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ABIOTIC STRESS MODERATION AND CROP PRODUCTION IN CHANGING CLIMATE: BENEFICIAL-TRACE ELEMENTS: REVIEW

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ABSTRACT

Concerns around food security have emerged in recent years, with rising food demand and the options to meet. The FAO projections indicate that global food demand may increase by 70 percent by 2050, with much of the projected increase in demand for major food crops expectedly coming from soaring population and their dietary changes.Moreover, various abiotic stresses accentuated with changing climate has jeopardized the crop production scenario. Ensuring secured food production in the face of climate change is a formidable challenge. Furthermore, in the post-green revolution period, practice of intensive cultivationand extravagant usage of high analysis fertilizers to over-responsive high yielding cultivars have caused havoc micronutrient mining from the soil itself and thus backfired on sustainable food production. In addition to micronutrients, certain beneficial elements are found to be very useful withbetter plant physiology led crop production and nutritive value of the consumables. These elements are collectively referred to as beneficial-trace elements and play a stellar role in moderating various abiotic stresses. Therefore, the application of beneficial-trace elementsas soil and foliar application is needed to be focusedon toassure quality food production through ensuring their effects on crop physiology.

Keywords: Abiotic stress, Beneficial-trace elements, Changing climate, Crop production, Food demand

INTRODUCTION

In the age of climate change, major crop yields are projected to drop by 17 percent globally in 2050 (Alexandratos and Bruinsma, 2012). Yet according to the FAO, agriculture must provide for a 50 percent rise in food production by 2050 due to population enlargement and dietary changes (FAO, 2020).Population trends project India to emerge as the most populous country in the world in the coming decades. The total cereal demand in 2026 is projected to be 273.5 mt. During the same period, demand for rice, wheat and pulses is expected to be 102.1 mt, 65.9 mt and 57.7 mt, respectively (Mittal, 2008).Changing climate poses an additional threat to India's long-term food security challenges as it affects food production in many ways. Almost 690 millionglobal populations were undernourished (or hungry) in 2019, up by 10 million from 2018 ("Number of undernourished people declines in India; obesity in adults on the rise: UN | International", 2020). In the coming decades, the unavoidable outcomes of changing climate such as seasonal drought, eratic weather with soaring atmospheric temperature, soils witnessing decreasing carbon and declining plant resilience *etc*will make the huge yield gap and malnutrition problem more pronounced. Furthermore, in the post green revolution period, extravagant usage of high analysis fertilizers to over-responsive high yielding crop cultivars and multiple cropping system caused more micronutrient removal from soil. Farmers' lack of awreness and inclination to incur less cost in manures and trace nutrients also acted as dampener to the soil fertility. On the other hand, though, beneficial elements were not remarkably deficientin soil, the effect of them at low levels should also be considered with regard to applying them to crops for boosting production under various stresses, also for enhancing plant nutritional value as a feed or food (Kaur *et al*., 2015). Therefore, strategic and scheduled promotion of benefial-trace elements as holistic soil and/orfoliar application in plant assumes more importance to ensure food and nutritional security through better crop physiology, productivity, and nutrient content.

The recent effects of changing climate are severely hampering the physiology of different crops by inducing various abiotic stresses viz. drought, salinity, heat stress and inadequate or non-availability of beneficial-trace elements and interfering in various important enzyme activities needed for the steady performance of plant metabolism. For example, the central enzyme of photosynthesis, Rubisco, is disrupted if the temperature increases from 35°C, and stops the photosynthetic process (Griffin *et al*., 2004).Drought along with heat stress reduces the grain number per spike in cereals (Stratonovitch and Semenov, 2015). Salinity stress also affected yield components like number of spikelets, spike length, fertility rates in the spikes, test weight and yield (Gholizadeh *et al*., 2014; Mishra *et al*., 2014). In legumes drought stress affects fertilization, gametogenesis, embryogenesis, grain formation and yield (Farooq *et al*., 2014).Flowering and reproductive phases are highly vulnerable to water scarcity during plant life cycle (Fang *et al*., 2010), leading to pollen grain sterility by reduced pollen tubes and pollen grain germination (Phillips *et al*., 2018*)*.Black gram (*Vignamungo* L.) yield has been reduced by drought stress from 31% to 57% during the flowering stage and 26% during the reproductive phase (Baroowa and Gogoi, 2014). Maleki *et al.,* (2013) reported a 42% reduction in soyabean yield by impeded grain filling under drought stress. These effects of various stresses amplified by changing climate are naturally being expected to cut down the final yield of various staple food crops. By 2030, rice and wheat are likely to show about 6-10 per cent decrease in yields ([Internet], 2020).

