm) was meaningfully effective for maintaining the broccoli heads' quality by keeping its nutrients intact at the highest shelf-life both at cold storage and room temperature conditions. Commination of pre-harvest

nutrients sprays such as Mo, B, Zn, and Mo + B + Zn and post-harvest treatments, such as eggshells (2%) and ascorbic acids (2%) demonstrated medium-to-low interaction effects for protein, fat, carbohydrates, vitamin C, antioxidants, and total phenols. HDP is a viable post-harvest packaging technology to extend the shelf-life of broccoli which slows down the respiration rate and ethylene production, intact color, texture, flavor, and nutritive values. These findings are consistent with the findings of Chingtham and Banik (29). According to Shirley (88), frozen broccoli losses ~50–55% of its vitamin C, while storing broccoli at a minimum of 4°C helps to retain vitamin C.

TABLE 6 Effects of pre-harvest foliar application of mineral nutrient sources and post-harvest packaging and chemical treatments on nutrient contents broccoli heads under different storage temperatures at the maximum shelf-life stage.

Treatment combination	Protein (%)		Fat (%)		Carbohydrates (%)	
	At room temperature condition (14–22°C)	In cold storage condition (4°C)	At room temperature condition (14–22°C)	In cold storage condition (4°C)	At room temperature condition (14–22°C)	In cold storage condition (4°C)
T ₁ × LDP	2.23 ± 0.01bc	2.38 ± 0.02c	0.3737 ± 0.03c	0.3823 ± 0.02c	2.46 ± 0.01cd	2.85 ± 0.01c
T ₂ × LDP	2.54 ± 0.05b	2.79 ± 0.06b	0.4253 ± 0.06ab	0.4301 ± 0.07a	3.59 ± 0.09b	4.05 ± 0.03abc
T ₃ × LDP	3.04 ± 0.03ab	3.27 ± 0.04ab	0.4243 ± 0.04ab	0.4310 ± 0.06a	3.98 ± 0.02abc	4.27 ± 0.09abc
T ₄ × LDP	3.15 ± 0.08ab	3.49 ± 0.09a	0.4060 ± 0.02abc	0.4126 ± 0.01abc	2.92 ± 0.08c	3.25 ± 0.06bc
T ₅ × LDP	2.85 ± 0.04b	3.15 ± 0.05ab	0.4307 ± 0.01a	0.4359 ± 0.04a	4.31 ± 0.03ab	5.09 ± 0.07a
T ₁ × HDP	2.36 ± 0.03bc	2.44 ± 0.03c	0.3753 ± 0.05c	0.3811 ± 0.01c	2.60 ± 0.07c	2.75 ± 0.08c
T ₂ × HDP	2.61 ± 0.07b	2.80 ± 0.08b	0.4279 ± 0.04ab	0.4317 ± 0.2a	3.76 ± 0.4b	4.09 ± 0.04abc
T ₃ × HDP	3.10 ± 0.09ab	3.29 ± 0.02ab	0.4271 ± 0.03ab	0.4341 ± 0.9a	4.08 ± 0.1abc	4.37 ± 0.09abc
T ₄ × HDP	3.22 ± 0.08a	3.51 ± 0.09a	0.4069 ± 0.07abc	0.4141 ± 0.4abc	3.13 ± 0.04bc	3.31 ± 0.05bc
T ₅ × HDP	2.92 ± 0.05ab	3.17 ± 0.06ab	0.4315 ± 0.08a	0.4371 ± 0.9a	4.69 ± 0.02a	5.15 ± 0.07a
T ₁ × ESP	2.19 ± 0.02c	2.27 ± 0.03cd	0.37205 ± 0.02c	0.3749 ± 0.04c	2.87 ± 0.07c	2.72 ± 0.04c
T ₂ × ESP	2.53 ± 0.07b	2.73 ± 0.08b	0.4244 ± 0.06ab	0.4283 ± 0.01ab	3.72 ± 0.09b	4.01 ± 0.06abc
T ₃ × ESP	3.05 ± 0.06ab	3.27 ± 0.07ab	0.4229 ± 0.02a	0.4293 ± 0.9ab	4.02 ± 0.01abc	4.26 ± 0.04abc
T ₄ × ESP	3.17 ± 0.09ab	3.46 ± 0.02a	0.4043 ± 0.07abc	0.4119 ± 0.4abc	3.10 ± 0.07bc	3.22 ± 0.02bc
T ₅ × ESP	3.01 ± 0.07ab	3.02 ± 0.08ab	0.4303 ± 0.09a	0.4359 ± 0.03a	4.47 ± 0.06ab	5.01 ± 0.07ab
T ₁ × AA	2.14 ± 0.04c	2.15 ± 0.05cd	0.3717 ± 0.04c	0.3694 ± 0.07d	2.36 ± 0.03d	2.59 ± 0.05c
T ₂ × AA	2.46 ± 0.03bc	2.69 ± 0.04bc	0.4227 ± 0.03ab	0.4226 ± 0.1ab	3.53 ± 0.07b	3.85 ± 0.07b
T ₃ × AA	2.95 ± 0.07ab	3.23 ± 0.08ab	0.4240 ± 0.05ab	0.4264 ± 0.08ab	3.78 ± 0.06b	4.08 ± 0.09abc
T ₄ × AA	3.05 ± 0.06ab	2.88 ± 0.07b	0.4017 ± 0.02abc	0.4089 ± 0.06ab	2.79 ± 0.01c	3.11 ± 0.04bc
T ₅ × AA	2.95 ± 0.02ab	3.01 ± 0.03ab	0.4339 ± 0.07a	0.4346 ± 0.04a	4.17 ± 0.03ab	4.91 ± 0.04a
T ₁ × Con	2.11 ± 0.04c	1.87 ± 0.05d	0.3667 ± 0.09cd	0.3671 ± 0.06d	2.21 ± 0.07d	2.46 ± 0.09d
T ₂ × Con	2.45 ± 0.01bc	2.50 ± 0.02bc	0.4186 ± 0.07abc	0.4145 ± 0.01abc	3.21 ± 0.06bc	3.7 ± 0.04b
T ₃ × Con	2.81 ± 0.08ab	2.96 ± 0.09ab	0.4205 ± 0.01ab	0.4218 ± 0.02ab	3.73 ± 0.01b	3.91 ± 0.02b
T ₄ × Con	3.05 ± 0.02ab	2.76 ± 0.03b	0.3977 ± 0.04abc	0.4011 ± 0.04b	2.77 ± 0.03c	2.84 ± 0.07c
T ₅ × Con	2.69 ± 0.04b	2.83 ± 0.05b	0.4271 ± 0.09ab	0.4317 ± 0.09a	4.09 ± 0.08abc	4.51 ± 0.02abc
Level of significance	**	**	**	**	**	**

