Environment and Ecology 41 (3C) : 1853—1859, July—September 2023
Article DOI: https://doi.org/10.60151/envec/LCCH4556
ISSN 0970-0420

Importance of Zinc and Molybdenum for Sustainable Pulse Production in India

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Received 10 March 2023, Accepted 22 June 2023, Published on 4 September 2023

ABSTRACT

Pulses are of paramount importance in Indian agriculture next to cereals and oilseeds in terms of acreage, production and economic value. Pulses are important sources of protein in a vegetarian diet, especially in India, where a large part of population is vegetarian and protein malnutrition is rampant and has not yet received adequate attention for micronutrient fertilization. To reduce the demand and supply gap, government of India launched various programs in pulses. Still, prime attention is required to meet the food security challenges, especially in case of pulse sector. In order to increase the pulse productivity while sustaining at high levels, greater attention on nutrient managements including micronutrients are among the promising technologies in pulse production. Among those micronutrients, zinc (zn) and molybdenum (Mo) are of major concerns. Mo acts as a cofactor for the enzymes namely nitrogenase and nitrate reductase, which take lead roles in bio-logical fixation and subsequent assimilation of nitrogen in legumes. Thus, Mo plays an important role in metabolism and biosynthesis of nitrogen into protein. Besides this, it facilitates the various physiological and biochemical process in pulses. Application of Mo enhances the bioavailability of other essential nutrients to crops. Plants subjected to zinc deficiency display alterations in the activity of many enzymes and decreased protein synthesis. Foliar spray of nutrient fertilizers at the critical stages of rainfed condition, application of micronutrients and secondary nutrients has been great focus in boosting up pulses productivity in India. Thus, this article represents critical review on constraints of low pulse productivity, role of Zn and Mo fertilization to gear up the present pulses productivity to larger extent while sustaining the productivity of pulses in India.

Keywords Micronutrients, Molybdenum, Sustainable production, Pulse productivity.

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INTRODUCTION

Pulses constitute an important ingredient in the vegetarian diet of developing countries like India and also ensure nutritional security to the poor masses. In

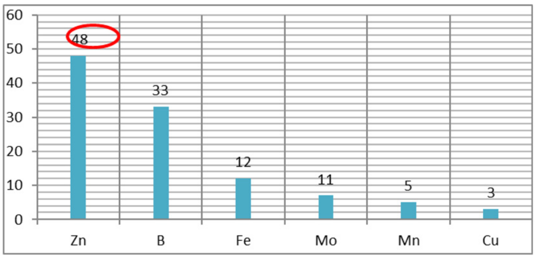
India, pulse holds a very important place right next to cereals for their richness in protein, vitamins and minerals (Praharaj *et al.* 2016). According to FAOSTAT (2016), India being a developing country consumes the world largest quantity of pulses (15.4 kg/year per capita) followed by Kenya (17.0 kg/year per capita) and Turkey (13.6 g/year per capita). Pulses grains contain vitamins, minerals and fibers besides having almost twice of the quality protein content of the cereals complements well with the protein in cereals enhancing nutritional value of cereal dominated diets (Table 1). Being leguminous crops, possess excellent properties of fixing atmospheric nitrogen biologically in root nodules in association with symbiotic *Rhizobium* bacteria and subsequently facilitating improvement of soil fertility status (Maheswari and Karthik 2017) and they are known to render significant impact on soil health and considered to be key component for sustainable agriculture (Laishram *et al.* 2020). Thus, pulses can meet the required challenges for providing food as well as nutritional securities in hugely populated countries like India while maintaining the environmental sustainability (Das and Jana 2015). The legumes which are highly nutritive in proteins content are considered as 'poor people's meat' (Iriti and Varoni 2017). Fortunately, the varied agro-climatic regions in India allow wide range of pulse crops to thrive throughout the country. Pulses are cultivated as an intercrop owing to the fact that they are more nutrient-dense than vegetables and less expensive than animal proteins. A healthy pulse crop always has a great demand for both the macro as well as micronutrients in right proportions i.e., balanced nutrition to facilitate bacterial functions in the root nodules, particularly in case of growing on a nutrient deficit soil. Proper nutrient management in agricultural production is essential for achieving improved yield and quality; otherwise, grain production decreases and chemical composition deteriorates (Shijagurumayum *et al.* 2022). Molybdenum is an essential ultra/micro-nutrient regulating various physiological and biochemical functions in pulse crops Molybdenum (Mo) and Zinc (Zn) are part of the limiting factors in pulses production. Mo is considered as ultra micronutrient acting as a cofactor for nitrogenase and nitrate reductase enzymes which have paramount roles in biological nitrogen fixation and subsequent assimilation in legumes. Thus, Molybdenum plays vital role in nitrogen metabolism and biosynthesis of protein. Besides, it also facilitates several physiological and biochemical processes in pulse crops. Application of Mo enhances the bioavailability of other essential nutrients to crops. It occurs in the envelope of chloroplasts in leaves also involved in synthesis of ascorbic acid and in making iron (Fe) physiologically available within the plant. The biological importance of Mo in plants is due to its highly beneficial action in the fixation of nitrogen from the air, by the nitrogen-fixing bacterium (*Azotobacter chroococcum*) and enzyme like nitrogenase. Moreover, Mo inhibits immature drops of flowers and pods in pulses (Banerjee *et al.* 2019). About 30% of world soils are deficient in available zinc and it has emerged an important plant nutrient limiting crop yields. In India, zinc (Zn) is now considered as fourth most important yield limiting nutrient in agricultural crops and likely to increase from 49 to 63% by 2025 (Ganeshamurthy *et al.* 2019). Zinc (Zn) deficiency is a commonly occur disorder in plants growing in different climatic conditions all over the world. Zinc is highly phloem-mobile, absorbed and translocated predominantly as a free divalent cation. Zinc deficiency induces changes in the antioxidant defence system disturbing the ultrastructure of thylakoid membranes of chloroplast due to enhanced lipid peroxidation. Plants subjected to zinc deficiency display alterations in the activity of many enzymes and decreased protein synthesis (Nautiyal and Shukla 2013). Nearly, 10% of protein needs zinc for their function and structure.