Emerging deficiencies of benefical-trace elements and its importance

In total there are 18 essential elements needed for plant growth. However it is challenging to mention an exact number of plant micronutrients,since some elements have not been strictly proposed yet either as essential or beneficial. But they have a ubiquitous presence in both soil and water and can be widely taken up and used by plants (Kaur *et al*., 2015). They also may enhance biomass and yield but may not be required for species to survive, are termed functional/beneficial elements (Marschner, 2012). Regarding the essentiality and/or beneficial effects of the micronutrients in plants, total 13 Beneficial-Trace elements including micronutrients are listed as useful for plant growth. These are Fe, Mn, Cu, Zn, B, Mo, Cl, Ni, Si, Se, Co, Al, and Na (Vatansever *et al.,* 2016).

Nutrient induced unsustainability of crop productivity are a result of imbalanced nutrient application, widespread deficiency of secondary and micronutrients: S, Zn, Fe, Mn, Cu, B. There is also a decline in response per unit of major unit nutrient applied owing to these deficiencies. Increased deficiency of trace elements in soilis indirectly affecting animal and human health along with plant nutrition. Deficiency of Zn, Cu, Bo, Mn and Fe has been noticed in 49, 4, 33, 5 and 12% soils of India respectively. Zn deficiency in soil is further expected to leap up from 49% to 63% by the year of 2025 (Singh *et al*., 2009). Intensive cropping of high yielding varieties of rice and wheat induced deficiency of Zn initially followed by subsequently deficiencies of Fe in rice, and Mn in wheat (Singh, 2008). B, Fe, Mo and Cu deficiencies are also common in cereals (Kihara *et al*., 2020). Iron Chlorosis is a conspicuous problem in Bengal gram, Sorghum and Groundnut (Singh, 2008). Deficiency ofbeneficial elements of Co and Si in rice soils has already been projected. A considerable deficiency of Se is predicted in major cereals i.e Upland- Rice, Wheat and Maize (Reis *et al*., 2020). Supplementation of these elements are needed to improve the physiology of crop plants and productivity.

Role of Beneficial elements in improving crop production and nutrition

It is important to understand the roles of beneficial elements which actually trigger the activity of different antioxidant enzymes and act as stress regulator to combat various stresses induced by changing climate. The addition of the specific nutrients can positively moderate the uptake of other micronutrients also in improving the overall nutritional status of the crop. Apart from enhancing crop nutritional quality, trace elements, when efficiently translocated to seeds, also enhance seed vitality that allows good seed emergence and vigorous seedling growth (Nestel *et al*., 2006; Velu *et al*., 2014).

Selenium

Selenium helps to ameliorate various stress injuries in plants induced by cold, drought, high temperature, water, salinity, heavy metals, UV-B rays, and desiccation. It protects plants against abiotic stresses by regulating the uptake and redistribution of elements essential in the antioxidative system and interfering with the electron transport complex (ETC) of the photosynthetic system (Kaur *et al*., 2014). Both foliar and soil application of Se increased Se content in the edible crops by redressing injuries from four different abiotic stresses (Pezzarossa *et al*., 2012). Protective role of Selenium during high-temperature stress has been reported by foliar spray of Se at 100 mg L^{-1} and seed treatment at 5 mg L^{-1} in Soyabeanwith decreased membrane damage and reactive oxygen species (ROS) content through increased antioxidant enzyme activity (Djanaguiraman *et al.,* 2004). At a low level of concentration, Se imparts diverse beneficial effects (Yassen *et al*., 2011) and stimulates growth as well (Malik *et al*., 2012;Han *et al*., 2013). Se-enriched fertilizers reportedly increased grain Se concentrations (in maize and wheat). In Finland, nationwide addition of Se to NPK fertilizers (15 mg Se/kg) increased cereal crop Se contents by 15-fold on average increasing Se intake of the population to well above nutrition recommendations (Alfthan *et al*., 2015). Other authors observed linear relationships between Se fertilization and maize grain Se concentrations (Chilimba *et al*., 2012).

