E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(4): 107-114
Received: 20-02-2024
Accepted: 25-03-2024

Ayesha Khatun
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Soumya Mukherjee
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Md. Mohib Bullah
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Parijat Bhattacharya
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Corresponding Author:
Parijat Bhattacharya
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Effects of micronutrients on crop quality

Ayesha Khatun, Soumya Mukherjee, Md. Mohib Bullah and Parijat Bhattacharya

DOI: https://doi.org/10.33545/2618060X.2024.v7.i4b.537

Abstract
Micronutrients or trace elements are fundamentally just as important as macronutrients for plants to thrive, yield, and produce higher-quality products. B, Cu, Fe, Zn, Mn, Mo, Cl and Ni are the essential micronutrients required by all types of crops in varying amounts. The micronutrient requirements of the plants are satisfied by the soil, chemical fertilizers and other sources. These mineral micronutrients play vital roles in various crops such as photosynthesis, respiration, chlorophyll synthesis, increased sugar content and TSS in fruits, increased pollen viability, symbiotic N-fixation, production of vitamins etc. Lack of micronutrient fertilizers causes plants to absorb trace elements insufficiently, which results in significant losses in yield and quality of various crops. Crop quality is significantly impacted by the synergistic and antagonistic interactions between various nutrients. Therefore, it's crucial to ensure optimal absorption of soil micronutrients. Consequently, it is acknowledged that a balanced nutrition is of utmost significance. Morphological, organoleptic, and nutritional qualities are essential for the value addition of harvested goods. The various crop quality parameters that are improved by applying micronutrients are aroma in rice, protein content in wheat and pulses, oil content in oilseed, curd\head size in cole crops, TSS and ascorbic acid content in fruits, etc. Enhancing crop quality still remains a major challenge in this era of increasing food demand, especially in the developing world. The objective of this article is to gain deeper insights into new advancements in the research of micronutrients contributing to the quality of various crops to ensure consumer preferences and nutritional attributes.

Keywords: Micronutrients, crop quality, plant nutrition, consumer preference

1. Introduction
Micronutrients are trace elements that are needed in small amounts but are crucial for plant growth and regulations of many plant functions (Vatansever *et al*., 2017) [98]. It includes Iron, Zinc, Copper, Boron, Manganese, Chlorine, Nickel and Molybdenum. For plants to produce a handsome output of high quality products, a regular fetilization programme with micronutrients is crucial (Saeed *et al*., 2012) [81]. Plant growth and development, may be retarded as well as yield and quality will be reduced, if any of these micronutrients are absent in the soil or are not properly balanced with other nutrients (Nadeem *et al*., 2018) [66]. Although crops may only require a little amount of micronutrients but their impact can be significant on crop quality (Ram *et al*., 2017) [75]. In general, micronutrients play an important role in the plant growth, development and metabolic processes including cell wall development, respiration, photosynthesis, chlorophyll formation, N-fixation, etc (Ballabh *et al*., 2013) [11]. However, their deficiencies may result in several physiological diseases in plants, which in turn may reduce the quality of crops (Sharma and Kumar, 2016) [86]. It has been found that in most cases, severe deficiencies of micronutrient causes stunted growth, discolouration of leaves and even development of necrotic spots on the leaves (Alloway, 2013) [3]. Symptoms can also include smaller or twisted leaves as well as loss of turgor (Wimmer and Eichert, 2013) [101]. In most cases visual symptoms provide convenient and affordable way to detect deficiency issues, especially in regions where recurrent deficiencies problems are found (Dary and Hurrell, 2006) [22]. Thus, visual symptoms can also be mistaken with signs of a lack of macro or micronutrients. Therefore, it is advisable to carry out plant or soil analysis to confirm the deficiency diagnosis instead of relying solely on visual symptoms.

On the other hand, these micronutrients can also show toxic effect when present at higher concentration and such toxicity level endangers the plant growth, quality, etc. Therefore, it is important to monitor the crops for ensuring that the availability of micronutrient concentration in soils are in the optimum range, being neither too low, nor too high.

