INFLUENCE OF MICRONUTRIENTS AND THEIR APPLICATION METHODS ON SEED YIELD OF BROCCOLI

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*This is to certify that the thesis entitled, "**INFLUENCE OF MICRONUTRIENTS AND THEIR APPLICATION METHODS ON SEED YIELD OF BROCCOLI**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **SEED TECHNOLOGY**, embodies the result of a piece of bonafide research work carried out by **MD. ZAHID UDDIN**, Registration No. **15-06771** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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ABSTRACT

A field experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka during the period from from October 2021 March 2022 in the Rabi season to study the influence of micronutrients and their application methods on seed yield of broccoli. The experiment consisted of two factors and followed Randomized Complete Block Design (RCBD) with three replications. Factor A: Levels of micronutrients (4) *viz;* F_0 = $Zn_0B_0Mo_0$ kg ha^{-1} (Control), F_1 = $Zn_2B_1Mo_1$ kg ha^{-1}, F_2 = $Zn_4B_2Mo_{1.5}$ kg ha^{-1}, F_3 = $Zn_6B_3Mo_2$ kg ha^{-1} and Factor B: Different methods of fertilizer applications (3) *viz;* M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray. Experimental result revealed that in case of micronutrients application the highest number of pods per plant (2204.90), seeds per pod (8.31), seed weight per pod (19.25 g), seed yield per plant (34.66 g), seed yield per plot (311.97 g), seed yield per hectare (1155.40 kg) and seed germination percentage (86.64 %) were observed by F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment. In terms of different methods of fertilizer applications, the highest number of pods per plant (2008.2), seeds per pod (7.33), seed weight per pod (17.42 g), seed yield per plant (30.87 g), seed yield per plot (277.79 g) as well as seed yield per hectare (1028 kg) were recorded from M_2 (Foliar spray before flowering). When applied together application of $Zn_6B_3Mo_2$ kg ha^{-1} along with fertilizer application through foliar spray before flowering affected broccoli plant growth and yield-contributing characteristics, leading to the maximum seed yield per plant (39.17 g), seed yield per plot (352.57 g) and seed yield per hectare (1305.80 kg). Therefore, it is suggested that application of $Zn_6B_3Mo_2$ kg ha^{-1} along with fertilizer application through foliar spray before flowering (F_3M_2) is beneficial for seed yield production of broccoli.

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LISTS OF ABBREVIATIONS

Abbreviations	Full word
AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization
N	Nitrogen
et al.	And others
TSP	Triple Super Phosphate
MOP	Muriate of Potash
RCBD	Randomized Complete Block Design
DAT	Days after Transplanting
ha^{-1}	Per hectare
g	gram (s)
kg	Kilogram
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
wt	Weight
LSD	Least Significant Difference
0_C	Degree Celsius
NS	Not significant
Max	Maximum
Min	Minimum
%	Percent
NPK	Nitrogen, Phosphorus and Potassium
CV%	Percentage of Coefficient of Variance

CHAPTER I

INTRODUCTION

Broccoli is one of the most important, nutrient-rich exotic vegetable from the family of Brassicaceae. Broccoli has a reputation as a supplementary vegetable in salads and in supper food. It is known to be a healthy and delectable vegetable which is rich in many nutrients. Broccoli is rich in vitamins, minerals, fibers and antioxidants that support many dimensions of human health (Tarafder *et al*., 2023). It is characterized by a low Glycemic Index (GI=10) for diabetics (Nagraj *et al*., 2020). The global production of broccoli was 27 million tons in 2019, of which 73% was produced by China and India. The rest was produced by USA, Mexico, Spain, Italy, Turkey, Bangladesh, Poland and France (FAOSTAT, 2020). In recent years broccoli is gaining popularity among the growers due to its palatability, high nutritive value as well as good marketing potential. But for commercial fir commercial cultivation it is still in its infancy stage and needs to be extended fully at different vegetable growing areas (Ahirwar and Nath, 2020).

Application of micronutrients in the soil during crop growth can be successfully used for correcting their deficits and improving the mineral status of plants as well as increasing the crop yield and quality (Ali, 2013). Besides major nutrients, micronutrients also play an active role in the plant metabolic process from cell wall development to respiration, photosynthesis, chlorophyll formation, enzymes activity, nitrogen fixationetc. Most of micronutrients work as a co-enzyme for a large number of enzymes. They also plays an essential role in improving yield and quality in most of the vegetable crops (Drobek *et al*., 2019).

Most of plants differ widely in their requirements, but the ranges of deficiency and toxicity are narrow. Boron, zinc and molybdenum deficiencies are very common in cole crops which cause certain anatomical, physiological and biological changes. In deficient plants, head/curd become irregular in shape, smaller in size and bitter in taste which adversely affects the consumer preference to the crop. Application of nutrients like zinc, molybdenum, copper and boron are advantageous as they furnish availability of nutrients, enhances uptake of applied nutrients.

Horticultural crops suffer badly by zinc deficiency followed by B, Mn, Cu, Fe (mostly induced) and Mo. Among these, zinc is also an essential micronutrient to improve growth and yield of a crop and is taken up by the plants in ionic form (Zn^{+2}). Zinc is applied in the form of zinc sulphate that is principal salt used as fertilizers. It is essential for the synthesis of tryptophan, precursor of IAA, which is essential for normal cell division and helps in the formation of chlorophyll. Zn deficiency cause interveinal chlorosis, reduced root growth, shortened internodes and chlorotic areas on older leaves. It is an important for the formation and activity of chlorophyll and play role in the functioning of several enzymes and the growth hormone like auxin. Zinc is an activator of enzyme involves in protein synthesis and has direct effect on the enzymatic regulation in plants (Umair *et al.,* 2020).

Application of boron significantly increases curd diameter, weight of curd, yield and quality of cauliflower (Poudel *et al.*, 2022). A suspected boron deficiency should be confirmed by soil and plant analyses before a boron fertilizer is applied since excessive boron can be highly toxic to plants. An abiotic disorder 'hollow stem' is commonly associated with boron deficiency (Jokanovic, 2020), which becomes an important quality factor particularly when displayed at market (Pakurár *et al.,* 2019). Boron is the only micronutrient not only specifically associated with either photosynthesis or enzyme functions, but also is associated with the carbohydrate chemistry and reproductive system of the plant. Boron is required for cell division and development in the growth regions of the plant near the tips of shoots and roots. It also affects sugar transport and appears to be associated with some of the functions of calcium. Its application to the soil increases curd yield of broccoli (Dhotra *et al*., 2018).

Molybdenum (Mo) act as catalyst of various enzyme activities in the plant. It also affects nitrogen metabolism, protein synthesis and sulphur metabolism. Molybdenum is a trace element found in the soil and is required for growth of most biological organisms including plants and animals. It play role in the activity of enzyme nitrate reductive which is responsible for reduction of nitrate to nitrite during N assimilation in plants. It is available to plants as the $HMoO_4^-$ ion. Mo deficiencies may occur on acid sandy soils and acid peats. Certain vegetable crops such as cauliflower are particularly susceptible to molybdenum deficiency (Hossain *et al*., 2021). When plants are grown under molybdenum deficient conditions certain phenotypes develop that hinder plant growth. Most of phenotypes are associated with reduced activity of molybdoenzymes. Moco binds to molybdenum requiring enzymes (molybdoenzymes) found in most biological systems including plants, animals and prokaryotes (Peng *et al*., 2018).

Different application method significantly influenced growth and yield of cole crops. Among different application method foliar nutrition is one of the most efficient way of fertilizer application as it facilitates rapid nutrient uptake by penetrating through the leaf cuticle. It is 8-10 times more effective than soil application. It is known to stimulate the chlorophyll production, cellular activity and respiration. It also triggers a plant response to increased water and nutrient uptake from the soil (Mahmoud *et al*. 2022). Foliar feeding could be useful in rainfed conditions when the fertilizers applied are subjected to different losses like runoff, leaching losses, fixation and unavailability of nutrients (Shete *et al.,* 2018). Foliar application of nutrients is feasible, economically viable and environmentally friendly approach of nutrient management. It is often the most effective and economical way to correct plant nutrient deficiencies at critical growth stages. Various reports indicate that foliar application promoted root absorption of the same nutrient or other nutrients through improving root growth and increasing nutrients uptake (Alshaal and El-Ramady, 2017). It also helps to maintain a nutrient balance within the plant, which may not occur with soil uptake (Rauniyar, 2020). It has the advantage of low application rates, uniform distribution of fertilizer materials and quick response to applied nutrients. Moreover, hidden hungers can easily be managed. It was found that balance fertilization of macro and micronutrients is essential for the production of high yield and quality products (Kumar *et al*., 2021), while foliar application of micronutrients to plant is the most effective and safest way (Zahir *et al.*, 2018). Foliar application of micronutrients during active crop growth stage was successfully used for correcting their deficits and improving the mineral status of the plants as well as increasing the crop yield and quality (Dass *et al*, 2022).

But broccoli cultivation could not be promoted commercially due to non availability of seed of the open pollinated varieties of this crop. No doubt farmers are getting hybrid varieties of broccoli in the market from different private company but due to higher price farmers are able to cultivate commercially. As sprouting broccoli is a new crop available information on seed production technology as well as not much work has been done on its seed production. Information is lacking on this aspects in the present condition of Bangladesh. Keeping this view in perspective the present investigation have been taken with the following objective-

i. To determine the effect of micronutrients on growth and seed yield of broccoli.
ii. To study the effect of micronutrient application methods on growth and seed yield of broccoli
iii. To identify the combined effect of micronutrients with application methods on growth and seed yield of broccoli.

CHAPTER II

REVIEW OF LITERATURE

A brief review of literature pertinent to present study is presented in this chapter. An attempt has been made to cite the relevant literature on "Influence of micronutrients and their application methods on seed yield of broccoli.". The available literature conveys that little work has been done on response of sprouting broccoli of micronutrients and fertilizer application methods. Therefore, similar work done on other field crops has also been reviewed in this chapter.

2.1 Effect of micronutrients

Bankar *et al.* (2022) carried out an investigation in shadenet of Instructional-cum-Research farm of Department of Horticulture, College of Horticulture, VNMKV, Parbhani during the year 2018-2019. The seven different treatments including control were used in Randomized Block Design (RBD). There were significant differences found in growth, yield and quality by the soil application of NPK and B and Zn with different treatments. Application of 130 kg N +60 kg P2O5 + 15kg B ha^{-1} gave maximum plant height (29.57 cm), stem diameter (4.06 cm), Number of leaves (20.63), Length of longest leaves (26.37 cm), Width of leaves (16.70 cm), leaf area (717.07 cm^2), leaf area index (0.199), days taken to central curd formation (53.43), days taken to central curd maturity (72.77), curd diameter (16.18 cm), curd length (14.20 cm), weight of central curd per plant (326.73 g).

Madhukara *et al*. (2021) conducted a field experiment during Rabi, 2019 to study the "Effect of macronutrients, bio- fertilizers and micronutrients on yield and yield attributing characters of broccoli (*Brassica oleracea* var. italica L.)" with the sole purpose of studying the effect of inorganic fertilizers, bio-fertilizers and micronutrients on yield of broccoli and to find out the most appropriate combinations of the inputs for broccoli crop required under Bhubaneswar agroclimatic condition. The results revealed that the treatment among different treatments the T8 (N 100% + PK Full (RDF) + biofertilizers + micronutrients) treatment recorded maximum values for curd length (14.11cm), curd diameter (25.27cm), curd circumference (46.37cm), curd yield $plot^{-1}$ (13.95 kg) and curd yield q ha^{-1} (118.01 q-1) which was followed by the treatment T5 (N 100% + PK Full (RDF)+ micronutrients) and T2 (N 100% + PK full (RDF)+ bio-fertilizer) respectively.

Pappu *et al.* (2021) conducted a field experiment to evaluate the effect of different micronutrients on growth and yield of cauliflower. The whole research experiment was carried out for two years (*i.e.*, *rabi* season 2017-18 and 2018-19 at Research cum Instructional farm of Horticulture, Department of Vegetable Science, IGKV, Raipur. The experiment was laid down under randomized block design in three replication, and consisting of fifteen treatments. The important growth parameters and curd yield encompassed in the study were plant height (cm), number of leaves plant^{-1}, width of leaves (cm), length of leaves (cm),length of root (cm), stem length (cm), stem diameter (cm), days to first curd initiation, days of 50% curd maturity and curd yield (q ha^{-1}). The experimental findings revealed that almost all the treatments showed a positive effect on growth and yield, however treatment T_5 (100% RDF + Borax @ 20 kg ha^{-1} + Ammonium molybdate @ 2 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1}) exhibited most significant influence on all above mentioned parameters when compared to T_1-Control (100% RDF). Therefore, on the basis of experimental it can be concluded that the application of micronutrients is an effective approach in cauliflower to enhance the growth, curd maturity and curd yield.

Bairwa *et al.* (2020) revealed that in cauliflower the maximum number of leaves plant^{-1} (22.74 and 21.96), width of leaves (22.77 cm and 21.87), Length of leaves (45.62 cm and 44.28 cm), plant height (63.22 cm and 61.75 cm), length of root (23.67 cm and 22.36 cm), highest stem length (12.46 cm and 11.84 cm), maximum stem diameter (4.52 cm and 4.21 cm), earliest days to first curd initiation 43.75 days and 45.14 days, earliest 50% curd maturity 60.27 days and 61.44 day were recorded from treatment T_5 (100% RDF + Borax @ 20 kg ha^{-1} + Ammonium molybdate @ 2 kg ha^{-1} + ZnSO4 @ 25 kg ha^{-1}) during both season (2017-18) and (2018-19).

Subedi *et al.* (2020) observed significantly taller plant at higher boron dose i.e 1.7 kg ha^{-1}, and the lowest plant height was recorded in control plots. The increase in plant height with increasing levels of boron can be attributed to the fact that boron promotes cell division and elongation and is especially required for actively growing regions of plant-like apical meristems.

Tudu *et al*. (2020) reported that the fresh head production of broccoli owing to B and Zn application under limed and non-limed conditions ranged from 122.78 to 136.80 q ha^{-1}. Borax @ 0.2 percent + ZnSO4 @ 0.5 percent produced the maximum yield. The mean head yield in the limed condition was 134.73 q ha^{-1}, whereas the yield in the unlimed condition was 124.06 q ha^{-1}, representing an increase of 8.60 percent in yield over the unlimed condition.

