



Assessment Concerning the Role of Foliar Administration of Micronutrients on Growth, Yield, and Quality Characteristics of Vegetable Crops

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Vegetables are one of the main elements in terms of ensuring a person's food security and nutritional well-being. Integrated application of macronutrients coupled with adequate incorporation of micronutrients is one of the key factors for quality vegetable production. For ensuring maximum vegetable production with superior quality foliar nutrition is the better alternative in the era of climate change. Foliar application is the easiest and most effective way to administer micronutrients as compared to other methods. Trace elements such as iron (Fe), zinc (Zn), manganese (Mn),

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molybdenum (Mo), boron (B), chlorine (Cl), copper (Cu), and nickel (Ni) are essential for vegetable crops. The primary goal of this review article is to investigate the merits of micronutrients and the production potential of various vegetable crops through foliar nutrition. Additionally, this study aims to clarify the role of micronutrients in quality vegetable production. Several studies suggested that the exogenous application of micronutrients has a tremendous effect on overall growth and quality in a variety of crops. Many researchers have demonstrated that applications of Boron @250ppm significantly influenced the fresh weight of fruit, number of fruits per plant, number of seeds per plant, germination%, vigour index and root and shoot lengths of seedlings in sweet pepper. Various researchers also concluded that the application of Zn @1000 ppm + B @200 ppm + Mo @50 ppm provides a significant impact on head diameter, volume of head, chlorophyll a, chlorophyll b and chlorophyll total in cabbage.

Keywords: Micronutrients; foliar spray; vegetable crops; growth; yield; quality.

1. INTRODUCTION

Vegetables are usually considered as a protective food because they are a potential source of vitamins, minerals, and dietary fibres. India is the leading producer of vegetables after China, as reported by (FAO) of the United Nations. India produced 204.61 million metric tonnes of vegetables across an area of 11.28 million hectares in the years 2021–2022 [1]. India mostly exports to its neighbours, especially the UAE, Bangladesh, Pakistan, Saudi Arabia, Sri Lanka, and Nepal. But the irony is India still has only 1% share of the global market. As a result, there is a large scope for improvement in the area of vegetable production and productivity to satisfy the demands of the expanding population and provide nutritional security.

This can be accomplished by combining existing technology with integrated nutrient management techniques (INM) Paramesh et al. [2]. INM is a technology that can provide effective and affordable solutions for supplying macro- and micronutrients to plants. Wang et al. [3]. In current era the vegetable cultivation is quite intensive and highly responsive to fertilisers and superior varieties or hybrids, which generates the issue of nutrient imbalance in soils due to excess nutrient mining. To fulfil the needs of future food security food production must increase substantially while agriculture's environmental impact must drop significantly. Foley et al. [4]. According to the criteria of essentiality of nutrients by Arnon and Stout, (1939) there are a total of 17 essential nutrients that plants need for the effective completion of their lives.

Micronutrients are an important factor in improving the quality and productivity of a variety of crops in the horticulture industry Tripathi et al. [5]. It aids in the catalytic process of nutrient

absorption and balances other nutrients [6]. Micronutrients are found in soil at lower levels than macronutrients, plants grown in micronutrient-deficient soils exhibit decreased productivity and yield Havlin et al. [7]. However, their deficiency may result in a variety of physiological disorders or diseases in plants, which may subsequently lead to a reduction in both the amount and quality of vegetable products Sharma et al. [8].

India suffers from a widespread zinc deficiency. The magnitude of the boron deficit is next to zinc in India. Sometimes, a nutrient's availability inhibits the activity of another nutrient, causing an antagonistic effect. When the roots are incapable of providing enough nutrition, a foliar spray of micronutrients is the best alternative Kinaci et al. [9]. Foliar feeding is an effective approach to supply nutrients during a period of rapid plant growth when it can strengthen the plant's mineral condition and increase crop output Kolota et al. [10]. In the current scenario, foliar spraying has become very popular, due to its effectiveness towards absorption Bozorgi et al. [11]. Within a few hours to a day of foliar spraying, the majority of micronutrients enter the plant body through the leaves. To address micronutrient deficiencies of Fe, Cu, Mn, Zn, and B, especially in dry and semi-arid areas, foliar spray is highly recommended Kaya et al. [12].