Table 1. Nutritional profiles of pulses vs cereals.

Parameters	Pulses	Wheat	Rice	Corn
Energy (Kcal)	333	339	349-373	361
Protein (g)	23	14	6-7	7
Carbohydrates (g)	60	72	71-87	77
Dietary fibers (g)	15	12	7-10	7
Fat (g)	0.83	1.7	0.3-0.5	4
Iron (mg)	8	3.9	0.2-3	2
Potassium (mg)	1400	405	429	315
Folate (μg)	394	44	56	25

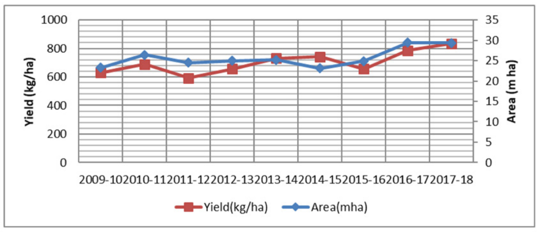
(Source: Food Data Central, USDA 2022)

Thus, keeping the key importance above, it is prime importance to introspect on the nutrient management through micronutrients and understanding the role of Zn and Mo fertilization to level up pulses



(Source: Singh, 2008)

Fig. 1. Status of micronutrient deficiency in Indian soil.
(Source: Singh 2008)



(Source:FAO STAT, 2018)

Fig. 2. Pulse productivity range with respect to area during 2017-18.
(Source:FAO STAT 2018)

for sustaining production in India.

Status of micronutrient deficiency and pulse production in Indian scenario

Crops grown in most soils in India suffer from deficiencies of one or more micronutrients, even though the soils often contain apparently adequate total amounts of the respective elements. The kinds and severity of deficiencies vary depending on the agro-ecological conditions, crop genotype, soil type and management. High levels of food crop production are at risk due to deficiencies in Zn and Mo due to substantial planting of high yielding ability cultivars of wheat and rice. Currently, it's common to find micronutrient deficits in crops grown intensively, such as grains, oilseeds, pulses, and vegetables. The incidence of zinc insufficiency has decreased recently due to the extensive and consistent application of Zn fertilizers but multiple micronutrient deficiency are increasingly becoming more prevalent. According to analysis of soil and plant samples, 48% of soils in India may be low in zinc (Zn), iron (Fe) 12%, manganese (Mn) 5%, copper (Cu) 3%, boron (B) 33%, and molybdenum (Mo) 11% (Fig. 1).

