Review Article

Eminent roles of micro-nutrients in quality seed production

ABSTRACT

There are seventeen essential nutrients required for plant growth and development. Out of these essential nutrients the elements needed in trace amounts are known as micro-nutrients. Seed treatment with micronutrients has the potential to meet crop micronutrient requirements and improve seedling emergence and stand establishment, yield, and grain micronutrient enrichment. In crop plants, micronutrients may be applied to the soil, foliar sprayed or added as seed treatments. Although the required amounts of micronutrients can be supplied by any of these methods, foliar sprays have been more effective in yield improvement and grain enrichment; but high cost has restricted its wider adaption, particularly by resource-poor farmers. Seeds may be treated with micronutrients either by soaking in nutrient solution of a specific concentration for a specific duration (seed priming) or by coating with micronutrients. The potential micronutrients for seed treatments are Zinc (Zn), Boron (B), Molybdenum (Mo), Manganese (Mn), Copper (Cu) and Cobalt (Co) for improving growth, yield and grain enrichment. Primed seeds usually have better, faster and more synchronized germination. Micronutrient application in seed can also be done through seed coating and pelleting. Seed treatment, by seed priming or seed coating, seems pragmatic, inexpensive and an easy method of micronutrient delivery especially by small landholders in developing countries.

Keywords: Field performance, germination, micro nutrient, nutri-primimg, vigour

Introduction

There are 17 essential elements that are required by crop plants. Macronutrients are minerals that are required in high amounts and when required in very low amounts they are known as micronutrients. Although micronutrients are required in smaller amounts, they are required for optimum plant growth and their deficiency may cause growth suppression and to the extent of complete inhibition (Mengel *et al.,* 2001). Micronutrients have several vital functions in plants such as co-factor in enzyme systems and part in redox reactions. They also have a key role in various physiological processes like respiration and photosynthesis (Marschner, 1995; Mengel *et al.,* 2001). Deficiency of micronutrients can halt various physiological processes which in turn will limit the grain yield. In case of wheat (Rerkasem and Jamjod, 2004), chickpea (Johnson *et al.,* 2005) and lentil (Srivastava *et al.,* 2000) yield will be decrease due to Boron (B) deficiency. In Asian countries Zinc deficiency limits the yield of rice (Wissuwa *et al.,* 2006; Rehman H *et al.,* 2012).

In the developing world mineral deficiency in grains for human consumption results into a major health hazard - ‘Hidden Hunger’ (Buyckx, 1993; Ramalingaswami, 1995). Zinc nutrition helps in providing immunity (Shankar and Prasad, 1998) and improving resistance against diarrhea (Black, 1998; Fuchs, 1998) and its deficiency will cause immunity loss, poor wound healing and skin disease like dermatitis (van Campen, 1991).

To increase yield where soil micronutrients supply is not adequate several methods are adopted to improve the plant micronutrient status. But application of fertilizer to soils requires higher dose because of low nutrient-use efficiency (Singh, 2007). Micronutrients can also be applied through foliar sprays or seed treatment. It has been seen that foliar sprays are most effective in seed enrichment and improving the yield (Biswas Johnson *et al.,* 2021; Ray Bordolui, 2020; Biswas Johnson *et al.,* 2020). Because of the high cost of foliar sprays poor farmers with less resource cannot adopt it widely (Johnson *et al.,* 2005). Another issue with foliar sprays is that it is applied to established crop stand at later stage. So from economical perspective seed treatment is a better option as smaller quantity of micronutrient is needed, easy application and seedling growth is also improved (Singh *et al.*, 2003).

Seeds can be treated with micronutrients in different ways according to needs. They can be either soaked in the nutrient solution of different concentrations and different time durations depending upon nutrient and the crop. They can also be coated with micronutrient. Seed invigoration is a relatively new term in seed treatment where reciprocally used for both methods of seed treatment (Farooq *et al.,* 2009; Chakraborty and Bordolui 2021; Ray and Bordolui, 2022).

The main objectives to get appropriate nutripriming technologies, identifying suitable nutrients for nutripriming, ways and means for better seed germination, better crop stand, supplying nutrients and ultimately ways to fight malnutrition in developing countries.

Seed priming with micronutrients

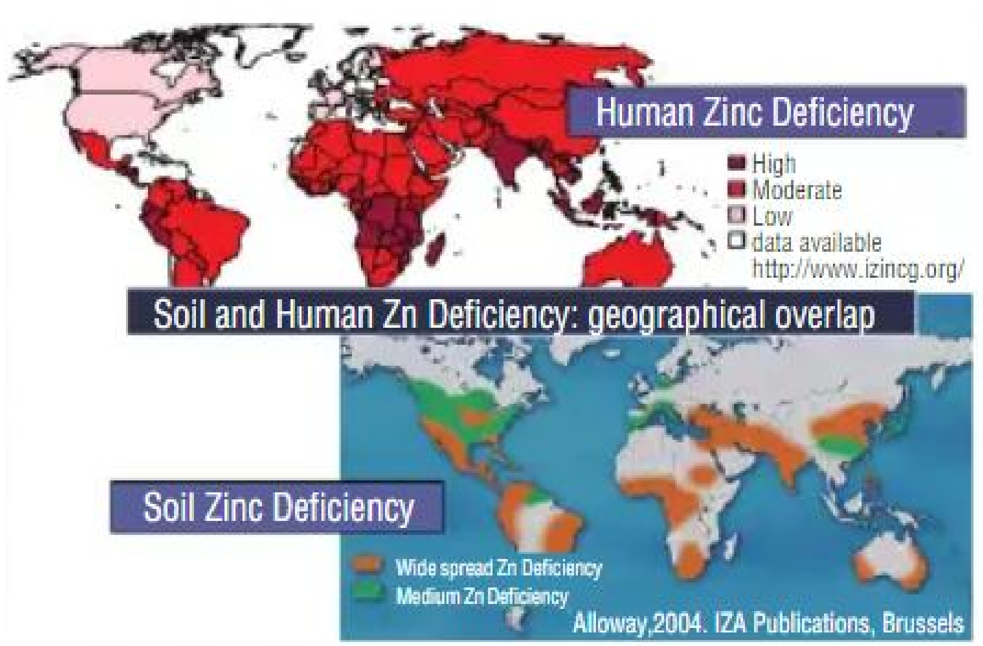
The method of seed priming involves 2 steps. First they are hydrated partially so that different metabolic events can take place without germinating. In the next step seeds are redried to their original weight for routine handling (Bradford 1986). The germination speed is higher in case of primed seeds in relation to non-primed seeds (Farooq *et al.,* 2006, 2009). Seed priming with micronutrients is known as nutripriming, where micronutrients function as osmotica (Imran *et al.,* 2004; Singh 2007). Primed seeds appear better and consistent germination (Farooq *et al.,* 2009) because of less imbibition time (Brock-lehurst and Dearman, 2008; McDonald, 2000; Taylor *et al.,* 1998) and obtainability of germination enhancing metabolites (Basra *et al.,* 2005; Farooq *et al.,* 2006).

