The Pharma Innovation Journal 2023; 12(9): 2807-2811

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(9): 2807-2811

www.thepharmajournal.com
Received: 10-07-2023
Accepted: 13-08-2023

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Effect of application of micronutrients on broccoli: A review

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Abstract
Broccoli (*Brassica oleracea* var. *italica*) is an exotic vegetable of the Brassicaceae family. The commercial part of broccoli is the head which is a large floral bud. Higher demand of this vegetable in the market and the competition has forced the farmers to produce more yields resulting in overusing of chemical fertilizers to increase the growth and yield. The combined and balanced application of micronutrients and macronutrients in proper amount and ratio in an integrated manner led to appropriate growth and development of the plant. Micronutrients are required in minute quantities for plant development and metabolism, chlorophyll synthesis, nutrient regulation, reproductive growth, flower retention, fruit and seed development. Lacking awareness of micronutrient deficiencies in crop production is one of the major constraints in agriculture. Considering these, the present review focuses on the importance and function of micronutrients in broccoli production.

Keywords: Broccoli, cole crops, micronutrients, nutrient management

1. Introduction
Broccoli (*Brassica oleracea* var. *italica*) is an exotic cool season vegetable of the Brassicaceae family which is gaining its popularity in recent years for its antioxidant and anti-cancerous properties. Broccoli is said to be one of the first cole crops to be evolved from wild cabbage (*Brassica oleracea* var. *sylvestris*). Broccoli is eaten raw, steamed, fried or made into a curry throughout India. On account of its high content of nutritional properties and the trends of eating a balanced diet and healthy low carb foods among people, thus the demand of broccoli is growing more and more in the markets. Due to the high demands in the market the farmers are forced to produce more of the crop with market desirable characteristics leading to excessive use of fertilizers, not practicing appropriate cultivation methods.

Agronomic and intercultural practices are important components of a successful production of a crop. Many activities are practiced during the period of cultivation to get an optimum growth and yield, they include practices like nutrient management, weed and pest control, water conservation, disease management and intercultural practices like training, pruning, thinning, mulching, etc. Nutrient management is an important part of cultivation of brassicas. For an optimized growth and yield of a crop while safeguarding sustainability and environmental health, one needs to apply the sources of required nutrients in a balanced and judicious manner such as manures, biofertilizers, macronutrients and micronutrients. A balanced supply of different nutrients is provided in different stages of growth in right time and quantities to ensure the optimum nutrient balance, growth and yield thereby preventing deficiencies. Majority of farmers are not aware of the importance of micronutrients and majority of cole crops farmers in India suffer from losses caused by micronutrient deficiencies. Micronutrient deficiency causes physiological disorders reducing their marketable quality. Whiptail due to molybdenum deficiency, browning due to boron deficiency and chlorosis due to iron deficiency are some major disorders in cole crops like broccoli. Micronutrients are provided either by foliar or soil application. Foliar application is widely accepted as compared to soil application due to reduced leaching losses and quicker uptake by plants as well as lesser amount of micronutrients are consumed. In this review, we will discuss the effects of application of micronutrients in broccoli.

2. Advantages of application of micronutrients
Studies have shown that foliar application of micronutrients can significantly improve the growth and yield of broccoli.

The beneficial effects of foliar application of micronutrients on broccoli can be attributed to several factors. Firstly, foliar application allows for the rapid uptake of nutrients by the plant, which can alleviate nutrient deficiencies quickly. Secondly, foliar application can increase the efficiency of nutrient use by the plant resulting in better growth and yield. Plants take up nutrients through the roots and the leaves, but when it comes to micronutrients, foliar applications are common by using spraying equipment. The main advantages of foliar application are smaller quantities of fertilizer is used at almost the precise rate, there will be no leaching loss, reduces labour as well as machinery cost and as a result reducing cost in crop production. Plants absorb and utilize the nutrients more quickly when applied to the foliage, which in turn results to rapid response to micronutrient deficiencies, ensuring an uninterrupted growth. However, the limitations of foliar application are mainly on surface run-off when the solution is applied in excess or there is rainfall right after the application. Excess application may also cause tissue burning. The integration of micronutrients along with macronutrients promotes sustainability and reduces the quantity of field applications, minimizing environmental effects.