India has lion share in area (42.6%) and production (25.7%) of pulses globally (Chauhan *et al.* 2016). In India, pulses constitute a group of 12 crops that include mainly chickpea, pigeonpea, mungbean, lentil, urdbean and fieldpea. Among major pulses grown and produced globally, Indian share is maximum for pigeonpea in area (73%) and production (67%) followed by chickpea (68% area and 66% production), dry beans (37% of area and 18% production). Most of the pulses have shown lower productivity as compared to global average yields for various pulses excluding chickpea where productivity is comparable globally. To overcome this problem to meet the sufficient protein energy and avoid malnutrition, minimum of 50g pulses/capita/day should be made available as source of protein in addition to other sources. To achieve this, growing rate of pulse production > 4.0% is expected. To reduce the demand and supply gaps, Government of India launched various incentive programs like Integrated Scheme of Oilseed, Pulses, Oilpalm and Maize (ISOPOM), Front Line Demonstrations (FLD) program and National Food Security Mission (NFSM). It is important that during 2018-19 pulses production of India is 23.40 Mt which is highest followed by Canada (8.7mt) and Myanmar (7mt) (Fig. 2). But in terms of productivity, Canada stood first with 2095kg/ha and India's productivity (835 kg/ha) is quite low comparative to other countries (Fig. 2). The pulses production at exponential rate of growth during last year was more than 9% Major producers in India which contributes for more than 90% pulses were Madhya Pradesh (> 8 Mt), Rajasthan (>3 Mt), Maharashtra (>3 Mt), Uttar Pradesh (>2 Mt) Karnataka (2 Mt) and Andhra Pradesh (>1 Mt) followed by Gujarat, Jharkhand, Tamil Nadu, and Chhattisgarh producing <1.0 Mt each. In *kharif*, Maharashtra (24%), Rajasthan (15%) , UP (13%) and MP (10%) while in *rabi* MP (33%) followed by UP (19%) are the leading states in producing pulses. Thus, a great challenge is developed for scientists, policy makers and other farming community to boost the pulse productivity and also diversify the entire cropping management systems to meet the pulse requirements in locals and national (Choudhary 2013).

Constraints of pulse productivity of India

Climatic factor: There has been a high degree of risk in pulses production. More than 87% of pulses area is presently rainfed condition. Moisture stress considered to be a major reasons of crop failure. Real-time climate change is already intensifying owing to temperature increases, rendering it more challenging for farmland cultivation and the future effects appear to be more detrimental (Laishram *et al.* 2023). An abrupt rises in atmospheric temperature not only induced forced maturation but also concurrently attracts a number of biotic stresses, including diseases and pests (Ali and Gupta 2012). However, optimum sowing time of lentil is first fortnight of October. Traditionally, rabi pulses sowing delayed up to end of November and sometimes under the extreme circumstances, then it goes up to 1st fortnight of December, obviously due to reasons already explained. Terminal drought and heat stress results in forced maturity with low yield level. Drought stress alone may reduce seed yield by 50% in the tropics. Irrigated area under pulses has virtually remained stagnant at 13% of the total area. Higher evapo-transpiration in south India during the *rabi* season causes severe problems to chickpea yield under drought.

Biotic and abiotic stresses: Pulses yield is mainly influenced by the various factors including both biotic factors viz; insects, pests, microbial attacks, and abiotic factors viz; salt, drought, heavy metals, Storage loss in pulses are mainly attributed to microbial bacteria, fungi, insects and rodent attacks and out of which insect damaged cause extensive losses (10–50%) in stored grains (FAOSTAT 2016). Though several resistant/tolerant varieties had been developed by research institutions the spread of such varieties in the farmers fields is very limited. The main reason could be our weak seed production program. Abiotic stress like extreme weather conditions such as sudden shifting of temperatures i.e. low and high beyond threshold level of tolerance cause flower abortion and hastens the reproductive period and ultimately lower grain yield. If rainfall intensity is too high it may cause flash flood which is vulnerable of *kharif* pulses to water stagnation (oxygen stress) and for *rabi* pulses, subjected to water deficit.

Varietal constraints: The non-availability of seeds of high-yielding varieties in the desired quantities is perhaps a major constraint in expansion of pulses. Although more than 200 improved varieties of pulses have been released since 1970's, its impact hardly get reflected in the yield. The failure of these varieties to make any real dent in pulse productivity could thus be due to their inherent weakness. In pulses, improved varieties hardly have a yield advantage of 15-20% over the traditional varieties. Lack of high potential yielding varieties with low harvest index, susceptibility to various pests and diseases, flowering drops, lack of shorter duration varieties, intermediate habits of growth, poor response to inputs and other instabilities in performances are some varietal constraints which needs immediate action (Singh *et al.* 2013).