There are several reports which indicate that nutripriming can improve wheat (Marcar and Graham, 1986; Wilhelm *et al.,* 1988), rice (Peeran and Natanasabapathy, 1980) and forage legumes (Sherrell 1984) yield. Although some reports showed that if seed priming is done with higher nutrient concentration, it can result into germination inhibition and seed damage.

Discussions of nutriprimung by using Zn, B, Mo, Mn, Cu and Co.

Zinc:

Solubility and uptake of Zinc is dependent upon various soil factors. For example, higher soil pH reduces Zn solubility and its uptake by plants. In many crops high content of soil Phosphorus (P) results into Zn deficiency (Chang, 1999; Foth and Ellis, 1997). In Zn-deficient soil small brown spots on leaves and reduced growth can be seen in Rice and Maize (Marschner, 1995; Sharma, 2006). Rosette like appearance with profuse shoot tips symptom is seen in Zn-deficient fruit tress (Marschner, 1995). In Zn-deficient citrus trees Interveinal leaf chlorosis and leaf mottling has been reported.



Source: Doctor Ismail Cakmak.

Fig 1 Geographical overlap for soil and human Zn deficiency

Crop emergence, stand establishment, further growth and yield can be improved by seed priming with Zn. Germination and field emergence increased by 38 and 41%, respectively in when seeds were primed with 0.05% $ZnSO_4$ solution, (Babaeva *et al.,* 1999). Zn-seed priming also improved yield and related traits of common bean *(Phaseolus vulgaris* L.) (Kaya *et al.,* 2007). Kaya found that in Barley *(Hordeum vulgare* L.) germination and seedling development can be improved by Zn-seed priming (Kaya *et al.,* 2007). During seed development Zinc content in newly developed radicles and coleoptiles are higher, which indicates that Zinc is involved in early seedling development, their physiological processes and possibly protein synthesis, cell elongation, various membrane function and resistance to abiotic stresses (Cakmak, 2000). Higher Zinc content in seed might be helpful in defence of soil-borne pathogens durin germination and seed development stage which in turn ensures a good crop stand (Marschner, 1995) and a better yield. Dry matter accumulation, improved mineral uptake, better water uses efficiency (44%) in drought stressed barley was achieved by seed priming (Ajouri *et al.,* 2004). Ullah *et al*. (2002) reported that when seeds were soaked in 0.5 M $ZnSO_4$ it gave better results than unsoaked, water soaked, $FeSO_4$ soaked and $MnSO_4$ soaked seeds in mustard (Brassica *carinata* L.). Significantly better results were achieved in terms of % field emergence, fresh and dry weight of root & shoot, root and shoot length.

By comparing Zinc ($ZnSO_4$ (0.4%) seed primed and non-primed seed it has been observed that the Zinc requirement of wheat can be entirely met and also higher yield (21%). Seed priming was also beneficial compared with soil application as benefit: cost ratio of 8 and 360 from soil application and seed priming, respectively (Harris *et al.,* 2005). The suitable concentration may vary from crop to crop. For example, in chickpea a diluted solution of $ZnSO_4$ (0.05%) was most effective in terms of yield with an average value of 48% and also benefit: cost ratio of 1500(Harris *et al.,* 2005). Harris and team also found that priming seeds with 1% ZnSO4 solution for 16 hours crop yield, grain yield, grain zinc content of maize. Primed seeds showed 27% higher yield in comparison to non-primed seeds. It should also be noted that the primed seeds gave better benefit: cost value compared to soil application (Harris *et al.*, 2007). In 2008 the same team found that seed priming with 0.3% Zn can increase wheat yield by 14%. 19% yield increase in chickpea was achieved by seed priming with 0.05% Zn. Zinc seed priming also increased zinc content of grain by 12% and 29% in wheat and chickpea, respectively (Harris *et al.*, 2008). In rice also seed treatment was better and more economically viable than soil application and no application. Slaton and others found that Zinc seed treatment in rice improved growth and grain yield (Slaton *et al.*, 2001). Another experiment where higher wheat grain yield was achieved by seed priming with Zn rather than foliar and soil application when cultivated on Zn-deficient soil. Although, grain Zn concentration was not affected by seed priming in contrast to soil and foliar application (Yilmaz *et al.*, 1997, 1998). Zn was adhered to the wheat seeds by using Arabic gum by using zinc sulfate ($ZnSO_4 7H_2O$) as a source. Control was sown with untreated dry seeds. Results showed that Zn seed treatments improved field emergence, seed priming with 0.01 M Zn solution gave maximum numbers of seedlings. Grain yield, biological yield, and other yield related traits improved by seed osmo-primed with 0.01 M Zn solution. Grain and straw Zn enrichment were also increased in seed osmo-primed with 0.01 M Zn solution (Hasan *et al.*, 2019).