The purpose of this research is to emphasise the importance of micronutrients in sustainable vegetable production by using an appropriate application strategy, to address the issues of micronutrient deficiency, and to develop strategies for their optimal management for long-term olericulture. As a result, an effort has been undertaken in the current review to summarise the research relating to the overall significance of foliar micronutrition in vegetable crops.

2. MICRONUTRIENTS' SIGNIFICANCE

Micronutrient deficiencies have a significant impact on plant growth, metabolism, and the reproductive stage. Contrarily, plants are affected by even a minor deficit or excess. Plants can absorb micronutrients in both ionic and non-ionic forms. The mobility of micronutrients in plants plays a significant role in determining the deficiency of a particular nutrient. The availability of nutrients to plants and the technique of administration both are significantly influenced by the mobility of micronutrients in the soil. An important aspect of regulating nutrient supply in plants is soil pH. All macro and micronutrients are most readily available in soils within a pH range of 6.5 to 7.0. Choudhary et al. [13].

Boron (B), is essential for growth, development, and a range of physiological activities, including fruiting, cell division, water interactions, hormonal movement, sugar translocation, cell wall formation, lignification, phenol, carbohydrates, IAA, and RNA metabolism, pollen germination, pollen tube growth conferring drought tolerance Ahmad et al. [15]; Malek et al. [16]. It is utilized by plants as boric acid (H_3BO_3). Moreover, plants need boron to efficiently fix nitrogen Hakala et al. [17]. The main function of boron in plants is to facilitate the metabolism and solubility of calcium. Iron (Fe) is an important element of chlorophyll biosynthesis. Furthermore, it is a part of numerous enzymes which is involved in the transfer of energy such as the reduction and fixation of nitrogen and synthesis of lignin etc. Leghemoglobin and cytochromes both contain iron, which is essential for their structural integrity. During respiration and photosynthesis, it engages in several oxidation-reduction activities. Borlotti et al. [18]. Zinc (Zn) is absorbed by plants as Zn^{2+} . Zn is primarily utilized by plants as a metal enzyme activator. Zinc is also involved in an array of enzymatic processes including the production of IAA which boosts flower production, fruit set, and seed

maturity. Zn is a critical element of several enzymes, including proteinase, peptidase, aldolase, dehydrogenase, and phosphohydrolase [19]. Copper (Cu) is an essential micronutrient for regulating a variety of biochemical reaction in plants due to its stability as a cofactor for many proteins and enzymes. It facilitates the utilisation of iron during chlorophyll synthesis [20]. Copper is essential for the transmission of electrons during photosynthesis and respiration.

Manganese (Mn) is taken by plants as Mn^{2+} , but it quickly oxidises to Mn^{3+} and Mn^{4+} forms. It is a part of the water-splitting enzyme involved in O_2 evolution and electron transfer in the photosystem-II of photosynthesis. (Pankaj et al., 2018). Due to its involvement with super oxide dismutase (SOD), it detoxifies cells from the effects of oxidative stress. Chlorine (Cl), is inexpensive and maintains fruit qualities like appearance, soluble solids content, acidity, pH, texture, and flavour, as well as controls bacteria development in plants Rahman et al. [21]. Plants take up chlorine as chloride (Cl^-) through both their roots and leaves. Additionally, it controls the water potential of plants by adjusting the osmotic pressure, which includes stomata opening, cell elongation, turgor pressure, and osmotic pressure. Plants absorb molybdenum (Mo) as molybdate ions. It accelerates the metabolic process and encourages photosynthesis [22]. Both the fixation of ambient nitrogen and the uptake of nitrates depend on Mo. Nickel (Ni) in the form of Ni^{2+} is absorbed by plants. Urease, an enzyme required for the metabolism of nitrogen and the regulation of senescence, is activated by nickel (Ni). Similarly, it substitutes Zn and Fe as a cofactor for several enzymes. An excess of one of the six metal ions— Ni^{2+} , Mg^{2+} , Fe^{2+} , Mn^{2+} , Cu^{2+} , and Zn^{2+} can generate a scarcity of the other with the lowest availability because they appear to be competing in their absorption, Wood et al. [23].