Silicon

Plant growth, development and reproduction are significantly affected by deficiency of Silicon which has also been classified as a ‘quasi essential’ element like Selenium (Epstein and Bloom, 2005) and it reportedly minimizes various stresses in changing climate scenario. According to Marschner (2012), Si^{4+} is deposited under cuticle epidermal cells of leaves which make leaves more erect improving their exposure to light and mitigates water scarcity by lowering the transpiration rate; it increases cell elongation in roots enhancing cell wall elasticity. Malav*et al*., (2015) reported significant increment of plant height, yield components and yield and straw yield in rice applied with Silicon fertilizers. Ahmed *et al*., 2015 observed 33% wheat yield scale up with silicon. Shedeed *et al*., (2016) reported that foliar application of Si improved yield of flax. Maximum silicon uptake at three leaf stage, (0.028 µg g-1 dry weight (DW), anthesis (0.072 µg g-1 DW) and maturity (0.103 µg g-1 DW) were recorded for silica gel application in wheat. Silicon uptake increased significantly in response to increase in Si concentration from in rice Malav *et al*., (2015).

Cobalt

Cobalt is an essential component of cobalamine, which is needed for activities of several enzymes in nitrogen fixation by rhizobia bacteria and cyanobacteria that live in root nodules of leguminous plants. The essentiality of Co^{2+} is required as a constituent of vitamin B_{12} into methyl and adenosyl vitamin B_{12}, which function as coenzymes. In higher plants, Co^{2+} plays a major physiological role, i.e. nitrogen fixation by leguminous crops. The supplementation of 8 mg cobalt to groundnut (*Arachishypogaea* L.) plants are found showing significant increment in nitrogenase activity and subsequently enhanced growth and yield, leading to improved quality of pods and oil yield (Gad, 2012). In pea (*Pisumsativum* L.), cobalt application to the soil increased growth, plant nutrient levels, nodule numbers and weight, and seed pod yield and quality (Gad, 2006).

Sodium

Some aquatic halophytes use Na^+ to facilitate nitrate uptake via Na/NO_3 co-transporters. Xi *et al*., (2018) on xerophyte *Z. xanthoxylum* under drought conditions revealed that Na^+ can significantly increase the survivability of this plant. These physiological drought adaptations are likely result of high concentrations of Na^+ distributed in leaves that act to lower leaf osmotic potential, swell leaf organs and decrease stomatal aperture size, enabling enhanced water uptake, storage and reducing water losses.

Role of Trace elements in improving crop production and nutrition

Iron

There are estimates that 30% of world's cultivated soil is iron sick (Cakmak, 2002). Plants and humans cannot easily acquire iron from their nutrient sources although it is abundant in nature and also an integral part of plant food and human diet. Low solubility of iron in aerated soils at neutral or alkaline pH has been recognized as a common yield-limiting factor in agriculture, which is difficult to correct due to the high costs and low efficiency of iron fertilizers. Iron plays an irreplaceable role in easing stress induced by salinity, drought, and heavy metals by activating plant enzymatic antioxidants like catalase (CAT), peroxidase, and an isoform of superoxide dismutase (SOD) who all act as scavengers of reactive oxygen species (ROS) (Hellín *et al*., 1995).Sharma *et al*., (2012) and Ghasemi *et al*., (2014) reported ameliorative effect of Fe against salinity by producing antioxidative enzymes. Application of iron improved salt tolerance to sunflower and maize (Ebrahimian *et al*., 2010). Iron acts an electron carrier facilitating respiration and photosynthesis. Fe helps in photosynthesis, nitrate and sulfate reduction, and nitrogen assimilation playing stellar role in the redox system.