2.1 Effect on growth of broccoli

The crop's growth is enhanced which in return gives better yield; as a result of better foliage the photosynthetic activity is increased, resulting in more chlorophyll synthesis, which increases the utilization of amino acids and plant nutrients during the stages of plant growth. This displayed that the micronutrients help in steady uptake of nutrients which tends to enhance the vegetative growth of plants.

Zinc and molybdenum applied as zinc sulphate and ammonium molybdate respectively tends to exhibit better leaf/foliar growth which could be attributed to the participation of zinc and molybdenum in cell division and growth of the plant (Singh *et al*, 2018) [15]. Farhan *et al* (2023) [7] studied the influence of nano iron and humic acid on growth and yield and iron content of broccoli. The treatment consisted of three levels of humic acid i.e., 0, 50 and 100 kg ha^{-1} and its interaction with iron @ 0 mg l^{-1}, 50 mg l^{-1} nano iron and 100 mg l^{-1} metallic iron. It is observed that spraying nano iron at a concentration of 50 mg l^{-1} gives significant results for growth characters including plant height, number of leaves, leaf area, root length etc. The effect of the interaction between the two factors were found significant, the combination of 100 kg ha^{-1} humic acid with 50 mg l^{-1} nano iron was found to be the best treatment. Vijaykumar *et al* (2023) [19] performed an experiment to study the effect of micronutrients i.e., boron, zinc and ferrous under different application methods i.e., soil application and foliar spray on broccoli variety Palam Samridhi. The experiment was conducted in Factorial RBD comprising of two factors i.e., seven levels of micronutrients i.e., given as sole application as well as combinations and application methods i.e., soil application, single spray of micronutrients at 25 DAT and two sprays of micronutrients at 25 and 50 DAT. The treatment of spraying of B + Zn + Fe @ 100 ppm each at 25 and 50 DAT was significant in terms of plant height (64.4 cm), number of leaves (18.6), days taken for head initiation (43.06) and days to harvesting (52.42). Sidhu and Kaur (2022) [14] studied the influence of different micronutrients on growth and yield of broccoli using micronutrients such as boron, zinc, manganese and molybdenum applied @ 1.5 kg/ha, 2.5 kg/ha, 2 kg/ha and 0.5 kg/ha respectively in single applications as well as combinations. Attributes regarding growth i.e., plant height 49.65 cm, head diameter of 17.33 cm was recorded significantly higher in treatment combination of Mn + Mo + B + Zn. Awan *et al* (2021) [3] studied the influence of zinc oxide nanoparticles on growth of broccoli by synthesizing zinc oxide nano particles and seed extract of *Nigella sativa*. Seven concentrations of ZnO-NPs were used for seed treatment of broccoli, i.e., at the rate of 0, 50, 100, 200, 400, 800 and 1000 µg/l and using $ZnSO_4$ treatment as control. The