Table 1. Types of micronutrients acquired by plants

Element	Ionic forms	Non-ionic forms
Boron (B)	$H_2BO_3^-$, HBO_3^{2-} , $B_4O_7^{2-}$	
Manganese (Mn)	Mn^{2+}	$MnSO_4$ with EDTA
Iron (Fe)	Fe^{2+} , Fe^{3+}	$FeSO_4$ with EDTA
Copper (Cu)	Cu^{2+}	$CuSO_4$ with EDTA
Molybdenum (Mo)	MoO_4^{2-}	
Chlorine (Cl)	Cl^-	
Zinc (Zn)	Zn^{2+} , $Zn(OH)_2$	$ZnSO_4$ with EDTA

EDTA: ethylenediaminetetracetic acid

Source: Singh et al. [14]. An introduction of plant nutrients and foliar fertilization: A review. Precision farming: A new approach

Table 2. Mobility of nutrients in soil and plant

Mobility	Soil	Plant
Mobile	BO_3^{2-} , Mn^{2+} , Cl^- , Mn^{2+}	N, P, K
Moderately mobile	-	Zn
Less mobile	Cu^{2+} , NH_4^+ , K^+ , Ca^+ , Mg^{2+}	S, Fe, Mn, Cu, Mo, Cl
Immobile	Zn^{2+} , HPO_4^{2-} , HPO_4^-	Ca, B

2.1 Deficiency symptoms of Micronutrients in vegetable crops

The adoption of an intensive cropping system leads to imbalanced use of chemical fertilisers, expansion of vegetable agriculture in marginal areas and micronutrient deficiency in soil. To get high-quality produce, micronutrient deficiencies must be detected before visual symptoms which are expressed by the plants at the stage of hidden hunger. In the event of a deficiency, a mobile nutrient in the plant travels to the growing tips. As a result, deficiencies become visible on the lower leaves. A deficiency in an immobile nutrient usually appears on the younger plant parts because it doesn't migrate to the growing sites. Therefore, careful application of micronutrients is crucial in vegetable production to produce a yield of exceptional quality.

Boron deficiency is extremely problematic in calcareous soils, sandy-leached soils, acidic soils and reclaimed yellow or lateritic soils. A lack of boron results in the breakdown of the growing tip, which ultimately kills the shoot tip. The rosette appearance of the plant due to the shortening of terminal growth, terminal leaves that are light green become thick, curled, and brittle, restricted root growth, and flowers abortion. Brown heart or heart rot in sugarbeet and turnips, browning of curds and hollow stem in cauliflower, knob splitting in knol-khol, akashin in radish, cracked stem in celery, and fruit cracking in tomatoes are some of the indications of boron deficiency. In the case of zinc deficiency plants show short terminal leaves, weak bud formation and leaves have dead regions. Short internodes and a reduction in leaf size are the most evident Zn deficiency symptoms. The main manifestations of zinc deficiency are mottling and rosetting in vegetables and fern leaf in potatoes. Tomato, potato, bean, and onion crops are particularly vulnerable to a Zn deficit Sainju et al. [24]. In India, iron deficiency is very common in alkaline and calcareous soil. An excess of iron could cause Fe-toxicity under anaerobic conditions (Singh *et al.*, 2003). Fe deficiency is primarily

exhibited by yellow leaves due to low quantities of chlorophyll. Green vein colour and yellow interveinal regions on immature leaves are signs of iron deficiency.

Copper deficiency is most frequent in sandy soil, calcareous soil, and soil with high organic matter contents. Its symptoms include slow growth, deformed young leaves, necrosis of the apical meristem, curled tips, dieback of stems and twigs, ragged leaf edges, and a chance of plant top withering [25]. Copper availability is reduced by 100 times with every unit increase in soil pH (between pH 7 and pH 8). Singh et al. [14]. A distinctive sign of Mn deficiency is interveinal chlorosis. The size of the leaves decreases. The main disorders caused by a manganese deficiency are speckled yellow in beetroot, interveinal yellow mottling in cabbage, yellow striping in the onion, chlorosis and necrosis of the bean leaves, and marsh spot in the pea. Mo deficiency is very common in alluvial soils. Mottling, burning, withering, and frequent cupping of elder and middle leaves are visual signs of Mo deficiency. Growth impairment, shoot distortion, and older leaves with interveinal yellowing and necrotic edges are the symptoms of Mo shortage. The most prevalent disorder caused by a deficiency of molybdenum in cauliflower is whiptail.