Table 1: Influence of Zinc seed Treatments on grain yield and grain enrichment in different crops

Source	**Application Mode**	**Application Rate**	**Crop**	**Increase in grain yield over untreated control**	**Increase in Zn grain contents over untreated control**	**References**
Zinc Sulphate	Seed Priming	1 g/kg seed	Rice	14.57	-	Slaton *et al.*, 2001
Zinc Sulphate	Seed Priming	2.2 g/kg seed	Rice	17.92	-	Slaton *et al.*, 2001
Zinc Sulphate	Seed Priming	4.7 g/kg seed	Rice	28.25	-	Slaton *et al.*, 2001
Zinc Sulphate	Seed Priming	0.3% Zn,10h	Wheat	14	12	Harris *et al.*, 2008
Zinc Sulphate	Seed Priming	0.05% Zn 10h	Chickpea	19	29	Harris *et al.*,2008
Zinc Sulphate	Seed Priming	0.3% Zn,10h	Wheat	17.05	-	Harris *et al.*, 2007
Zinc	Seed	0.05% Zn 6h	Chickpea	17.70	-	Harris *et al.*, 2007

Sulphate	Priming					
Zinc Sulphate	Seed Priming	1% Zn 16h	Maize	27.10	-	Harris *et al.*, 2007
Zinc Sulphate	Seed Priming	0.004 M 8h	Chickpea	-	1066	Johnson *et al.*, 2005
Zinc Sulphate	Seed Priming	0.004 M 12h	Lentil	-	1160	Johnson *et al.*, 2005
Zinc Sulphate	Seed Priming	0.004 M 36h	Rice	-	580	Johnson *et al.*, 2005
Zinc Sulphate	Seed Priming	0.004 M 12h	Wheat	-	900	Johnson *et al.*, 2005
Zinc Sulphate	Seed Priming	0.1 M 12h	Wheat	5.42	-	Nazir *et al.*, 2000
Zinc Sulphate	Seed Priming	0.05% Zn	Chickpea	36	-	Arif *et al.*, 2007
Zinc Sulphate	Seed Priming	0.075% Zn	Chickpea	0.5	-	Arif *et al.*, 2007
Zinc Sulphate	Seed Priming	0.1% Zn	Wheat	34.87	-	Arif *et al.*, 2007
Zinc Sulphate	Seed Priming	0.2% Zn	Wheat	16.22	-	Arif *et al.*, 2007
Zinc Sulphate	Seed Priming	0.3% Zn	Wheat	26.58	-	Arif *et al.*, 2007
Zinc Sulphate	Seed Priming	0.4% Zn	Wheat	27.83	-	Arif *et al.*, 2007
Zinc Sulphate	Seed Priming	10 mg/kg	Barley	-	708	Ajouri *et al.*, 2004
Zinc Sulphate	Seed Coating	250 mg/kg seed	Cowpea	32.10	-	Masuthi *et al.*, 2009
Zn-EDTA	Seed priming	1.4g/kg seed	Rice	20.73	-	Slaton *et al.*, 2001
Zn-EDTA	Seed priming	2.8g/kg seed	Rice	26.50	-	Slaton *et al.*, 2001
Zn-EDTA	Seed	5.7g/kg seed	Rice	20.45	-	Slaton *et*

	priming					*al*, 2001
ZnO coated Urea	Seed Coating	0.5%(w/w)	Rice	19.1	4.38	Shivay *et al*, 2008
ZnO coated Urea	Seed Coating	1%(w/w)	Rice	10.63	16.50	Shivay *et al.*, 2008
ZnO coated Urea	Seed Coating	1.5%(w/w)	Rice	18.48	30.98	Shivay *et al.*, 2008
ZnO coated Urea	Seed Coating	2%(w/w)	Rice	27.59	40.07	Shivay *et al*,2008
$ZnSo_4$ coated Urea	Seed Coating	0.5%(w/w)	Rice	6.84	12.79	Shivay *et al.*, 2008
$ZnSo_4$ coated Urea	Seed Coating	1%(w/w)	Rice	13.16	27.61	Shivay *et al.*, 2008
$ZnSo_4$ coated Urea	Seed Coating	1.5%(w/w)	Rice	20.25	36.03	Shivay *et al.*, 2008
$ZnSo_4$ coated Urea	Seed Coating	2%(w/w)	Rice	29.62	48.15	Shivay *et al.*, 2008

Papaya *(Carica papaya* L.) stand establishment and growth was improved by soaking the seeds with 0.50% borax (Deb *et al.*, 2010). Seeds soaked in Zn ($ZnSO_4$) for 12 hours improved germination of *Chlorophytum borivilianum* (L.) (Kaur *et al.*, 2009). Kang and Okoro reported that seed soaking with Zn-EDTA and fritted Zn improved can improve yield and uptake of Zn, although their efficiency is different (Kang and Okoro, 1976). Another study revealed that stand establishment was increased by 29% when seeds were treated with $ZnSO_4$ (0.1%) for 24 h (Foti *et al.*, 2008).

Chickpea, lentil, rice and wheat seeds primed with Zn had no effect on grain yield in a two year trial conducted by Johnson *et al.* (2005). They also reported that in the first year chickpea seeds primed with Zn failed to emerge and resulted in a crop failure. In the second year although seeds germinated but there was no yield gain. It should be also noted that Zinc solution priming increased the grain Zn content in all the tested crops (Johnson *et al.*, 2005). They suggested that there is a risk involved in micronutrient priming. So to minimize the risk micronutrient seed priming should be first optimized by doing them in laboratory and then field test for germination. Based on the results whole batch should be primed (Johnson *et al.*, 2005).

Several studies have shown that crop Zinc requirement may not be fulfilled by seed priming with Zn. Like Rasmussen and Boawn in 1969 showed that Kidney beans Zn requirements were not fulfilled by Zn seed priming. It should be also noted that it depends on soil Zn content level, in severe Zn deficiency seed priming was not alone sufficient to meet the crop Zn requirement (Rasmussen and Boawn, 1969; Rehman H *et al.*, 2012). But in case of moderate Zn deficiency a cost effective method of Zn application is seed priming application (Harris *et al.*, 2007, 2008; Slaton *et al.*, 2001).

Boron

Boron deficiency leads to disturbances in various metabolic processes like metabolism of carbohydrate, protein, nucleic acid and indole acetic acid, cell wall synthesis membrane integrity and function, phenol metabolism. This in turn results into reduction in crop yield (Dell and Huang, 1997; Tanaka and Fujiwar, 2008). Boron is also part of other processes like flowering and fruiting, cell division, calcium utilization, water relations, disease resistance, carbohydrate and nitrogen metabolism and catalyst of several other reactions (Sprague, 1951).

