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IMPROVING MAIZE PRODUCTIVITY AND QUALITY THROUGH AGRONOMIC BIOFORTIFICATION

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Abstract

The demand for food is increasing to feed the population and to ensure food security. In developing countries, micronutrient malnutrition is dominant mainly in resource poor families. Low content of Fe and Zn in the diet can be the major reason behind deficiencies of Fe and Zn in human beings. Biofortified maize is a possible viable option for sustainable and cost-effective solution to overcome malnutrition. Agronomic biofortification is a process in which plants are allowed to take up the mineral from the soil and accumulate them in the grains so as to produce nutritionally rich grains that support dietary requirement of human. Development of multinutrient rich maize would help in providing nutritional security more holistically. Thus, agronomic biofortification where possible, is the most cost effective and sustainable solution for tackling the micronutrient deficiencies as the intake of micronutrients is on a continuing basis with no additional costs to the consumer in the developing countries.

Keywords : Agronomic biofortification, Malnutrition, Nutritional security

Introduction

Maize (*Zea mays*) is also known as corn, *makka* or *makki* which belongs to family *Poaceae*. It is world's 3rd most important cereal crop after rice and wheat. It is produced largely worldwide than any other cereal grain and it has a pivotal role in increasing the income of both subsistence and commercial farmers. Maize is known as "Queen of Cereals" and is grown in more than 130 countries worldwide. Intensive agriculture involving use of modern technologies for production along with the introduction of high yielding sweet corn, coupled with use of high analysis fertilizers has resulted in the deficiency of micronutrients, mainly zinc and iron. Maize is a main source of calories and minerals for most of the people living in rural areas. But unfortunately, maize is inherently poor in content of protein and minerals particularly zinc. It is a high nutrient demanding crop which is sensitive to micronutrient deficiency especially Zn. Thus, agronomic biofortification in the form of various fertilizer application, has become an important agricultural practice to increase the delivery of prime nutrients to crop tissues.

Different Use of Maize

Maize is used as a staple food for humans, feed for livestock and raw material for industrial purpose. It is one of the most important food resources of human and as C_4 crop absorbs high amounts of nutrients from the soil. Maize is enriched with protein known as *zein*. It has high nutritional value as it contains about 62.3% starch, 11.1% protein, 4.6% oil, 1.8% fiber, 4.3% sugar and 1.3% ash. Different alcoholic beverages and industrial products are produced by maize distillery and fermentation industries. The fermentation of maize starches has made it important feed stock for ethanol which is being used as a bio-fuel; a mixture of 10% ethanol and 90% gasoline is called as 'gasohol'. In India, at present, about 35% of the maize produced in the country is used for human consumption, 25% each in poultry feed and cattle feed and 15% in food processing (corn flakes, popcorn etc.) and other industries such as starch, dextrose, corn syrup, corn oil *etc*.

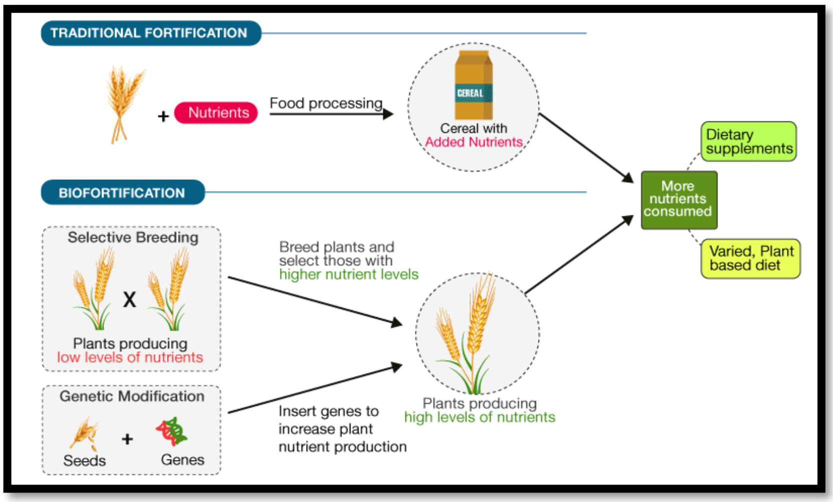
Current Status of Maize Cultivation

India ranks fifth in area and third in production and productivity among cereal crops. In India, maize is being cultivated in an area of 8.38 million ha with a production of 19.78 million tons and an average productivity of 2.36 t ha^{-1} the fifth largest producer in the world contributing 3 percent of the global production. Among the major producing states in India, Andhra Pradesh tops the list with the contribution of 17% to the total Indian maize production. It indicates that productivity of maize in India is still lower than the productivity of world. Maharashtra in particular is much lower than world average with productivity of 4.34 t ha^{-1}.