Chowdhury and Sikder (2019) reported that tallest plant (61.32 cm) was recorded in combination of 0.05% Mo, 0.25% S and 1% Zn. Again, the combined treatment of 0.03% Mo, 0.05% S and 1.5% Zn showed significant maximum positive effect on head length (29.36 cm) and head diameter (30.22 cm) indicated that this treatment combination might be very effective in sprouting broccoli and the maximum leaf length and leaf width were recorded to be significantly highest at combined treatment of 0.05% Mo+ 0.05% S + 1.5% Zn i.e., 41.58 cm, and 29.35 cm.

Sourabh *et al*. (2019) recorded that combined application of borax 0.2 per cent + $ZnSO_4$ 0.5 per cent significantly increased vegetative growth *i.e*. plant height (61.71 cm), plant girth (10.22 cm) and leaf area (440.35 cm^2) compared to sole application irrespective of lime application and spraying schedule in broccoli var. " Palam Samridhi".

Chaudhari *et al.* (2018) reported that application of 1% general grade-1 (Fe-2.0, Mn-0.5, Zn-4.0, Cu-0.3, B-0.5) + T_1 (0.1% Ammonium molybdate) shown significant impact on highest head yield ha^{-1} (24.24 t), yield of head plot-1 (31.42 kg) and other yield attributes *viz*., polar diameter of head (15.46 cm), equatorial diameter of head (13.35 cm), gross weight of head (1.24 kg $plant^{-1}$) and net weight of head (748.00 g $plant^{-1}$).

Farooq *et al.* (2018) reported higher curd diameter in broccoli with increasing boron dose.

Jakhar *et al.* (2018) recorded that application of boron @ 2.25 kg ha^{-1} significantly increased the plant height, stem diameter, number of leaves $plant^{-1}$, leaf area and chlorophyll content in leaves (2.98 mg g^{-1}), of sprouting broccoli over control and found statistically at par to boron @ 1.5 kg ha^{-1}.

Kiran *et al.* (2018) carried out an experiment comprising of five phosphorus levels viz., 0, 40, 60, 80 and 100 kg/ha; and four zinc levels, i.e., 0, 5, 10 and 15 kg ha^{-1} at Research Farm, Department of Vegetable Science, CCS HAU, Hisar to observe effects on plant height, number of branches per plant, days to 50% flowering, number of pods per plant, pod length, pod girth, pod weight, seeds per pod, seed yield per plant, seed yield per plot and seed yield per hectare. Plant height and number of branches per plant increased with the increase in fertilizer dose. The tallest plant at 45, 60 and at final harvest (39.10, 57.50 and 69.54 cm, respectively) and maximum number of branches per plant (5.73) were recorded when the crop was sown with the application of phosphorus 60 kg $ha^{-1}$and zinc 10 kg ha^{-1}. Flowering was delayed significantly with the increase in phosphorus and zinc levels. The maximum number of days to 50% flowering was taken by the crop under phosphorus 60 kg/ha and zinc 10 kg ha^{-1}. The number of pods per plant (14.23), number of seeds per pod (13.36), pod weight (18.02), seed yield per plant (43.48), per plot (3.13kg) and per hectare (21.74q/ha) were recorded maximum when the crop was supplied with phosphorus 60 kg $ha^{-1}$and zinc 10 kg ha^{-1}.

Pankaj *et al.* (2018) studied the effect of different micronutrient on sprouting broccoli (*Brassica oleracea* var. *italica*) cv. green magic. Results of the experiment showed the maximum plant height (52.23 cm), number of leaves (26.06) and plant spread (55.25cm) at 60 DAT when treated with T_5 (B 3.0 + Mn 2.0 + Zn 2.5 kg ha^{-1}).

Singh *et al*. (2018) found the positive influence of micronutrients on plant spread, stalk length and root length over control. Application of zinc sulphate 0.60 percent exhibited the highest value for above characters in sprouting broccoli.

Singh *et al*. (2018) conducted an experiment on broccoli and examine that application of micronutients at (B, Mo, Mn, and Zn.) (2, 0.5, 2.5, 3kg ha^{-1}), respectively gives better results on diameter of curd 16.90 cm.

Xaxa *et al.* (2018) recorded that application of 2.5 kg B, 3 kg Mn, 2 kg Zn ha^{-1} significantly increased the plant height (53.61 cm), number of leaves (25.23), plant spread (54.51 cm), fresh weight of plant (897.00 g), plant dry matter (96.48 g), fresh root weight (46.63 g) and dry root weight (12.63 g) in sprouting broccoli.

Hossain *et al.* (2017) carried out an experiment was at the Agronomy Research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from November, 2013 to April, 2014 with a view to observe the effect of micronutrients (Zn, B and Mn) with different levels of macronutrients (NPKS fertilizers) on onion (Allium cepa L.) seed yield. The experiment was conducted with four levels of micronutrients viz. M_1= Zn_0B_0Mn0 kg ha^{-1}, M_2= $Zn_4B_1Mn_2$ kg ha^{-1}, M_3 = $Zn_6B_2Mn_3$ kg ha^{-1} and M_4= $Zn_8B_3Mn_4$ kg ha^{-1} and three doses of macronutrients viz. F_1= $N_{57}P_{21}K_{39}S_9$ kg ha^{-1}, F_2= $N_{114}P_{42}K_{78}S_{18}$ kg ha^{-1} and F_3 =$N_{171}P_{63}K_{117}S_{27}$ kg ha^{-1}. All doses of micro and macronutrients are applied to the soil. Application of micronutrients and different doses of macronutrients increased number of umbels/plot, number of seeds per umbel, weight of seeds per umbel, seed yield per plant. The highest seed yield (879.9 kg/ha) were recorded from M3 treatment and the lowest seed yield (787.4 kg ha^{-1}). The positive effects of micronutrients were found in order of M_3> M_4> M_2> M_1. The F_2 treatment produced the highest seed yield (957.6 kg/ha) and F_1 treatment produced lowest (776.6 kg/ha). The positive effects were found in order of F_2> F_3> F_1. Amongst the treatment combinations, M_3F_2 produced the highest seed yield (1027.0 kg/ha) and M_1F_1 produced the lowest yield (734.4 kg ha^{-1}).

Meena (2017) recorded that the boron 2.5 kg ha^{-1} significantly increased the plant height, number of leaves and leaf area at 30 and 60 DAT in cauliflower as compared to control and boron 1.5 kg ha^{-1} although, it was found statistically at par with boron 2.0 kg ha^{-1}.

Patel *et al.* (2017) showed that in broccoli application of borax (1.5%) gives curd diameter 14.48 cm and curd length 13.02 cm.

Shivran *et al.* (2017) revealed that application of Zn @ 30 kg ha-1 at 30 to 60 DAT recorded maximum and significant values on growth *viz*. plant height (29.75 cm and 55.16 cm), number of leaves plant-1 (7.91 and 16.90), stem diameter (1.38 cm and 2.62 cm) and plant spread (22.41 cm and 35.60 cm) in broccoli.

Singh *et al*. (2017) studied the effect of different micronutrients on plant growth of broccoli (*Brassica oleracea* var. *italica*) cv. green bud during *rabi* season of 2014-15. Application of B at 2 kg ha^{-1}, Mo 0.5 kg ha^{-1}, Mn 2.5 kg ha^{-1} , Zn 3 kg ha^{-1} significantly increased the plant height (51.30 cm), number of leaves (22.92), plant spread (52.83 cm), fresh weight of plant (908.28 g), dry matter of plant (95.61 g), fresh root weight (45.02 g) and dry root weight (11.65 g).

Singh and Singh (2017) studied the response of zinc fertilization on cabbage (*Brassica oleracea*, var. *capitata*). The results revealed that the application of zinc up to 6 kg/ha significantly increased the edible head yield and dry matter production of cabbage over control.

Deepika and Pitagi (2016) recorded that the combined application of recommended dose of fertilizer (RDF) + ZnSo4 @ 10 kg/ha + borax 0.1 per cent as foliar spray at bud initiation stage were found highly effective for plant height (33.80 cm), number of leaves plant^{-1} (34.30) at bud initiation stage and length of inflorescence (93.80 cm) over control in radish.

Metwaly *et al.* (2016) revealed that application of nitrogen and boron (60, 70, 80, 90 kg ha^{-1}) and (0.4, 0.8, 1.2 kg ha^{-1}) in broccoli gives curd length at nitrogen 60 and boron 1.2 kg ha^{-1}gives 14.9 cm, 14.2 cm, 14.0 cm, 13.6 cm, respectively.

Ningawal *et al*. (2016) recorded that morphological characters of cauliflower (*Brassica oleracea* var *botrytis* L.) increased significantly with the different levels of boron and molybdenum at every stage of observation. The maximum plant height (34.35 cm), number of leaves plant^{-1} (19.45), leaf length (32.02 cm), leaf width (28.31 cm), stem girth (5.14 cm) at 60 DAT curd diameter (18.41 cm), fresh weight of curd (1.24 kg), yield ha^{-1} (400.29 q) and dry matter of curd (11.37 %) were recorded with borax 10 kg ha^{-1} + ammonium molybdate 1 kg ha^{-1} as soil application, whereas the minimum plant height (32.50cm), number of leaves plant^{-1} (16.49), leaf length (29.07 cm), leaf width (25.72 cm) and stem girth (4.50 cm) were observed in control.

Thapa *et al.* (2016) observed that growth of sprouting broccoli (*Brassica oleracea* L. var. *italica*) was influenced by boron and molybdenum. Application of borax 18 kg ha^{-1} and ammonium molybdate 1.8 kg ha^{-1} was found beneficial for growth and yield attributes like plant height, number of leaves, chlorophyll content, days taken to curd initiation and yield in broccoli in sprouting broccoli.

Islam *et al.* (2015) noted the contribution of boron doses on growth of different broccoli genotypes. There was a significant and positive effect of boron application on the growth of sprouting broccoli. Control (without boron) treatment required maximum days (48.92) for curd initiation but minimum days (61.75) for curd harvest.

Lal *et al*. (2015) reported that foliar application of zinc 30 kg ha^{-1} significantly increased the plant height and number of leaves per plant in sprouting broccoli. Whereas, chlorophyll content and leaf area increased significantly with zinc 20 kg ha^{-1}.

Singh *et al.* (2015) reported that application of 120:60:40:15 NPKB kg ha^{-1} produced maximum plant height $plant^{-1}$ (65.33 cm), number of leaves $plant^{-1}$ (18.26), length leaf (52.99 cm), width of leaf (17.98 cm), spread of plant (55.53) and stem diameter (4.47 cm) in broccoli.

Azza *et al.* (2013) reported that enhanced carbohydrates metabolism, formation of cells and tissue development due to applied boron and increased photosynthetic activities might have caused increase in plant height.

Kant *et al.* (2013) conducted a field experiment to investigate the effect of four basal dose of boron in form of borax (0, 5, 10 and 15 kg/ha) and zinc in the form of zinc sulphate (0, 10, 20 and 30 kg/ ha). The plant height, number of leaves $plant^{-1}$ of cauliflower were recorded maximum with combined soil application of 20 kg $ZnSo_4$ + 10 kg B/ha, being statistical at par with 30 kg $ZnSo_4$ + 10 kg B ha^{-1}.

Sarker *et al.* (2015) conducted an attempt of searching out of deficient micronutrient for okra in the Old Meghna Estuarine Floodplain (AEZ 19). The study was conducted in Chandina upazila of Comilla district covering AEZ 19. The experiment was laid out in a Randomized Complete Block Design with 3 (three) replications at farmers' field during 2011-2012. In this study 7 (seven) treatment combinations including a control were tested and the treatments were designed taking all essential micronutrients except Cl following additive element trial technique. The rates of micronutrients were 3 kg Zn, 2 kg B, 2 kg Cu, 3 kg Mn, 5 kg Fe and 1 kg Mo ha^{-1}. Sole application of Zn along with recommended doses of N, P, K and S was found sufficient for the highest yield of pod and stover, pod length and pod diameter whereas pod yield $plant^{-1}$ and average pod weight were showed the highest responses by the combine application of Zn and B. Although, the highest yield of pod and stover (11.23 and 3.21 t ha^{-1}, respectively) was produced from T_7 treatment, there was observed no additive effect due to the application of micronutrients other than Zn and B. Almost similar trend was observed in other growth and yield parameters, and uptake of different nutrient elements.

Singh *et al.* (2013) revealed from their research findings that maximum foliage cover was obtained from the application of boron at the rate of 1.5-2 kg ha^{-1} i.e Borax 15-20 kg ha^{-1}, the findings of which are similar to the findings of our research work.

Kumar *et al.* (2012a) observed that among all the treatment combinations, boron 2.0 kg + sodium molybdate 2 kg/ha and boron, 1.5 kg + sodium molybdate, 1.0 kg/ha gave best performance when applied as basal and foliar application, respectively. They observed significantly higher plant height (cm), number of leaves $plant^{-1}$, fresh weight of leaves $plant^{-1}$ (g), length of leaves (cm),width of leaves (cm) total weight of plant (kg), days taken to curd maturity, diameter of curd (cm), gross weight of curd (kg), net weight of curd and total yield (q ha^{-1}) of cauliflower.

Singh *et al.* (2011) reported that the maximum value for the characters *viz.* plant weight (1439.30 g), plant height (63.98 cm) and number of leaves (16.25) were recorded with boron @ 1.50 kg ha^{-1} over control in cauliflower.

Singh (2011) observed positive effect of due to application of micronutrients viz. molybdenum, boron and zinc that increasing the number of seeds per pod has been reported in green gram. The micronutrients might have enhancing role in seed setting that resulted in improvement in number of pod $plant^{-1}$.

Moniruzzaman *et al.* (2007) observed that larger plant spread at 1.5 kg B ha^{-1} and 2 kg B ha^{-1} application and minimum plant spread at control plots.

2.2 Effect of different methods of fertilizer application

Doddamani *et al*. (2020) conducted a field bean experiment to determine the influence of foliar Zn and B administration on vegetative development, fruiting order, and yield. The results of the experimental trial indicated that the vegetative growth like number of branches $plant^{-1}$ was significantly influenced by Zn and B foliar application treatments.

Ranjan *et al.* (2020) conducted an experiment and observed significantly higher plant height, number of leaves per plant, stem length, stem diameter, plant spread and leaf area index of cauliflower under combined foliar application of 0.2 per cent borax + 0.5 per cent manganese sulphate + 0.1 per cent ammonium molybdate.

Taheri *et al*. (2020) recorded that foliar application of zinc and boron @ 1 per cent of each at 45 and 60 DAT led significantly higher plant height, plant spread, in number of leaves, stem length, stem diameter and fresh weight of loose leaves of cabbage.

Chethana *et al*. (2019) reported significantly higher yield attributes such as curd diameter (16.65 cm), weight of curd (0.678 kg), yield/plot (35.813 kg) and yield/ha (33.16 tonnes) under zinc 4 kg/ha through ZnSO4 as soil application + 0.5 % Zn through ZnSO4 as foliar spray alongwith RDF and FYM in cauliflower.