There are some symptoms through which B deficiency can be identified in crop plants. Like interruption of flowering and fruiting (Ho, 1999) and reduced yields, with discolored or deformed fruit or grain (Shorrocks, 1997). Deficieny symptoms are also different among species. 'Hollow Heart' symptom (empty seeds) can be seen in soybean *(Glycine max* L.) or groundnut *(Arachis hypogaea* L.). in black gram*(Vigna mungo* L.) symptoms are not visible in seeds but reduction of grain yield can be upto 50% (Keerati-Kasikorn *et al.*, 1987).

Fig 2 : Symptoms of B deficiency of maize(cv. NS72) grown in sand culture without added B at anthesis showing: white stripes or transparent streaks on leaf lamina (a), multiple ears (b, c) and short silks(e: arrow, removed husk)compared with normal ear of B20 (d, f : ear after removal of husk). **Source**- Lordkaew, S., Dell, B., Jamjod, S., & Rerkasem, B. (2010).

When priming is done with B the most critical factor is concentration of the priming solution. Shorrocks in 1997 shown that various concentrations of B ranging from 2-20 mM had both increased and decreased the effect on germination in crops like turnip *(Brassica rapa* L.), sunflower *(Helianthus annuus* L.), soybean, sugar beet *(Beta vulgaris* L.), alfalfa *(Medicago sativa* L.), wheat and barley (Shorrocks, 1997). Seed priming on the aforesaid crops with 0.5% B solution led to non-emergence of seedlings altogether. Same can be observed with rice seeds primed with 0.5% B solution but when rice seeds were primed with 0.001% and 0.01% B solution improved crop stand was observed (Rehman A *et al.*, 2012). In a similar study fine-grain aromatic rice cultivars Super Basmati and Sha-heen Basmati seeds were primed in aerated B

(0.001, 0.01, 0.1 and 0.5%) solutions and it was observed that 0.001 and 0.01% solutions showed better crop stand and the rest two concentrations 0.1 and 0.5% suppressed the growth(Farooq *et al.,* 2011). Interestingly papaya seeds soaked in 2 mg L^{-1} B solution for 6 h showed better germination rate and early seedling growth (Deb *et al.,* 2010).

When oats*(Avena sativa* L.) seeds were primed with 0.02% solution of H_3BO_3 tillering, panicle length and grain weight showed substantial improvement and a grain yield increase of 8.42% over untreated seeds but did not show any significant effect on seed germination(Saric and Saciragic, 1969). Similarly, when rice seeds were primed with 0.001% B solution, marked improvement was seen in rates of leaf emergence, leaf elongation and tiller appearance (Rehman A *et al.,* 2012). B seeds priming can show profound influence even in advanced growth stages of plants. For example, pea *(Pisum sativum* L.) seeds primed in 0.5% B solution showed higher plant height, fruiting and pod yield and a reduction in days to 50% flowering (Kumar *et al.,*2008).

Yield of of chickpea, lentil, rice or wheat was not affected by priming with Boron but grain Boron content rose in all crops tested (Johnson *et al.,* 2005). In contrast B application through seed treatment was effective and economical in seed yield increase (10.53%) in pigeon pea compared to soil application(5.26%) and control(Malla *et al.,* 2007).

In various reports it has been concluded that seed priming with B is most effective and economical way of B application. But the solution concentration is of utmost importance and it must be tested and standardized before field application.

Table 2: Influence of boron seed treatments on grain yield and grain enrichment in different crops

Source	**Application Mode**	**Application Mode**	**Crop**	**Increase in Grain yield over untreated control (%)**	**Increase in Grain B contents over untreated control (%)**	**Reference**
Boric Acid	Seed Soaking	0.02%,24h	Oat	8.42	-	Saric and Sclragic (1969)
Boric Acid	Seed Priming	0.008M,8h	Chick Pea	-	900	Johnson *et al.* (2005)
Boric Acid	Seed Priming	0.008M,12h	Lentil	-	1566	Johnson *et al.* (2005)
Boric Acid	Seed Priming	0.008M,36h	Rice	-	700	Johnson *et al.* (2005)
Boric Acid	Seed Priming	0.008M,12h	Wheat	-	2122	Johnson *et al.* (2005)
Borax	Seed Coating	100mg/kg Seed	Cowpea	37.25	-	Masuthi *et al.* (2009)

Molybdenum

For nitrogen nutrition and assimilation Molybdenum is the most important micronutrient in plants. In non-legume plants Mo helps to use nitrates taken up from soil. If plants have insufficient Mo then nitrates start getting accumulated in leaves and don't get assimilated into proteins. And not just non-legumes, Molybdenum helps legume crops by helping root nodule bacteria to fix atmospheric nitrogen (Campo *et al.*, 2000). So, Mo and N deficiency symptoms are often identical. In legumes, Mo deficiency can lead into N deficiency because nitrogen-fixing ability of soil microorganisms are severely damaged. 'Yellow-spot' in citrus, 'Blue-chaff' in oats and 'whiptail' in cauliflower are some examples of Mo deficiency (Chang, 1999).

For Mo application seed treatment has effect than soil application by several studies (Donald and Spencer, 1951; Johansen *et al.*, 2006a,b). For example, Johansen and team thorough 48 trials in eastern india showed that Mo applied through seed priming increased mean yield by 17-22% compared with the control (without Mo) and 20-25% when Mo was applied to the soil (Johansen *et al.*, 2006a). Similarly, Malla et al. reported that Mo application through seed treatment (4 g kg^{-1} seed) and soil application(1.5 kg ha^{-1}) increased seed yield by 15.79% and 10.53% repectively (Malla *et al.*, 2007). In improving growth and yield of subterranean clover *(Trifolium subterraneum* L.), seeds were priming with in 0.1 or 1% sodium molybdate solution and seeds shown equal effect as soil application in a Mo-deficient soil. At application levels in excess of the requirements for maximum yield, seed priming resulted in higher Mo and N contents in grains than equivalent soil applications (Donald and Spencer, 1951). Improved dry matter accumulation, nodulation, nitrogen fixation and yield were achieved through priming common bean seeds in sodium molybdate (Table 3; Mohandas, 1985). In a chick pea pot study compared to Mo soil application 27% yield increase was achieved through seed priming with Mo (0.5 g l^{-1} solution of sodium molybdite) for 8 h (Kumar Rao *et al.*,2004). However, in a field study yield increase of 20 % was achieved with the same treatment in chick pea (Khalan *et al.*, 2005).