applications resulted an enhancement in germination rate (37.5%), root and shoot length (56.6% and 16.6%), seedling mass (41%), number of leaves (11.5%), plant height (17.1%) and leaf area (24.4%). Al-Tameemi *et al* (2019) [2] studied the effect of chelated and nano particles of zinc and iron on the growth and yield of broccoli with three levels of treatment i.e., 0, 50 and 100 mg l^{-1}. As compared to other concentrations, results in the treatment of foliar application of iron nano particles @ 200 mg l^{-1} showed the superiority in plant height, leaf area, dry weight, total chlorophyll content, and flower disc diameter. Regarding sole application, 200 mg Fe/l results in superior values than other treatments such as plant height (67.6 cm), leaf area (65.5 dcm2/plant), dry weight (177 g), total chlorophyll content (66.8 mg/100 g). In treatment combinations, interaction between chelated iron and chelated zinc @ 200 mg Fe/l and 100 mg Zn/l were found superior with significant values in plant height (71 cm), leaf area (70.7 dcm^2/plant), dry matter (186 g) and total chlorophyll content (70.9 mg/100 g). The treatment combination of 100 mg Fe/l and 100 mg Zn/l showed significant results with a total yield of 24.63 ton/ha and 25.68 ton/ha. The interaction between iron and zinc at 200 mg Fe/l and 100 mg Zn/l of both chelated and nano iron and zinc were superior to other interactions and produced the significant values of growth and yield parameters. Pankaj *et al* (2018) [8] analysed the influence of different micronutrients i.e., B, Mo, Mn and Zn on growth and yield of broccoli. The micronutrients were applied @ 3, 0.5, 2 and 2.5 kg ha^{-1} for B, Mo, Mn and Zn respectively. The treatment combination of (B+ Mn +Zn) significantly enhanced plant height (52.23 cm), number of leaves per plant (26) and plant spread (55.25 cm) as compared to the other treatment combinations. Similarly, using treatments of boron, zinc and molybdenum, Choudhury and Sikder (2017) [5] examined the effects of foliar application of the mentioned on the growth and yield characters of broccoli by applying borax (0.3%), zinc sulphate (0.5% and 1.0%) and ammonium molybdate (0.03% and 0.05%) as single and combined treatments. Treatment with zinc showed significant effect on leaf characters and head quality among single applications. Sole treatment with Zn @ 0.5% had positive influence in increasing the growth such as height (58.25 cm), leaves per plant (16.15) and head weight (502.15 g). In the same year Singh *et al* 2018 [16] studied the effects of different micronutrients on growth, yield and quality of broccoli. Boron, molybdenum, manganese and zinc were applied @ 2 kg, 0.5 kg, 2.5 kg and 3 kg per hectare respectively in different combinations i.e., as single and combinations of each with a treatment as control. Combination of B, Mn and Zn showed significantly higher plant height (51.30 cm), number of leaves (24.25) and plant spread (52.83 cm).