Kobree (2019) conducted a field experiment to investigate the effect of zinc (Zn) and manganese (Mn) foliar fertilization on yield, dry matter accumulation, Zn and Mn concentration in leaf and seed of chickpea cultivars on a research field of the Islamic Azad University of Kermanshah Province, Iran. The result indicated that zinc spraying had the greatest effect on the number of seed pod^{-1} of chickpea plant.

Mahmoud *et al.* (2019) carried out a study to compare different concentrations of zinc and boron foliar spray in broccoli. Foliar spray of zinc + boron (200 ppm of each) increased vegetative growth However, there were no significant differences recorded to 100 ppm dose of each.

Islam *et al*. (2018) reported that agronomic bio-fortification through foliar boron application might have enhanced the seed setting that resulted in an increasing number of seeds pod^{-1}.

Moklikar *et al.* (2018) studied the effect of micronutrient such as Zn (0.5 %), B (0.2 %) and Fe (0.5 %) at 45 and 60 DAT. The significant growth in terms of the maximum length of leaf (32.26 cm) and total biomass production (2849.20 g) was recorded in the foliar application of $FeSo_4$ 0.5% + borax 0.2 percent + $ZnSo_4$ 0.5 percent in cauliflower.

Nandan *et al*. (2018) found that Zn and Fe treatments through foliar as well as soil treatments resulted in significantly higher number of pods plant^{-1}.

Pawar and Tambe (2017) carried out a study in poly house during the year 2010-2011. The maximum weight of central head (202.31 g plant^{-1}), diameter of central head (10.45 cm), volume of central head (306.75 cm^{3}), total yield plant^{-1} (376.30 g) and yield (27.49 Mt/ha) of broccoli were recorded with foliar application of boron 0.3 per cent and ammonium molybdate 0.05 per cent however, maximum height of plant (56.98 cm) was recorded with the foliar application of boron 0.3 per cent alone.

Singh *et al.* (2017) reported that micronutrients (B, Mo, Mn, and Zn) add @ 2 kg (B), 0.5 kg (Mo), 2.5 kg (Mn), 3 kg (Zn) per hectare significantly increased plant height (51.30 cm), number of leaves (22.92 cm), plant spread (52.83 cm), and bud or head diameter (16.90 cm) in broccoli.

Deepika and Pitagi (2016) studied that the combined application of RDF + ZnSo4 10 kg/ha + borax 0.1 % as foliar spray at bud initiation stage were found to be highly effective for length of inflorescence (93.80 cm), number of siliqua plant^{-1} (363), siliqua weight plant^{-1} (26.30 g), siliqua length (5.34 cm), no. of seeds siliqua^{-1} (5.67), seed recovery per cent (92.87), seed yield (199.93 kg/ha), germination per cent (92.20), seedling vigour index I and II (2100 and 467) in radish over control.

Melash *et al*. (2016) concluded that foliar spray, soil application and seed treatment are the most effective application strategies for some micronutrients.

Yadav *et al.* (2015) reported that, double foliar spray of 1.5% N and 40 ppm Zn (30 and 45 DAT) individually found to be the best for vegetative growth parameters in cauliflower.

Kumar *et al.* (2014) made a study to find out the efficiency of foliar application of nitrogen and zinc on growth. Zinc had a significant increase in plant spread, number of unfolded leaves, days taken for curd initiation, maturity of curd diameter of curd, fresh weight (curd and roots) and yield in cauliflower.

Ballabh *et al.* (2013) found that treatments consist of foliar sprays of five micronutrients, viz., Cu, Zn, B, Fe, and Mn, each in two concentrations (Cu @ 2 and 4 mg l^{-1},, Zn @ 4 and 6 mg l^{-1}, B @ 1 and 2 mg l^{-1}, Fe @ 100 and 200 mg l^{-1},, Mn @ 1 and 2 mg l^{-1},) along with tap water as control. Two foliar sprays of micronutrients were done at 15 days intervals after 50 days of seedling transplanting. Results were found to be significant in most of the growth parameters of onion. The number of leaves per plant (14.1), plant height (66.9 cm), leaf width (4.3 cm), leaf length (63.9 cm), neck length (1.6 cm), neck diameter (2.0 cm), roots length (8.1 cm), number of roots per plant (162.1).The results clearly indicated that foliar feeding of Zn @ 4 mg l^{-1}, significantly improved vegetative growth parameters.

Devi *et al.* (2012) conducted an experiment on cabbage with foliar application of borax @ 0.1 per cent and found significant increase in plant height, number of leaves, shoot fresh weight, dry weight, root fresh weight, dry weight. head weight, diameter and volume.

Montessori *et al.* (2012) revealed that the effects of foliar application of borax @ 0.1% solution on cabbage. The foliar spray was done twice at 25 and 50 days after transplanting (DAT). It showed significant increase in plant height, number of leaves, shoot fresh weight, dry weight, root fresh weight and dry weight and yield. The head size (diameter) was increased with application of borax.

Mohamed and Abdelnaser (2011) observed the effect of foliar spray of molybdenum and magnesium on vegetative growth and curd yield in cauliflower (*Brassica oleraceae* L.var. *botrytis*). Plants sprayed with 15, 30 and 45 μg/l Mo and Mg at 20, 40, 60 and 80 days after transplanting. Results showed that application of 30 and 45 μg/l Mo significantly improved growth parameters improved curd yield and its components and chemical composition of leaves and curd of cauliflower.

According to Sitapara *et al.* (2011) foliar application of gibberellic acid @ 100 ppm and boric acid 0.2 % at 15 and 30 DAT in cauliflower produced higher weight of curd (925.10 g) and maximum (312.16 qha^{-1}) yield.

Kumar *et al.* (2010b) while working on snowball cauliflower PSBK-1 observed maximum number of leaves plant-1 (16.13) and number of primary branches $plant^{-1}$ (12.53) with basal application of lime @ 500 kg ha^{-1} and borax @ 5.0 kg ha^{-1} followed by foliar sprays of borax @ 0.25 % at 40, 60 and 80 days after transplanting (DAT).

Saha *et al.* (2010) conducted an experiment with spray of borax and ammonium molybdate alone and in combination on sprouting broccoli (cv. Kabuki). Spraying of borax (0.3 %) at 30 and 45 DAT gave significantly higher stem length (45.57 cm), stem diameter (2.56 cm), leaf width (15.62 cm) total head yield (14.38 t ha^{-1}) and plant weight (945.65 g).

Tejeswara and Subbaiah (2006) reported that combined (Zn, B and Mo) foliar application of micronutrient recorded significantly higher plant height (176 cm), primary branches (7.0 $plant^{-1}$) and dry matter production at different stages of Indian mustard as compared to control (144 cm, 5 $plant^{-1}$ and dry matter production at different stages, respectively).

CHAPTER III

MATERIALS AND METHODS

A field experiment to investigate the "Influence of micronutrients and their application methods on seed yield of broccoli" was conducted at the Horticulture Farm, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during Rabi seasons from 14 October 2021 to 18 March 2022. The details of procedure adopted for crop growing and criteria used for treatment evaluation during the entire course of investigation are described in this chapter as under.

3.1 Experimental period

The experiment was conducted during the period from 14 October 2021 to 18 March 2022 in the Rabi season.

3.2 Description of the experimental site

3.2.1 Geographical location

The experiment was conducted both in the Central laboratory and Agronomy field of Sher-e-Bangla Agricultural University (SAU). The experimental site is geographically situated at 23°77′ N latitude and 90°33′ E longitude at an altitude of 8.6 meters above sea level.

3.2.2 Agro-Ecological Zone

The experimental field belongs to the Agro-ecological zone (AEZ) of "The Modhupur Tract", AEZ-28. This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain. For a better understanding of the experimental site has been shown in the Map of AEZ of Bangladesh in Appendix-I.

3.2.3 Soil

The soil texture was silty clay with pH 6.1. The morphological, physical, and chemical characteristics of the experimental soil have been presented in Appendix-II.

3.2.4 Climate and weather

The climate of the experimental site was subtropical, characterized by the winter season from November to February and the pre-monsoon period or hot season from March to April, and the monsoon period from May to October (Edris *et al.*, 1979). Meteorological data related to the temperature, relative humidity, and rainfall during the experiment period was collected from Bangladesh Meteorological Department (Climate division), Sher-e-Bangla Nagar, Dhaka and has been presented in Appendix-III.

3.3 Experimental materials

The 'BARI Broccoli-1' variety was used in the experiment. The seeds were obtained from the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur-1701.

3.4 Seedbed preparation

On October 12, 2021, a seedbed of 3 m × 1 m was prepared for raising broccoli seedlings. To obtain good tilth, the soil was thoroughly ploughed to remove friable and dried masses. Weeds, stubbles, and dead roots were removed from the seedbed. Cowdung was applied to the prepared seedbed. To protect the young plants from mole crickets, ants, and cutworms, the soil was treated with Sevin 50WP @ 5kg ha^{-1}.

3.5 Seed treatment

Seeds were treated with Provax 200WP @ 3g/1kg seeds to protect against seed-borne diseases.

3.6 Seed sowing

Seeds were sown on 29 October 2021 in shallow furrows 5 cm apart by dropping the seeds at 2 cm depth. A thin layer of sand was applied to cover the seeds. Regular watering, hoeing, weeding, plant protection measures *etc*. were adopted as per package of practices. When the seeds germinated, white polythene shade was provided to protect the young seedlings from the scorching sun and rain.

3.7 Raising of seedlings

Watering and weeding were done several times. No chemical fertilizers were used during seedling growth. No insect or disease attacked the seedlings. On November 20, 2021, healthy, 25-day-old seedlings were transplanted into the experimental field.

3.8 Experimental treatment

There were two factors in the experiment namely application of different levels of micronutrients and different methods of fertilizer applications as mentioned below:

Factor A: Levels of micronutrients (4) *viz;*

Treatments	Micronutrients plot^{-1}		
	Zinc sulphate	**Boric acid**	**Ammonium molybdate**
$F_0 = Zn_0B_0Mo_0$ kg ha^{-1}	Control	Control	Control
$F_1 = Zn_2B_1Mo_1$ kg ha^{-1}	1.5 g	1.50 g	0.6 g
$F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}	3.00 g	3.00 g	1.02 g
$F_3 = Zn_6B_3Mo_2$ kg ha^{-1}	4.50 g	4.00 g	1.36 g

* F_0 (Control): Water application only.

Factor B: Different methods of fertilizer applications (3) *viz;*

M_1= Direct soil application (Before transplanting)

M_2= Foliar spray (Before flowering) and

M_3= M_1 + M_2

3.9 Design and layout of experiment

To begin, the experimental field was divided into three sections. Each block was divided into 12 plots for the treatment combinations. There were a total of 36 plots. According to the experimental design, each block was then assigned to 12 treatment combinations. The plot was 1.50 × 1.50 m in size. A distance of 50 cm was maintained between the rows and 50 cm between the plants in each unit plot. The distance between the two plots was 0.5 m, and the blocks were 1 m apart.

3.10 Field preparation

The experiment plot was opened with a power tiller in the third week of November 2021 and left exposed to the sun for a week. After one week, the land was harrowed, ploughed, and cross-ploughed several times before laddering to achieve good tilth. Weeds and stubbles were removed, and a desirable tilth of soil was obtained for seedling transplantation. Drainage channels were built around the land to avoid water logging caused by rainfall during the study period. When the plot was finally ploughed, the soil was treated with Furadan 5G at a rate of 15 kg ha^{-1} to protect the young seedlings from cut worm attack.

3.11. Application of fertilizers

The fertilizer doses listed below are recommended for broccoli production.

Fertilizers	Doses (t/kg ha^{-1})
Cowdung	15 t ha^{-1}
Urea	250 kg
TSP	200 kg
MoP	150 kg
Zinc sulphate	As per treatment requirement
Boric acid	As per treatment requirement
Ammonium molybdate	As per treatment requirement

Fertilizer were applied according to BARI, 2019 recommendation and as per treatment requirement.

3.12 Transplanting of seedlings

To avoid root damage, the seedbed was watered before uprooting the seedlings. On November 26, 2021, twenty five-days-old healthy seedlings were transplanted at a spacing of 50 cm × 50 cm in the experimental plots. As a result, each unit plot could accommodate 9 plants. The planting was completed in the afternoon. For better establishment, light irrigation was applied immediately after transplanting around each seedling. The transplanting seedlings were shaded for five days with a banana leaf sheath to protect them from scorching sunlight, and they were watered every five days until they were capable of establishing their own root system.

3.13 Intercultural operations

3.13.1 Gap filling

Gap filling was also done to maintain the plant population in each plot uniformly.

3.13.2 Hoeing and weeding

First hoeing and weeding was done at 20 days after transplanting however, second hoeing and weeding was done at 20 days after first one.

3.13.3 Irrigations

For better establishment, light irrigation was applied immediately after transplanting around each seedling. Watering was done every five days until they could establish their own root system. The soil moisture condition was used to determine irrigation. During the crop period, irrigation was performed four times.

3.13.4 Earthing up

Only unmulched plots were earthed up, with soil taken from the space between the rows 15 days after transplanting. In mulched plots, there was no need to earth up.

3.13.5 Insects and diseases management

Spraying Dithane M-45 @ 2 g L^{-1} water as a preventative measure against Fusarium rot was used. Cutworms, mole crickets, and field crickets attacked the crop during the early stages of seedling growth in February. This insect was initially controlled by beating and hooking, and then by spraying Dieldrin 20 EC @ 0.1%.

3.14 General observation

In order to detect any changes in the plants or any pest or disease attacks, the field was frequently observed, and any necessary action was taken to ensure normal plant growth.

3.15 Harvesting of curds

The green compact heads and axillaries sprouts were harvested at full maturity stage with the help of sharp knife. The harvesting was carried out in stages as per the maturity of central head and secondary heads. Harvesting began on January 18, 2022, and ended on March 2, 2022. The curds were harvested with 10 cm of stem and sprouts attached.

3.16 Collection of data

The data about the different characters were recorded from three plants randomly selected from each plot except the yield of curds which was recorded plot wise.