To enhance the efficiency of seed priming with Mo rhizobium can be added to the priming solution. For example, in Bangladesh 37%-90% yield increase over untreated control and up to 50% more than water-soaked control (Johansen *et al.*, 2006b). Similarly in green gram (*Vigna radiata* L.) sodium molybdate + rhizobia seed priming showed increased nodulation, nutrient uptake, nitrogen fixation, plant growth and crop yield. It also increased fertilizer application efficiency showing better uses of resources (Pattanayak *et al.*, 2000). The protocol of incorporation of rhizobial strains with priming media needs to further fine-tuned and for different crops and micronutrient requirements.

In a summarized manner we can say that in comparison to soil application seed priming is more pragmatic, effective and economical in fulfilling Mo requirements of crops but its incorporation with rhizobia needs more research and fine -tune.

Table 3 : Influence over Molybdenum seed treatments on grain yield and grain enrichment in different crops

Source	Application Mode	Application Rate	Crop	Increase in grain yield over untreated control(	Increase in nodule number over untreated	Increase in grain mineral content over	Reference

				%)	control(%)	untreated control(%)	
Sodium Molybdate	Seed Soaking	1mg/L,1h	Common Bean	12.66	122.73	-	Mohandas (1985)
Sodium Molybdate	Seed Soaking	2mg/L,1h	Common Bean	53.68	272.73	-	Mohandas (1985)
Sodium Molybdate	Seed Soaking	5mg/L,1h	Common Bean	11.61	90.91	-	Mohandas (1985)
Sodium Molybdate	Seed Priming	0.0026M,8h	Chick Pea	-	-	7400	Johnson *et al.* (2005)
Sodium Molybdate	Seed Priming	0.0026M,12h	Lentil	-	-	0	Johnson *et al.* (2005)

Manganese

Manganese is required for photosynthesis, nitrogen and other metabolisms in plant (Stout and Arnon, 1939). Interveinal chlorosis is the most common symptom of Mn deficiency in plants. In some other species maturity is delayed (Park *et al.,* 1999). Premature leaf shedding and Brown necrotic spots can be seen under acute Mn deficiency conditions. In case of cereal leaves white and grey spots are signs of Mn deficiency (Stout and Arnon, 1939; Chang, 1999).

When wheat seeds were primed with MnSO4 solutions it showed improved growth, grain Mn contents and grain yield. Another observation was that with increasing priming solution concentration upto 0.2% MnSO4 solution for 12h grain yield and grain Mn content increased linearly (Khalid and Malik, 1982). Similar results of wheat seed priming with MnSO4 has been obtained from other studies also (Marcar and Graham, 1986). Mn seed priming can also increase stand establishment. In another report when seeds of *Echinacea purpurea* (L.), were primed with 0.1% $MnSO_4$ solution germination rate and field emergence increased by 36% and 27% respectively over untreated control (Babaeva *et al.,* 1999). Mn seed priming observed substantial development in stand establishment, growth, yield, and grain enrichment, compared with soil application (Babaeva *et al.,* 1999; Marcar and Graham, 1986; Khalid and Malik, 1982).

Table 4 : Influence over Manganese seed treatments on grain yield and grain enrichment in different crops

Source	Applicati	Applicatio	Cro	Increase	Increase	Increase	Referenc

	on Mode	n Rate	p	in grain yield over untreated control(%)	in nodule number over untreated control(%)	in grain mineral content over untreated control(%)	e
Manganese Sulphate	Seed Priming	0.1M,12h	Whe at	12.79	-	-	Nazir *et al*(2000)

Copper

Copper is a vital micronutrient responsible for nitrogen metabolism and carbon assimilation. Deficiency of copper results in severe growth retardation. Cu also provides cell wall strength and prevents wilting because it is involved in lignin biosynthesis (Taiz and Zeiger, 2010). Some common symptoms of Cu deficiency are stunted growth, leaf chlorosis and stem and twig die-back (Chang, 1999; Osotsapar, 1999; Stout and Arnon, 1939).

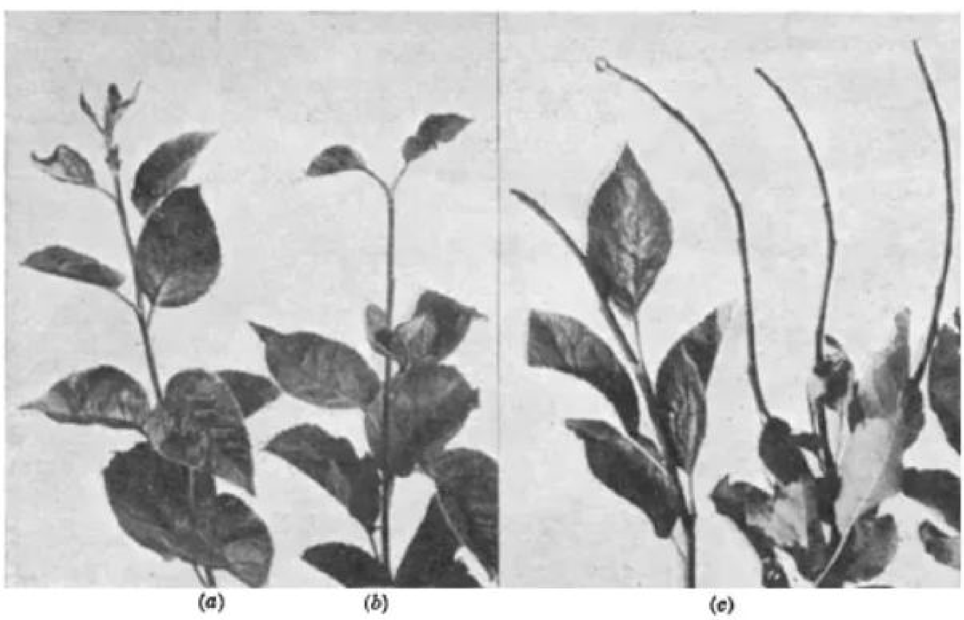


Fig 3: (a) Growth restriction and necrosis of leaflets near growing point, (b) Onset of defoliation of young leaves (c) Basipetal defoliation and dieback of shoots in apple. Source: Bould *et al.,* (1950).