2. Role of micronutrient elements in crop plant

2.1 Zinc (Zn)

Zinc as a micronutrient, is essential for the plant growth and its low application can results in reduced size of anther, poor pollen producing capacity, reduced pollen size and its viability (Pandey *et al*., 2006) [71]. Zinc also helps in mitigating phosphorus toxicity by affecting phosphorus metabolism in the roots, thus increase in the permeability of the cell membrane of root cells to phosphorus and chloride (Kumar *et al*., 2022) [54]. Zn treatment causes a noticeable increase in leaf area, chlorophyll content, and other photosynthetic pigments, as well as stomatal conductance, which improves growth and production (Umair *et al*., 2020) [97].

2.2 Boron (B)

Yadav *et al*. (2013) [103] reported that B has a role in the translocation of carbohydrates, increase in pollen viability and fertilization. Its primary function is related to the composition and structure of the cell wall, in the differentiation of the meristem cells in plants and i in the transportation of sugar to storage portions (Yang *et al*., 2021) [104].

2.3 Manganese (Mn)

According to the Mousavi *et al*. (2011) [64] Mn plays an important role in plant growth, cell division, lipid metabolism and also assists in the production of chlorophyll. Mn also serves as an activator for enzymes in growth processes (Millaleo *et al*., 2010) [61].

2.4 Iron (Fe)

Fe is an essential micronutrient, takes part in the electron transport chain of respiration and photosynthesis, however it can become toxic if accumulated in higher concentration (Krohling *et al*., 2016) [62]. Fe plays an important role in symbiotic N-fixation and also required for the formation of chlorophyll in plant cells (Reddy *et al*., 2020) [79].

2.5 Copper (Cu)

Copper is essential for controlling various physiological and metabolic process in plants. The formation of Vitamin A, as well as the transport of electrons and energy by oxidative proteins and enzymes, are all facilitated by copper (Kerchev and Van Breusegem, 2022) [50].

2.6 Molybdenum (Mo)

Molybdenum is an integral component of nitrogenase and nitrate reductase enzymes, which are necessary for N-metabolism and helps in fixation of atmospheric nitrogen. Mo also plays an indispensable role in improving the phosphorous uptake by plants (Arabhanvi *et al*., 2015) [5].

2.7 Chlorine (Cl)

Chlorine controls the water balance in plants and make them drought resistant (Toshtemirovna and Ergashovich, 2019) [95]. Chlorine molecules are a crucial component in the photosynthesis process that splits water molecules and releases oxygen (Colmenero-Flores *et al*., 2019) [20].

2.8 Nickel (Ni)

Many bacterial enzymes depend on Ni, including crucial enzymes in *Bradyrhizobium japonicum*, the symbiont that fixes nitrogen (Kamboj *et al*., 2018) [47]. It is crucial element of urease enzyme and involves in the metabolism of plant anti-oxidants (Fabiano *et al*., 2015) [30].

3. Deficiency symptoms of Micronutrients on major crops

Unlike macronutrients, crops requires micronutrients in trace for proper functioning of their metabolism. The absence of any of these micronutrients can hamper plant growth (Godswill *et al*., 2022) [36]. Most commonly observable visual symptoms of deficiency of some essential micronutrients are given below-