3.17 Data collection procedure

i. Plant height (cm)

Plant height of only three tagged plants was measured from the ground level to the top of the longest leaf at 30 DAT and 45 DAT with the help of measuring scale. The height of plants was measured and the average height was then calculated in centimetres.

ii. Number of leaves

The numbers of open leaves per plant of three tagged plants were counted manually in a plot at periodical interval of 30 DAT and 45 DAT. The average number of leaves per plant was calculated.

iii. Leaf length (cm)

The leaf length of broccoli was measured using the measuring tape and express as a centimeter (cm).

iv. Leaf breadth (cm)

The leaf breadth of broccoli was measured using the measuring tape and express as a centimeter (cm).

v. Canopy diameter (cm)

The canopy diameter of broccoli was measured using the measuring tape and express as a centimeter (cm).

vi. Primary curd diameter at 45 DAT

The diameter of primary curd was measured in several directions with meter scale and the average of all directions was finally recorded and expressed in centimeter (cm) at 45 DAT.

vii. Curd length at 60 DAT

At 60 DAT, curd length was measured from one side to the other. Curd length was measured on a meter scale and expressed in centimeters (cm).

viii. Curd diameter at 60 DAT

The diameter of curd was measured in several directions with meter scale and the average of all directions was finally recorded and expressed in centimeter (cm) at 60 DAT.

ix. Number of branches plant^{-1}

The number of branch plant^{-1} was counted from three randomly sampled plants. It was done by counting the total number of branches of all sampled plants then the average data were recorded. Data were recorded at harvest respectively.

x. Number of inflorescences branch^{-1}

The number of inflorescences branch^{-1} was counted from three randomly sampled plants. It was done by counting the total number of inflorescences of all sampled branchs then the average data were recorded. Data were recorded at harvest respectively.

xi. Number of flower inflorescence^{-1}

The number of flower inflorescence^{-1} was counted from three randomly sampled plants. It was done by counting the total number of flower of all sampled inflorescences then the average data were recorded. Data were recorded at harvest respectively.

xii. Number of pod inflorescence^{-1}

The number of pod inflorescence^{-1} was counted from three randomly sampled plants. It was done by counting the total number of pod of all sampled inflorescences then the average data were recorded. Data were recorded at harvest respectively.

xiii. Individual pod length (cm)

Pod length is measured by scale on three tagged plants and averaged to measured individual pod length.

xiv. Number of pods plant^{-1}

Number of pods plant^{-1} was counted from the 3 selected plant sample and then the average pod number was calculated.

xv. Number of seeds pod^{-1}

The number of seeds pod^{-1} was counted randomly from selected pods at the time of harvest. Data were recorded as the average of 3 pods from each plot.

xvi. Seed weight pod^{-1} (g)

Dried seeds were counted from each harvest sample pods and weighed by using a digital electric balance and weight was expressed in gram (g).

xvii. Seed yield plant^{-1}

Seed yield from each plant were taken expressed as g/plant on about 12% moisture basis. seed moisture content was measured by using a digital moisture tester.

xviii. Seed yield plot^{-1} (g)

It was recorded by weighing the total number of seeds from each plot separately

xix. Seed yield (kg ha^{-1})

Seed yield was recorded from 1 m^2 area of each plot were sun dried properly. The weight of seeds was taken and converted the yield in kg ha^{-1}.

xx. Germination (%)

The germination percentage of seed was calculated with the following formula Germination %= (Number of germinated seeds/Total number of seeds) × 100

xxi Vigority index

Vigor index was calculated by using following formula of (Abdul-Baki and Anderson., 1970).

$$\text{Vigor index} = \frac{\text{Total seed germination} \times \text{Seedling length}}{100}$$

3.18 Statistical analysis

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program Statistix 10 software. The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

This section contains a presentation and discussion of the study's findings on the growth and seed yield of broccoli as influence by micronutrients with its application methods. The information have been presented in various tables and figures. The findings have been discussed, and possible interpretations wherever necessary have been provided under the headings listed below.

4.1 Plant height (cm)

Plant height is an essential character of the vegetative stage of the crop plant and indirectly impacts on yield of crop plants. Different doses of micronutrient application significantly influenced on plant height of broccoli at different days after transplanting (DAT). It was seen that height increased gradually with the age of the crop up to 45 DAT. The plant height reached the highest value at 45 DAT (Figure 1). Experimental result revealed that the highest plant height (31.98 and 53.67 cm 30 and 45 DAT respectively) was observed in F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}). While the F_0 (Control) treatment had the lowest plant height (24.50 and 46.62 cm) at 30 and 45 DAT respectively. The significant increase in plant height due to different doses of micronutrient application might be attributed to increase in the availability of cytokinine to shoot which in turn play a role in cell elongation process either through cell division or cell elongation. The result was similar with the findings of Pappu *et al.* (2021) the application of micronutrients is an effective approach in vegetables crops to enhance the growth, maturity and yield.

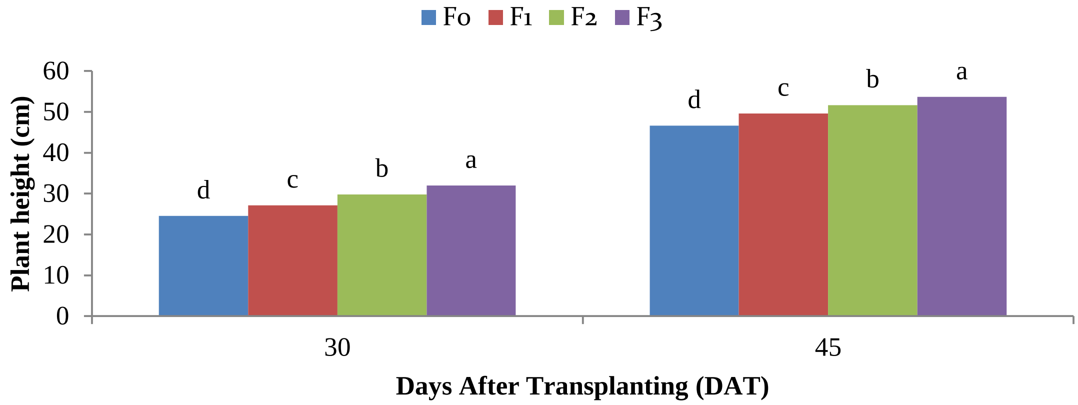

Figure 1. Effect of different doses of micronutrient application on plant height of broccoli at different days after transplanting

Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

Significant variance in broccoli plant height, was observed as a result of various method of fertilizer application at different days after transplanting (Figure 2). Experimental result showed that the highest plant height (30.12 and 52.36 cm) at 30 and 45 DAT respectively, was observed in M_2 (Foliar spray before flowering) treatment. While the M_1 (Direct application or Basal dose) treatment had the lowest plant height (26.43 and 48.71 cm) at 30 and 45 DAT respectively. In most crops, direct application of the full dose of fertilizer is a common practice, though it may lead to low fertilizer use efficiency as fertilizer demand of crops varies with crop growth pattern, nutrient needs at different physiological stages, and productivity level. Whereas proper supply of fertilizer before flowering stage of crop through foliar application resulted in better utilization of nutrients by the plants which improved the growth and yield attributes of broccoli plant. The findings were similar to those of Ranjan *et al.* (2020) who discovered that the vegetative growth like plant height of cauliflower under combined foliar application of 0.2 per cent borax + 0.5 per cent manganese sulphate + 0.1 per cent ammonium molybdate.

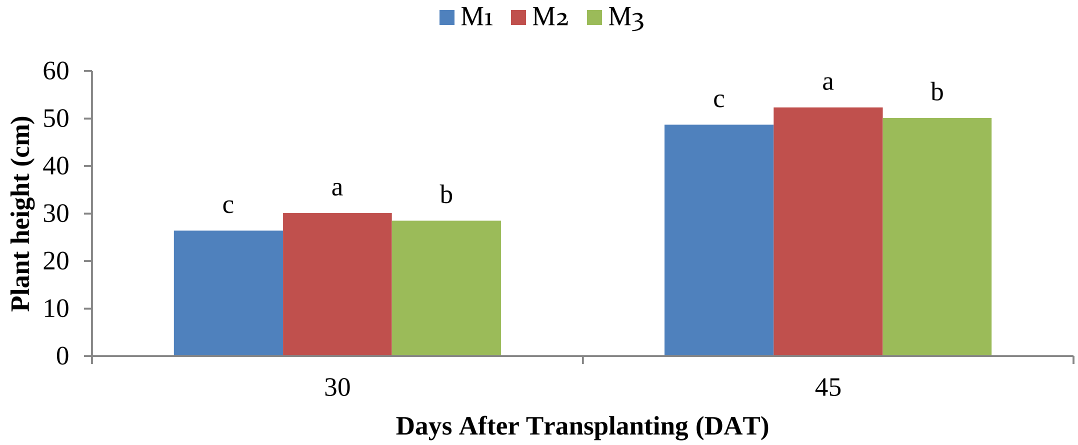

Figure 2. Effect of fertilizer application methods on plant height of broccoli at different days after transplanting

Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

Different doses of micronutrients and fertilizer application method had shown significant effect on broccoli plant height at different days after transplanting (Table 1). The results of the experiment showed that the F_3M_2 treatment combination gave the highest plant height (34.79 and 56.16 cm) at 30 and 45 DAT respectively. While F_0M_1 treatment combination showed the lowest plant height (22.73 and 45.15 cm) at 30 and 45 DAT respectively which was statistically similar with F_1M_3 (24.00 cm) treatment combination at 25 DAT and with F_0M_3 (46.52 cm) at 45 DAT.

Table 1. Combined effect of micronutrients and application methods of fertilizer on plant height of broccoli at different days after transplanting

Treatment combinations	Plant height (cm) at	
	30 DAT	45 DAT
F_0M_1	22.73 h	45.15 i
F_0M_2	24.90 fg	48.20 f-h
F_0M_3	25.88 fg	46.52 hi
F_1M_1	27.82 de	49.90 ef
F_1M_2	29.64 cd	51.69 cd
F_1M_3	24.00 gh	47.32 gh
F_2M_1	26.49 ef	48.98 fg
F_2M_2	31.14 bc	53.39 bc
F_2M_3	31.78 b	52.68 bc
F_3M_1	28.70 d	50.81 de
F_3M_2	34.79 a	56.16 a
F_3M_3	32.44 b	54.04 b
$LSD_{(0.05)}$	1.9272	1.7815
CV (%)	4.25	5.68

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.2 Number of leaves

Different doses of micronutrients application significantly influenced number of leaves plant^{-1} of broccoli at different days after transplanting (Figure 3). Experimental result showed that the highest number of leaves plant^{-1} (9.77 and 15.42) at 30 and 45 DAT, respectively was found in F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}). While the F_0 (Control) had the lowest leaves number plant^{-1} (6.65 and 12.13) at 30 and 45 DAT, respectively. Micronutrients play an important role in many physiological processes and cellular functions in the plants. In addition to that they play a vital role in improving plant growth through biosynthesis of endogenous hormones which is responsible for promoting plant growth. Islam *et al*. (2018) reported that the application of micronutrients either singly or in combination had significant effects on the number of leaves per plant of lentil.

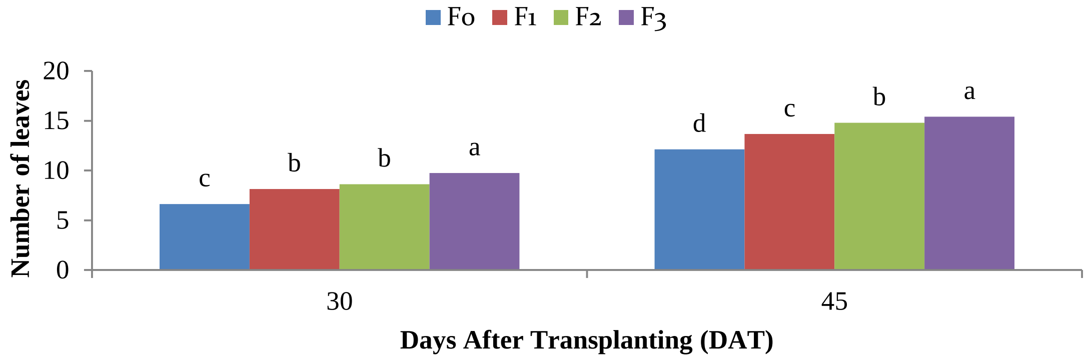

Figure 3. Effect of different doses of micronutrient application on number of leaves of broccoli at different days after transplanting

Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

The number of leaves on broccoli plants varied significantly depending on the method of fertilizer application used at different days after transplanting (Figure 4). Experimental result showed that the highest number of leaves (9.01 and 14.91) at 30 and 45 DAT, respectively was found in M_2 (Foliar spray before flowering) treatment. While the M_1 (Direct application) treatment had the lowest leaves number (7.38 and 12.64 at 30 and 45 DAT, respectively). The better efficacy of combined application of boron and zinc in broccoli, in the present study might be due to stimulating influence of B and Zn enhancing the rate of absorption of NPK and other nutrients. Ranjan *et al.* (2020) observed significantly higher number of leaves per plant of cauliflower under combined foliar application of 0.2 per cent borax + 0.5 per cent manganese sulphate + 0.1 per cent ammonium molybdate.

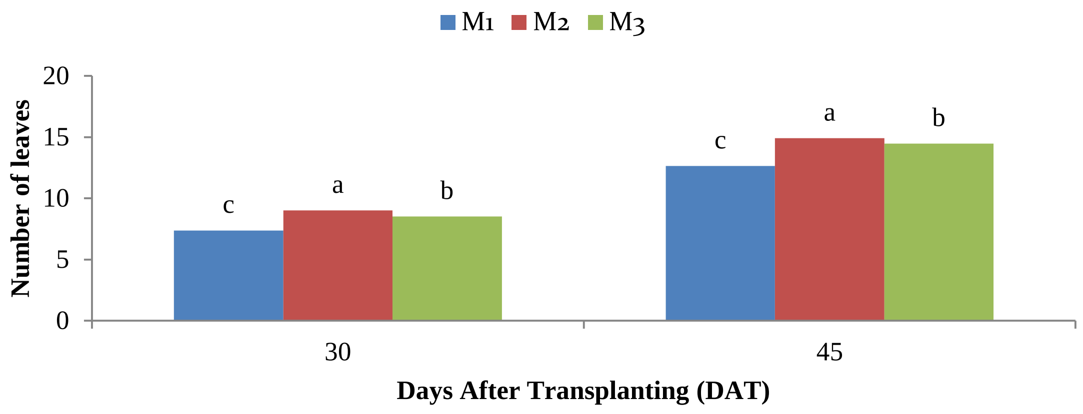

Figure 4. Effect of fertilizer application methods on number of leaves of broccoli at different days after transplanting

Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The number of broccoli leaves at various days after transplanting was significantly affected by various micronutrient doses and fertilizer application techniques (Table 2). The results of the experiment showed that the F_3M_2 treatment combination gave the highest leaves number (10.82 and 16.82) at 30 and 45 DAT respectively which was statistically similar with F_3M_3 (10.21 and 16.28) treatment combination at 30 and 45 DAT respectively. While F_0M_1 treatment combination showed the lowest leaves number (6.09 and 11.59) at 30 and 45 DAT respectively which was statistically similar with F_0M_3 (6.65 and 12.18) treatment combination at 30 and 45 DAT respectively.