Malhi in 2009 showed that wheat seeds primed in CuEDTA solution (0.04 to 0.16 kg Cu ha^{-1}) suppressed seedling emergence but increased grain yield. But very low concentration i.e 0.04 kg Cu ha^{-1} did not significantly enhance the seed yield (Malhi, 2009). There was effect on germination in oats seeds when these were primed with 0.001% solution of $CuSO_4$ but yield increased by 16.53% compared to untreated control because no. of grains per panicle and grain weight increased (Saric and Saciragic, 1969). Moreover in a recent study by Foti *et al*. observed 43% higher stand establishment in comparison to control when seeds were primed with copper sulphate (0.1%) for 24 h (Foti *et al.,* 2008).

Table 5 : Influence over Copper seed treatments on grain yield and grain enrichment in different crops

Source	Application Mode	Application Rate	Crop	Increase in grain yield over untreated control(%)	Reference
Copper Sulphate	Seed Soaking	0.001%, 24h	Oat	16.53	Saric and Saclragic (1969)
Copper Sulphate	Seed Priming	0.1M, 12h	Wheat	12.79	Nazir *et al.* (2000)

Cobalt

In some plants cobalt is beneficial and in some they are essential. Legumes need Co for nitrogen fixation and it has effects on metabolism and plant growth. It is beneficial in retardation of leaf senescence, inhibition of ethylene biosynthesis, and trigger alkaloid biosynthesis. But it is essential component of several enzymes and co-enzymes (Palit *et al.*, 1994).

In pigeon pea *(Cajanus cajan* L.) grain yield, plant height, branch and leaf numbers, dry matter accumulation was substantially increased by seed priming with cobalt nitrate (Raj, 1987). Similarly, growth, pod yield, shelling percentage, seed weight and harvest index of peanut significantly increased by seed priming with cobalt nitrate (Raj, 1987). The leghemoglobin content and nodule density saw an increase in both pigeon pea and peanut (Raj, 1987). By priming seeds of summer squash *(Cucurbita pepo* L.) with cobalt sulfate it was concluded that dry matter accumulation, femaleness and fruit yield increases in seed primed crops compared to water-soaked seeds (Atta-Aly, 1998). It was also derived that $CoSO_4$ primed seeds started endogenous ethylene synthesis at fourteen days after sowing, and it continued upto flower initiation (30 DAS). Seeds soaked in $CoSO_4$ @1.00, 0.50 and 0.25 ppm produced 56, 40, and 26% more fruit yield, respectively, than the control (Atta-Aly, 1998). Priming common bean seeds with cobalt nitrite at 1 and 5 mg L^{-1} observed significant increase nodulation, dry matter, nitrogen and grain yield (Mohandas, 1985). Panicle length, number of grains per panicle and grain weight increased leading to 11.17% yield increase over untreated control in oat seed after priming but it did not have any effect on germination (Saric and Saciragic, 1969).

Table 6: Influence of cobalt seed treatments on grain yields and grain enrichment in different crops

Source	Application Mode	Application Rate	Crop	Increase in economic yield over untreated contol(%)	Increase in nodule number over untreated control (%)	Reference
Cobalt Nitrate	Seed Soaking	1 mg/L,1h	Common Bean	52.50	334.09	Mohandas (1985)

Cobalt Nitrate	Seed Soaking	2 mg/L,1h	Common Bean	5.04	147.73	Mohandas (1985)
Cobalt Sulphate	Seed Soaking	0.001% solution,1h	Oat	11.17	-	Saric and Saclragic (1969)
Cobalt Sulphate	Seed Soaking	0.25 mg/L,1h	Summer Squash	26.42	-	Atta-Aly (1998)
Cobalt Sulphate	Seed Soaking	0.50 mg/L,48h	Summer Squash	40.45	-	Atta-Aly (1998)
Cobalt Sulphate	Seed Soaking	1 mg/L,48h	Summer Squash	53.73	-	Atta-Aly (1998)

Use of combination of micronutrients in seed priming like 0.16 mg g^{-1} Mo as sodium molybdate and 0.008 mg g^{-1} Co as cobalt chloride along with rhizobium shown promising results in significantly improving plant growth, N fixation, nodulation, nutrient uptake and yield. It also aids in better use of resources by making fertilizer application more efficient (Pattanayak *et al.,* 2000). Co seed priming with specific concentrations and specific duration can effectively increase plant performance but more studies are needed in these areas.