Foliar sprays of ferrous sulfate or chelates were found highly effective in correcting Fe chlorosis in wheat. Majeed *et al*., (2020)reported split application of Fe at 15 kg ha^{-1} enhancing yield, economic returns, grain-Fe concentration and bioavailability of Fe in mungbean. Iron-humic complexes provide a readily available iron form in the soil and directly impact physiological and developmental programs (Schmidt *et al*., 2019). Iron in combination with molybdenum helps the plant to fix atmospheric nitrogen (Malvi, 2011), and results in greater yield in wheat (Abbas *et al*., 2009) and Rice (Ram *et al*., 2013). Iron fertilization has been found useful in increasing the concentration of iron in rice grain (Jin *et al*., 2008). Application of Fe-EDTA @ 0.5 Kg ha^{-1} recorded significantly higher Fe content in grain as compared to other micronutrient treatments in Rice (Ram *et al*., 2013).

Zinc

Membrane permeability, activity of antioxidant substances, photosynthetic efficiency and water use efficiency are the indicating attributes of drought stress that are positively influenced by adequate Zn supply (Karam *et al*., 2007). Defensive antioxidant activity of plant system contains various enzymes protecting plants from the reactive oxygen species(ROS) under drought stress (Reddy *et al*., 2004). SOD contains Cu/Zn-SOD, Mn SOD and Fe-SOD, which constitute the first protective systems against O_2^-, and converts it into H_2O_2 and O_2 (Gratao *et al*., 2008). Zn increases the activities of superoxide dismutase (SOD), Catalase (CAT) and Ascorbate peroxidase (APX) enzymes in drought stressed Cotton and Rice (See table no. 1). Higher germination and yield of maize, wheat and chickpea have been reported with application of Zn through seed priming (Harris *et al*., 2007). Under drought conditions, seed priming with Zn hastens synthesis of IAA and GA_3 and augments plumule length and weight (Cakmak, 2008). Zn application resulted in appreciable increase in leaf area, the content of chlorophyll and other photosynthetic pigments, and stomatal conductance, thus resulting in improved growth and yield (Karim *et al*., 2012). Hera *et al*., (2018) revealed that foliar applied Zn diminished the negative impacts of water deficit and increased growth and yield of wheat. Fe concentration also can be increased with soil Zn application in moist soil (Mao *et al*., 2016). A review of experiments from ten African

Table 1: Alleviation of different stresses accentuated with changing climate by beneficial-trace elements in crop plants

Beneficial/ trace element	**Stress type**	**Affected crop/crops**	**Ameliorating effect on Physiological traits**	**Reference**
Selenium (Se)	Heat stress	Wheat (*Triticum aestivum)*	Mitigated the deleterious effects of heat stress through Se-mediated up-regulation of antioxidative system (both enzymatic and non-enzymatic).	Iqbal *et al*., 2015; Kaur and Nayyar, 2015
	Oxidative stress and heat stress (High temperature stress)	Sorghum (*Sorghum bicolor*)	Improved plant physiology by decreasing membrane damage via enhancement of antioxidant defense which was reflected in increased growth, and grain yield.	Djanaguiraman *et al*., 2010
	Drought stress	Barley *(Hordeum vulgare)*	Foliar application of sodium selenate exhibited better protection by strengthening antioxidant defense system	Habibi, 2013
	Heavy metal stress (Arsenic)	Mungbean*(Vigna radiata)*	Antagonized the adverse effects of arsenic stress by reducing its uptake and enhancing defense mechanisms.	Malik *et al*., 2012
Silicon (Si)	Water stress	Rice *(Oryza sativa)*	Lowered transpiration rates to the extent of 30% through the manipulation of cuticle thickness.	Ma *et al*., 2001a
	Salt stress	Barley *(Hordeum vulgare)*	Assisted changes in structural integrity and function of plasma membranes by suppressing lipid peroxidation and stimulating root H+ -ATPases in membranes and antioxidant machinery.	Rizwan *et al*., 2015
Iron (Fe)	Drought stress	Wheat (*Triticum aestivum)*	Increased flag leaf area by 11.7% and also relative leaf water content (RWC) by 8.3%	Jalilvand *et al*., 2014.
Zinc (Zn)	Drought stress	Indian mustard *(Brassica juncea)*, Triticle	Improved relative leaf water content along with chlorophyll, and carotenoid contents, thereby reduction of the electrolyte leakage and water loss.	Khan *et al*., 2016; Arough *et al*. 2016
	Oxidative stress caused by drought stress	Rice *(Oryza sativa),* Cotton (*Gossypium sp)*	Accelerated the activities of superoxide dismutase (SOD), Catalase (CAT) and Ascorbate peroxidase (APX) enzymes thus contributing to the alleviation of oxidative stress caused by drought stress	Wu *et al*., 2015; Thounaojam *et al*., 2014
	Salt stress	Rice *(Oryza sativa)*	Increased photosynthetic rate, transpiration rate, stomatal conductance, water use efficiency, total soluble protein, amino acid	Ashraf *et al*., 2014
	Drought stress	Sesamum *(Sesamum indicum)*	Increased chlorophyll content, resulting in significant increase in photosynthesis and thereby quantum yield	Dehnavi *et al*., 2017
Boron (B)	Salt stress	Maize (*Zea mays* L. amylacea)	Partially mitigated the negative effect of salinity through the recovery of K^+ levels and maintenance of membrane integrity.	Bastías *et al*., 2004
Zn+B+Mn	Drought stress	Wheat (*Triticum aestivum)*	Increased the rate of photosynthesis, water-use efficiency (WUE) and pollen viability	Karim *et al*., 2012
Fe + Zn + Mn	Phasic water stresses	Sunflower *(Helianthus annuus)*	Enhanced synthesis and aggregation of carbohydrate and proline.	Babaeian *et al*., 2011