T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively. LDP = low-density polyethylene (35 μm) bag, HDP = High-density polyethylene (15 μm) vacuum pack, ESP = 2% eggshell powder solution, AA = 2% ascorbic acid solution, and Con = control condition. **Significant level at 1%, level of significance, in a column, means having a similar letter(s) are not significantly different.

Economic performance

The economic performance of broccoli varied due to different treatment combinations as influenced by the foliar application of different mineral nutrients. The results revealed that the maximum production cost of BDT 114648 ha⁻¹ was recorded in B + Zn + Mo followed by Mo (BDT 111734 ha⁻¹) (Table 8). The lowest production cost (BDT 107620 ha⁻¹) was noted in control. The lowest gross return (BDT 420300 ha⁻¹) and net return (BDT

305652 ha⁻¹) were documented in B + Zn + Mo, followed by B with a gross return of BDT 398250 ha⁻¹, the net return of BDT 288985 ha⁻¹. Whereas the lowest gross return (BDT 339600 ha⁻¹) and net return (BDT 231980 ha⁻¹) were noted in control. The lowest benefit–cost ratio (BCR) of 3.67 was documented in B + Zn + Mo followed by B (BCR 3.64) and Zn (BCR 3.57). The lowest BCR (3.16) was found in the control. These findings conform with a few previous studies (28, 58, 59, 89).

TABLE 7 Effects of pre-harvest foliar application of mineral nutrient sources and post-harvest packaging and chemical treatments on nutrient contents broccoli heads under different storage temperatures at the maximum shelf-life stage.