Imbalance fertilizer use and lack of biofertilizer inoculation: The fertilizer use in pulses was very low with chickpea receiving the highest priority and pigeon pea the least. For the growth and development of root nodules properly inside root, phosphorus is absolutely necessary and application of P_2O_5 @40 kg per hectare has been recommended. It is apparent that the distortion in fertilizer subsidy / pricing policy making the phosphatic and potassic fertilizers more costly relative to the nitrogenous fertilizer also contributed to the adverse effect on the growth of pulse crops .The impact of such an unbalance in fertilizer use would be more severe in pulses as phosphorus, Molybdenum are considered the most important nutrient for pulses. *Rhizobium* inoculation of legume crops has long been considered as an important factor for increasing yields. Besides, the bio-fertilizers are also environment-friendly and free from the adverse effects of chemical fertilizers. Seeds should be inoculated with efficient *Rhizobium* cultures to activate the process of nodulation. Though efforts to popularise these *Rhizobium* inoculants have been going on for a long time and several public and private sector units are manufacturing them, the adoption of these bio-fertilizers is found to be very negligible.

Poor farm management: Furthermore, there is hardly any visible technological change in pulse farming in the country. This clearly shows that technological stagnation is primarily responsible for the backwardness of pulses not only in Madhya Pradesh but in the country as a whole. For example, no proper irrigation at critical stages, especially in rainfed *rabi* season, limits the yield as *rabi* pulse are grown mostly to utilize residual soil moisture.

Grown in marginal lands: Pulses are the major important crop next to cereal and oilseed that grown largely under energy starved environment, marginal and sub-marginal soils and also rainfed pulses occupied more than 75% of the area which resulted into poor crop yield despites their potential (Choudhary 2013). In general, pulse crops prefer neutral soil reactions and are highly sensitive to acidic, saline and alkaline soil conditions. As per Agriculture Census 2010-11, marginal and small land holdings (< 2 ha) account for 85% of the total operational holdings and 44% of the total operated area. Small farm sizes inhibit mechanization.

Soil factors affecting zinc availability to roots

Calcium carbonate ($CaCO_3$) : High $CaCO_3$ affects Zn availability in three aspects - due to calcium pH of soil will be increase ultimately, solubility of zinc is reduced and hence less available for plants to uptake. Zn is directly adsorbed or precipitated along with carbonates again which makes unavailable for plants. Calcium present in $CaCO_3$ forms insoluble complex like calcium zincate.

High ph: In fact, solubility of Zn is highly ph dependent, it decreases by 100 fold with each unit increases in pH. In high pH, it is associated with increases, adsorption of zinc on soil components like hydroxides, carbonates ,humic acids thus less available in soil solutions for plants.

Clay minerals: Availability of zinc differs in different clay minerals like 1:1 and 2:1 type . 2:1 layer has more CEC, specific surfaces area and more Zn is fixed in lattice. So, soils dominant in kaolinite type 1:1 will have more availability than 2:1. That means soils rich in high clay will also affect zinc availability in soil.

Low organic matter (OM): In general, organic matters can hold micronutrient cations like Zn, Fe, Cu, and are available to plants India's climate is prominent in tropical and sub tropical where OM content is generally low, otherwise it could contribute towards Zn availability in plants.

High Fe & Al oxides: When there is high Fe and Al content in the soil Zn is adsorbed and also precipitated and these forms Fe-Zn complex (franklinite).

Fertilization with micronutrients

Fertilizer management encompasses adding of nutrients at the correct amount and right time through appropriate method to ensure minimum nutrient losses from soil, thereby, efficient use of nutrients for gearing crop productivity while maintaining the soil fertilities (Dass *et al.* 2014). Generally, pulses required lesser amount of nutrient nitrogen as an input as they are equipped with capacities that can fixing atmospheric nitrogen biologically through the bacteria *Rhizobium* but they need adequate nutrients throughout the early phases the root proliferation and synthesis of amino acids (Devi *et al.* 2023). This mechanism of legume plant nitrogen fixation starts once the formation nodule in their roots. They require higher amount of micro nutrients like Mo and Zn comparatively than other crops since these are integral components of enzyme nitrogenase and carbonic acid anhydrase which are very much essential for nitrogen fixation in the soil (Choudhary and Suri 2014).

Importance of molybdenum on pulses

N fixation: Mo is a crucial component of the enzyme nitrate reductase, which reduces atmospheric nitrogen in two steps: First, nitrate is converted to nitrite in cytoplasm, and then nitrite is reduced to ammonia in the chloroplast. Nitrogenase enzyme is necessary by *Rhizobia* in root nodules for fixing atmospheric nitrogen. Thus, these two enzymes are important in legumes.