Table 2: Interaction of Beneficial elements with macro and micronutrients

Beneficial/trace element	Concentrations	Synergistic effect	Antagonistic effect	Crop	References
Selenium	5 µmol·dm^{-3}	**P**	**-**	Maize	Hawrylak-Nowak, 2008
	25 µmol· dm^{-3}	**K**	**-**		
	50 µmol· dm^{-3}	**P, Ca**	**-**		
	100 µmol· dm^{-3}	**P, Ca**	**K**		
	2 ml L^{-1}	**Fe, Ca, Na**	**K, Zn**	Strawberry	Narváez-Ortiz *et al.*, 2018
	4 ml L^{-1}	**Na, Cu, Mn**	**K, Ca, Mn and Zn**		
Selenium Selenate	-	**Mo, S**	**K, Mn, P**	Lettuce	Silva *et al.*, 2018
Selenite	-	**Mn**	**Mo**		
Selenate	Up to 20 µM	**Fe, Mn**	**-**	Lettuce	Rios *et al.,* 2013
Selenite	Up to 80 µM	**Fe**	**Mn**		
Selenate	Up to 120 µM	**-**	**Cu**		
Selenite	Up to 60 µM	**Cu**	**-**		
Both (Selenate and Selenite)	Up to 120 µM	**B**			
Silicon	20 mg L−1	**As, P, Fe**	**-**	Rice	Agostinho *et al.*, 2017
	40 mg L−1	**P**	**As, Fe**		
	80 mg L−1	**As, Fe**	**P**		
Cobalt	-	**-**	**Zn**	Pea, wheat	Babalakova *et al.* 1986; Chaudhury & Loneragan, 1972; Palit *et al.*, 1994

countries on the impact of Zn-enriched fertilizers showed that soil Zn application increased the Zn concentration in maize, rice and wheat grains by respectively 23%, 7% and 19% and by 30%, 25% and 63% through foliar application (Joy *et al*., 2015b). Soil application of Zn-EDTA @ 1 Kg ha^{-1} recorded significantly higher Zn content in rice grain (Ram *et al*., 2013).