Treatment combination	Vitamin C (mg/100 g)		Antioxidants (mg/100 g)		Phenols (mg/100 g)	
	At room temperature condition (14-22°C)	In cold storage condition (4°C)	At room temperature condition (14-22°C)	In cold storage condition (4°C)	At room temperature condition (14-22°C)	In cold storage condition (4°C)
T ₁ × LDP	54.10 ± 0.02d	60.04 ± 0.06d	44.05 ± 0.06ef	51.71 ± 0.08e	20.40 ± 0.02f	24.14 ± 0.08de
T ₂ × LDP	71.35 ± 0.04abc	74.02 ± 0.09abc	57.25 ± 0.07c	64.57 ± 0.04b	31.43 ± 0.06b	35.21 ± 0.01ab
T ₃ × LDP	73.35 ± 0.07abc	76.23 ± 0.01ab	59.75 ± 0.01bc	67.32 ± 0.02ab	33.29 ± 0.01abc	37.52 ± 0.4a
T ₄ × LDP	66.13 ± 0.03bc	70.22 ± 0.03bcd	52.36 ± 0.04d	60.76 ± 0.1cd	29.32 ± 0.04c	31.36 ± 0.6cd
T ₅ × LDP	75.72 ± 0.01ab	79.69 ± 0.06a	64.63 ± 0.07ab	70.56 ± 0.03a	35.65 ± 0.09ab	38.69 ± 0.07b
T ₁ × HDP	57.03 ± 0.06cd	62.81 ± 0.01d	47.16 ± 0.2e	54.19 ± 0.02de	23.26 ± 0.04e	25.33 ± 0.01de
T ₂ × HDP	74.43 ± 0.08ab	76.47 ± 0.05ab	59.19 ± 0.8bc	65.82 ± 0.07abc	33.38 ± 0.06ab	36.78 ± 0.07bc
T ₃ × HDP	76.39 ± 0.05a	78.405 ± 0.1ab	61.91 ± 0.6b	68.82 ± 0.03ab	35.41 ± 0.03ab	38.86 ± 0.3b
T ₄ × HDP	69.06 ± 0.09b	73.16 ± 0.8abc	55.87 ± 0.02bc	62.82 ± 0.07c	31.57 ± 0.07b	33.31 ± 0.7c
T ₅ × HDP	77.63 ± 0.03a	81.75 ± 0.2a	66.49 ± 0.07a	71.75 ± 0.01a	37.33 ± 0.06a	39.85 ± 0.04a
T ₁ × ESP	52.04 ± 0.1d	57.28 ± 0.01e	41.98 ± 0.03d	49.94 ± 0.09ef	19.20 ± 0.04fg	23.61 ± 0.07de
T ₂ × ESP	69.45 ± 0.5b	70.97 ± 0.07bcd	56.17 ± 0.08cd	62.35 ± 0.01c	29.90 ± 0.02c	34.7 ± 0.02bc
T ₃ × ESP	72.10 ± 0.06abc	74.44 ± 0.03ab	58.24 ± 0.06c	65.21 ± 0.08abc	31.96 ± 0.07b	36.62 ± 0.03bc
T ₄ × ESP	64.55 ± 0.08bc	67.51 ± 0.2cd	51.18 ± 0.03d	59.615 ± 0.05cd	27.79 ± 0.06cd	30.33 ± 0.05cd
T ₅ × ESP	73.15 ± 0.04ab	77.81 ± 0.3ab	62.21 ± 0.04ab	67.331 ± 0.07ab	33.62 ± 0.01abc	36.29 ± 0.01b
T ₁ × AA	49.91 ± 0.07de	55.10 ± 0.08c	40.75 ± 0.03d	47.21 ± 0.02f	16.29 ± 0.03g	21.09 ± 0.08e
T ₂ × AA	67.38 ± 0.01ab	67.29 ± 0.1cd	55.06 ± 0.07cd	60.29 ± 0.05cd	27.22 ± 0.04cd	32.86 ± 0.04c
T ₃ × AA	70.19 ± 0.06a	71.41 ± 0.04c	57.07 ± 0.01c	63.26 ± 0.09bc	29.16 ± 0.07c	34.43 ± 0.06bc
T ₄ × AA	61.98 ± 0.09c	63.36 ± 0.09abc	49.05 ± 0.06e	56.19 ± 0.03a-d	25.25 ± 0.01d	29.27 ± 0.07d
T ₅ × AA	73.66 ± 0.02ab	73.75 ± 0.07abc	65.43 ± 0.04a	66.59 ± 0.4ab	33.96 ± 0.03ab	34.77 ± 0.03bc
T ₁ × Con	46.83 ± 0.04f	53.01 ± 0.02f	37.26 ± 0.06g	45.31 ± 0.7fg	15.41 ± 0.04gh	20.31 ± 0.06e
T ₂ × Con	65.43 ± 0.06bc	65.40 ± 0.08ab	53.17 ± 0.02d	57.96 ± 0.09d	25.32 ± 0.09d	31.81 ± 0.08c
T ₃ × Con	68.21 ± 0.02b	70.25 ± 0.3a	55.09 ± 0.07cd	61.09 ± 0.04cd	27.41 ± 0.04cd	33.42 ± 0.04c
T ₄ × Con	58.33 ± 0.07cd	61.11 ± 0.04d	47.16 ± 0.03e	54.21 ± 0.03de	22.75 ± 0.01ef	28.01 ± 0.06d
T ₅ × Con	68.33 ± 0.03b	70.36 ± 0.07a	60.03 ± 0.07b	61.75 ± 0.04b	28.45 ± 0.04c	33.85 ± 0.01bc
Level of significance	**	**	**	**	**	**