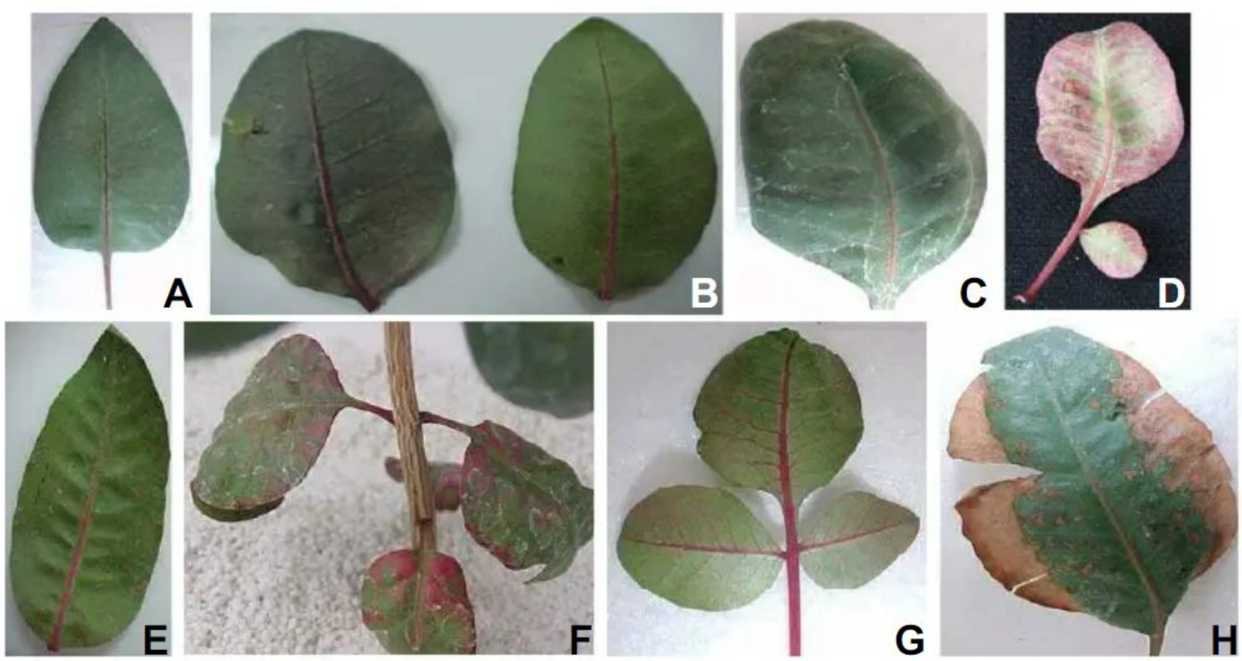


Fig 3(b): **Visual symptoms of macro- and micronutrient deficiencies in pistachio leaves.** (**A**) Normal leaf; (**B**) Mo-deficiency; (**C**) Mg-deficiency; (**D**) N-deficiency; (**E**) Mn-deficiency; (**F**) N-deficiency; (**G**) Mn-deficiency; (**H**) Fe-deficiency. Source- Afrousheh *et al.* (2007).

Chlorine

Chlorine which is found in the plant as Cl^- ion in plants is required for oxygen production. It helps in water splitting reaction of photosynthesis (Clarke and Eaton-Rye 2000). In leaves and roots it is required for cell division (Harling *et al*. 1997). There are number of symptoms that are seen in plants in case of chlorine deficiency. For example, leaf tip wilting, leaf chlorosis and necrosis, reduced growth. Also leaves may show bronze type colour which is called bronzing. Roots remain stunted and thickened near the root tips. Chlorine has many important functions like maintenance of trans-membrane electrical neutrality and as a principal osmotically active solute in the vacuole. In most cases plants take up more chlorine in excess of their optimum requirement (Hopkins and Huner 2008).

Table 7: Influence over Chlorine seed treatments in different crops

Source	Application Mode	Application Rate	Crop	Effects on primed seeds	Reference
NaCl	Seed priming		*Marsdenia tenacissima*	Improved germination and germination percentage	Xiao *et al*. (2015)
Calcium chloride (CaCl2)	Seed priming	100 mg L^{-1}	Rice	Better germination and vigorous growth, lesser damage of chilling stress	Hussain *et al*. (2016)
NaCl	Seed priming	2% for 6 and 12 hr	Bitter gourd (*Memordica charantia* L.)	Significant high percent of seed germination, seedling length, fresh weight, dry weight, speed of germination and vigor as compared to unprimed	Saini *et al*. (2017)
NaCl	Seed priming	2, 3, 4%	Cotton	Better germination rates, radicle length, hypocotyl length and seedling length in cold and warm temperature	C¸okkizgin and B€ole (2015)

Iron

Because iron is required by plants in largest amount some consider it as macronutrient. Generally it has been observed that iron is taken up as ferrous ion although ferric ion is also taken up. Iron has two main functions. Firstly it is part of the catalytic group for many redox enzymes. Important redox enzymes are heme-containing cytochromes and non-heme iron-sulfur proteins (e.g. Rieske proteins, ferredoxin, and photosystem I) involved in nitrogen fixation, photosynthesis and respiration. Secondly it is required for the synthesis of chlorophyll. Iron is also part of oxidase enzumes like catalase and peroxidase.

Losses of chlorophyll and chloroplast structure are degeneration simultaneously which is sign of iron deficiency. Because of low iron mobility chlorosis appears in the interveinal region of young leaves first. In case of severe deficiency veins also show chlorosis symptoms and small leaves turns white (Hopkins and Huner 2008).

Table 8: Influence over Iron seed treatments in different crops

Source	**Crop**	**Application mode**	**Application rate**	**Effects on primed seeds**	**Reference**
Ferrous sulfate ($FeSO_4,7H_2O$, Fe 26%, S 11.5%)	Dill (*Anethum graveolens*)	Seed priming		Higher germination rate and seed yield	Mirshekari (2012)
Fe solution	Groundnut (*Arachis hypogaea* L.)	Seed priming		Higher growth and yield	Khan *et al*. (2017)
Iron coated seed	Rice	Seed coating		Higher germination, coleoptile length, seedling emergence rate	Mori *et al*. (2012)
Fe solution	Bread Wheat	Seed priming	1mg L^{-1} to 8 mg L^{-1}	Better germination and yield	Reis *et al*. (2018)

Sodium

Sodium ions are mostly required by C4 and CAM plants for carbon fixation pathway. In C4 and CAM pathways the substrate for the first carboxylation is phosphoenolpyruvate. Sodium is required for regeneration of phosphoenolpyruvate (Johnstone, Grof, and Brownell 1988). In sodium deficiency plants may show chlorosis, necrosis and failure in flowers formation process. Sodium helps in cell expansion which in turn stimulates growth. Sodium can also substitute for potassium as an osmotically active solute (Taiz and Zeiger 2010). Now because important pre-germinative steps such as DNA and RNA synthesis happens within seeds priming with sodium sulfate is beneficial for germination (Mcdonald, 1999). Kulkarni and Shanna (1998) reported that primed seeds started germination from day 1 as opposed to non-primed seeds which started germination after 4 days.

Table 9: Influence over Sodium seed treatments on grain yield and grain enrichment in different crops

Source	Crop	Application mode	Application rate	Effects on primed seeds	Reference
NaHCO3	*Vigna mungo*	Seed priming	15–120mM for 20 hr	Early flowering, higher seed nitrogen content	Bose, Srivastava, and Mathur (1988)
$NaHCO_3$	Rice	Seed priming	5–20mM for 18 hr	Higher germination, vigour index, soluble and insoluble sugars od primed seedling	Pant and Bose (2015)
$NaHCO_3$	*Vigna mungo*	Seed priming	5–120mM for 20 hr	Seedling growth and its dry weight were enhanced at 15 and 30mM NaHCO3 while inhibited at 60 and 120 mM.	Bose, Srivastava, and Mukherji (1982)
NaCl	*Marsdenia tenacissima*	Seed priming		Improved germination index	Xiao *et al.* (2015)
NaCl	Bitter gourd (*Memordica charantia* L.)	Seed priming	2% for 6 and 12 hr	Higher seed germination % and speed of germination	Saini *et al.* (2017)

NaCl	Cotton	Seed priming	2, 3, 4%	Improved germination rate	C¸okkizgin and B€ole (2015)
Sodium Sulfate	Maize	Seed priming	0.1%	Better seed emergence	Foti *et al.* (2008)

Factors affecting nutripriming

Various environmental and other factors affect seed priming (Farooq *et al.,* 2009). Among environmental factors oxygen, temperature and solution concentration (water potential) are the most important factors affecting seed priming (Corbineau and Come, 2006).