Boron

Boron is involved in protein and enzymatic functioning of the cell membrane, leading to improved membrane integrity (Brown *et al*., 2002). Optimum Boron concentration enhances the plasma membrane hyperpolarization, while its deficiency alters the membrane potential and reduces H$^+$-ATPase activity (Goldbach and Wimmer, 2007), also activates enzymatic and nonenzymatic oxidation by using phenol as substrate, resulting in elevated level of hazardous polyphenol oxidase and quinine concentrations (Hajiboland *et al*., 2013). Boron deficiency may trigger reactive oxygen species generation which drastically reduces ascorbic acid and glutathione metabolism (Marschner, 2012). In fine grain Basmati rice improved leaf elongation, tillering, leaf chlorophyll contents and water relations were reported with foliage applied Boron associated with decline in panicle sterility (Rehman *et al*., 2014). Jabeen and Ahmad (2011) reported enhanced growth and yield of Sunflower due to application of Boron along with Manganese. Phonglosa *et al*., (2018) found the effect of Boron nutriment on growth parameters and yield attributes of rice (var. Mandakini) resulting highest rice (var. Mandakini) grain yield of 4.30 t/ha in the plots enjoying combined application of Boron in soil with NPK and as foliar spray at 45 days after transplanting.

Manganese

It is widely believed that the reduction in photosynthesis is the major reason behind the decline in dry matter production and yield under Mn-deficient conditions. Mn in plant system naturally catalyzes activity of Mn-SOD contributing greatly to plant tolerance against different abiotic stress factors such as winter hardiness, ozone stress, salinity and drought stress. Deposition of wax layer on leaves also improve drought tolerance in plants. The wax layer limits the non-stomatal water loss and reduces the heat load on leaves (Hebbern *et al*., 2009). In barley, latent Mn deficiency was found to significantly reduce the wax content (up to 40%), resulting in increased transpirational water loss and lower water-use-efficiency . Mn deficiency can weaken this wax layer and thus the susceptibility of crops to both drought and heat stress can be increased. (Hebbern *et al*., 2009). Manganese plays an important role in stress defense mechanism of plant mainly contributing to functionalizing of SOD enzyme, which is responsible for the detoxification of the destructive free radicals. It functions as an essential cofactor for the oxygen-evolving complex (OEC) of the photosynthetic machinery, catalyzing the water-splitting reaction in photosystem II (PSII) (Alejandro *et al*., 2020). The yield responses of wheat, rice, potato and sorghum to Mn fertilisation in a large number of experiments varied between 2–226% for wheat, 4–98% for rice, 8.5–17% for sorghum, 4–15.6% for potato and 2.5–86% for soybean (Singh, 2001c).

Interaction of Beneficial elements with macro and micronutrients

There are plenty of literature regarding interaction of micronutrients with themselves and other nutrients. But the same informations regarding beneficial elements are still lacking. Se, Si, and Co related informations are found and presented here. Interactions of other beneficial elements with major and minor nutrients also must be explored and reckoned in taking up advosories and prescription for sustainable crop production. Cited literature evidence that the antagonistic and synergistic interactions among and between elements are specific to concentrations of judicious use, mollecular forms, and in plant parts of respective crops. While selenium shows synergy with potassium and calcium, concentartion of the same beyond 100 $\mu mol \cdot dm^{-3}$ is antagonistic to K for maize (Hawrylak-Nowak, 2008). Again Selenum enjoys synergistic interaction with iron calcium and sodium in strawberry with antagonistic interaction with potassium and zinc in strawberry when applied @ 2 ml L^{-1}. When applied at higher concentration the behaviour is different and exhibits antagonism to a other set of nutrients (See table no. 2). Silicon profoundly influences rice at various concentrations and has registered positive effect with iron and and phosphorus and both synergies and antagonism with heavy metal Arsenic (Agostinho *et al*., 2017).

CONCLUSION

Beneficial-trace elements are contributory to combat low productivity owing to climate change and adverse physiological responses in crop plants. The positive effects of these elements on plants include improved yield and postharvest quality, absorption of other nutrientsor tolerance to abiotic stress factors such as heavy metals, drought, and salinity. The beneficial effects of these elements have been shown to be associated when administered in foliar applications, low quantities and concentrations. It can be further observed that adequate intracellular concentrations of beneficial metal ions (in traces) are required for optimal growth and development of plants. More research is welcome to understand the dose of application which makes them toxic to plants, the efficacy of the chemical forms and phenological stages of application which unfolds their contribution better to make them more cost effective. In this era of research, the effects of beneficial elements at low levels and their interactions with the other nutrients deserve more awareness by developmental programs in order to fertilize crops with these nutrients to boost crop production under stressed environments as well as enhance plant nutritional value as food or feed.

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