Necessity of Biofortification in Maize

Among micronutrients, Zn and Fe deficiency is occurring in both crops and humans. About half of the world's population suffers from micronutrient malnutrition, including iron, zinc and iodine which are mainly related with low dietary intake of micronutrients in diets with less diversity of food. Recent research shows that approximately 5,00,000 children under 5 years of age die annually due to Zn and Fe deficiencies. Zinc deficiency is currently listed as a major risk factor for human health and cause of death globally. Though iron (Fe) is the second most abundant metal in nature and fourth most abundant element in the earth crust, about 11% Indian soils are in deficient supply of iron (Singh,1999). As per WHO report on the risk factors responsible for development of illnesses and diseases, Zn deficiency ranks 11th among the 20 most important factors in the world and 5th among the 10 most important factors in developing countries. Incidence of zinc deficiency in soils is becoming more important due to its impact on human health (Singh *et al.*, 2005). Increasing productivity through proper management is one of the important strategies to increase the production of maize as well as micronutrient enrichment in grains.The reliance on cereal-based diets may induce Zn and Fe deficiency-related health problems in humans, such as impairments in physical development, immune system and brain function. Biorfortification can be a solution of all these problem. It is of mainly two types i.e. genetic biofortification, traditional or agronomic biofortification (Fig. 1). Among these two strategies, plant breeding strategy (genetic biofortification) appears to be a most sustainable but it is too much time consuming and not cost-effective approach for improving Zn and Fe concentrations in grain. So, agronomic biofortification can be an alternate viable option.

Fig. 1: Methods of Biofortification



Agronomic Biofrtification in Maize

Biofortification is a process in which plants are allowed to take up the minerals (Zn) from the soils and immobilize them in the grains so as to produce nutritionally rich grains that support dietary requirement of humans. Maize is a high nutrient demanding crop, which also requires micronutrients (in particular the Zn) (Obrador *et al.*, 2003) along with major elements for better growth and yield (Verma, 2011). Zn, B, Fe, Mn are the important micronutrients for maize crop. Thus, agronomic biofortification with soil and foliar applications of micronutrient not only increase the corn yield but also improve the nutrient quality of the specialty corn for obtaining good economic returns and also nutritional security.

Effect of Agronomic Biofrtification in Maize

With application of recommended dose of fertilizers (120- 50- 40 N, P_2O_5, K_2O kg ha^{-1}) + soil application of 50 kg $ZnSO_4$ ha^{-1} along with foliar application of 0.2% $ZnSO_4$ at 30 and 40 DAS recorded the maximum dry matter production (6695 kg ha^{-1}) of maize (Sulthana *et al.*, 2015). Duraisami *et al*. (2007) reported that with soil application of 5 kg Zn + 40 kg S + 1.5 kg B ha^{-1} maximum zinc content was noticed in grain (79.1 mg kg^{-1}) and stover (92.7 mg kg^{-1}), which was however comparable with application of 5 kg Zn + 40 kg S + 1.5 kg B + 0.5 kg Mo ha^{-1}. Kumar and Salakinkop (2017) revealed that, significantly higher Zn (47 mg kg^{-1}) and Fe (75.2 mg kg^{-1}) density in maize grain was recorded with soil application of FYM enriched with $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} than control and it was on par with the soil application of FYM enriched with $ZnSO_4$ and $FeSO_4$ each @ 15 kg ha^{-1}. Tariq *et al.* (2014) reported that the soil and foliar application of $ZnSO_4$ obtained significantly maximum grain and stover yield over control. Similarly, Khan *et al.* (2015) reported that the soil application of 15 kg ha^{-1} $ZnSO_4$ and 15 kg ha^{-1} $MnSO_4$ significantly increased the biological yield (20.15 tons ha^{-1}) and grain yield (7.42 t ha^{-1}) of maize. Hossain *et al.* (2011) stated that differential response was observed in yield among the maize varieties to Zn fertilization. Like seed yield, the stover yield of maize for all varieties increased significantly due to Zn fertilization. Agronomic biofortification of RDF+ $ZnSO_4$ @ 20 kg ha^{-1} + $FeSO_4$ @ 30 kg ha^{-1} was recorded significantly superior grain yield (85.64 q ha^{-1}), stover yield (110.16 q ha^{-1}) beings at par with RDF + $ZnSO_4$ @ 20 kg ha^{-1} and RDF + $FeSO_4$ @ 30 kg ha^{-1} (Table 1). The increase in seed yield is ascribed to the reason that application of zinc, iron and sulphur along with nitrogen, phosphorus and potassium resulted in vigorous root development, which promotes growth and development of plant leading to higher photosynthetic activity, which in turn results in better development of yield attributes.