Required for protein synthesis: Mo is also a component of enzyme *Xanthin dehydrogenase* enzyme and its function is to transport nitrogen from root nodules to other parts of the plant in form of ureid allantoin and allantoic acid. In roots, xanthin is oxidize to uric acid which is the precursor of allantoic acid and this oxidation of xanthin is catalyzed by xanthin dehydrogenase which contains Mo.

Catabolism of S containing amino acids: Sulphite oxidase enzyme oxidize sulphite to sulfate, this enzyme contains Mo thus, involved in the catabolism amino acids like methionine, which are deficient in pulses. Khalil and Ved (2014) reported that application of Mo to 1.0 kg/ha (ammonium molypdate) significantly enhanced seed yield. This increase was due to fact that application of molybdenum enhancing nodule formation and thus, seed yield of the crop.

The application of Mo along with *Rhizobium*+PSB+RDF increases seed yield, and this may be due to improved nodulation and assimilation of BNF, N, and other complementary elements as a result of the positive effects of Mo and Mo-Fe on nitrogenase activity in nodules and nitrate reductase activity in the plant system. Therefore, it may be concluded that the application of Mo through ammonium molybdate @1g/kg seed preferably by seed treatment in combination with *Rhizobium*+PSB+RDF enhanced the productivity of rainfed chickpea (Gupta and Gangwar 2012). Devi *et al.* (2023) revealed that application of Mo increases the yield significantly, quality and economic returns of rice bean. The beneficial effects of Mo enhanced the nitrogen fixation resulting in overall plant growth and development. Singh *et al*. (2017) obtained higher dry matter accumulation, number of pods per plant, plant height, test weight, grain yield and nutrient uptake in lentil applied with molybdenum. They interpreted these findings with the virtue of Mo improving nutritional environment with respect to increased symbiotic N fixation in lentil. Verma *et al.* (2019) in an experiment with seed priming and foliar spray with B and Mo opined that these two micronutrients recorded marked enhancement in leaf turgidity and chlorophyll intensity as well as in yield attributes of pigeonpea.

Importance of Zinc (Zn) in pulses

Detoxification of superoxides radicals: Zn a key constituent of the enzyme superoxide dismutase is essential for the detoxification of superoxides radicals (O_{2-}). In case of deficiency, these free radicals destruct the phospholipids in membrane and there will be leakage of solutes like K+ and amino acids. Similarly, the increased in lipid oxidation in leaves lead to destruction of chlorophyll, necrosis and stunted growth in plants.

Necessary for chlorophyll & photosynthesis: It is because of enzyme anhydrase which contains Zn, located in cytoplasm and chloroplast and it facilitates the transfer of CO_2/H_2O for photosynthesis. Hasanain *et al.* (2020) reported that nutrient combination of RDF along with micronutrients (Zn) spray in mungbean significantly higher protein and grain and is because it ensured a proper supply of both macro and micronutrients and their uptake.

Protein synthesis: Zinc is also linked with RNA polymerase enzyme which is highly necessary for protein synthesis. While in case of zinc deficiency, inhibition of protein synthesis in zinc deficient plants is due to decline in RNA.

Enzyme activation: Zn is required in synthesis of growth hormone IAA, and when Zn is deficient in plants there will be reduced auxin concentration thereby accumulation of tryptophan which is a precursor of IAA.

In a study, combination of all the three micronutrients viz; Zn+Mo+B had resulted a significant increased in grain yield (Anonymous 2009). Application of Zn, Fe, and seed priming with Mo significantly enhanced the number of branches, leaf chlorophyll content, root nodules, grain as well as straw yield, seed protein, and oil contents in soybean (Reshma *et al.* 2014). This is due to vigorous vegetative developments coupled with higher photosynthesis rate, assimilation and cell division. *Rhizobium* seed treatment and molybdenum application along with soil applied Zn resulted sturdy root system with better nodulation activities. These in turn improved the efficiency of the lentil crop to utilize native and applied nutrients, which ultimately led to higher yields.

CONCLUSION

Pulses are grown predominantly in areas where resource poor environments conditions, more prone to both biotic as well as abiotic stresses. Pulses have greater potential to tolerate the vagaries of present climate change, provided improved nutrient management ways are followed strictly to harness good yield. They are being neglected due to the inception of green revolution. As a result, the pulses productivity is low in India. Besides, demand of pulses to fulfil the entire population, India imports a huge amount every year. Hence, there is great challenges to boost the pulse productivity upto a level to meet the national pulse demand. In this paper, we have discussed various ways to improve pulse production through the involvement of micronutrients that plays vital role in achieving sustainable pulse productivity in India.

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