Oxygen supply during seed soaking improved the effectiveness of seed priming (Farooq *et al.,* 2009). During seed priming in various crops substantial difference can be seen in the performance of aerated vs. non-aerated solutions. Oxygen availability improved seed performance upon sowing (Farooq *et al.,* 2011b).

Seed priming effectiveness also depends upon temperature of the priming media. In low temperature although seeds absorb water in optimal amounts but the physiological processes of germination are delayed (Lee *et al.,* 1998). It should be also noted that the possibility of microbial contamination during priming is less in low temperatures (Lee *et al.,* 1998).

In seed priming the effectiveness is determined by two factors; Solution concentration and solution water potential. These factors are very significant because the range between deficiency and toxicity of micronutrients in seed priming is very narrow (Farooq *et al.,* 2011a; Rehman A *et al.,* 2011; Shorrocks, 1997). After a critical level of water potential reaches in the seed germination gets started. Seed germination mostly starts when seed water potential ranges from 0 to -2 MPa, though there are inter and intra-specific variations (Corbineau and Come, 2006; McDonald, 2000). Dormant seeds or seeds with hard coats are exceptions.

Seed coating and pelleting

Seed coating is the application of finely-ground solids or liquids containing dissolved or suspended solids to form a more or less continuous layer covering the natural seed coat. It includes pelleting and many other seed treatments (Scott, 1989). Materials that have effects on seed or soil at the seed-soil interface are used for seed coating.

Seed pelleting is most sophisticated Seed Treatment Technology by addition of inert materials to modify seed shape and size for precision planting to enhance pelletibility and handling. Pelleting requires specialized application machinery and techniques and is the most expensive application.

While in seed coating, useful materials like microorganisms, plant growth regulators, nutrients and other chemicals are adhered around the seed with the help of some sticky material. However, both of these terms are being used interchangeably.

Nutrient, coating material, moisture, fertility status, nutrient: seed ratio and coating material affects the success and effectiveness of seed coating with micronutrients (Halmer, 2008).

Zinc

Reports on Zn seed coating show encouraging results for crop improvement (Masuthi *et al.,* 2009; Singh, 2007). In cowpea *(Vigna unguiculata* L.) seed yield and other yield-related traits were significantly increased by Zn seed pelleting. $ZnSO_4$ (250 mg kg^{-1} seed) pelleted seeds showed significantly higher 100 seed weights, seed weight/ plant which in turn led to 32.1% seed yield increase over non-pelleted control (Masuthi *et al.,* 2009). Commercially-available formulations like 'Teprosyn-ZnP' or 'Teprosyn-Zn' for seed pelleting showed promising results in sunflower, maize, wheat, soybean and peanut by improving their growth, grain yield and corrected their Zn deficiency (Singh, 2007). However, further research must be initiated in this regard.

Boron

In cowpea seed pelleting with Borax (100 mg kg^{-1} seed) significantly increased pod weight, seeds/pod and pod weight/plant leading to pod yield grain of 37.25% over non-pelleted control (Masuthi *et al.,* 2009). But in rice Boron sources such as borax, boric acid and sodium tetraborate used for seed coating and B: seed ratios (0.5-2 g kg^{-1} seed) did not improve the germination (unpublished data). We need more work with a range of B: seed ratios to explore its potential.

Molybdenum

There are many studies that concluded that Mo seed coating is effective (Biscaro *et al.,* 2009; Ramesh and Thirumurugan, 2001). When common bean seeds were treated with Mo (80 g ha^{-1}) they resulted in increasing relative chlorophyll index, pod number, seed weight and grain yield (Biscaro *et al.,* 2009). Ramesh and Thirumurugan (2001) treated soybean seeds with 250 mg ammonium molybdate + 500 mg ferrous sulfate kg^{-1} resulting in improving plant height, leaf area index, dry matter production and growth rate. While experimenting with cowpea and soybean in field it was observed that Mo application, singly or in combination with rock phosphate, was comparable or greater than the effect of liming in increasing yield in acid soil (Rhodes and Nangju, 1979).

On the other hand, there are several reports that indicate no improvement or toxicity from Mo seed-coating. When seeds were pelleted with sodium molybdate suppression of bacterial survival, nodulation and N fixation was observed. After seeds were treated with inoculant and Mo, 99% of inoculated bacteria died within 4 days (Burton and Curley, 1966). Mo salts also have suppressive effect on brady rhizobium (Albino and Campo, 2001; Campo *et al.,* 2000).

While some scientists specify that Mo seed coating is fruitful in improving crop performance, it may have toxic effects from bacterial strains used for inoculation. So, before using Mo seed coating must be evaluate the effectiveness of Mo seed coating with bacterial strains.

6. Conclusion

Seed treatment through priming or coating is an easy, inexpensive and pragmatic. Micronutrient seed priming can help in meeting the crop's micronutrient requirement. It can also improve seedling emergence, stand establishment, yield and grain micronutrient enrichment. It is an effective way of micronutrient delivery to small landholders in developing countries. Various crops and varieties/hybrids/genotypes show different response to different treatments, which will help researchers to identify useful accessions for further work such as (a) Developing techniques using a range of micronutrient with appropriate concentrations and durations; (b) Oxygenation requirements optimizing the temperature range, and water potential; (c) Utilizing available fertilizers for seed priming and coating osmoticum; (d) Estimating broad field trials using nutriprimed seeds; (e) Combining inoculation and micronutrient seed invigoration; (f) Potentiality of storage of nutriprimed seeds extended storage period and the primed seeds may be critical for technology transfer and marketing.

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