Deficiency of nickel can result in delayed nodulation and less efficient nitrogen fixation in leguminous vegetable crops. It is crucial for cowpea throughout the reproductive period. In vegetable crops like potatoes and beans, the susceptibility to chlorine deficit is higher [26].

2.2 Foliar Application of Micronutrients (Foliar Nutrition)

Foliar application is the technique of exogenous application of micronutrient solutions to the foliage of the plants at appropriate concentrations. Foliar treatments of micronutrients including molybdenum, zinc,

copper, iron, manganese, and boron are preferable because they provide rapid availability of nutrients, improve instant uptake of applied nutrients, eradicate the issue of soil fixation, supplement when an immediate response is required, and last but not least, provide nutrients that may not be easily available for root uptake. Foliar treatment is thus a potentially effective strategy to maximise the profitability of vegetable crops in a limited amount of time. When micronutrients are sprayed on leaves, several of those nutrients are quickly absorbed by the leaves. In the current scenario foliar spraying has become very popular, due to its effectiveness towards absorption Bozorgi et al. [11]. Within a few hours to a day of foliar spraying, the majority of micronutrients enter the plant body through the leaves. To address micronutrient deficiencies of Fe, Cu, Mn, Zn, and B, especially in dry and semi-arid areas, foliar spray is highly recommended Kaya et al. [12]. Foliar application of micronutrients is a common practice to reduce environmental pollution because it enhances nutrient uptake by reducing the amount of fertiliser given to the soil (Abou-El-nour, 2002).

3. FACTORS AFFECTING THE EFFECTIVENESS OF FOLIAR FEEDING

Growth stages are one of the most important aspects that affect the efficacy of foliar nutrition concerning its optimum effectiveness. Various endogenous (related to leaf anatomical structure, crop type, and leaf coverage), exogenous (nutrient concentrations, soil type, and pH of solution), and environmental factors (daytime, humidity, temperature, rainfall, wind speed, etc.) influence the feasibility of foliar feeding. Hot and humid climate conditions are more conducive to the highest level of tissue permeability. Early mornings and late nights are the times when these conditions are most frequently observed Zahed et al. [43]. Within 24 to 48 hours of application, rain may decrease the effectiveness of foliar treatment. Micronutrients must be water-soluble for foliar treatment. The concentration of the spray solution shouldn't injure the leaf tissue or leave any residue on the plant's surface. To prevent the leaves from getting scorched, which could have catastrophic consequences, the pH of the spray solution must be controlled. The spray solution is most frequently neutralized with lime.

Table 3. Meteorological condition favouring foliar applications

Time of Day	Late evening; after 6:00 p.m. Early morning; before 9:00 a.m.
Temperature	Low temperature 18-19°C (Ideal 21°C)
Humidity	Greater than 70 % relative humidity
Wind speed	less than 5 mph
Rainfall	Within 24 to 48 hours after a foliar application may reduce the application effectiveness, as not all nutrient materials are immediately absorbed into the plant tissue

Source: Patil and Chetan, [27]. Foliar fertilization of nutrients.

Table 4. Commonly used micronutrient fertilizers for foliar spray

Micronutrient	Fertilizers
Boron	Solubor (20% B), Boric acid (17% B), Borax (11% B),
Iron	Ferrous sulphate (19% Fe), Ferrous ammonium sulphate (14% Fe), Chelated Fe (12% Fe)
Zinc	Zinc oxide (55-70% Zn), Zinc sulphate (33% Zn), Chelated Zn (12% Zn)
Copper	Cuprous oxide (89% Cu), Cupric oxide (75% Cu), Copper sulphate (25% Cu), Chelated Cu (13% Cu)
Molybdenum	Ammonium molybdate (54% Mo), Sodium molybdate (39% Mo)
Manganese	Manganese oxide (41-68% Mn), Manganese sulphate (30% Mn), Manganese chloride (17% Mn), Chelated Mn (12% Mn)
Chlorine	Ammonium chloride (66% Cl), Potassium chloride (47% Cl)

Source: Patel et al. [28]. Role of Micronutrients Foliar Nutrition in Vegetable Production: A Review. Journal of Experimental Agriculture International