Sl. No	Elements	Deficiency symptoms	Reference
1	Zinc	In rice brown blotches on leaves and streaks occurs that fuses to cover older leaves entirely.	(Ramesh and Gundappagol, 2019) [76]
		In wheat, deficiency of zinc leads to release of root exudates Zn deficient plants and have higher root and lower shoot dry weight.	(Widedo *et al*., 2010) [100]
		In pulses like chickpea, delayed maturity, short internodes, and reduced leaf size are common symptoms in initial stages which in advanced stage, can cause leaf bronzing and browning resulting reduced photosynthesis and retarded growth.	(Singh *et al*., 2011) [89]
2	Boron	Boron deficiency can result in failure of maturation as well as malformed or absence of seeds in grains and reduced productivity of rice.	(Rehman *et al*., 2018) [80]
		Failure of grain setting in wheat as well as loss of florets fertility in wheat	(Iqbal *et al*., 2017) [43]
		Hollow stem and browning of heads and curds in crops of brassicaceae family like broccoli and cauliflower	(Masarirambi *et al*., 2011) [55]
3	Manganese	In cereals like maize and wheat, deficiency of Mn results in leaf chlorosis and change in root and shoot growth, increased activities of anti oxidative enzymes and increased susceptibility to heat stress.	(Mengutay *et al*., 2013) [59]
		In peas and beans, appearance of marsh spots occurs	(Jia *et al*., 2021) [45]
		Fruits like raspberries and cherries and vegetables like potatoes, beetroots and peas are highly susceptible towards manganese deficiency.	(Karthika *et al*., 2018) [48]
4	Copper	In cereal crops like rice, deficiency of copper cause reduced pollen viability and increase in sterility of spikelets thus developing chaffy grains and yield loss	(Yang *et al*., 2017) [105]
		In tomato, upward leaf curl, leaf chlorosis followed by necrotic conditions, blackening of leaf veins, poor flowering and fruit settings are symptoms which occurs due to copper deficiency.	(Rajasekar *et al*., 2017) [74]
5	Iron	Deficiency of iron in rice causes inter-venal chlorosis in immature leaves, decreased synthesis of dry matter and sugar-metabolizing enzymes, and stunted grow	(Abbas *et al*., 2021) [1]
		In leguminaceae crops, Iron deficiency affects initiation and development of root nodules.	(Brear *et al*., 2013) [15].

		In citrus, Fe deficiency results in inter-venal chlorosis that in later stages of deficiency, results in whitish yellowing of the entire leaf and proceed to necrosis.	(McCauley, 2009) [57].
		In oilseed crops (ex- Indian mustard), dwarfing, inter-venal chlorosis, occurrence of small leaves and hence reduced yield occurs.	(Dhaliwal, 2021) [25].
6	Molybdenum	Mo deficiency in maize can shorten internodes, decrease leaf areas and leaf chlorosis and also cause poorly developed stamens.	(Mesurani *et al*., 2020) [60]
		Cause Millerandage or 'hen and chicken' disorder in grapevine.	(Gastol and Damagala-Swiatiriewicz, 2014) [35].
		Molybdenum helps in N-fixation and thus deficiency in Mo induces deficiency in Nitrogen in legume crops.	(Hackney *et al*., 2019) [39]
7	Chlorine	In sugar beet, cl deficiency shows inter-venal chlorosis and stunting of secondary roots.	(Soetan *et al*., 2010) [92]
		In tomato, rolling of leaf edges upward can be observed.	(Pandey, 2015) [72]
		In citrus fruits, much severe cases of chlorine deficiency have not yet been reported.	(Kafkafi, 2011) [46].
8	Nickel	Leguminous crops experience decreased urease activity which results in necrosis at the tip of leaves.	(Hassan *et al*., 2019) [41].
		In soybean deficiency symptom of Ni in soil results in reduced nodulation.	(Zobiole *et al*., 2010) [108].

4. Toxicity symptoms of micronutrients

4.1 Zinc (Zn)

General symptoms of high toxicity of zinc include stunting of shoots, curling and rolling of young leaves, death of leaf tips and chlorosis. For example in cowpea and soybean higher concentration of Zn considerably reduce plant germination (Bae *et al*., 2016) [9]. In tomato toxic concentration of zinc affect plant growth and caused leaf chlorosis (Monnet *et al*., 2001) [63].

4.2 Boron (B)

The most common visual symptoms in crops due to boron toxicity is appearance of burned edges on the older leaves (Archana *et al*., 2017) [6]. For example, in peanuts it has been noticed that boron toxicity causes chlorosis in marginal leaflets, which progresses to necrosis (Mithare, 2019) [62]. In citrus toxicity of boron leads to yellowing of leaf tips and mottling followed by premature drop (Grattan *et al*., 2015) [37].