2.2 Effect on yield of broccoli

Providing adequate levels of micronutrients on crop ensure

proper nutrition and plant metabolism which ultimately enhance on the productivity. Primary micronutrients like Fe (iron), Zn (zinc), Cu (copper), Mn (manganese), Mo (molybdenum) and B (boron) are important in the growth and developmental process of any plant. Major roles of micronutrients in plant metabolism are enzyme activation, synthesis of chlorophyll, increased respiration and synthesis of hormones like auxin and cytokinin which increased the overall growth of the plant resulting in healthy crops with higher yield. Foliar application of micronutrients enhances the nutrient uptake allowing the leaves to absorb the nutrients rapidly. Tudu *et al* 2020 [17] reported that foliar application of 0.2% borax and 0.5% $ZnSO_4$ combined significantly increased head quality in terms of TSS (7.03 ^{O} Brix), ascorbic acid (97.25 mg/100g) and crude protein (1.69%). The effect of foliar spray of nano and chelated copper on growth and yield of broccoli was studied by Al-Shamry and Abbas (2023) [1] with treatment consisting of three levels of micronutrients i.e., 0, 10, 20, 40 mg l^{-1}, and five cultivars of broccoli viz, Jassmine (V_1), 2004 (V_2), Zen (V_3), Masturi (V_4), and Danar (V_5). The highest production and commendable treatment were at spraying of 20 mg l^{-1} nano-copper on V_2 with the highest florets and total yield. According to Farhan *et al* (2023) [7], combined application of nano iron particles as FeO @ 20 mg/l and humic acid @ 100 kg recorded the highest total plant yield. Vijaykumar *et al* (2023) [19] conducted a study on the effect of different micronutrients under different application methods on broccoli variety Palam Samridhi. The results show that two spraying of B + Zn + Fe @ 100 ppm each at 25 and 50 DAT was significant in terms of fresh weight of head (283.79 g), yield per plot (4.19 kg) and maximum yield per hectare (258.4 q). Intercultural and agronomic practices also serve an important part in the growth and yield of broccoli. Using the combination of micronutrients and biofertilizers Bhattarai *et al* (2020) [4] conducted an analysis on the effect of combination of micronutrients with phosphate solubilizing bacteria (PSB). Boron, manganese, zinc and molybdenum with PSB were used as treatments. PSB were applied in the soil as per the treatment dose with half dose of boron and zinc as per treatment combination. The remaining B and Zn were applied at 25 DAT. Mo and Mn were applied as foliar applications at 25 and 50 DAT. The combination of B (15 kg ha^{-1}) + Zn (1 kg ha^{-1}) + Mn (1 kg ha^{-1}) + Mo (1 kg ha^{-1}) + PSB (10 kg ha^{-1}) gives better results in terms of yield and quality parameters as compared to other treatments with recorded yield of 14.39-ton ha^{-1}. Another study which included application of boron, manganese and zinc is done by Pankaj *et al* (2018) [9] in which treatment combination of B + Mn + Zn @ 3, 2 and 2.5 kg/ha sequentially resulted in maximum yield per hectare (138.58 q/ha) with significantly enhanced head diameter (18.02 cm) and fresh weight of head (511.5 g). Dhotra *et al* (2018) [6] investigated the influence of micronutrient and organic fertilizers on the growth and yield of broccoli. The treatments were given as control (T_1) foliar spray of boron @ 0.3% with 100% FYM at 20 DAT, 35 DAT and 45 DAT (T_2,T_3,T_4 respectively) for three different treatments; soil application of borax at the rate of 10 kg ha^{-1}, 12.5 kg ha^{-1}, 15 kg ha^{-1} with 100% FYM (T_5,T_6,T_7 respectively) and soil application of borax at the rate of 10 kg ha^{-1}, 12.5 kg ha^{-1}, 15 kg ha^{-1} with 50% FYM (T_8,T_9,T_{10} respectively). Among the treatments given, soil application of borax @ 15kg/ha + 100% of FYM give significantly better yield parameters i.e., head diameter (16.03 cm), fresh weight of head (461 g) and total yield (208.1 q/ha). Singh *et al* (2018) [15] conducted an analysis on the influence of foliar spray of micronutrients viz., zinc, molybdenum, copper, boron and ferrous on growth and yield attributes of broccoli. The micronutrients were sprayed in three different formulations at @ 0.20%, 0.40% and 0.60% each along with control and sprayed at 25th, 45th and 65th days after transplanting. It was concluded that the application of zinc @ 0.60% resulted in maximum yield attributes such as fresh weight of head i.e., 385.64 g and yield per ha i.e., 134 q/ha. Singh *et al* (2017) [20] analysed the impact of different micronutrients on growth, yield and quality of broccoli. Boron, molybdenum, manganese and zinc were applied @ 2 kg, 0.5 kg, 2.5 kg and 3 kg per hectare respectively in different combinations i.e., applied as single and combinations of each micronutrient and T_0 as control. Combination of B, Mn and Zn showed significantly higher head diameter i.e., 16.28 cm, fresh weight of head i.e., 303.69 g and yield per ha i.e., 121.48 q ha^{-1}. Similarly, Saha *et al* (2010) [13] examined the impact of foliar application of borax and ammonium molybdate on sprouting broccoli and found maximum plant height (56.06 cm) at single application of boron. It was concluded that application of 0.3% borax at 30 + 45 DAT and 0.05% ammonium molybdate at 45 DAT gives better yield attributes like fresh weight of head (234.38 g) and yield per plant (388.68 g) as compared to their individual application and control.