Table 1: Grain yield (q ha^{-1}), stover yield (q ha^{-1}), biological yield (q ha^{-1}) and harvest index (%) of maize as influenced by various treatments (Sonone, 2019)

Treatments	Grain yield (q ha-1)	Stover yield (q ha-1)	Biological yield (q ha-1)	Harvest index (%)
RDF (120:60:30) NPK kg ha^{-1}	78.28	101.73	180.01	43.45
RDF + $ZnSO_4$ @ 20 kg ha^{-1}	83.23	107.01	190.24	43.75
RDF + $FeSO_4$ @ 30 kg ha^{-1}	82.14	105.61	187.75	43.75
RDF + $ZnSO_4$ @ 20 kg ha^{-1}+ $FeSO_4$ @ 30 kg ha^{-1}	85.64	110.16	187.75	43.74
SE(m)±	1.56	2.00	3.53	-
CD at 5%	4.57	5.87	10.34	-

Faujdar *et al.* (2014) revealed that application of FYM @ 10 t + 7.5 kg Zn ha^{-1} followed by inoculation with Azotobacter + VAM resulted in significantly higher iron content in grain and stover in maize during two consecutive years of study compared to the rest of the treatments tried at Faisalabad, Pakistan. Subramanian *et al.* (2009) opined that mycorrhizal symbiosis enhances Zn supply to the host plants by extensive root development enabling the plant to maintain higher nutritional status and produce grains with rich tryptophan concentrations. Subramanian *et al.* (2014) revealed that the inoculation of Zn + P + AMF (*Glomus intraradices)* had significantly higher root length (AMF- 16.8; AMF+ 23.5 cm), root volume and leaf area in maize. Matsumura *et al.* (2013) found that the inoculation with AMF significantly increased maize dry matter production over control. Abdelmoneim *et al.* (2014) revealed that the inoculation of AM fungi (*Glomus mosseae)* increased the plant height, stem length, root length, plant fresh weight, shoot dry weight, root dry weight and root/shoot ratio in maize.

Khan *et al.* (2014) reported that soil application of 15 kg $ZnSO_4$ + 15 kg $MnSO_4$ ha^{-1} resulted in higher protein content (8.96%) in maize compared to rest of the treatments in Faisalabad, Pakistan. Aruna *et al.* (2006) revealed that improved the protein content in maize with foliar spray of 0.5 % of zinc sulphate at 50 % silking stage; as compared to soil application of 50 kg $ZnSO_4$ ha^{-1}. The increase in the protein content might be due to marked influence of Zn treatments on the enzymatic activity in the plants which could bring about significant changes in the crude and true protein contents in maize grains. Zinc is essential for protein synthesis, reduction in RNA-polymerase activity and increase in RNA destruction. Formation of NADPH or NADH depending on the Zn concentration might have involved in tapping and converting the radiation energy for photosynthetic activities and increased formation of sugars and starch. Among the three specialty corn, sweet corn significantly improved the starch content in corn grain. Higher starch content of 71.54% was obtained with sweet corn and the starch content 63.44% and 62.20% with QPM and popcorn respectively. Likewise, grain starch content of specialty corn as influenced by applying Zn_4 resulted in higher starch content (67.76%) compared to Zn_2, Zn_3, Zn_1, Zn_5 and Zn_0 (66.55%, 65.63%, 65.32%, 64.98% and 64.12%) respectively (Table 2). Interaction effect between three types of corn and Zn on starch content of specialty corn was found to be non-significant.

Table 2 : Protein content (%) and starch content (%) as influenced by different types of corn and zinc levels (Debnath *et al*., 2016)

Treatments	Protein content (%)	Starch content (%)
Specialty corn types		
Pop corn	6.80	62.20
Sweet corn	5.61	71.54*
QPM	7.89	63.44
SEm±	0.18	1.97
CD (P=0.05)	0.53	5.66
Zinc levels		
Zn_0 (Control, only recommended dose of fertilizer)	5.70	64.12
Zn_1 (12.5 kg ZnSO4 ha^{-1} as Soil application)	6.35	65.32
Zn_2 (25 kg ZnSO4 ha^{-1} as Soil application)	7.77	66.55
Zn_3 (Zn_1 + 2 Foliar sprays at tasseling and milking stage)	6.51	65.63
Zn_4 (Zn_2 + 2 Foliar sprays at tasseling and milking stage)	8.09	67.76
Zn_5 (2 Foliar sprays at tasseling and milking stage)	6.18	64.98
SEm±	0.26	2.78
CD (P=0.05)	0.76	NS
Interaction (C × Zn)	NS	NS