Table 5. Effect of foliar application of micronutrients on vegetable crops

Crop	Foliar nutrition	Stage	Improved characters	References
Cabbage	Zn @1000 ppm + B @200 ppm + Mo @50 ppm	At 15 DAS and 20 & 35 DAT	Maximum head diameter (12.96 cm) and volume of head (842.42 cm ³), chlorophyll a (0.276 mg/g), chlorophyll b (0.295 mg/g) and chlorophyll total (0.637 mg/g) at 45 DAT	Patel et al. (2021)
Sweet Pepper	<ul style="list-style-type: none"> Boron @250ppm Boron @350ppm 	at the pre-flowering and flowering stage	<ul style="list-style-type: none"> Maximum number of fruits per plant (4.50), fresh weight of fruit (80.25g), seeds per fruit (161), number of seeds per plant (727.25), % germination (78.25%), root length (2.75cm) of seedling, shoot length (2.94cm) of seedling, vigor index (1.833) Fruit length (7.70cm) with an average fresh weight (75.25g) average number of seeds per fruit (55.66) and weight of 500 seeds (2.549 g) 	Maria et al., (2021)
Onion	Micronutrient Mixture i.e. iron- @ 2.5%, boron @0.5%, zinc @3%, copper @1% and manganese- @1%	at 30 and 45 DAP	Plant height (63.72 cm), number of leaves/plant (12.71), polar diameter (58.62 mm), equatorial diameter (46.88 mm), average weight (61.72 g) of bulb, yield ha-1 (266.80 q), highest % of A grade bulb (29.82), and B: C ratio (4.61)	Biswas et al. (2020)
Chilli	FeSO ₄ @0.2 % + CaNO ₃ @0.2% + Boron @0.1 %	60, 90 and 120 DAT	Plant height (70.02.cm), no. of primary branches per plant (8.51), plant spread (36.13 cm), number of fruits per plant (47.80), dry fruit yield per ha (52.61 q ha-1), average fruit weight (6.64 g), fruit length (10.52 cm), fruit width (1.36 cm) and seed yield (9.61 q ha-1. oleoresin content (6.34%), vitamin c content (67.60 mg /100 g)	Malik et al. (2020)
	ZnSO ₄ @ 0.4%	1 st spray at flower bud initiation stage and second spray after 25 days	Plant height (101.8 cm), No. of branches (12.33), Fruit Length (7.28cm), Fruit diameter (2 cm), No. of fruits per plant (131), Fruit yield per plant (378.67g)	Angami et al. [29].
	<ul style="list-style-type: none"> H₃BO₃ @0.25% H₃BO₃ @0.1% 	at 30 and 60 DAT	<ul style="list-style-type: none"> Fruit yield per plant (395.33 g) and maximum yield per hectare (109.8 q/ha) Average fruit length (11.12 cm) and fruit diameter (1.175 cm) 	Dongre et al., (2000)

Crop	Foliar nutrition	Stage	Improved characters	References
	<ul style="list-style-type: none"> H₃BO₃ @0.50%, 		<ul style="list-style-type: none"> Average number of seeds per fruit (55.66) and weight of 500 seeds (2.549 g) 	
Cauliflower	Boric acid @0.2 % + Ammonium molybdate @0.1 % + ZnSO ₄ @ 0.5 % + MnSO ₄ @0.5 %	30, 45, 60 DAT	The highest plant height (76.78 cm), number of leaves per plant (25.60), days to first curd initiation (44.06), days to 50 % curd maturity (56.66), curd diameter (41.22cm), Curd depth (9.54cm), gross curd weight (1.84 kg), net curd weight (0.65 kg) and curd yield (34.98 t/ha)	Punam et al. (2020)
	FeSO ₄ @0.5 % + Borax @0.2 % + ZnSO ₄ @0.5 %	At 45 and 60 DAT	Maximum length of leaf (32.26 cm) and total biomass production (2849.20 g), yield per plot (34.80 kg), curd size per plant (235.68 cm ²), number of days required for curd initiation (67.89) and curd maturity (81.19), total biomass production, curd size, curd yield, ascorbic acid content (65.96 mg/100g), net Income and B:C ratio (2.65)	Moklikar et al. (2018)
Broccoli	Borax @0.2 % + ZnSO ₄ @0.5 %	20, 35 and 50 DAT	Recorded significantly maximum plant height (46.27 cm), leaves plant-1 (24.62), stem girth (16.85 cm), plant spread (62.20 cm), leaf area (557.50 cm ²), weight and diameter of central head (313.67g,17.37cm), secondary head (88.83g, 5.33cm), total head weight (402.50g) with total head yield (136.80 qha-1)	Tudu et al. (2020)
	ZnSO ₄ @0.60 % CuSO ₄ @ 0.40% Boric acid @ 0.40% Ammonium molybdate @ 0.40%	At 25th day of planting and 45 th and 65th DAT	<ul style="list-style-type: none"> Plant spread (63.86 cm), stalk length (17.92 cm), root length (6.40 cm) and ascorbic acid content (86.29 mg/100g). Minimum number of days to 50% maturity (72.36). Maximum curd yield (135.05 q/ha), TSS% (7.52) and carbohydrate % (39.83) Maximum reducing sugar content (0.81%) 	Singh et al. [30].
Tomato	B @100 ppm+ Zn @100+ Mo @50	at an interval of 10 days starting from 30	Number of flowers cluster ⁻¹ (5.33), number of fruits cluster ⁻¹ (4.06) and percentage of fruit set (76.26%), fruit diameter (6.21), fruit length (6.28	Ahirwar et al., (2019)

