Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; SP1: 332-340

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**(Special Issue- 1)**
**2nd International Conference**
**"Food Security, Nutrition and Sustainable Agriculture - Emerging Technologies"**
**(February 14-16, 2019)**

# Role of micronutrients in vegetable production: A review

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## Abstract
Proper plant nutrition is essential for successful production of vegetable crops. Integrated supply of micronutrients with macronutrients in adequate amount and suitable proportions is one of the most important factors that control the plant growth and development. Micronutrients are usually required in minute quantities, nevertheless, are vital to the growth of plant. Judicious use of micronutrients is essential for vegetable cultivation to get maximum yield of high quality produce. Plant metabolism, nutrient regulation, chlorophyll synthesis, reproductive growth, flower retention, fruit and seed development etc., are such effective functions performed by various micronutrients. Micronutrients which are essential for all higher plants are boron (B), chlorine (Cl), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), molybdenum (Mo) and nickel (Ni). Micronutrients like Cl, Cu, Fe and Mn are involved in various photosynthetic processes and Zn, Cu, Fe and Mn are associated with various enzymatic activities, Mo is specific for nitrate reductase only. Boron is associated with the carbohydrate metabolism and reproductive phase of the plants along with photosynthesis or enzymatic activities. Taking this into consideration, in the current review focus on major functions of micronutrients in vegetable production and also gives a brief overview of recent research findings related to role of micronutrients on vegetable production, which can contribute to a better understanding of the role of micronutrients in vegetable plants.

**Keywords:** Vegetable crops, micronutrients, functions, importance

## Introduction
Vegetables are non woody herbaceous plant or part of the plant eaten as food by humans in whole or in part. It is the science of vegetable growing, dealing with the culture of non-woody (herbaceous) plants for food. It is the production of plants for use of their edible parts such as root, fruits, flower bud, bulbs, tubers etc. The importance of micronutrients in agriculture is truly well recognized and their uses have significantly contributed to the increased productivity of several crops (Tirpathi *et al*., 2015) [82]. The nutrient elements which are required comparatively in small quantities are called as micro or minor nutrients or trace elements. Micronutrients are essentially as important as macronutrients to have better growth, yield and quality in plants (Yadav *et al*., 2018) [42, 88]. The requirement of micronutrients (boron, iron, copper, zinc, manganese, chloride and molybdenum) is only in traces, which is partly met from the soil through chemical fertilizer or through other sources.
Micronutrients improve the chemical composition and general condition of vegetable crops and are known to acts as catalyst in promoting various organic reactions in plants (Karthick *et al*., 2018) [34]. Micronutrients play an eminent role in plant growth, development and plant metabolism. However, their deficiencies may induce several physiological disorders/ diseases in plants and later, can reduce the quality as well as quantity of vegetable crops (Sharma and Kumar, 2016) [69]. The incidence of their deficiencies in crops has increased markedly in recent years due to intensive cropping, soil erosion, losses of nutrients through leaching, liming of acid soils, unbalanced fertilizer application including NPK and no replenishment (Aske *et al*., 2017) [10].

On the other hand, these micronutrients can also be proven toxic effect when present at accelerated concentrations and such toxicity level endangers the plant growth. Growers should carefully follow recommendation for micronutrients to avoid unnecessary costs and possible toxic effects or deleterious interaction in other nutrients (Mauraya *et al*., 2018) [42].

Micronutrients are to be necessarily taken up by the plants from soil or supplemented through foliar application improves vegetative growth and yield of crops. Foliar application of micronutrients shows better efficiency than soil application as the uptake and assimilation of micronutrients by later method take more time (Pandev *et al.*, 2016) [49]. Factors such as soil pH, redox potential, biological activity, cation-exchange capacity and clay contents are important in determining the availability of micronutrients in soils.

Nowadays, micronutrients are gradually gaining momentum among the vegetable crops because of their beneficial nutritional support and at the same time ensure better harvest and returns. The demand for increasing vegetable production will require a thorough knowledge of micronutrients in vegetable crops. But the available information regarding the impact of micronutrients on vegetable crops is scanty. Therefore, in current review an attempt has been made to summarize the literature pertaining to overall significance of micronutrients in vegetable plants.