2.3 Effect on quality of broccoli

As per studies, foliar application of micronutrients can significantly improve the nutritional quality of broccoli. Bhattarai *et al* [4] mentioned in his research work that using a combination of PSB and boron increased the vitamin C content of broccoli. Zinc applied as foliar spray improved the texture, color, and taste of broccoli as stated by Hussain *et al* (2017) [21]. Tudu *et al* (2020) [17] analysed the influence of lime and micronutrients i.e., boron and zinc on head quality of broccoli. The experiment was conducted on a split plot design with main plot as lime (with/without) and 7 different levels of micronutrients given as soil application and foliar spray. The results showed that lime application leads to better attributes on broccoli head as compared to treatment without lime. Similarly, foliar spray with borax @ 0.2% and $ZnSO_4$ @ 0.5% combined results to good quality heads than other treatments, the values recorded were TSS of 7.03 ^{O} Brix, ascorbic acid content of 97.25 mg/100 g, protein- 1.70% and total sugar-1.79%. Foliar spray of micronutrients recorded better quality of heads than corresponding soil application of micronutrients. Similarly, Bhattarai *et al* (2020) [4] carried out an experiment on the effect of combination of micronutrients with phosphate solubilizing bacteria (PSB) where Boron, manganese, zinc and molybdenum were used. PSB were applied in the soil as per the treatment dose with half dose of boron and zinc as per treatment combination. The remaining B and Zn were applied at 25 DAT. Mo and Mn were applied as foliar applications at 25 and 50 DAT. The combination of B (15 kg ha^{-1}) + Zn (1 kg ha^{-1}) + Mn (1 kg ha^{-1}) + Mo (1 kg ha^{-1}) + PSB (10 kg ha^{-1}) gives better results in quality parameters such as TSS (6.03 ^{O} Brix) and vitamin C content (21.16 mg/100g).

Singh *et al* (2018) [16] analysed the outcome of foliar spray of micronutrients viz., zinc sulphate, ammonium molybdate, copper sulphate, boric acid, and ferrous sulphate on growth

and yield attributes of broccoli. The micronutrients were sprayed in three different formulations @ of 0.20%, 0.40% and 0.60% each along with control and sprayed at 25th, 45th and 65th days after transplanting. The application of zinc sulphate @ 0.60% results to maximum quality parameters such as non-reducing sugars content (1.78%), phenol (8.86%), ascorbic acid content (86.29 mg/100 g), TSS (7.15 ^{O} Brix) and carbohydrate content (36.48%). Similarly, Pankaj *et al* (2018) [10] evaluated the influence of different micronutrients such as B, Mo, Mn and Zn on quality of broccoli. The micronutrients were applied @ 3, 0.5, 2 and 2.5 kg ha^{-1} for B, Mo, Mn and Zn respectively. The treatment combination of (B+ Mn +Zn) recorded the highest content of TSS (8.8 ^{O} Brix) and ascorbic acid content (94.8 mg/100 g). During the same year Xaxa *et al* 2018 [18] conducted a similar experiment on effect of different micronutrients, i.e., boron, molybdenum, manganese and zinc on head quality of broccoli. The micronutrients B, Mo, Mn and Zn were applied @ 2.5 kg ha^{-1} 0.5 kg ha^{-1} 3 kg ha^{-1} and 2.5 kg ha^{-1} respectively and treatments were given as sole applications and combinations of each with T_0 as control. It was concluded that the treatment combination of B + Mn + Zn was the best treatment combinations for flower bud quality i.e., ascorbic acid content (92.34 mg/100 g) and TSS (8.23 ^{O} Brix) of fresh head. Similarly, Singh *et al* (2017) studied the effects of boron, molybdenum, manganese and zinc applied @ 2 kg, 0.5 kg, 2.5 kg and 3 kg per hectare respectively and their combinations. According to results, the treatment combination of B, Mn and Zn had significant effect on quality parameters such as maximum TSS value (8.37 ^{O} Brix) and ascorbic acid content (93.92 mg/100 g).

3. Conclusion

Micronutrients plays a key role in the growth and development of broccoli as an insignificant but important element. Although they may be trace elements they play a crucial role in the physiological processes, from photosynthesis to hormone regulation and its presence is very important for an optimum plant growth and productivity. Deficiency of micronutrients causes a variety of physiological disorders to crops. A balanced and judicious amount must be applied as excess may cause toxicity and tissue burning. The productivity as well as the quality of the crop is enriched by application of micronutrients, thus it can be concluded that broccoli may be provided micronutrients in its optimum amount either by foliar application or in the soil and further studies be encouraged for a better future and development towards sustainable agriculture and food security.

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