Crop	Foliar nutrition	Stage	Improved characters	References
	ppm+ Cu @100 ppm,+Fe @100 ppm+ Mn @100 ppm	DAT	cm), fruit weight (67.62g) and number of fruits plant ⁻¹ (24.66), yield plant ⁻¹ (1.43kg) and yield qha ⁻¹ (288.77)	
	FeSO ₄ @0.2 % + CaNO ₃ @0.2 % + Boron @0.1 % + ZnSO ₄ @0.2 %	15 and 21 DAT	Plant height (135.75cm), Plant girth (3.20 cm), Days to first flowering (24.29), Days to first fruiting (35.33), Days to maturity (63.33 days), No. of fruits per plant (72.07), Fruit length (5.66 cm), Fruit diameter (4.77 cm), Fruit weight (80.06g), Yield per plant (4.77 kg) and Yield per ha (562.57 q).	Dixit et al. (2018)
	B @1.25g/l + Zn @1.25 g/l	foliar sprays two times	Plant height (2.93m) number of leaves (39.33)	Shnain et al., [31]
	Boric acid @100 ppm, ZnSO ₄ @100 ppm, Ammonium molybdate @50 ppm, CuSO ₄ @100 ppm, FeSO ₄ @100 ppm, MnSO ₄ @100 ppm	an interval of 10 days starting from 40 DAT	Highest plant height (95.7 cm), number of fruits per plant (46.4), fruit weight (61.9 g), fruit yield per plot (63.5 kg), yield/ha (564.1 q) and benefit cost ratio (3.04)	Sathiyamurthy et al. [32]
	Boron @100 ppm + Zn @100 ppm + Cu @100 ppm + Fe @100 ppm + Mn @100 ppm	thrice times foliar spray were made at 10 days interval starting from 40 DAT	Plant height (131.73 cm), number of branches plant-1 (5.81), fresh weight of plants (25.65 t ha-1), dry matter yield of plants (7670.03 kg ha-1), maximum days to last picking (166.68), number of fruits plant-1 (34.26), fruit length (5.52 cm), fruit diameter (4.64 cm), fruit volume (67.53 cm ³), single fruit weight (49.20 g), fruit weight plant-1 (1.68 kg), number of locules fruit-1 (3.03), pericarp thickness (6.23 mm), fruit yield ha-1 (46.78 t) and marketable fruit yield ha-1 (45.62 t). This treatment had maximum net return (1, 66,757 Rs./ ha) and B:C Ratio (2.72 : 1)	Saravaiya etal. [33].
	Nitrogen @5.5 g/100 ml+ boron @5 g/100 ml + zinc @5 g/ml	15 and 21 DAT	Plant height (80.4 cm), number of leaves per plant (57), leaf length (10.42 cm), maximum per cent fruit set (57%), number of fruits per plant (33.67), fruit weight (92.7g), fruit length (7.48cm), fruit diameter (5.08cm), number of large sized fruits (15.67) with least number of small fruits (6.33), yield per plant (1.14kg) and yield per hectare (1275kg ha ⁻¹)	Ali et al., (2013)
Potato	• Borax @0.1% + ZnSO ₄ @0.2 % +	-	<ul style="list-style-type: none"> • Highest tuber weight (127.00g) • The highest Dry matter content (22.67%) • Highest starch content (21.42%) 	Miyu et al. [34].