**Importance of Zinc**

Zinc is indispensable for normal growth and development of plants. It is effective for the synthesis of plant hormones like auxin and carbohydrate formation (Pankaj *et al*., 2018) [51]. It plays a fundamental role in several critical functions in the cell such as protein metabolism, gene expression, structural and functional integrity of bio-membranes and photosynthetic metabolism (Sanju *et al*., 2003) [61]. Zinc is also a constituent of ribosomes and is essential for their structural integrity (Trivedi *et al*., 2013) [83]. It promotes starch formation, seed maturation, production, enhances seed viability and seedling vigor. Zinc is helpful in reproduction of certain plants and various enzymatic activities. It also plays a vital role in sulphur and nitrogen metabolism (Pandev *et al*., 2016) [49]. Its deficiency causes interveinal chlorosis of older leaves then leaves turn grey-white and fall prematurely or die. Stunted growth, distortion in shape and clustering of leaves on short branches known as rosette. The crops like tomato, potato, beans and onion are highly sensitive to Zn deficiency.

**Effect of Zinc**

Zinc always has been a significant mineral element for agriculture. Heavy metal zinc is one of the trace elements necessary to the growth of vegetable, but Zn excessiveness also could cause damage. It is essential for regular growth, development and reproduction of plant. Furthermore, application of zinc was found to increase the green pigments of necrotic leaf of plants. The application of Zn significantly increased the bulb weight (73.9 g), bulb yield (45 t/ha) when applied with 2, 4-D (3 ppm) as foliar spray in onion (Trivedi *et al*., 2013) [83]. Kalroo *et al.* (2014) [32] indicated that all the growth and production traits were influenced under foliar application of zinc at different concentrations in chillies and revealed that Zn @ 4 ml/l was an optimum level for obtaining economical fruit yield in chillies. According to Harris and Mathuma (2015) foliar application of zinc at 250 ppm results the maximum plant height, total dry weight, number and fresh weight of fruits/plant and yield of tomato. Singh *et al.* (2017) [74, 75, 77] indicated that foliar application of zinc (30 ppm) significantly increased the number of tubers/plant, average weight, length, diameter of tuber, tuber yield/plot and tuber yield/hectare as compared to control in potato.

**Importance of Boron**

Boron plays an essential role in the growth and development of new cells in the meristematic region of plants. Boron is necessary for cell wall formation, development of fruit and seed. It helps in pollen formation, pollination and flowering of plants (Malek and Rahim, 2011) [39]. The primary role of boron in plants is to improve solubility and metabolism of Ca and its mobility and also helps in the absorption of nitrogen (Pandav *et al*., 2016) [49]. It also involves in metabolism and transport of carbohydrates, nucleic acid synthesis, root elongation, photosynthetic activities and water absorption in plant parts (Islam *et al*., 2018) [26]. Boron increases the stability of plant cells and is involved in the reproductive phase of plants. Its inadequacy is often associated with sterility and malformation of reproductive organs (Katyal and Randhawa, 1983). Boron does not easily move around the plant and therefore, the deficiency appears first in young tissues, growing points, root tips and developing fruits. Its deficiency may cause sterility, poor fruit set, small fruit size and ultimately lower yield. The shortening of the terminal growth results rosetting occurs due to boron deficiency. Leaves may have thick coppery texture and sometimes curled and become brittle with scorched appearance. Growth is also ceased at the growing points (Bubarai *et al*., 2017) [13]. A deficiency of boron also causes cracking and distorted growth in fruits (Harris, 2016) [23]. The vegetable crops like cabbage, cauliflower, sugar beet, potato etc. are highly sensitive to boron deficiency. The sources of Boron are borax (Sodium tetraborate, 10.5% boron, Boric acid (17.0% boron) and Disodium octaborate tetrahydrate (20% boron).