4.3 Manganese (Mn)

Toxicity of Manganese is generally found in crops growing on strong acid soils and on soils having high level of water soluble or exchangeable Mn salts (Wang *et al*., 2021) [99]. Mn toxicity in barley can result in severe incidence of brown spotting of older leaves (Huang *et al*., 2018) [42]. In sorghum toxicity symptoms of Mn consists of dark green older leaves with large number of small dark reddish purple spots all over the leaf (Fakrudin *et al*., 2021) [31].

4.4 Iron (Fe)

Delias *et al*. (2022) [23] found that iron toxicity lowers photosynthetic pigments level, leaf gaseous exchange and overall plant growth. Similarly iron toxicity can also cause poor growth, tillering, reduction in crops spike number, flowering delay or even failure and severe reduction in yield (Sikirou *et al*., 2015) [87]. In sorghum due to Fe toxicity, leaves turn light yellowish with appearance of brownish or straw-coloured lesions at the margins (Jadon *et al*., 2020) [44].

4.5 Copper (Cu)

Excess of copper in soil can led to cytotoxic effects in plants by inducing stress as well as causing injury to plants. This leads to retardation of growth and leaf chlorosis. Exposure of plants to excess Cu generates oxidative stress and ROS (Residual Oxidative Species). Oxidative stress cause disturbance of metabolic pathways as well as damage to macronutrients. For example, in bean (*Phaseolus vulgare*), accumulation of Cu in plants results in root malformation and roots reduction (Asati *et al*., 2016) [7].

4.6 Molybdenum (Mo)

Toxicity of molybdenum has been rarely reported in agronomical crops. It has been found that higher amounts of Mo in vegetables like tomato, cauliflower and others resulted in turning their leaves purple due to accumulation of anthocyanin (Chaves-Silva *et al*., 2018) [19]. In some of the solanaceous crops, golden colouration of leaves is a sign of molybdenum toxicity. (Shambhavi, 2020) [85].

4.7 Chlorine (Cl)

The overall concentration of chlorine is generally too low in the whole plant, however chlorine tends to accumulate in certain plant tissues particularly leaves or single cells to toxic levels and cause injury symptoms like leaf burn or drying of leaf tissues. Excessive necrosis often followed by early leaf drop or defoliation (Krishna Kumar *et al*., 2017) [51].

4.8 Nickel (Ni)

Nickel toxicity in plants negatively affects respiration and photosynthesis as well as high uptake of Ni induces a decline of water content in dicots and monocots plant (Bhalerao *et al*., 2015) [12]. In cereals like what, barley and oat, chlorosis and necrosis of leaves and browning of root system are main Ni toxicity symptoms. (Asati *et al*., 2016) [7].

5. Crop Quality

The augmentation of crop output and the enhancement of crop caliber continue to hold paramount significance, notably within developing regions. Within the purvie of agricultural practitioners, emphasis is predominantly placed on augmenting crop yield; however, an equally imperative aspect to consider pertains to the intrinsic quality of the harvested produce. One noteworthy quandary in the pursuit of ameliorating crop quality within the practical realm of agriculture pertains to the attainment of a sufficient and well-balanced provision of essential minerals and micronutrients in crop nutrition. Quality differs on the fundamental elements of human demands from the perspectives of seed, crop products, post harvest technologies, consumer references, cooking quality, etc. (Gupta, 1992; Sardar *et al*., 2022) [38, 82].

All the characteristics of the harvested goods that increase their value to the consumers are referred to as quality (Fig 1), and these characteristics include:

- External attributes such as colour, appearance and grading.
- Organoleptic qualities including taste, aroma, juiciness, etc. (Causse *et al*., 2006) [17] and,
- Nutritional quality like protein, oil and mineral contents of crops (Njira and Nabwami, 2015) [67].