Table 2. Combined effect of micronutrients and application methods of fertilizer on number of leaves of broccoli at different days after transplanting

Treatment combinations	Number of leaves at	
	30 DAT	45 DAT
F_0M_1	6.09 g	11.59 h
F_0M_2	7.20 ef	12.61 fg
F_0M_3	6.65 fg	12.18 gh
F_1M_1	7.10 f	12.34 g
F_1M_2	8.42 d	14.32 d
F_1M_3	8.92 cd	14.36 d
F_2M_1	8.04 de	13.44 e
F_2M_2	9.59 bc	15.88 b
F_2M_3	8.27 d	15.05 c
F_3M_1	8.29 d	13.17 ef
F_3M_2	10.82 a	16.82 a
F_3M_3	10.21 ab	16.28 ab
$LSD_{(0.05)}$	0.8938	0.6627
CV (%)	7.23	4.02

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, F_0 = $Zn_0B_0Mo_0$ kg ha^{-1} (Control), F_1 = $Zn_2B_1Mo_1$ kg ha^{-1}, F_2 = $Zn_4B_2Mo_{1.5}$ kg ha^{-1}, F_3 = $Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.3 Leaf length (cm)

The result of the experiment due to different levels of micronutrients application had shown significant effect on the leaf length of broccoli at different days after transplanting (Figure 5). According to the experimental result, the highest leaf length of broccoli (24.79 and 42.93 cm at 30 and 45 DAS, respectively) was found in F_3 treatment. Whereas the lowest leaf length of broccoli (18.79 and 36.35 cm) at 30 and 45 DAS, respectively was found in F_0 treatment. The difference in leaf length and width might be due to increased intensity of auxins (IAA), may be due to application of micronutrients especially ZnSO4 , which promotes growth by cell division and cell elongation. The size of the leaf plays an important role in photosynthetic activity, which greatly influence the growth and flower yield. Similar variations were also observed by Bankar *et al.* (2022) who reported that macro and micronutrient application significantly influenced leaf length of broccoli.

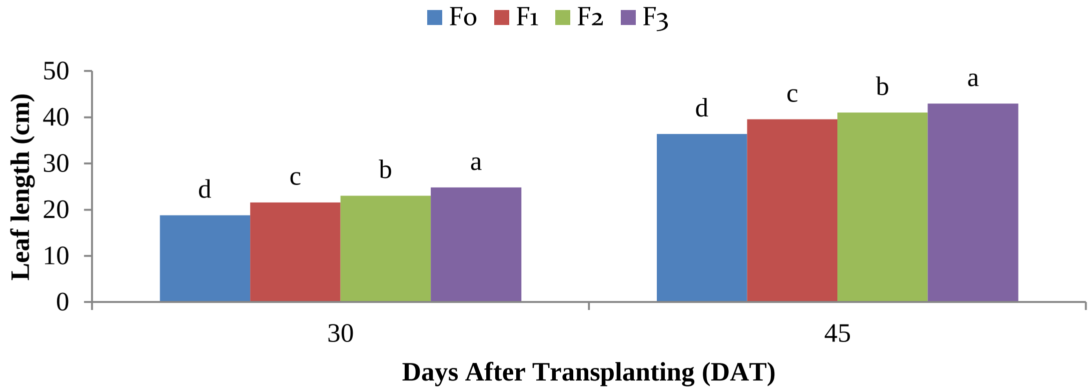

Figure 5. Effect of different doses of micronutrient application on leaf length of broccoli at different days after transplanting

Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

Application method of fertilizer on leaf length of broccoli had shown significant effect at different days after transplanting (Figure 6). The results showed that, the M_2 treatment (Foliar spray before flowering) had the highest leaf length (23.32 and 41.34 cm) at 30 and 45 DAS, respectively. However, the M_1 (Direct application) treatment, was found to produce the lowest leaf length of broccoli (20.70 and 38.45 cm) at 30 and 45 DAS, respectively. The nutrient demand of the crop could not be meet through soil nutrition alone. The better growth of the crop due to foliar sprays indicate that the higher nutrient demand of the crop was compensated through foliar nutrition. The result was similar with the findings of Yadav *et al.* (2015) who reported that, double foliar spray of 1.5% N and 40 ppm Zn (30 and 45 DAT) individually found to be the best for vegetative growth parameters in cauliflower.

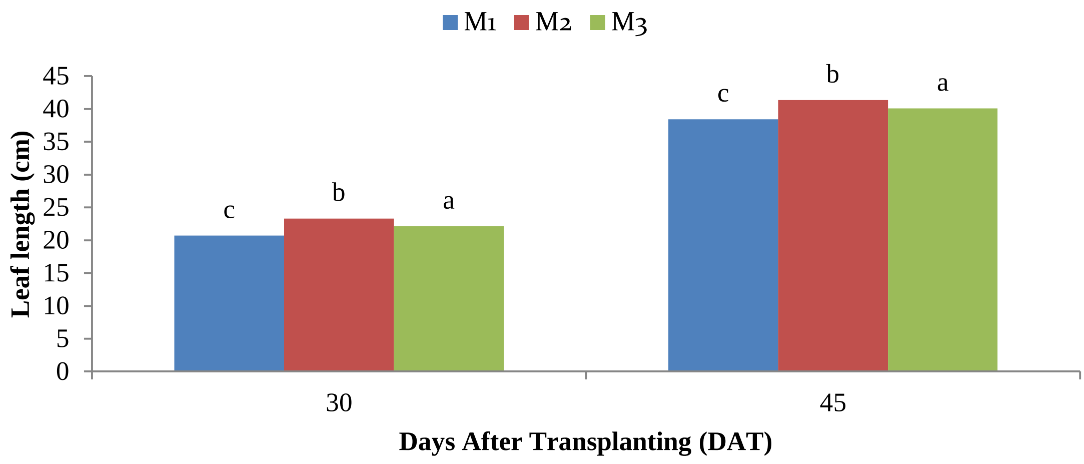

Figure 6. Effect of fertilizer application methods on leaf length of broccoli at different days after transplanting

Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The leaf length of broccoli at various days after transplanting was significantly affected by various micronutrient doses and fertilizer application techniques (Table 3). The results of the experiment showed that the F_3M_2 treatment combination gave the highest leaf length of broccoli (26.85 and 45.28 cm) at 30 and 45 DAT respectively. On the other hand F_0M_1 treatment combination showed the lowest leaf length of broccoli (18.02 and 35.16 cm) at 30 and 45 DAT respectively which was statistically similar with F_0M_3 (18.72 and 36.58 cm) treatment combination at 30 and 45 DAT respectively.

4.4 Leaf breadth (cm)

The experimental findings revealed that the leaf breadth of broccoli at various days after transplantation was significantly affected by the application of various levels of micronutrients. (Figure 7). According to the experimental result, the highest leaf breadth of broccoli (12.23 and 17.69 cm) at 30 and 45 DAS, respectively was found in F_3 treatment. Whereas the lowest leaf breadth of broccoli (9.82 and 14.62 cm) at 30 and 45 DAS, respectively was found in F_0 treatment.

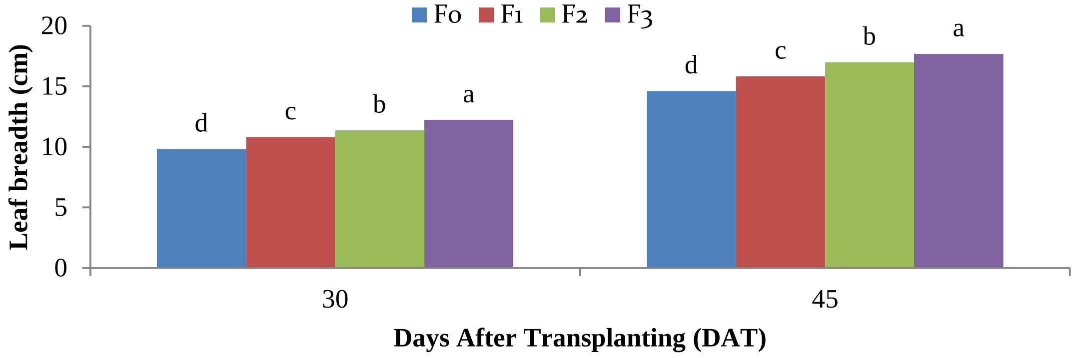

Figure 7. Effect of different doses of micronutrient application on leaf breadth of broccoli at different days after transplanting

Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

The fertilizer application strategy exhibited a significant effect on broccoli leaf breadth at different days after transplanting. (Figure 8). The results showed that, the M_2 treatment (Foliar spray before flowering) had the highest leaf breadth (11.72 and 17.07 cm) at 30 and 45 DAS, respectively. However, the M_1 (Direct application) treatment, was found to produce the lowest leaf breadth of broccoli (10.46 and 15.42 cm) at 30 and 45 DAS, respectively.

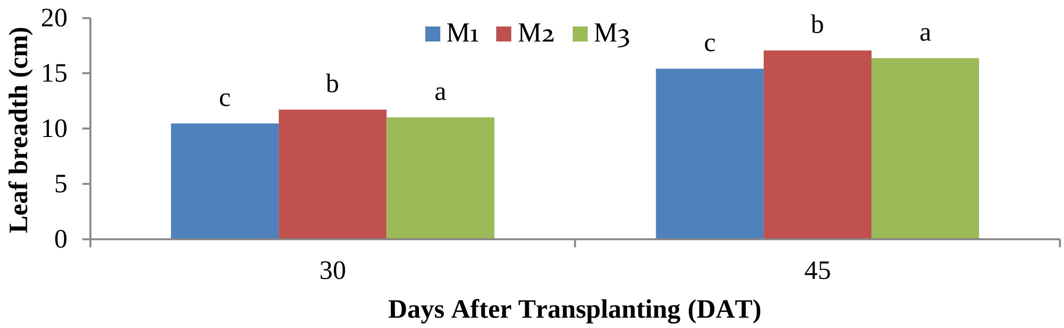

Figure 8. Effect of fertilizer application methods on leaf breadth of broccoli at different days after transplanting

Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The leaf breadth of broccoli at various days after transplanting was significantly influenced by different micronutrient doses and fertilizer application method (Table 3). The results of the experiment showed that the F_3M_2 treatment combination gave the highest leaf breadth of broccoli (12.97 and 18.58 cm) at 30 and 45 DAT respectively which was statistically similar with F_3M_3 (12.12 and 18.25 cm) treatment combination at 30 and 45 DAT respectively and with F_2M_2 (17.85 cm) treatment combination at 45 DAT. While F_0M_1 treatment combination showed the lowest leaf breadth (9.12 and 14.02 cm) at 30 and 45 DAT respectively which was statistically similar with F_0M_3 (9.53 and 14.62 cm) treatment combination at 30 and 45 DAT respectively.

Table 3. Combined effect of micronutrients and application methods of fertilizer on leaf length and breadth of broccoli at different days after transplanting

Treatment combinations	Leaf length at		Leaf breadth at	
	30 DAT	45 DAT	30 DAT	45 DAT
F_0M_1	18.02 j	35.16 j	9.12 e	14.02 h
F_0M_2	19.63 hi	37.32 hi	10.8 cd	15.23 e-g
F_0M_3	18.72 ij	36.58 ij	9.53 e	14.62 gh
F_1M_1	21.59 fg	39.54 e-g	10.55 d	15.89 c-e
F_1M_2	23.04 de	41.02 c-e	11.40 b-d	16.60 c
F_1M_3	20.15 h	38.06 g-i	10.53 d	15.03 fg
F_2M_1	20.88 gh	38.80 f-h	10.57 d	15.54 d-f
F_2M_2	23.77 cd	41.76 b-d	11.70 bc	17.85 ab
F_2M_3	24.45 bc	42.5 bc	11.88 b	17.58 b
F_3M_1	22.32 ef	40.28 d-f	11.61 bc	16.24 cd
F_3M_2	26.85 a	45.28 a	12.97 a	18.58 a
F_3M_3	25.23 b	43.24 b	12.12 ab	18.25 ab
$LSD_{(0.05)}$	1.3257	1.5711	0.9296	0.8425
CV (%)	5.58	6.32	7.21	3.58

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.5 Canopy diameter (cm)

Different levels of micronutrients application had a significant influence on canopy diameter of broccoli at different days after transplanting (Figure 9). The result of the experiment showed that the F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment had the highest canopy diameter of broccoli (40.74 and 56.24 cm) at 30 and 45 DAT, respectively. However the F_0 (Control) treatment had the lowest canopy diameter of broccoli (30.66 and 49.71 cm) at 30 and 45 DAT, respectively. This may be due to increased supply of major and micronutrients which are required in larger quantities for growth and development of plants. Plant nutrients accelerate the development of growth and reproductive phase and protein synthesis, thus promoting canopy diameter of broccoli at different days after transplanting. The result obtained from the present study was similar with the findings of Thapa *et al.* (2016) who observed that growth and development of sprouting broccoli was influenced by increased application of boron and molybdenum.

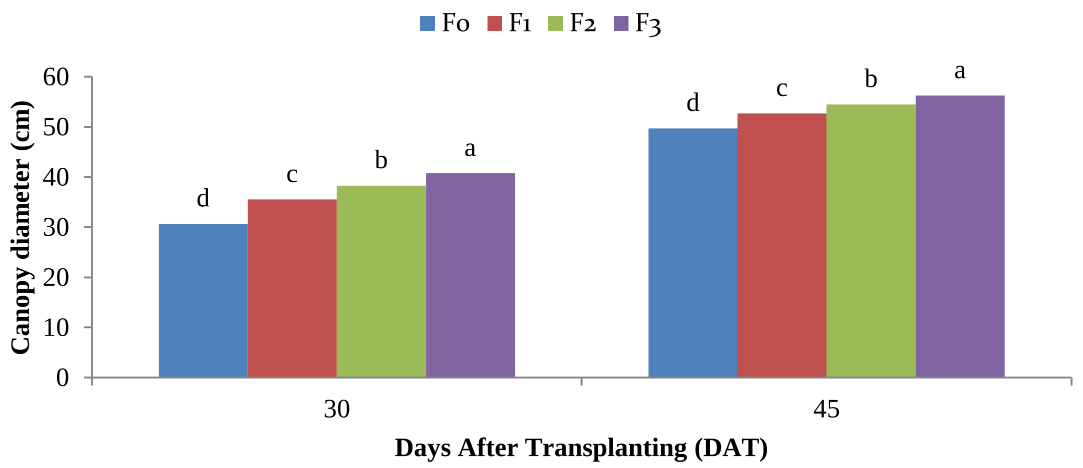

Figure 9. Effect of different doses of micronutrient application on canopy diameter of broccoli at different days after transplanting

Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

The fertilizer application strategy exhibited a significant effect on canopy diameter of broccoli at different days after transplanting (Figure 10). The results showed that, the M_2 treatment (Foliar spray before flowering) had the highest canopy diameter of broccoli (38.16 and 54.58 cm) at 30 and 45 DAS, respectively. However, the M_1 (Direct application) treatment, was found to produce the lowest canopy diameter of broccoli (33.93 and 51.62 cm) at 30 and 45 DAS, respectively. The beneficial effected of foliar application of micronutrients on growth parameters might be due to balance supply of micronutrients during growing season. Similar result also observed by Doddamani *et al*. (2020) indicated that the vegetative growth of field bean was significantly influenced by Zn and B foliar application treatments.