T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively. LDP = Low-density polyethylene (35 μm) bag, HDP = High-density polyethylene (15 μm) vacuum pack, ESP = 2% eggshell powder solution, AA = 2% ascorbic acid solution, and Con = control condition. **Significant level at 1%, level of significance, In a column, means having a similar letter(s) are not significantly different.

TABLE 8 Economic performance of broccoli production by pre-harvest foliar application effects of mineral nutrients.

Treatment	Marketable head yield (t ha ⁻¹)	Cost of production (BDT ha ⁻¹)	Gross returns (BDT ha ⁻¹)	Net returns (BDT ha ⁻¹)	Benefit-cost ratio (BCR)
T ₁	22.64	109760	339600	231980	3.16
T ₂	26.55	111734	398250	288985	3.64
T ₃	26.1		391500	281740	3.57
T ₄	25.39		380850	269116	3.41
T ₅	28.02	114648	420300	305652	3.67

Sale rate of broccoli (BDT15/kg). T₁ = control, T₂ = B, T₃ = Zn, T₄ = Mo, and T₅ = B + Zn + Mo, 0.40%, respectively.

Conclusion

The present study confirmed the maximum marketable head yield of 28.02 t ha⁻¹, a gross return of BDT 420300 ha⁻¹, a net return of BDT 305652 ha⁻¹, and a maximum benefit–cost ratio (BCR) of 3.67. Combined nutrient spray during the growing of broccoli efficiently improves physicochemical attributes, viz., compactness, color, texture, carbohydrates, fats, energy, antioxidants, vitamin C, and total phenol content in broccoli heads. Furthermore, combined nutrient spray and HDP vacuum pack (15 μm) during post-harvest also established a shelf-life of 24.55 days at cold storage (RH 90–95% and 4°C) and 7.05 days at room temperature (RH 60–65% and 14–22°C) conditions. HDP vacuum pack (15 μm) was suggestively effective in maintaining the quality of broccoli heads and keeping nutrients at the highest shelf-life stage both at cold storage and room temperature conditions. Therefore, we recommend the application of combined nutrient elements B + Zn + Mo and HDP (15 μm) vacuum packaging for the end users to obtain optimum marketable head yield for anticipating physicochemical attributes and maximum shelf-life of broccoli. Though this study was accomplished in an arbitrarily selected location, we recommend multilocation trails (MLTs) in the agro-ecological zones (AEZs) to explore the genotype and environmental interaction for further confirmation of the findings.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

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Author contributions

MB and ST: conceptualization. ST and US: methodology, original draft preparation, and software. ST, US, SE, ZO, RM, and KG: formal analysis. ST: data curation and investigation. US, SE, ZO, RM, and KG: writing of review and editing. US: visualization. MB: supervision. US, SE, RM, and KG: validation. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fnut.2023.1057084/full#supplementary-material>

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