***** Starch content was analysed in green cob stage only

Chand *et al.* (2017) reported that the cob length was significantly increased by the different zinc fertilization treatments with soil application of $ZnSO_4$ @ 25 kg ha^{-1}+ foliar spray of $ZnSO_4$ @ 0.2% at 25 and 40 DAS which recorded significantly higher cob length (19.03) over control. Maximum cob length (9.13 cm) was found with application of 5 t ha^{-1} of FYM + 100 kg of inorganic N ha^{-1} followed by application of 100 % recommended nitrogen (8.94 cm) (Singh *et al.*, 2016). Mohsin *et al.* (2014) found that the combined application of Zn as seed priming (2.0%) and foliar spray (2.0%), significantly improved plant height, cob length, cob diameter, 1000-grain weight and biological yield in maize. Mohseni and Haddadi (2015) found that the application of Zn + B had significant effect on length and diameter of corn ear. Khan *et al.* (2015) reported that the soil application of ZnSO4 and MnSO4 significantly increased the plant height at maturity (225 cm), cob diameter (4.29 cm) and number of grains per cob (415) in maize.

Girth of cob, cob length was significantly influenced by different micronutrient management (Fig. 2). Foliar application of 0.5% of $ZnSO_4$ + 0.2% $FeSO_4$ at booting and silking along with RDF (N, P_2O_5 and K_2O 180:60:50 kg ha^{-1}) (T_{10}), recorded significantly higher cob length (22 cm) over the rest of the treatments which was however comparable with soil application of $ZnSO_4$ @ 50 kg^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + RDF, 0.5% foliar application of $ZnSO_4$ + 0.2% $FeSO_4$ at booting + RDF and 0.2% foliar application of $FeSO_4$ at booting and silking + RDF (T_4, T_9 and T_8). RDF (N, P_2O_5 and K_2O 180:60:50 kg ha^{-1}) (T_1) recorded the lowest stature of cob length (11 cm) compared to soil applications of $ZnSO_4$ @ 50 kg ha^{-1} + RDF, soil application of $FeSO_4$ @ 25 kg ha^{-1} + RDF and 0.5% foliar application of $ZnSO_4$ at booting and silking + RDF, (T_2, T_3 and T_6). T_{10} recorded significantly higher cob girth (17 cm) over the rest of the treatments tried, which was however comparable with 0.5% foliar application of $ZnSO_4$ + 0.2% $FeSO_4$ at booting + RDF, soil application of $ZnSO_4$ @ 50 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + RDF and 0.2% foliar application of $FeSO_4$ at booting and silking + RDF (T_9, T_4 and T_8).

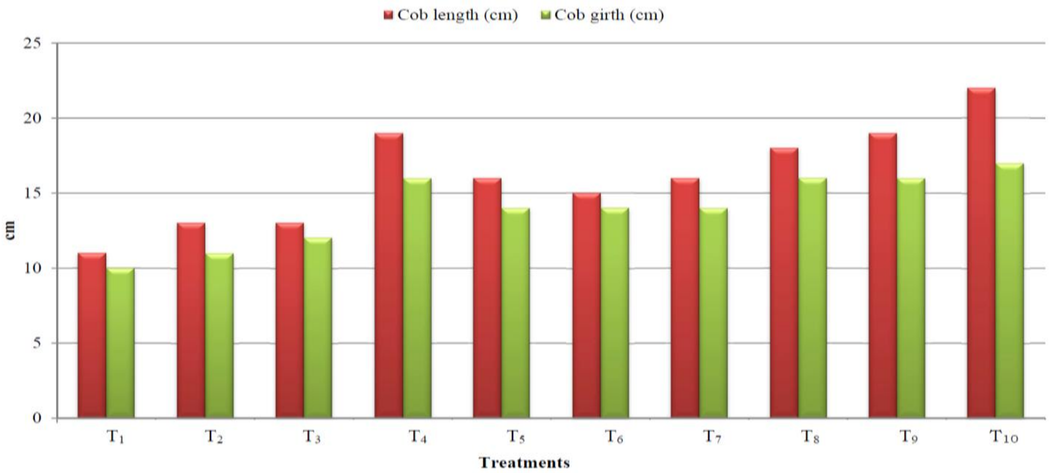


Fig. 2: Cob length and Cob girth (cm) of sweet corn as influenced by zinc and iron nutrition (Karrimi *et al.*, 2018)

Conclusion

Biofortification with micronutrients is becoming regular practice and zinc and iron are the front liner in maize biofortification. Hence, there is a possibility of enriching nutrient content of grain by biofortification. It is considered to be potentially more cost-effective than other methods to deliver the benefits of micronutrient enhancement to the rural populations in developing countries.

Maize crop responded widely to Zn fertilization and the crop is very sensitive for Zn deficient soil. Zinc sulphate application either through soil (or) foliage enhances the growth and yield attributes resulting in higher yield and grain quality. Thus, for maximizing maize yield, it is essential to see the way to increased productivity but more research and farmer's awareness is needed. However, agronomically biofortified maize will enhance the nutritional security and also maintain the environmental sustainability.

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