**Effect of Boron**

Boron is necessary for cell wall formation, development seed and fruit. Firoz *et al*. (2009) [18] observed the effect of boron application on the yield of the broccoli. A result revealed that application of boron @1kg/ha produced the highest yield (512.3g/plant) and the lowest (445.4g/plant) was observed in control. According to Dursun *et al.* (2010) [16] boron application decreased the concentration of nitrogen (N), calcium (Ca), and magnesium (Mg) but increased phosphorus (P), potassium (K), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) concentrations. Thus it concluded that addition of boron @ 2.5 kg/ha is sufficient to elevate boron level in soil. Malek and Rahim (2011) [83] indicated that application of boron level @ 3 kg/ha gave the highest seed yield (1769.11 kg/ha) which was followed by 0 kg B/ha (control) gave the lowest seed yield (1371.93 kg/ha) in carrot. Saha *et al.* (2010) revealed that, spraying of borax @ 0.3per cent at 30 and 45 DAT gave maximum total head yield of 13.37 t/ha in broccoli. Naz *et al.* (2012) [46] studied the effect of Boron (B) on the flowering and fruiting of tomato and reported that application of boron @ 2 kg/ha, enhanced number of flower clusters per plant, fruit set percentage, total yield, fruit weight loss and total soluble solids. Manna *et al*. (2014) [40] revealed that the application of 0.5% boron significantly increased the growth (plant height and number of leaf per plant), yield and quality (TSS and Pyruvic acid) of onion. Islam *et al.* (2015) [25] reported positive effect of boron @ 2.0 kg B/ha on the yield and quality of broccoli. Mekdad (2015) [43] investigated that foliar spraying of boron at 120 and 150 ppm in sugar beet, significantly improved root yield, its attributes and percentage of white sugar content.

**Combine effect of Boron and Zinc**

The application of zinc and boron increases the number of mature fruits per plant in tomato (Yadav *et al.* 2001). Srivastava *et al*. (2005) [79] recorded that the foliar application of $ZnSo_4$ and boric acid increases the TSS content in garlic. Salam *et al*. (2011) [62] investigated that the combination of boron and zinc @ 2.5 kg B/ha + 6 kg Zn/ha, resulted the highest pulp weight, dry matter content, ascorbic acid, lycopene content, chlorophyll content in tomato. Kant *et al.* (2013) [33] revealed that the plant height, number of leaves per plant, biological yield, curd weight and marketable yield were found highest with combined application of zinc and boron (20:10kg/ha) in cauliflower. Shil *et al.* (2013) [70] evaluated the interaction effect between zinc and boron in the yield of dry chilli and weight of ripe chilli/plant. The highest yield (1138 kg/ha) was recorded from Zn, B @ 3.91:1.70 kg/ha and the lowest in case of control. Abd *et al.* (2014) [1] studied that application of zinc (100 and 200 ppm) and boron (50 and 100 ppm) significantly affected the growth, head yield, yield components and quality of broccoli (*Brassica oleracea* L. var. *italica.*). Acharya *et al*. (2015) [4] revealed that foliar application of zinc sulphate at 0.5% results maximum plant height, number of leaves/plant, fresh leaf weight, fresh bulb weight, bulb yield/plot and bulb yield/hectare, while soil application of borax @ 10 kg/h showed highest polar and equatorial diameter and the highest TSS content was also observed in the soil application of zinc sulphate (10 kg/ha) in onion. Ali *et al.* (2015) [8] indicated that the maximum plant height, number of leaves, leaf area, number of fruits, fruit length, fruit diameter and yield and early flowering with minimum diseased infested plant were found from foliar application of $ZnSo_4$ @12.5 ppm + $H_3Bo_3$ @12.5ppm while minimum from control in tomato. Mansourabad *et al*. (2016) [41] evaluated the effects of some micronutrients like iron, zinc and silicon on the root-knot nematode and plant growth parameters of cucumber. Micronutrients (iron, zinc and silicon) at 5mg/kg of soil significantly reduced the number of galls/g of root and also improved the shoot dry and fresh weights and fruit yield. Haleem *et al.* (2017) [22] found that the interaction of B and Zn increases the plant height, number of primary and secondary branches, number of leaves/plant, number fruits/plant in tomato.