Crop	Foliar nutrition	Stage	Improved characters	References
	<p>MnSO₄ @0.2%</p> <ul style="list-style-type: none"> • Borax @ 0.1% + ZnSO₄@0.2% • ZnSO₄ @0.2%+ MnSO₄ @0.2% 			
Sponge gourd	<ul style="list-style-type: none"> • Boron @ 0.75 g/L • Boron @0.25g/l • ZnSo4 0.25g/L • Boron and Iron @0.75g foliar 	30,45 and 60 days of sowing	<ul style="list-style-type: none"> • Fruit diameter (14.45mm), fruit length (26.3cm), Fruit yield (1.75 kg per plant) and individual fruit weight (170.09g.), no. of fruits, (15.00), highest percentage of fruit set (75.33) • TSS content (7.6°Brix) • Titratable acidity (4.30 g/L) • Maximum deduction in pH (5.1) 	Ashraf et al. [35].
Moringa	<p>FeSO₄ @1% + Citric Acid 0.1% ; ZnSO₄ @0.5% ; MnSO₄ @0.5% ; Boric Acid 0.2% ; (FeSO₄ @1% + 0.1% Citric Acid) + ZnSO₄ @0.5% ;ZnSO₄ @0.5% + MnSO₄ @0.5%</p>	Vegetative, flowering, and pod setting stage	Maximum plant height (1.43m, 2.39m, 5.36m), trunk girth (2.20m, 18.01m, 32.00 m), number of pods per tree (120 pods), pod length (80.25cm), pod girth (7.9cm), ascorbic acid content (61.34 mg/100g, 65.39 mg/100g, 68.91mg/100g and in pod 43.06 mg/100g) and carotenoid (29.50 mg/100g, 30.13mg/100g, 35.10mg/100g and in pod 5.11 mg/100g) content were recorded in T8 (Mixture of all micronutrients) number of panicles per tree (20.71, 64.20,120.00), number of flowers per panicle (16.97, 29.33, 54.67) and number of pods per panicle (2.29).	Sandeep etal., 2019
Brinjal	<p>Borax @0.2% + FeSO₄ @0.5% + ZnSO₄ @0.5%</p>	-	Plant height (82.67 cm),no. of leaves (173.27), no of branches (12.60), leaf area (2431.12 cm ²), leaf area index (0.540), and days to 1st flower initiation (37.33), days to first fruit set (42.33), days to 1st picking (58.33), number of clusters/plant (3.6), no. of flowers per cluster (5.2),	Uikey et al., (2018)

Crop	Foliar nutrition	Stage	Improved characters	References
			number of fruits/ cluster (3.3)	
	Boron @0.25% +APSA-80	At 30, 45 and 60DAT.	Maximum plant height (62.93 cm), number of branches (6.36) and leaves (55.67) per plant, Earliest flowering and fruiting (72 and 94 days), number of fruits per plant (8.63) and total yield (356.55 q/ha), seed viability 30DAH (93.02%), highest (8.50 g/fruit), benefit : cost ratio of (4.07 and 4.63)	Gogoi et al., (2012)
	Borax @0.5%	at 35, 50 and 65 DAT	Number of flowers per plant, number of productive flowers per plant, number of fruits per plant, individual fruit weight and yield (32.15 t/ha)	Karuppaiah, (2005)
Bitter gourd	Boric acid @100 ppm (0.571g/l) and mixture of micronutrients viz., (Boric acid @100 ppm + ZnSO ⁴ @100 ppm + Ammonium molybdate @50 ppm + CuSO ₄ @100 ppm + FeSO ₄ @100 ppm + MnSO ₄ @100 ppm	at 30, 40 and 50 DAS	maximum length of vines (5.58 m), fruit length (25.01 cm), fruit girth (10.75 cm), fruit weight/vine (2.197 kg), yield (197.01 q/ha) and vitamin C (64.65 mg/100gm). Highest B: C ratio (2.69).	Bharati et al. (2018)
	ZnSO ₄ @0.5 % + FeSO ₄ @0.5%	at 30, 45 and 60 DAS	Highest fruit yield (16.33 t/ha)	Vala and Savaliya. [36].
	ZnSO ₄ + FeSO ₄ + MgSO ₄ each @0.5%	at 35 and 45 DAS	Maximum vine length (547.54 cm), number of nodes (155.69), total leaf area per plant (3749.70 cm ²), leaf area index (1.253), Total chlorophyll content at 90 DAS (2.20 mg g ⁻¹), Soluble protein at 90 DAS (8.71mg g ⁻¹), No. of female flowers plant ⁻¹ (34.61), Sex ratio (1:10.77), Fruit set percentage (77.75 %)	Karthick et al., [37].
Water spinach	Borax @1.5 g/litre + ZnSO ₄ @1.5 g/litre twice at 15 days interval	twice at 15 days interval at vegetative stage	Maximum vine length (49.19 cm), no. of nodes/plant (23.89) and average internode length (2.18 cm), days to 50% flowering (131.00), days to fruit harvest (249.20) and chlorophyll content (46.16 SPAD-502)	Sarkar et al. [38].
Okra	MgSO ₄ @0.5 % + MnSO ₄ @0.5 % +	at 30, 45 and 60 DAS	Maximum weight of fruit (910.11 g), maximum length of fruit (7.30 cm), maximum diameter of fruit (1.98 cm) and maximum yield (20.72 mt/ha)	Dubalgunde et al. [39].