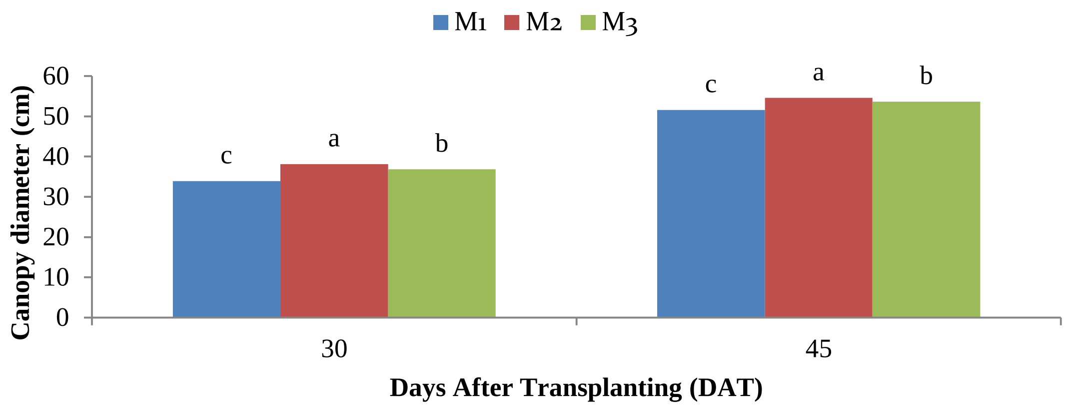

Figure 10. Effect of fertilizer application methods on canopy diameter of broccoli at different days after transplanting

Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

Different micronutrient doses and fertilizer application methods significantly influenced the canopy diameter of broccoli at various days after transplanting. (Table 4). The experiment results showed that the F_3M_2 treatment combination produced the largest canopy diameter of broccoli (42.93 and 58.05 cm) at 30 and 45 DAT, which was statistically identical to the F_3M_3 (42.55 cm) treatment combination at 30 DAT. At 30 and 45 DAT, the F_0M_1 treatment combination had the smallest canopy diameter (29.50 and 48.50 cm, respectively).

Table 4. Combined effect of micronutrients and application methods of fertilizer on canopy diameter of broccoli at different days after transplanting

Treatment combinations	Canopy diameter at	
	30 DAT	**45 DAT**
F_0M_1	29.50 k	48.50 h
F_0M_2	31.82 i	50.69 fg
F_0M_3	30.657 j	49.95 g
F_1M_1	35.33 f	52.17 e
F_1M_2	38.24 d	54.49 cd
F_1M_3	32.99 h	51.43 ef
F_2M_1	34.14 g	52.17 e
F_2M_2	39.65 c	55.11 c
F_2M_3	41.08 b	56.17 b
F_3M_1	36.75 e	53.65 d
F_3M_2	42.93 a	58.05 a
F_3M_3	42.55 a	57.01 b
$LSD_{(0.05)}$	0.6494	1.0094
CV (%)	5.24	7.26

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, F_0 = $Zn_0B_0Mo_0$ kg ha^{-1} (Control), F_1 = $Zn_2B_1Mo_1$ kg ha^{-1}, F_2 = $Zn_4B_2Mo_{1.5}$ kg ha^{-1}, F_3 = $Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.6 Primary curd diameter (cm)

Broccoli primary curd diameter was significantly influence by different levels of micronutrients application at 45 days after transplanting (Table 5). The result of the experiment showed that the F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment had the highest primary curd diameter of broccoli (5.14 cm) at 45 DAT. However the F_0 (Control) treatment had the lowest primary curd diameter of broccoli (2.44 cm) at 45 DAT.

At 45 days after transplanting, the method of fertilizer application had a significant impact on the diameter of broccoli's primary curd. (Table 6). The results showed that, the M_2 treatment (Foliar spray before flowering) had the highest primary curd diameter of broccoli (4.44 cm) at 45 DAT which was statistically identical with M_3 treatment (3.99 cm). However, the M_1 (Direct application) treatment, was found to produce the lowest primary curd diameter of broccoli (3.32 cm) at 45 DAT.

The primary curd diameter of broccoli at 45 days after transplanting was significantly influenced by various micronutrients doses and fertilizer application method (Table 7). According to the experimental findings, the F_3M_2 treatment combination had the largest primary curd diameter of broccoli at 45 DAT (5.96 cm), which was statistically comparable to the F_3M_3 (5.42 cm) treatment combination's having curd diameter of broccoli 5.42 cm. The lowest primary curd diameter of broccoli was found in the F_0M_1 treatment combination (2.12 cm), which was statistically comparable to the F_0M_2 (2.76 cm) and F_0M_3 (2.44 cm) treatment combinations.

4.7 Curd length (cm)

Different doses of micronutrient application had shown significant effect on broccoli curd length at 60 days after transplanting. (Table 5). The experimental findings revealed that the F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment's broccoli curd length at 60 DAT was the highest (18.01 cm). However, at 60 DAT, the F_0 (Control) treatment exhibited the shortest curd length of broccoli (13.68 cm).

Table 5. Effect of different doses of micronutrient application on primary curd diameter, curd length and curd diameter (cm) of broccoli

Treatment combinations	Primary curd diameter (cm)	Curd length (cm)	Curd diameter (cm)
F_0	2.44 c	13.68 d	10.19 d
F_1	3.72 b	15.79 c	12.39 c
F_2	4.36 b	16.88 b	13.24 b
F_3	5.14 a	18.01 a	14.37 a
$LSD_{(0.05)}$	0.7350	0.7124	0.7532
CV%	4.21	4.56	8.25

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, F_0 = $Zn_0B_0Mo_0$ kg ha^{-1} (Control), F_1 = $Zn_2B_1Mo_1$ kg ha^{-1}, F_2 = $Zn_4B_2Mo_{1.5}$ kg ha^{-1} and F_3 = $Zn_6B_3Mo_2$ kg ha^{-1}.

The methods of fertilizer applications had shown significant effect on the curd length of broccoli at 60 days after transplanting (Table 6). The M_2 treatment (Foliar spray before flowering) had the highest curd length (17.05) of broccoli at 60 DAT. However, at 60 DAT, the M_1 (Direct application) treatment had the lowest curd length of broccoli (14.99 cm).

Table 6. Effect of fertilizer application methods on primary curd diameter, curd length and curd diameter (cm) of broccoli

Treatment combinations	Primary curd diameter (cm)	Curd length (cm)	Curd diameter (cm)
M_1	3.32 b	14.99 c	11.58 c
M_2	4.44 a	17.05 a	13.37 a
M_3	3.99 a	16.23 b	12.70 b
$LSD_{(0.05)}$	0.6365	0.6170	0.6523
CV%	4.21	4.56	8.25

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The crud length of broccoli at 60 days after transplanting was significantly influenced by various micronutrients doses and fertilizer application method (Table 2). According to the experimental findings, the F_3M_2 treatment combination had the highest curd length (19.57) of broccoli at 60 DAT. However the lowest crud length of broccoli was found in the F_0M_1 treatment combination (12.46 cm) at 60 DAT.

4.8 Curd diameter (cm)

Broccoli curd diameter was significantly influence by different levels of micronutrients application at 60 days after transplanting (Table 5). The result of the experiment showed that the F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment had the highest curd diameter of broccoli (14.37 cm) at 60 DAT. However the F_0 (Control) treatment had the lowest curd diameter of broccoli (10.19 cm) at 45 DAT. This variations in curd diameter of broccoli might be due to the increased availability of micronutrients which enhances soil aggregation, aeration, water holding capacity thereby increasing nutrients adsorption by plant and influence growth and development of the plant. Farooq *et al.* (2018) reported higher curd diameter in broccoli with increasing boron dose. Patel *et al.* (2017) showed that in broccoli application of borax (1.5%) gives curd diameter 14.48 cm and curd length 13.02 cm.

The methods of fertilizer application had a significant effect on the curd diameter of broccoli at 60 days after transplanting (Table 6). The results showed that, the M_2 treatment (Foliar spray before flowering) had the highest curd diameter of broccoli (13.37 cm) at 60 DAT. However, the M_1 (Direct application) treatment, was found to produce the lowest curd diameter of broccoli (11.58 cm) at 45 DAT. The higher curd diameter of broccoli may be attributed to accelerated photosynthates from the source to the sink which is influenced by growth hormones either released or synthesized due to foliar applied nutrients. These findings are in agreement with the findings of Mahmoud *et al.* (2019) who reported that the foliar spray of zinc + boron (200 ppm of each) increased curd diameter of broccoli.

The curd diameter of broccoli at 60 days after transplanting was significantly influenced by various micronutrients doses and fertilizer application method (Table 7). According to the experimental findings, the F_3M_2 treatment combination had the largest curd diameter of broccoli at 60 DAT (15.88 cm), which was statistically comparable to the F_3M_3 treatment combination (14.63 cm). The lowest primary curd diameter of broccoli was found in the F_0M_1 treatment combination (9.42 cm), which was statistically comparable to the F_0M_2 (10.31 cm) treatment combination.

Table 7. Combined effect of micronutrients and application methods of fertilizer on primary curd diameter, curd length and curd diameter (cm) of broccoli

Treatment combinations	Primary curd diameter (cm)	Curd length (cm)	Curd diameter (cm)
F_0M_1	2.12 i	12.46 i	9.42 h
F_0M_2	2.76 g-i	14.53 gh	10.31 gh
F_0M_3	2.44 hi	14.07 h	10.85 fg
F_1M_1	3.72 d-g	15.81 ef	12.41 de
F_1M_2	4.36 b-e	16.60 c-e	13.39 b-d
F_1M_3	3.08 f-i	14.96 f-h	11.37 e-g
F_2M_1	3.40 e-h	15.40 e-g	11.89 ef
F_2M_2	4.68 b-d	17.49 b-d	13.88 bc
F_2M_3	5.00 a-c	17.73 bc	13.95 b
F_3M_1	4.04 c-f	16.31 de	12.60 c-e
F_3M_2	5.96 a	19.57 a	15.88 a
F_3M_3	5.42 ab	18.16 b	14.63 ab
$LSD_{(0.05)}$	1.2731	1.2339	1.3045
CV (%)	4.21	4.56	8.25

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.9 Number of branches per plant

Depending on the micronutrients application doses broccoli branch per plant varied significantly (Table 8). According to the experimental results, the F_3 treatment had the highest number of branch per plant (5.69) followed by (5.32) F_2 treatment. While the

F_0 (Control) treatment, had the lowest number of branch per plant (4.17). The positive response of secondary micronutrients with recommended NPK can be attributed to the availability of sufficient amount of plant nutrients throughout the growth period, resulting in better lateral root growth, catalyzing the metabolism of carbohydrates, increase in enzyme activity, other biological oxidation reactions and growth and yield advantage. Islam *et al*. (2018) reported that the application of micronutrients either singly or in combination had significant effects on the number of branches per plant of lentil.

Table 8. Effect of different doses of micronutrient application on number of branches per plant, number of inflorescences per branch, number of flowers per inflorescence and number of pod per inflorescence of broccoli

Treatment combinations	Number of branch per plant	Number of inflorescences per branch	Number of flowers per inflorescence	Number of pod per inflorescence
F_0	4.17 d	10.26 d	43.14 d	24.30 d
F_1	4.96 c	12.80 c	54.04 c	29.35 c
F_2	5.32 b	14.637 b	59.52 b	31.85 b
F_3	5.69 a	15.49 a	69.37 a	34.62 a
$LSD_{(0.05)}$	0.1455	0.3644	3.4647	0.8344
CV%	7.25	5.36	6.45	5.02

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1} and $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

Different doses of fertilizer application significantly influenced branch per plant of broccoli at different days after transplanting (Table 9). Experimental result showed that the highest number of branch per plant (5.32) was found in M_2 treatment and followed by (5.06) M_3 treatment. While the M_1 treatment had the lowest number of branch per plant (54.72). Spraying of fertilizer ensured favorable condition for the growth of broccoli plant with maximum branches plant^{-1}. Increase in number of branches may be due to more nutrient uptake during vegetative growth. While at later stage nutrients were diverted towards reproductive parts of plants. Doddamani *et al*. (2020) reported that in field bean the vegetative growth like number of branches plant^{-1} was significantly influenced by Zn and B foliar application treatments.

The combined effect of micronutrients doses and fertilizer application method had shown significant effect on number of branches per plant of broccoli (Table 10). Experimental result showed that the highest number of branches per plant (6.00) was observed in the F_3M_2 treatment combination which was statistically similar (5.88) to the F_3M_3 treatment combination. While the lowest number of branches per plant of broccoli was found in the F_0M_1 treatment combination (4.00), which was statistically comparable to the F_0M_3 (4.17 cm) treatment combinations.

4.10 Number of inflorescences per branch

The branching of broccoli inflorescences varied significantly depending on the micronutrient application doses. (Table 8). According to the experimental data, the F_3 treatment had the highest number of inflorescence branches (15.49). While the F_0 (Control) treatment had the lowest inflorescence branches (10.26).

Different doses of fertilizer application significantly influenced on the inflorescences branches of broccoli (Table 9). Experimental result showed that the highest number of inflorescence per branch (14.44) was found in M_2 treatment. While the M_1 treatment had the lowest number of inflorescence per branch (11.96).

The combined effect of micronutrients doses and fertilizer application method had shown significant effect on number of inflorescences branches of broccoli (Table 10). Experimental result showed that the highest number of inflorescence branches (16.67) was observed in the F_3M_2 treatment combination which was statistically comparable to the F_3M_3 treatment combination (16.33). While the lowest number of inflorescences branches of broccoli was found in the F_0M_1 treatment combination (9.67), which was statistically comparable to the F_0M_3 (10.26) treatment combinations.

4.11 Number of flowers per inflorescence

The number of flower per inflorescence of broccoli varied significantly depending on the micronutrient application doses. (Table 8). According to the experimental data, the F_3 treatment had the highest number of flower per inflorescence (69.37). While the F_0 (Control) treatment had the lowest number of flower per inflorescence of broccoli (43.14).