**Importance of Iron**

Iron is an essential micronutrient required for normal growth and plant function. Iron act as catalyst in synthesis of chlorophyll molecule and helps in the absorption of other elements (Pandev *et al*., 2016) [49]. It is a structural component of porphyrin molecules like cytochrome, hemes, hematin, ferrichrome and leg hemoglobin. These substances are involved in oxidation- reduction reactions in respiration and photosynthesis (Borlotti *et al*., 2012) [22]. It also involves in DNA synthesis, protein synthesis, reduction of nitrates and sulphates. Further many metabolic pathways are activated by iron and it is a prosthetic group constituent of many enzymes (Rout and Sahoo, 2015) [58]. Vegetable crops like tomato, onion, carrot and spinach contain high percentage of Iron. Iron deficiency is common with interveinal chlorosis of young leaves and veins remain green except in severe cases. Its deficiency is mainly manifested by yellow leaves due to low levels of chlorophyll, twig dieback. In severe cases, death of entire limbs or plants. It is more problematic usually due to pH problems for which iron sulfate or chelated iron may be used. The sources of iron are ferrous sulphate ($FeSo_4.7H_2O$, 20%) and Fe-EDTA chelate (12% iron).

**Effect of Iron**

Iron treatment has a greater effect on the nutrient uptake and protein percentage of seed than other treatments. Ahmad *et al*. (2000) [7] revealed that application of Fe and Mn results the maximum tuber yield, mineral matter, and carbohydrate accumulation and moisture contents in potato tubers. Shivaprasad *et al.* (2009) [71] revealed that RDF + Ca+S+Fe @ 50+50+20 kg/ha significantly higher yield in chilli (1189 kg/ha) as compared to the rest of the treatments. Ejraei (2013) [17] indicated that the best iron concentration for growth of tomato was 0.6 mg/L among different concentrations. The highest fresh and dry weight, total uptake of manganese, chlorophyll content and total iron uptake were observed in this level.

**Combine effect of Iron, Boron and Zinc**

The application of iron, boron and zinc either alone or in combination helped to increase the uptake of iron, zinc, boron, manganese and copper by vegetable crops. Hatwar *et al.* (2003) [24] reported the combination of micronutrients *viz*., Zinc, Iron and Boron improved the both growth and yield parameters in chilli crop. Lashkari *et al*. (2007) [37] indicated that leaf area ($cm^2$) and marketable yield (q/ha) were found significantly highest with combined foliar sprays of zinc and iron at 0.5% concentration each. However, the minimum days taken for curd initiation and curd maturity were recorded with individual foliar spray of zinc and iron at 0.5% in cauliflower. Uikey *et al.* (2017) revealed that plant height, number of leaves, number of clusters/plant, number of fruits/cluster and days to 1st flower initiation, days to first fruit set, days to 1st picking were recorded best in treatment (RDF+ Borax (0.2%) + $FeSo_4$ (0.5%) + $ZnSo_4$ (0.5%) in brinjal. Maurya *et al.* (2018) studied that application of ferrous sulphate and zinc sulphate @ 50kg/ha and Borax @ 10 kg/ha in kharif onion maximize the TSS, dry weight of leaves/plant, dry weight of bulb/plant and minimize the sugar content, bulb rotting and physiological loss in weight. Satpute *et al*. (2013) [65] indicated that soil application of $FeSo_4$ + $ZnSo_4$ @ 20 kg/ha each + borax @5 kg/ha resulted significantly higher plant height (155.64 cm), number of nodes per plant (24.96), number of days to 50% flowering (43.67). The application of $FeSo_4$, $ZnSo_4$ and borax either alone or in combination helped to increase the uptake of iron, zinc, boron, manganese and copper by okra.

**Importance of Copper**

Copper plays pivotal role in regulating multiple biochemical reactions in plants (Tripathi *et al*., 2015) [82]. Arnon and Stout (1939) earlier declared copper as an important nutrient for plants in their experiments with tomato. Being the stable cofactor of various enzymes and proteins, copper plays an indispensable role in regulating several metabolic and physiological processes of plants. It helps in the utilization of iron during chlorophyll synthesis (Harris, 2016) [23]. Copper has been also some indirect effect on nodule formation. Deficiency of copper leads to reduced growth, distortion of the younger leaves and possible necrosis of the apical meristem. Yellowing of young leaves, curling of tips, leaf edges ragged and plant top may wither (Das, 2018) [15, 84].