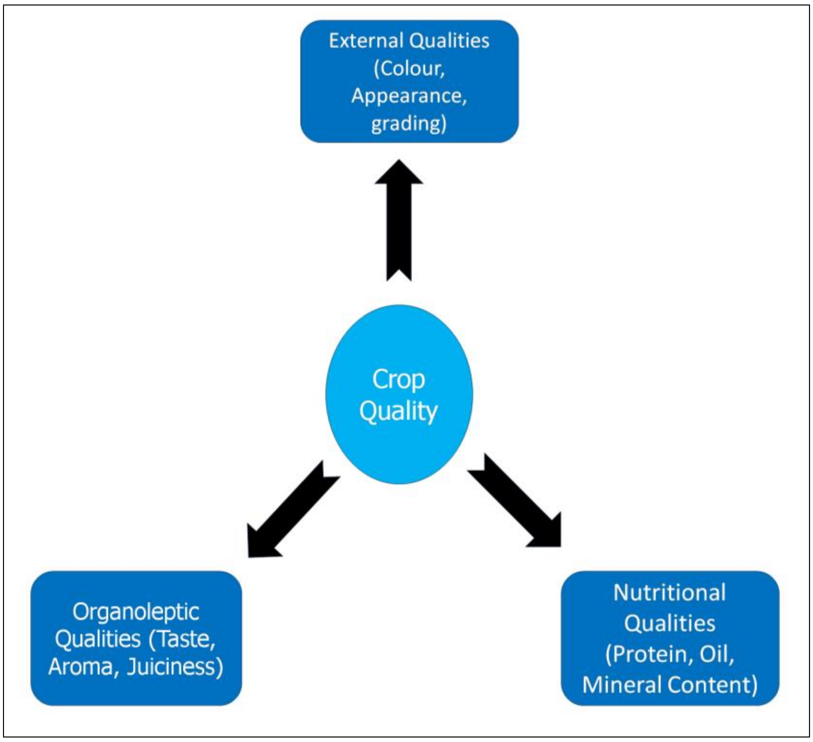

Fig 1: Crop Quality

5.1 The different crop quality characteristics that are improved by applying some micronutrients to different crops are

- Rice - Amino acid content, protein content, grain Zn and Fe content (Yuan *et al*., 2013) [107].
- Maize - Bold flint grains, high lysine content (Singh *et al*., 2021) [85].
- Groundnut - Protein content and oil content (Nadaf *et al*., 2013) [65].
- Pulses - High protein content, high methionine and tryptophan content (Singh, 2017) [90].
- Cotton - Ginning percentage, spinning consistency index (SCI) (Efe and Yapuzi, 2011) [27].
- Chilli - Ascorbic acid concentration (Singh and Rathore, 2018) [91].
- Sweet pepper - Protein, total carbohydrate content, ascorbic acid content (Gad *et al*., 2013) [32].
- Pomegranate- Fruit weight, fruit diameter (Hasani *et al*., 2012) [40].

6. Effect of micronutrients on crop quality

Micronutrients control different quality parameters of agricultural crops (Fig 2). According to Dadkhah *et al*. (2015) [21], Zn fertilizer application increases the Fe and protein content in grains of wheat. By applying zinc to rice, grains carry higher levels of zinc and other micronutrients (Gashu *et al*., 2021) [34]. Guava fruits had more TSS, acidity, total sugar, and sugar-acid ratio when Zn, Co, and B are applied through foliar routes (Rawat *et al*., 2010) [78]. The biochemical properties, inflorescence, fruit setting percentage, and flushes of *Langra* (mango) are improved by foliar treatment of boric acid. Additionally, ascorbic acid and fruit sugar content are increased by foliar Zn delivery, which also increases grain production (Anees, 2012) [4]. TSS content and maximum acidity content in litchi are both increased by the application of boron and zinc (Kaur, 2017) [49]. In oilseed crops, application of Zn, Fe, Cu and Mn has proved to have significant role in increasing the oil percentage and oil yield though when it comes to being the superior, zinc was reported to have outperformed Cu, Mn and Fe in terms of improving oil yield (Kumar *et al*., 2012) [53]. Application of Zn from various sources enhanced the general growth and development of cotton, increasing the number of bolls retained and lint index at the same time (Sathiyamurthi *et al*., 2019) [83].