Crop	Foliar nutrition	Stage	Improved characters	References
	FeSO ₄ @0.5 % + ZnSO ₄ @0.5 %			
Eggplant	<ul style="list-style-type: none"> ZnSO₄ @0.5% Borax @0.5 % 	micronutrients were sprayed at an interval of 10 days, starting from flowering	<ul style="list-style-type: none"> Plant height (64.48cm) cm, no. of fruits plant⁻¹ (26.13) Fruit length (24.04 cm), fruit diameter (5.10 cm) and average fruit weight (75.77 g) 	Pandav et al. [40].
Coriander	FeSO ₄ @0.5 %	30 and 45 DAS	Net assimilation rate (0.085 mg g ⁻¹ day ⁻¹ in rabi and 0.063 mg g ⁻¹ day ⁻¹ in kharif), crop growth rate (7.52 mg m ⁻² day ⁻¹ in rabi and 7.78 mg m ⁻² day ⁻¹ in kharif, umbels per plant (33.7 in rabi and 13.8 in kharif) and highest seed yield per hectare (623.3 kg in rabi and 599.9 kg in kharif)	Diana and Nehru [41]
Cowpea	Fe @ 2 ppm	sprayed every 15 days	Nutrient uptake (Fe- 154.00 mg.kg-1, B- 47.00 mg.kg-, Zn- 42.00 mg.kg-1) and protein percentage of seed (28.9)	Salih [42]

*DAS- days after sowing
*DAT- days after transplanting

4. BENEFITS OF FOLIAR NUTRITION IN VEGETABLE CROPS

Foliar spray of micronutrients facilitates in the rapid restoration of nutritional deficiencies. It can be used in conjunction with other sprayings, such as insecticides, pesticides. It is advantageous when the soil is deficient in nutrient content, It is applicable even under adverse conditions, such as root rot disease, drought condition etc. It is also beneficial when the top soil is insufficiently moist for plant roots to absorb nutrients. Foliar application requires only a small dose of micronutrients for enhancing factors for yield and yield quality characteristics.

5. LIMITATIONS OF FOLIAR NUTRITION IN VEGETABLE CROPS

A high concentration of the sprays will result in a scorching or burning effect. To increase efficiency, an adhesive agent is required. Maximum leaf area is required for efficient spraying. The effectiveness of foliar spraying is based on environmental factors such as temperature, humidity, wind speed, etc. Costs associated with multiple applications may be prohibitive. Excess application may cause foliar burn.

6. CONCLUSION

Foliar application of micronutrients has a dynamic role in elevating crop yields and productivity. Under intensive cropping systems, foliar micronutrient supplementation has a huge potential to increase productivity while also improving crop quality under drought condition and ensure disease resistance. This assessment of the review of literature leads us to the conclusion that micronutrient foliar feeding is effective in enhancing the growth, production, and quality characteristics of vegetable crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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