**Effect of Copper**

Trehan and Grewal (1995) [81] found that soil and foliar application of copper sulphate ($CuSo_4$) resulted the increase in potato tuber yield as compared to control. Further, they concluded that foliar spray of copper was found better than soil application. Tamilselvi *et al*. (2002) [80] noticed that application of Cu at 100 ppm to tomato resulted in production of more number of fruits/plant (20.02) which was significantly superior over control (15.84). Agrwal *et al*. (2004) [6] reported that the application of copper at 5% under drip irrigation increased the uptake of major and micronutrients like N, P, K, Zn, Fe and Cu as compared to control.

**Importance of Manganese**

Manganese involve in the activation of many enzymes which helps in photosynthesis and respiration (Pankaj *et al*., 2018) [51]. It activates several important metabolic reactions, accelerates germination and maturity while increasing the availability of phosphorus (P) and calcium (Ca). It enhances root growth, development of fruit and develops disease resistance. It also helps in the movement of iron in plants. High concentration of Mn favors the breakdown of indole acetic acid (IAA). Its availability is reduced in high pH calcareous soils but is often very high in the acid soils (Jawad *et al*., 2016). Manganese deficiency causes a light green mottle between the main veins and interveinal chlorotic areas become pale green or dull yellowish colour (Mousavi *et al*., 2011) [45]. Dry edible beans, cucumbers, lettuce, onions, peas, potatoes, radishes are the most responsive crops.

**Effect of Manganese**

Seresinhe (1996) [68] evaluated the different manganese concentration in the culture medium on the biomass production, nutrient content, cell division and viability using tomato cells in suspension culture, resulted that the biomass and the dry weight were highest at Mn levels of 0.002 and 0.1 mM when compared with cells grown with 0 or 0.2 mM. Rahman *et al*. (2011) [54] studied that the plant height, number of leaves/plant, number of tubers, weight of tubers were maximum at 4kg Zn + 1kg Mn/ha, while the minimum values were recorded from the control. Przybysz *et al*. (2016) evaluated that increased concentrations of Mn (5, 25 and 50 mg $dm^{-3}$) in the growing medium led to a significantly higher the concentration of Mn, biomass accumulation, levels of reactive oxygen species (ROS), the activity of antioxidative enzymes, the content of phenolic compounds in lettuce leaves, but concentrations of potassium, calcium and magnesium were almost unchanged.

**Importance of Molybdenum**

Molybdenum is required for the assimilation of nitrates, as well as, for the fixation of atmospheric nitrogen. It helps in protein synthesis and sulphur metabolism. Low and adequate levels of molybdenum has a positive effect on carotenoid formation. It also helps in absorption and translocation of iron in plants. Deficiency symptoms resemble those of nitrogen because the function of molybdenum is to assimilate nitrogen in the plant. Molybdenum deficiency can be common in nitrogen-fixing legumes.

**Effect of Molybdenum**

Most of the vegetable crops are prone to molybdenum deficiency. Mohamed *et al*. (2011) [44] showed that 30 and 45 μg/l molybdenum significantly improved vegetative growth parameters like curds yield and its components and chemical composition of leaves and curds in cauliflower. Adiloglu *et al.* (2013) [5] studied the effects of increasing molybdenum application on some nutrient element contents of head lettuce plant. Results indicated that N, P and K contents of head lettuce increased with increasing of molybdenum applications. The level of Fe, Zn and Mn contents of plant decreased with increasing level of molybdenum applications, while Cu content of plant was not affected. Singh *et al*. (2017) [74, 75, 77] revealed that the combined soil application of borax at 20 kg/ha and sodium molybdate 2 kg/ha gave the maximum height of the plant, length of leaf, width of leaf, total weight of plant, width of curd, average weight of curd and curd yield in cauliflower.