The number of flowers per inflorescence of broccoli was significantly influenced by different methods of fertilizer application (Table 9). The M_2 treatment had the highest number of flowers per inflorescence (63.29), according to the experimental results. However, the M_1 treatment had the lowest number of flowers per inflorescence (48.43).

Table 9. Effect of fertilizer application methods of on number of branch per plant, number of inflorescences per branch, number of flower per inflorescence and number of pod per inflorescence of broccoli

Treatment combinations	Number of branches per plant	Number of inflorescences per branch	Number of flowers per inflorescence	Number of pod per inflorescence
M_1	4.72 c	11.96 c	48.43 c	30.18 b
M_2	5.32 a	14.44 a	63.29 a	31.21 a
M_3	5.06 b	13.49 b	57.83 b	28.70 c
$LSD_{(0.05)}$	0.1260	0.3156	3.0005	0.7226
CV%	7.25	5.36	6.45	5.02

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The combined effect of micronutrient doses and fertilizer administration method on the number of flowers per inflorescence of broccoli was significant. (Table 10). The experimental results revealed that the F_3M_2 treatment combination recorded the highest flowers per inflorescence (77.00), which was statistically equal to the F3M3 treatment combination. (73.69). While the F_0M_1 treatment combination had the fewest flowers per inflorescence of broccoli (37.67), it was statistically equal to the F_0M_3 (40.84) treatment combination.

4.12 Number of pod per inflorescence

The number of pod per inflorescence of broccoli varied significantly depending on the micronutrient application doses. (Figure 3). According to the experimental data, the F_3 treatment had the highest number of pod per inflorescence (34.62). While the F_0 (Control) treatment had the lowest number of pod per inflorescence of broccoli (24.30).

Different fertilizer application techniques had a significant effect on number of pod per inflorescence of broccoli (Table 9). According to the experimental findings, the M_2 treatment had the highest number of pods per inflorescence (31.21). Nevertheless, the M_3 treatment had the fewest number of pods per inflorescence. (28.70). This increase in pods number in foliar application of fertilizer might be due to the better utilization of photosynthates for reproductive growth instead of rapid development of vegetative growth.

The combined effect of micronutrient doses and fertilizer application method on number of pod per inflorescence of broccoli was found to be significant. (Table 10). The experimental results revealed that the F_3M_1 treatment combination recorded the highest number of pod per inflorescence of broccoli (37.67). While the F_0M_3 treatment combination had the lowest number pod per inflorescence of broccoli (23.00), it was statistically equal to the F_0M_2 (24.31) treatment combinations.

Table 10. Combined effect of micronutrients and application methods of fertilizer on number of branches per plant, number of inflorescences per branches, number of flowers per inflorescence and number of pod per inflorescence of broccoli

Treatment combinations	Number of branches per plant	Number of inflorescences branch	Number of flowers per inflorescence	Number of pod per inflorescence
F_0M_1	4.00 j	9.67 i	37.67 k	25.6 ij
F_0M_2	4.33 hi	10.86 gh	50.9 gh	24.31 jk
F_0M_3	4.17 ij	10.26 hi	40.84 jk	23.00 k
F_1M_1	5.00 f	12.65 e	54.15 fg	29.35 fg
F_1M_2	5.37 de	14.29 c	60.32 de	31.85 de
F_1M_3	4.50 gh	11.45 fg	47.64 hi	26.85 hi
F_2M_1	4.67 g	12.05 ef	44.49 ij	28.1 gh
F_2M_2	5.58 cd	15.93 b	64.92 cd	33.1 cd
F_2M_3	5.71 bc	15.93 b	69.14 bc	34.35 bc
F_3M_1	5.20 ef	13.47 d	57.41 ef	37.67 a
F_3M_2	6.00 a	16.67 a	77.00 a	35.60 b
F_3M_3	5.88 ab	16.33 ab	73.69 ab	30.60 ef
$LSD_{(0.05)}$	0.2519	0.6311	6.0010	1.4453
CV (%)	7.25	5.36	6.45	5.02

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.13 Individual pod length (cm)

Individual pod length of broccoli showed non significant effect depending on the micronutrient application doses. (Table 11). According to the experimental data, the F_3 treatment had the highest pod length of broccoli (5.89 cm). While the F_0 (Control) treatment had the lowest pod length of broccoli (4.72 cm).

Different fertilizer application methods had shown non significant effect on pod length of broccoli (Table 12). According to the experimental findings, the M_2 treatment had the highest pod length (5.65 cm). Nevertheless, the M_1 treatment had the lowest pod length of broccoli (4.78 cm).

The combined effect of micronutrient doses and fertilizer application method on pod length of broccoli was found to be non-significant. (Table 13). The experimental results revealed that the F_3M_3 treatment combination recorded the highest pod length of broccoli (6.27 cm). While the F_0M_2 treatment combination had the lowest pod length of broccoli (4.33 cm).

4.14 Number of pods per plant

The different doses of micronutrients application significantly affected the number of pods per plant of broccoli (Table 11). Experimental result revealed that the highest number of pods per plant of broccoli (2204.90) was found in F_3 treatment. Whereas the lowest number of pods per plant (1426.20) was found in F_0 treatment. The result was similar with the findings of Islam *et al*. (2018) revealed that the application of micronutrients either singly or in combination had significant effects on the number of pods per plant of lentil.

Table 11. Effect of different doses of micronutrient application on individual pod length, number of pods per plant and number of seed per pod of broccoli

Treatment combinations	Individual pod length (cm)	Number of pods per plant	Number of seed per pod
F_0	4.72	1426.20 d	4.96 d
F_1	4.94	1797.70 c	6.46 c
F_2	5.49	1988.20 b	7.28 b
F_3	5.89	2204.90 a	8.31 a
$LSD_{(0.05)}$	1.2273 ^{NS}	63.400	0.4161
CV%	8.25	4.23	6.85

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1} and $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

The number of pods per plant of broccoli was significantly influenced by the various fertilizer application method (Table 12). According to the experimental results the highest number of pods per plant (2008.2) was observed in the M_2 treatment. However. the M_1 treatment had the lowest number of pods per plant (1682). This might be due to the stimulating influence of boron enhancing the rate of absorption of N, P and K and other nutrients and took part in sugar translocation. Besides the role of zinc in chlorophyll formation, it also influenced cell division, meristematic activity of tissues, and expansion of cell and formation of cell wall which might be lead to the increased pod number of broccoli. Melash *et al*. (2016) concluded that foliar spray, soil application and seed treatment are the most effective application strategies for some micronutrients. Pandey and Gupta (2012) at Lucknow reported that foliar application of boron at 0.1% increase the yield attributing parameter like number of pod plant^{-1} in black gram.

Table 12. Effect of fertilizer application methods on individual pod length, number of pods per plant and number of seed per pod of broccoli

Treatment combinations	Individual pod length (cm)	Number of pods per plant	Number of seed per pod
M_1	5.34	1682 c	6.0275 c
M_2	4.78	2008.2a	7.3388a
M_3	5.65	1873.1 b	6.8975 b
$LSD_{(0.05)}$	1.0628 ^{NS}	54.906	0.3604
CV%	8.25	4.23	6.85

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The combined effect of micronutrient doses and fertilizer application method on pod number of broccoli was found to be significant. (Table 13). The experimental results revealed that the F_3M_2 treatment combination recorded the highest pod number of broccoli (2449.30). While the F_0M_1 treatment combination had the lowest number of pods of broccoli (1332.80 cm) which was statistically similar with the F_0M_3 (1425.80) treatment combination.

4.15 Number of seed per pod

The number of seeds per pod of broccoli was significantly affected by the different doses of micronutrients applied. (Table 11). Experimental result revealed that the F_3 treatment had the highest number of seeds per pod of broccoli (8.31). The F_0 treatment had the fewest seeds per pod (4.96). This might be due to the application of micronutrients, enhanced the proper vegetative growth and development of broccoli plants result in increased seeds per pod of broccoli. The result was similar with the findings of Hossain *et al.* (2017) reported that application of micronutrients influences number of seeds per umbel in onion.

The number of seeds per pod of broccoli was significantly influenced by fertilizer application method. (Table 12). According to the experimental results the highest number of seeds per pod of broccoli (7.33) was observed in the M_2 treatment. However. the M_1 treatment had the lowest number of seeds per pod of broccoli (6.03). The variation of seeds per pod among different treatment due to reason that foliar application of micronutrients was more suitable than soil application due to the rapid availability, ease of use and reduced toxicity that could be caused by accumulation and element stabilization in the soil. Moreover, nutrient availability to plant from soil application could be reduced due to binding in the soil and restricted uptake when moisture is limiting. Islam *et al*. (2018) reported that agronomic bio-fortification through foliar boron application might have enhanced the seed setting that resulted in an increasing number of seeds pod^{-1} in lentil.

The combined effect of micronutrient doses and fertilizer application method on seeds per pod of broccoli was found to be significant. (Table 13). The experimental results revealed that the F_3M_2 treatment combination recorded the highest number of seeds per pod of broccoli (9.10) which was statistically similar with the F_3M_3 (8.95) treatment combination. While the F_0M_1 treatment combination had the lowest number of seeds per pod of broccoli (4.60) which was statistically similar with the F_0M_3 (4.97) treatment combination.

Table 13. Combined effect of micronutrients and application methods of fertilizer on individual pod length, number of pods per plant, and number of seed per pod of broccoli

Treatment combinations	Individual pod length	Number of pod per plant	Number of seed per pod
F_0M_1	4.66	1332.80 k	4.60 h
F_0M_2	4.33	1520.00 ij	5.32 g
F_0M_3	5.16	1425.80 jk	4.97 gh
F_1M_1	4.83	1799.90 fg	6.45 e
F_1M_2	4.49	1982.70 de	7.26 cd
F_1M_3	5.49	1610.50 hi	5.68 fg
F_2M_1	5.82	1706.80 gh	6.19 ef
F_2M_2	4.99	2080.80 cd	7.67 bc
F_2M_3	5.67	2178.90 bc	7.99 b
F_3M_1	6.07	1888.40 ef	6.87 de
F_3M_2	5.32	2449.30 a	9.10 a
F_3M_3	6.27	2277.10 b	8.95 a
$LSD_{(0.05)}$	2.1257^{NS}	109.81	0.7207
CV (%)	8.25	4.23	6.85

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

4.16 Seed yield per plant (g)

The effect of different micronutrient application doses on broccoli seed yield per plant was found to be significant. (Table 14). The F_3 treatment had the highest seed yield per plant of broccoli (34.66 g). While the F_0 treatment had the lowest seed yield per plant of broccoli (19.76 g). These results are in accordance with Kiran *et al.* (2018) who reported that increased application of micronutrients significantly influenced seed yield per plant of cowpea.

The seed yield per plant of broccoli was significantly influenced by fertilizer application method. (Table 15). According to the experimental results the highest seed yield per plant of broccoli (30.86 g) was observed in the M_2 treatment. However. the M_1 treatment had the lowest seed yield per plant of broccoli (24.69 g). Manjunath *et al*. (2020) reported that foliar spray of zinc and boron showed increased seed yield per plant of field bean. El -Habbasha *et al.* (2013) reported that the foliar application of Zn (0.2 %) at seed filling stages regardless N application significantly increased seed yield per plant of groundnut.

The combined effect of micronutrient doses and fertilizer application strategy greatly influenced broccoli seed yield per plant. (Table 16). The experimental results demonstrated that the F_3M_2 treatment combination produced the highest seed yield per plant of broccoli (39.17 g). While the F_0M_1 treatment combination had the lowest seed yield per plant of broccoli (17.99), which was statistically similar to the F_0M_3 (19.76 g) treatment combination.

4.17 Seed yield per plot (g)

Different micronutrient application levels had shown significant effect on broccoli seed yield per plot. (Table 14). According to the experimental result The F_3 treatment had the highest seed yield per plot of broccoli (311.97 g). While the F_0 treatment had the lowest seed yield per plot of broccoli (177.84 g).

Table 14. Effect of different doses of micronutrient application on seed yield per plant, seed yield per plot, seed yield per hectare, germination % and vigority index of broccoli

Treatment combinations	Seed yield per plant (g)	Seed yield per plot (g)	Seed yield per hectare (kg)	Germination %	Vigority index
F_0	19.76 d	177.84 d	658.70 d	82.49	1237.20 d
F_1	26.91 c	242.18 c	897.00 c	84.38	1416 .00 c
F_2	30.50 b	274.51 b	1016.70 b	85.40	1550.80 b
F_3	34.66 a	311.97 a	1155.40 a	86.64	1644.80 a
$LSD_{(0.05)}$	1.3881	12.493	46.269	4.2139^{NS}	19.607
CV%	5.25	5.25	5.25	7.58	5.24

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1} and $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}.

Broccoli seed yield per plot was significantly influenced by fertilizer application method. (Table 15). According to the experimental results the highest seed yield per plot of broccoli (277.79 g) was observed in the M_2 treatment. However. the M_1 treatment had the lowest seed yield per plant of broccoli (222.27 g).

The combination of micronutrient doses and fertilizer application strategy had a significant impact on broccoli seed yield per plot. (Table 16). The experimental results showed that the F_3M_2 treatment combination resulted in the highest seed yield per plot (352.57 g). While the F_0M_1 treatment combination had the lowest seed yield per plot of broccoli (161.95), it was statistically comparable to the F_0M_3 treatment combination (177.83 g).

4.18 Seed yield per hectare (kg)

The seeds yield of broccoli per hectare had been significantly influenced by various micronutrient application levels. (Table 14). According to the results of the experiment, the F_3 treatment produced the highest seed yield per hectare of broccoli (1155.40 kg). While broccoli plants grown under the F_0 treatment produced the fewest seed yield per hectare (658.70 kg).

Broccoli seed yield per hectare was significantly influenced by fertilizer application method. (Table 15). According to the experimental results the highest seed yield per hectare of broccoli (1028 kg) was observed in the M_2 treatment. However. the M_1 treatment had the lowest seed yield per plant of broccoli (823.2 g).

Table 15. Effect of fertilizer application methods on seed yield per plant, seed yield per plot, seed yield per hectare, germination % and vigority index of broccoli

Treatment combinations	Seed yield per plant (g)	Seed yield per plot (g)	Seed yield per hectare (kg)	Germination %	Vigority index
M_1	24.69 c	222.27 c	823.2 c	83.23	1359.00 c
M_2	30.86 a	277.79a	1028.8a	85.27	1535.80 a
M_3	28.31 b	254.82 b	943.8 b	85.68	1491.90 b
$LSD_{(0.05)}$	1.2021	10.819	40.070	3.6493 ^{NS}	16.98
CV%	5.25	5.25	5.25	7.58	5.24

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

The combination of micronutrient doses and fertilizer application strategy had a significant impact on broccoli seed yield per hectare. (Table 16). The experimental results showed that the F_3M_2 treatment combination resulted in the highest seed yield per hectare (1305.80 kg). While the F_0M_1 treatment combination had the lowest seed yield per hectare of broccoli (599.80 kg), it was statistically comparable to the F_0M_3 treatment combination (658.60 kg).