According to Hasani *et al*. (2012) [40] foliar application of Zn, Mn and Fe significantly increased the amount of juice in pomegranate fruit. The application of Zn and B enhanced protein and oil content of Mustard (Yadav *et al*., 2016) [102]. Due to the application of higher levels of zinc, chickpea seed's protein content increased (Straw, 2014) [94]. In tomato, fruit acidity, ascorbic acid, TSS of fruit juice, crude protein, crude fibre content of fruit and lycopene content were improved due to the application of boron (Sathya *et al*., 2010) [84]. There was an increase in protein and oil content in soybean due to application of B (Devi *et al*., 2012) [24].

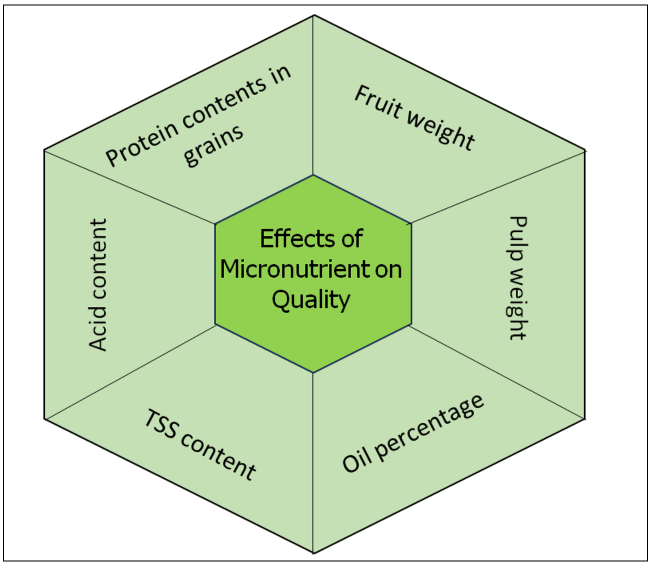

Fig 2: Effects of Micronutrient on Quality

According to Bakshi *et al*. (2013) [10] plants treated with zinc displayed the highest levels of TSS, ascorbic acid, TSS/acid ratio, and lowest acidity in strawberry plants. According to Srivastava *et al*. (2005) [93] foliar Zn and B treatment increases TSS content in garlic. According to Babu and Yadav, (2005) [8] applying Mn and Zn to Khasi mandarin orange plants increases the number of fruits produced per tree, the amount of juice, TSS, ascorbic acid, and total sugar. Meena *et al*. (2008) [58] demonstrated that applying Fe and B to ber trees increased their average fruit weight, length, breadth, pulp weight, and pulp to stone weight. According to Sardar *et al*. (2022) [82] applying Zn and B considerably improves the quantity and quality of broccoli heads.

7. Conclusion

In the realm of crop managment, the pivotal role of micronutrients, including but not limited to zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), boron (B), molybdenum (Mo), nickel (Ni), and chlorine (Cl), in shaping the quality of crops is indisputable. The discernible variations in the application rates of these micronutrient elements to diverse crop species wield a profound influence over the ultimate attributes of the economic agricultural produce. Notably, it is imperative to recognize that the quality of crops can be adversely impacted by both an excess and an insufficiency of micronutrient availability within the growing environment. An excess of micronutrients, beyond the critical thresholds required for optimal plant growth and development, may lead to an array of physiological aberrations in crops, including toxicity symptoms, impaired nutrient uptake, and imbalances in the nutrient profile of the plant tissue. Conversely, an undersupply of essential micronutrients can have equally deleterious effects on crop quality. The inadequacy of these micronutrients hampers various biochemical and physiological processes vital for crop development and product quality. The judicious and balanced application of micronutrients is crucial within agriculture, as it not only enhances crop yield but also improves crop health and quality. This approach is particularly important in today's context, where global food security depends not just on quantity but also on high-quality food products which is now recognized as a paramount concern alongside traditional yield and growth considerations. Managing micronutrient elements wisely is an indispensable aspect of modern agriculture, with a pivotal role in addressing the evolving dietary needs of the global population, highlighting the need for a holistic approach encompassing both quantity and quality in agricultural production.

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