**Importance of Chlorine**

Chlorine is most commonly used as sanitizer, due to its low cost for maintaining the fruit quality like appearance, soluble solids content, acidity, pH, texture and flavor, shelf life and also control microbial growth (Rahman *et al*., 2012) [55]. It is essential for photosynthesis (chlorotic tissues), helps in stomatal regulation and raises cell osmotic potential, necessary for shoot apex and root growth. Chlorosis of younger leaves and overall wilting of the plant is a common symptom. Deficiency seldom occurs because chlorine is found in the atmosphere and rainwater. Vegetable crops like potato and beans are more sensitive to chlorine deficiency (Singh, 2016) [76].

**Effect of Chlorine**

Park and lee (1995) evaluated the effect of chlorine treatment for cut vegetables to reduce microbial populations and improve keeping quality. Treatment with ≤100 ppm chlorine effectively reduced the microbial load in onion without significant quality losses. Acedo *et al.* (2009) studied that tomato fruits were washed for 3 min in water or 200 ppm chlorine prepared using sodium hypochlorite before storage at ambient conditions (27-33 °C; 61-90% RH), resulted that chlorine treated fruits reduced decay process and better shelf life than untreated ones. Rahman *et al.* (2012) [55] studied that the green chilli pre-treated with chlorine water and then packaging in 0.3% perforated polypropylene packet resulted substantial reduction of weight loss, rotting/shriveling, and also retained vitamin C, carotene, moisture content, etc. Under this condition the retention of quality and shelf life of green chili could be extended up to 10 days at ambient condition as compared to non-treated and without packaging. Komosa and Gorniak (2012) [35] evaluated the effect of increased chloride concentration (90 to 120 mg $Cl^{-}dm^{-3}$) in the nutrient solutions, resulted the increased chlorine content and decreased the nitrogen, ascorbic acid, reducing sugars and dry matter content in tomato fruits. There were no effects on the content of nitrate and nitrite as well as the acidity and carotene content in fruits.

**Importance of Nickel**

It is important for activation of urease, an enzyme essential for nitrogen metabolism and also control senescence. It is required for iron uptake and it can substitute for zinc and iron as a cofactor for some enzymes. The deficiency of nickel causes leaf tip necrosis in nitrogen fixing plants. The deficiency of nickel also delayed nodulation and reduced efficiency of nitrogen fixation in leguminous vegetable crops. Nickel was needed in cowpea at reproductive phase (Das, 2018) [15, 84].

**Effect of Nickel**

Nickel is considered as an essential element for higher plants nutrition; on the other hand, Ni at relatively higher concentrations may be toxic to most of plant species (Rehman *et al*., 2016) [57]. Gad *et al*. (2007) [20] studied that the highest plant height, number of branches, leaf area, root length, fruit quality, auxins and gibberellins contents, was obtained at 30 mg Ni/kg soil. Addition of all nickel concentration (15, 30, 45 and 60 ppm) also have a significant promotive effect on nitrogen, phosphorus and potassium content in fruits as compared with that of control in tomato. Pandey and Gopal (2010) [50] evaluated the effect of different concentration (0.1 to 400 μM) of Nickel in eggplant, revealed that plant exposure to Ni > 50 μM decreased the biomass, concentration of photosynthetic pigments in leaves, concentration of Fe in leaves and stem, activities of catalase and peroxidase, chlorophyll content and also interfere with iron metabolism of plants. Pandey and Singh (2011) [72] evaluated that plants exposed to high nickel (1.0 and 10.0 ppm) showed visible toxicity symptoms, such as wilting, chlorosis in young leaves, browning of root tips, broken off roots and decreased chlorophyll a, b contents in lettuce. Rehman *et al*. (2016) [57] evaluated that the tomato plants were treated with different doses of nickel *viz*., 10, 20, 30 and 40 mg Ni Kg/soil and observed that lower doses of Nickel did not show any marked impact on growth of tomato plants, but on receiving its higher doses (30- 40 mg Ni Kg/soil) chlorophyll a and b content, dry weight of roots, shoots, leaves, fruit production and plant growth were decreased.

**Combine effect of micronutrients**

Bajapai and Chuahan (2001) [11] studied the effect of zinc (2.5, 5.0 and l0 mg/kg), boron (0.5, 1.0 and 2.0 mg/kg) and manganese (5.0, 10.0 and 20.0 mg/kg) on yield of okra. The maximum fruits/plant (15.3), seeds/fruit (17.4), dry and fresh fruit weight (4.825 and 61.650 g), respectively and seed weight (3.670 g) were recorded in plants grown in soil with the highest level of zinc (10.0 mg/kg). Yuanxin *et al*. (2009) [89] reported that boron and manganese at low concentrations significantly reduced fruit yield and the antioxidative content but at its high concentrations increased fruit yield and antioxidative capacity in tomato.

Abedin *et al.* (2012) [2] studied that the combinations of different treatments (Zn:B:Mo:Mn:Cu:Cl) resulted significant effect on growth and yield parameters like number of leaves/plant, plant height, diameter of bulb, fresh weight leaves/bulbs and bulb yield of onion. Kumar *et al.* (2012) [36] concluded that the combinations of treatments (Boron 20kg + sodium molybdate 2 kg/ha) + (Boron 100ppm + molybdenum 50ppm) gave best performance on characters *viz.* plant height (cm), leaves length (cm), leaves width (cm), total weight/plant (kg), curd diameter (cm), days to curd maturity, net weight of curd and total yield (q/ha) in cauliflower. Sivaiah (2012) [78] evaluated that application of different treatment combination (boron, zinc, molybdenum, copper, iron, manganese), resulted the improvement in plant growth characteristics *viz*., plant height, number of primary branches and fruits/plant in tomato. Saravaiya *et al*. (2014) [64] observed that foliar application of micronutrients (RDF + B, Zn, Cu, Fe, Mn) had significantly enhanced the plant height (131.73 cm), number of branches/plant (5.81), number of fruits/plant (34.26), fruit length (5.52 cm), fruit diameter (4.64 cm), fruit volume (67.53 $cm^3$), fruit yield/ ha (46.78 t) and marketable fruit yield/ ha (45.62 t) in tomato. Joshi and Bhamburdeka (2015) [30] investigate the effect of different concentrations of micronutrients on morphological characters of spinach. Micronutrients ($CaCl_2$, $CuSo_4$, $MgSo_4$, $MnSo_4$, $ZnSo_4$, $H_3BO_3$ and $FeSo_4$) are used at different concentration but 1 ppm concentration showed better results for shoot, root length, plant height, fresh and dry weight of plant, number of leaves per plant and leaf area per plant.

Aske *et al*. (2017) [10] observed that the soil application of $ZnSo_4$, Borax and $CuSo_4$ @ 10kg/ha resulted the highest plant height, number of leaves, highest polar diameter, equatorial diameter, pseudo stem length, maximum bulb weight, total yield, TSS whereas, lowest values from control in onion. Chaudhari *et al.* (2017) [14] reported that the foliar spray of micronutrients of 1% General grade-1 (Fe-2.0, Mn-0.5, Zn-4.0, Cu-0.3 and B-0.5) + $T_1$ (Ammonium molybdate) is favorably influenced plant growth and yield attributes in cauliflower.

Some nutrients are not considered necessary always because either their essential character has been proved only in some plants or in certain metabolic processes that are not always necessary e.g. - (Al), (Co), (Na), (Si), (V). Aluminium induced growth enhancement in various plants. Aluminium alleviates $H^+$ toxicity at a low pH, or alleviates excess P by the formation of aluminium phosphate (Watanabe *et al*., 2005) [86]. It has also reduce the toxic effects of copper and Zinc (Singh, 2016) [76]. Cobalt forms vitamin $B_{12}$ during growth and development of symbiotic micro-organism like rhizobia, cyanobacteria etc. (Singh, 2016) [76]. It also influences the growth of the plant, transpiration, photosynthesis, nitrogen fixation, ribonucleotide reductase in rhizobium etc (Das, 2018) [15, 84]. Sodium is essential for halophytic plant species which accumulate sufficient of its salts in vacuoles to maintain turgor and growth. Many plants that possess the $C_4$ dicarboxylic pathway require sodium as an essential nutrient (Singh, 2016) [76]. It has some roles in stomatal opening, nitrate reductase, oxalic acid accumulation and also influences potassium sparing action (Das, 2018) [15, 84].

The beneficial effects of silicon contributes to the structure of cell wall, strengthen the tissues, reduce water loss, inhibit fungal infection and correction of soil toxicities arising from high levels of available Mn, $Fe^{2+}$ and active aluminium (Maksimovic *et al.*, 2016) [38]. Silicon also tends to maintain erectness of leaves, increases photosynthesis, resistance to lodging, increased availability of phosphorus, reduced transpiration etc (Das, 2018) [15, 84]. Silicon applied to a variety of plant species including horticultural crops to increase crop yield, quality, and disease resistance (Ma, 2004; Hodson *et al.*, 2005). The Low concentrations of vanadium are beneficial for the growth of micro-organism and higher plants. Vanadium may partially substitute for Mo in fixation of atmospheric nitrogen by micro-organism such as the rhizobia (Das, 2018) [15, 84]. It plays a role in biological oxidation-reduction reactions. It absence reduces the pollen viability in tomatoes, cucumber and soybean (Singh, 2016) [76].

**Effect of Micronutrients**

Osaki *et al.* (1997) [48] studied that the growth and N, P, and K uptake in AI-tolerant plant were stimulated by Al application, especially P uptake, while in AI-sensitive plant they were reduced by Al application. Gad and Kandil (2009) [19] studied that cobalt concentration at 7.5 ppm significantly maximized the growth, root yield, mineral composition, sugar yield, and percentage of protein, carbohydrate, vitamin C, sucrose and glucose content in sugar beet. Vachirapatama *et al*. (2011) [85] indicated that nutrient solution of $NH_4VO_3$ at 0-20 mg/l significantly enhanced the stem length, number of leaves dry weight of leaf, stem and root. As the vanadium concentration (40-80 mg/l) increased, resulted in the decrease of the stem length, root and fruit fresh weight were noted in Chinese green mustard and tomato plants. Jarosz (2014) [28] studied that tomato plants fertigated with the nutrient solution enriched with silicon showed significantly higher total fruit yield (15.98 kg/plant) and leaves contained more silicon as well as less manganese and zinc compared to control in tomato. Kahouli *et al*. (2014) [31] showed that germination is possible until the highest concentration of NaCl salt (16 g/l) but germination and speed of germination decrease according to the concentration increases in carrot.

Weerahewa and David (2015) [87] investigated that silicon applied at 50 and 100 mg/L showed a significantly higher fruit size, fruit firmness, titrable acidity and disease resistance against anthracnose in tomato. Maksimovic *et al.* (2016) [38] studied that application of Silicon @ 1.5 mM silicic acid, clearly decreased the Mn toxicity, also improved growth and biomass production as compared to non-Si treated plants in cucumber. Alkarim *et al*. (2017) [9] evaluated that application of diatomite as foliar spraying (50, 100, 200 mg/l or soil drenching (500, 1000 and 2000 mg/l) resulted the highest fruit firmness, TSS, Ascorbic acid and fruit yield in cucumber. Tissue analyses also showed that Si-treated plants had more Si in the leaves/fruits and phosphorus and potassium in the leaves as compared to untreated plants. Jimenez (2018) [29] studied that application of 5 μM vanadium increased plant growth, induced floral bud development, flowering, chlorophyll concentration, amino acids; and also increased the concentrations of Nitrogen, phosphorus, potassium, Calcium, Magnesium, Copper, manganese, Boron in stems of pepper. Sable *et al*. (2018) [59] showed that application of sodium azide at 0.04% increases the number of leaves, plant height, fresh weight, and dry weight as compared to control. The increasing dose of sodium azide was also showed adverse effect on germination percentage (%) of okra.

## Conclusion

Micronutrients play an indispensible role in growth and development of vegetables crops. The nutritional value of crops is becoming a major issue, therefore, application of micronutrients to sustain soil health and crop productivity besides maintaining the quality of vegetables is of profound importance. Micronutrients are beneficial for improve yield, quality, earliness, fruit setting, increases post-harvest life, and develop resistance to biotic and a biotic stresses.

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