4.19 Seed germination %

The application of different of doses of micronutrient on seed germination percentage of broccoli was found to be non-significant. (Table 14). Experimental result showed that the highest seed germination percentage (86.64 %) was observed in F_3 treatment. While the F_0 treatment had the lowest seed germination percentage (82.49%).

Broccoli seed germination percentage was shown non significant effect due to different fertilizer application method. (Table 15). According to the experimental results the highest seed germination percentage of broccoli (85.68 %) was observed in the M_3 treatment. However. the M_1 had the lowest seed germination percentage of broccoli (83.23 %).

The combination of micronutrient doses and fertilizer application strategies had no significant effect on broccoli seed germination percentage. (Table 16). The experimental results showed that the F_3M_2 treatment combination resulted in the highest seed germination percentage (88.32 %). While the F_0M_1 treatment combination had the lowest seed germination percentage of broccoli (81.33 %).

4.20 Vigority index

The effect of different doses of micronutrients application significantly affected the seed vigority index of broccoli (Table 14). Experimental result showed that the highest seed vigority index of broccoli (1644.80) was found in F_3 treatment. While the lowest seed vigority index of broccoli (1237.20) was found in F_0 treatment.

The seed vigority index of broccoli was significantly influenced by fertilizer application method. (Table 15). According to the experimental results the highest seed vigority index of broccoli (1535.80) was observed in the M_2 treatment. However. the M_1 treatment had the lowest seed vigority index of broccoli (1359.00). The use of micronutrients has a profound effect on the growth and development of plants as they are essential for plant growth since they increase the absorption and uptake of NPK and also trigger the defense mechanism of plants and ultimately enhance plant growth. The improvement in seed vigority index of broccoli in increased micronutrients applied plots may be due to the increase amount of assimilates translocation, activation of photosynthetic enzymes and chlorophyll formation thereby increased plant growth, development and seed yield.

The combined effect of micronutrient doses and fertilizer application method significantly influenced seed weight per pod of broccoli (Table 16). The experimental results revealed that the F_3M_2 treatment combination recorded the highest seed vigority index of broccoli (1766.40). While the F_0M_1 treatment combination had the lowest seed vigority index of broccoli (1180.00).

Table 16. Combined effect of micronutrients and application methods of fertilizer on seed yield per plant, seed yield per hectare, germination % and vigority index of broccoli

Treatment combinations	Seed yield per plant (g)	Seed yield per plot (g)	Seed yield per hectare (kg)	Germinat ion %	Vigority index
F_0M_1	17.99 k	161.95 k	599.80 k	81.33	1180.00 j
F_0M_2	21.53 ij	193.76 ij	717.60 ij	83.15	1287.50 h
F_0M_3	19.76 jk	177.83 jk	658.60 jk	83.00	1244.20 i
F_1M_1	26.94 fg	242.50 fg	898.20 fg	84.00	1380.10 g
F_1M_2	30.48 de	274.30 de	1015.90 de	84.33	1513.30 e
F_1M_3	23.30 hi	209.75 hi	776.80 hi	84.81	1354.60 g
F_2M_1	25.12 gh	226.13 gh	837.50 gh	84.00	1421.20 f
F_2M_2	32.28 cd	290.52 cd	10760 cd	85.31	1575.90 d
F_2M_3	34.10 bc	306.88 bc	1136.60 bc	86.89	1655.30 c
F_3M_1	28.72 ef	258.52 ef	957.50 ef	83.61	1454.50 f
F_3M_2	39.17 a	352.57 a	1305.80 a	88.32	1766.40a
F_3M_3	36.09 b	324.81 b	1203.00 b	88.00	1713.50 b
$LSD_{(0.05)}$	2.4042	21.638	80.140	7.2987 NS	33.96
CV (%)	5.25	5.25	5.25	7.58	5.24

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 5% level of significance. Here, $F_0 = Zn_0B_0Mo_0$ kg ha^{-1} (Control), $F_1 = Zn_2B_1Mo_1$ kg ha^{-1}, $F_2 = Zn_4B_2Mo_{1.5}$ kg ha^{-1}, $F_3 = Zn_6B_3Mo_2$ kg ha^{-1}, M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray.

CHAPTER V

SUMMARY AND CONCLUSION

A field experiment was conducted at research field of Sher-e-Bangla Agricultural University, Dhaka during the period from from October 2021 March 2022 in the Rabi season to study the influence of micronutrients and their application methods on seed yield of broccoli. The experiment consisted of two factors and followed Randomized Complete Block Design (RCBD) with three replications. Factor A: Levels of micronutrients (4) *viz;* F_0 = $Zn_0B_0Mo_0$ kg ha^{-1} (Control), F_1 = $Zn_2B_1Mo_1$ kg ha^{-1}, F_2 = $Zn_4B_2Mo_{1.5}$ kg ha^{-1}, F_3 = $Zn_6B_3Mo_2$ kg ha^{-1} and Factor B: Different methods of fertilizer applications (3) *viz;* M_1= Direct application (Before transplanting), M_2= Foliar spray (Before flowering) and M_3= Direct soil + foliar spray. Experimental results revealed that different doses of micronutrients and fertilizer application methods significantly influenced the growth and seed yield of broccoli.

In case of micronutrients application the highest growth parameters *i.e*. plant height, number of leaves, leaf length, leaf breadth and canopy diameter were observed by F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment. However this treatment also recorded the highest primary curd diameter of broccoli (5.14 cm), curd length (18.01 cm), curd diameter (14.37), number of branch per plant (5.69), number of inflorescence branches (15.49), number of flower per inflorescence (69.37), number of pod per inflorescence (34.62), pod length (5.89 cm), number of pods per plant of broccoli (2204.90), number of seeds per pod of broccoli (8.31), seed weight per pod of broccoli (19.25 g), seed yield per plant (34.66 g), seed yield per plot (311.97 g), seed yield per hectare (1155.40 kg) and seed germination percentage (86.64 %). Whereas the lowest yield contributing characteristics and yield *viz;* primary curd diameter (2.44 cm), curd length (13.68 cm), curd diameter (10.19 cm), number of branch per plant (4.17), number of inflorescence branches (10.26), number of flower per inflorescence (43.14), number of pod per inflorescence (24.30), pod length of (4.72 cm), number of pods per plant (1426.20), seeds per pod (4.96), seed weight per pod of broccoli (11.92 g), seed yield per plant of broccoli (19.76 g), seed yield per plot of broccoli (177.84 g), seed yield per hectare (658.70 kg) and seed germination percentage (82.49%) were observed in F_0 (Control treatment).

However in terms of different methods of fertilizer applications, M_2 (Foliar spray before flowering) treatment showed the highest growth characteristics, including plant height, number of leaves, leaf length, leaf breadth and canopy diameter. In contrast to other treatments, this (M_2) treatment recorded the highest primary curd diameter of broccoli (4.44 cm), curd length (17.05), curd diameter (13.37 cm), number of branch per plant (5.32), number of inflorescence branches (14.44), number of flowers per inflorescence (63.29), number of pods per inflorescence (31.21),pod length (5.65 cm), number of pods per plant (2008.2), seeds per pod of broccoli (7.33), seed weight per pod (17.42 g), seed yield per plant (30.87 g), seed yield per plot of broccoli (277.79 g) and seed yield per hectare (1028 kg). However, the M_1 (Direct application) treatment, was found to produce the lowest primary curd diameter of broccoli (3.32 cm), curd length of broccoli (14.99 cm), curd diameter (11.58 cm), number of branch per plant (54.72), number of inflorescence branches (11.96),number of flowers per inflorescence (48.43), pod length of broccoli (4.78 cm), number of pods per plant (1682), seeds per pod of broccoli (6.03), seed weight per pod of broccoli (14.34 g), seed yield per plant (24.69 g), seed yield per plant of broccoli (222.27 g), seed yield per plant of broccoli (823.2 g) and seed germination percentage of broccoli (83.23 %) comparable to other treatments.

In case of combination, the F_3M_2 treatment combination demonstrated the best growth traits in terms of plant height, number of leaves, leaf length, leaf breadth and canopy diameter. This treatment combination, however, also recorded the highest primary curd (5.96 cm), curd length (19.57), curd diameter (15.88 cm), number of branches per plant (6.00), number of inflorescence branches (16.67), number of pod per inflorescence (37.67), pod number (2449.30), number of seeds per pod of broccoli (9.10), seed weight per pod of broccoli (21.60 g), seed yield per plot (352.57 g), seed yield per hectare (1305.80 kg) and seed germination percentage (88.32 %). However the corresponding lowest value were observed in F_0M_1 treatment combination.

Conclusion

Based on the above findings experimental results revealed that different doses of micronutrients and fertilizer application methods significantly influenced the growth and seed yield of broccoli.

i. In case of micronutrients application the highest number of pods per plant (2204.90), number of seeds per pod (8.31), seed yield per plant (34.66 g) and seed yield per hectare (1155.40 kg) were observed by F_3 ($Zn_6B_3Mo_2$ kg ha^{-1}) treatment.
ii. In terms of different methods of fertilizer applications, M_2 (Foliar spray before flowering) treatment recorded the highest number of pods per plant (2008.2), seeds per pod of broccoli (7.33), seed yield per plant (30.87 g) and seed yield per hectare (1028 kg).
iii. When applied together application of $Zn_6B_3Mo_2$ kg ha^{-1} along with fertilizer application through foliar spray before flowering affected broccoli plant growth and yield-contributing characteristics, leading to the maximum seed yield per plant (39.17 g), seed yield per plot (352.57 g) and seed yield per hectare (1305.80 kg).

Therefore, it may be concluded that application of $Zn_6B_3Mo_2$ kg ha^{-1} along with fertilizer application through foliar spray before flowering (F_3M_2) is beneficial for better seed yield production of broccoli crop.

Recommendation

Further research in the following areas may be suggested based on the results of the current experiment:

i. A similar study in different agro-ecological zones (AEZ) of Bangladesh is required for regional adaptability;
ii. Other management practices may be included for additional research, and
iii. Other macro and micro inorganic fertilizer doses could be used for further research to narrow down the specific combination.

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APPENDICES

Appendix I. Map showing the experimental location under study

Appendix II. Soil characteristics of the experimental field

A. Morphological features of the experimental field

Morphological features	Characteristics
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0-15 cm depth)

Physical characteristics	
Constituents	**Percent**
Clay	29 %
Sand	26 %
Silt	45 %
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	**Value**
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10
Organic carbon (%)	0.45
Organic matter (%)	0.78
pH	5.6
Total nitrogen (%)	0.03

Sourse: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka.

Appendix III. Monthly meteorological information during the period from October 2021 to March, 2022.

Year	**Month**	**Air temperature (^0C)**		**Relative humidity (%)**	**Average rainfall (mm)**
		Maximum	**Minimum**		
2021	October	31.2	23.9	76	52 mm
	November	29.6	19.8	53	00 mm
	December	28.8	19.1	47	00 mm
2022	January	25.5	13.1	41	00 mm
	February	25.9	14	34	7.7 m
	March	31.9	20.1	38	71 mm

Source: Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix IV. Analysis of variance of the data on plant growth characteristics of broccoli

Source of variation	Degree of freedom	Mean square									
		Plant height (cm)		Number of leaves		Leaf length		Leaf breadth		Canopy Diameter	
		30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS
Replication	2	8.0039	4.0951	0.5364	0.0125	1.891	0.7706	0.08526	0.3575	0.483	1.7273
Nutrients(A)	3	94.479**	81.531**	15.095**	18.7807**	69.426**	58.075**	9.244**	16.25**	168.3**	69.73**
Method of application(B)	2	40.972**	40.552**	8.307**	17.4383**	25.376**	20.619**	4.745**	8.168**	56.04**	27.46**
Interaction (AxB)	6	15.014**	6.495**	0.847**	1.2083**	5.0825**	4.7192**	0.406**	1.458**	15.00**	4.214**
Error	22	0.6992	0.8469	0.2581	0.1676	0.7763	0.6051	0.3242	0.2402	0.118	0.2344

** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix V. Analysis of variance of the data on yield contributing characteristics of broccoli

Source of variation	Degree of freedom	Mean square						
		Primary Curd Diameter	Curd Length	CUD60	Number of Branch /Plant	Number of Inflorescences Branch	Number of flower per Inflorescence	Number of pod per Inflorescence
Replication		4.8994	0.9228	2.3795	0.22361	0.2706	18.73	1.325
Nutrients (A)	3	11.7369**	30.5503**	28.1135**	3.8295**	48.1723**	1077.92**	173.005**
Method of application (B)	2	3.8073**	12.8254**	9.7852**	1.095**	18.7592**	677.54**	19.174**
Interaction (AxB)	6	0.9401**	1.8941**	2.3969**	0.35961**	4.2408**	145.84**	25.698**
Error	22	0.1772	0.501	0.4374	0.00406	0.1284	12.13	0.682

** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data on yield characteristics of broccoli

Source of variation	Degree of freedom	Mean square							
		Individual Pod Length	Number of Pod per Plant	Number of seed per Pod	Seed Weight per Pod	Seed yield per plant	Seed yield per plot	Seed yield per ha	Germination %
Replication	2	0.06318	8195	0.0335	0.0236	1.766	143.1	1963	42.194
Nutrients (A)	3	2.54501^{NS}	982573**	17.9267**	86.9264**	359.162**	29092.1**	399068**	35.028 ^{NS}
Method of application (B)	2	2.30981^{NS}	322441**	5.3425**	28.6528**	115.261**	9336.1**	128068**	223.139 ^{NS}
Interaction (AxB)	6	0.10979^{NS}	80553**	1.4507**	6.9696**	28.889**	2340**	32099**	9.694 ^{NS}
Error	22	1.73004	3887	0.1965	0.5572	2.06	166.9	2289	20.619

** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VII. Analysis of variance of the data on vigority index of broccoli

Source of variation	Degree of freedom	Mean square		
		Root	shoot	Seedling
Replication	2	0.08096	0.0518	0.121
Nutrients (A)	3	3.52194**	11.1429**	27.1131**
Method of application (B)	2	1.15913**	3.3713**	8.4106**
Interaction (AxB)	6	0.20699**	0.6845**	1.5891**
Error	22	0.18646	0.0781	0.1166

** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability