REVIEW ARTICLE

Role of Plant Breeding in Nutritional Quality Improvement of *Sorghum* (*Sorghum bicolor* L. Moench)

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Malnutrition, a continuing problem, results from inadequate intake of nutritious, high quality food. In particular, micronutrient deficiencies are a continuing health problem worldwide, especially in poor rural areas. Various measures are taken to combat this hidden hunger. Biofortification is a sustainable option for addressing micronutrient malnutrition, and dietary diversification, food fortification, and supplementation are currently used to address micronutrient deficiencies in the human diet.

Sorghum is one of the top five cultivated grains in the world. It has the potential for high photosynthetic efficiency and high biomass yield. It is also very resilient to drought and waterlogging, and very tolerant of high temperatures and problematic soils. *Sorghum* is one of the cheapest sources of micronutrients. Therefore, *Sorghum* biofortification is a top priority. This review will go over the value of *Sorghum* as a food and energy source, as well as how its grain structure encourages maximum utilization of accumulated micronutrients. Additionally, there are genetic controls/genes, Quantitative Trait Loci (QTL) for Fe and Zn concentrations, studies on the heterosis of Fe and Zn in *Sorghum*, genetic variability in grain trait associations between Fe and Zn and other agronomic traits, and the potential to forecast Fe and Zn hybrid performance based on parental line performance. It was also given a brief update on product development and the prospects for consuming bio-enhanced *Sorghum* in the near future.

Keywords: Gene action; General combining ability; Heterosis; Nutrition sensitive agriculture; Quantitative trait loci; Specific combining ability

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a tropical cereal grain native to East Africa, possibly Ethiopia [1]. It is the fifth most important grain in the world after wheat, rice, maize, and barley. *Sorghum* is a staple food in Africa and Asia, with India, Nigeria, Sudan, and Ethiopia being the main producers [2]. Interestingly, it is drought tolerant and can withstand heavy rains, making it well adapted to the African climate. It is processed into various forms of attractive, nutritious, and conventional foods that are ideal for brewing local African beers [3].

Sorghum is a self-pollinated, diploid (2n=2x=20) plant with a genome measuring 25% that of maize or sugarcane. It is a C4 plant with good photosynthetic efficiency and abiotic stress tolerance [4]. Their tolerance to the dry season and high temperatures, as well as their adjustment to problematic soils, make them progressively critical for food and nutrient security in the confront of climate change. It is additionally the cheapest source of micronutrients; for this reason, *Sorghum* biofortification has of high significance [5].

In most parts of the world common food source crops are grown in areas where the soil is depleted of essential minerals [6]. The three micronutrients (Fe), zinc (Zn,) and provitamin A are seriously insufficient, particularly among low income individuals in developing nations. Fe and Zn lacks are the foremost common with about three billion individuals influenced around the world [7]. The problem has been recognized by the World Health Organization being a genuine issue for human health around the world [8].

Global food security, both in quantity and quality, remains a challenge with a developing population. At the same time, the need for micronutrients within the human count calories leads to poor health and a collectively known as "hidden hunger" which is a series problem around the world. Biofortification could be a potential tool to enhance food crops with micronutrients to reduce nutrient security and a sustainable solution for developing nations.

Plant breeding as a tool in Nutrition Sensitive Agriculture (NSA) has to follow an integrated approach to solving malnutrition problems. It requires that the inherent focus of most breeding programs on crops and varieties be broadened toward people and their needs. In addition, there's should be coordination between breeding programs and cross the partition between technology oriented and framework or agent oriented approaches [9].

In the modern era of agriculture supply of calory foods to meet the energy needs of poor people in developing countries has been possible. In the past 50 years research on agriculture has increased the productivity of cereals. But now agriculture has to score a paradigm shift to improve nutrient availability in staple food crops as well. Through plant breeding, biofortification can move forward in improving nutrient compositions giving a generally cheap, cost effective, sustainable, and long term supply of more micronutrients to the poor in developing nations. This approach not as it was decreasing the number of extremely malnourished individuals requiring treatment with extra interventions, but also will help them maintain improved nutritional status. In addition, biofortification gives a helpful way to reach undernourished country populations who may have been inhibited to get micronutrient fortified diets and supplements commercially promoted [10].

LITERATURE REVIEW

In this review, an attempt is being made to explain the role of plant breeding in nutrition sensitive agriculture discussing *Sorghum* biofortification and describing the genetic basis of Fe and Zn concentrations in *Sorghum*.

Sorghum biofortification and its importance

More than 300 million sub-Saharan Africans depend on *Sorghum* as their primary calorie source. Its drought and heat tolerant properties mean it is a vital crop in drought prone countries, where irrigation is not always accessible or affordable. Improving the nutritional level of staple crops can provide both food and nutritional security [11].

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*S*orghum grain is rich in starch, protein, micronutrients, and crude fiber but low in fat, making it a good staple. It is one of the cheapest sources of energy and micronutrients, and a vast majority of the population in Sub-Saharan Africa depends on it for their dietary energy and micronutrient requirements. *Sorghum* provides more than 50% of the dietary micronutrients to the low income group, particularly in sorghum growing areas where both physical and economic access to nutrient-rich foods is limited [12].

With regard to specific biofortification techniques, plant breeding can raise the micronutrient levels of plants. Micronutrients are another category of essential nutrients that the human body requires in very minute amounts. These consist of vitamin A, iron, zinc, copper, manganese, iodine, selenium, molybdenum, cobalt, and selenium [13]. Numerous micronutrients control vital bodily and metabolic processes by working as cofactors for several enzymes in the human body. The main source of nutrients for people is agriculture; cereals, which are a staple of the human diet, fall short of providing all the nutrients that are needed daily. Therefore, nutrient poor agricultural goods cannot support healthy lives and may instead cause illness, an increase in the risk of morbidity and death, a fall in the socio-economic development of a nation, impaired development, stunted mental and physical growth, and diminished livelihoods [14].

Micronutrient malnutrition, primarily the result of diets poor in bioavailable vitamins and minerals, causes blindness and anemia (even death) in more than half of the world's population, especially among women of reproductive age, pregnant and lactating women, and preschool children [15]. Dietary diversification, supplementation, and food fortification are being employed to combat micronutrient malnutrition in vulnerable groups of society [16]. Biofortification is the enhancement of bioavailable micronutrient concentrations in food crops through plant breeding. It is a cost effective and sustainable solution for tackling micronutrient deficiencies, particularly in the developing world.

Techniques of biofortification

There are three common approaches to biofortification: Agronomic, conventional, and transgenic.

Agronomic biofortification provides a temporary increase in micronutrients through fertilizer application. This approach is useful for increasing micronutrients that plants can absorb directly, such as zinc, but is less effective for micronutrients that are synthesized in the plant and cannot be absorbed directly [17]. It involves the application of mineral fertilizers to soil or crops to increase the concentration and biological accessibility of specific nutrients in the crop [18]. Initially, agronomic practices were aimed at improving crop health and increasing yields. However, the importance of nutrition has been emphasized over the years; as a result, agronomic practices have been extended to improve the nutritional quality of crops [19]. Changes in climatic conditions and rapid depletion of soil nutrients indicate the need to improve and expand agronomic practices to include improving the nutritional quality of plants [20]. This method focuses on improving mineral solubility and mobilization [21]. The effectiveness of agronomic interventions depends on soil composition, mineral solubility and mobility, the plant's ability to absorb minerals, and the accumulation of bioavailable minerals at non-toxic levels. in the edible part of the plant [22]. Agronomic biofortification mainly focuses on minerals and not vitamins because vitamins are synthesized in plants. Therefore, agronomic biofortification cannot be used as a sole strategy to eliminate micronutrient deficiencies and must complement other strategies for effective bio fortification [23]. The use of fertilizers to enhance agronomic practices must be done carefully as improper application of fertilizers can have unintended and sometimes severe consequences for the environment and plants. On the other hand, a balanced fertilization strategy is both more economically beneficial and more ecologically sustainable. In addition, soil microorganisms play an important role in soil ecology and are very sensitive to fertilizer application. A deficient fertilization regimen leads to nutrient deficiencies and subsequent changes in the soil microbial community. Imbalanced fertilization can have adverse effects on the biological health of the soil in the long run [24].

Conventional plant breeding involves identifying and developing vitamin or mineral rich parent lines and crossing them over several generations to produce crops with desired agronomic and nutritional properties [25]. Plant breeding is the production of new or genetically distinct plant varieties with improvements in essential micronutrients [26]. Biofortification through plant breeding aims to improve mineral concentrations and bioavailability in crops by using genetic differences between crops of similar species [27]. Plant breeding was originally focused on promoting yield and improving the agronomic properties of crops, but more recent plant breeding techniques have focused on promoting both nutritional quality and agronomic traits. Plant breeding techniques should focus on introducing genotypes that enhance mineral uptake, transport, and redistribution to improve the efficiency of bio fortification [28]. To this end, it is necessary to improve mineral mobility in the phloem vessels responsible for the redistribution and re-mobilization of these minerals. Translocation and redistribution of Zn from shoots to fruit or edible parts of plants is challenging due to the low mobility of Zn in the phloem circuit, resulting in lower Zn concentrations in edible parts compared with leaves or root systems. Plants were selected using three main techniques: Conventional, molecular, and mutant breeding. Conventional breeding is the most common and accepted form of plant breeding for biological enhancement. Conventional breeding improves the nutritional quality of the crop without affecting other agronomic traits. Conventional breeding for bio nutrient enhancement involves crossing crops with high nutrient density genotypes and other agronomic traits to produce new varieties with desired agronomic and nutritional traits. This requires identifying bio diverse cultivars, assessing traits and target nutrient availability in those varieties, and determining the impact of growing conditions on plant stability for those traits.

Transgenic plant breeding seeks to do the same in crops where the target nutrient does not naturally exist at the required level. Recently, omics technology has been introduced to improve the efficiency of gene delivery as a bio enhancement strategy [29]. This involves identifying the appropriate genes through genomics/transcription; overexpression of the desired gene by different transformation methods; studying protein function in the synthesis, absorption, and transport of nutrients through proteomics; evaluating the metabolic pathways that control the biosynthesis of natural metabolites by metabolites; and assessment of mineral responses to environmental and genetic factors through bionomics [30].

Genetic variation between crops creates opportunities for biological enhancement through plant breeding. Unlike plant breeding, genetic engineering is not limited to crops of related species. Genetic engineering has been shown to be a possible solution to this problem and has been shown to be effective in microbial improvement of crops such as bananas and rice, which conventional crops cannot be improved. Genetic engineering provides the foundation for introducing new nutrients or agronomic techniques into specific crop varieties by applying principles of plant breeding and biotechnology, and when used in biofortification, it identifies and characterizes suitable genes that can be introduced into crops translates into desired nutritional quality. It uses genes from many different species, including bacteria, fungi, and other organisms. Some microorganisms improve the absorption of nutrients by plants. The genes of these microorganisms can be genetically engineered in plants to improve nutrient uptake, transport, and concentration. Fluorescent pseudomonas is a bacterium that enhances Fe uptake by plants. Plant growth promotes rhizobacteria and mycorrhizal fungi improving soil mineral uptake and plant growth (Figure 1). Genes from bacteria and *Aspergillus* species have been used to regulate the lysine and phytate content of crops such as rice and wheat. Genome editing, also known as gene editing, corrects, introduces or removes nearly all DNA sequences in many types of cells and organisms [31]. Gene editing provides the ability to develop GMOs without the use of transgenes; to address regulatory challenges related to GM crops [32].

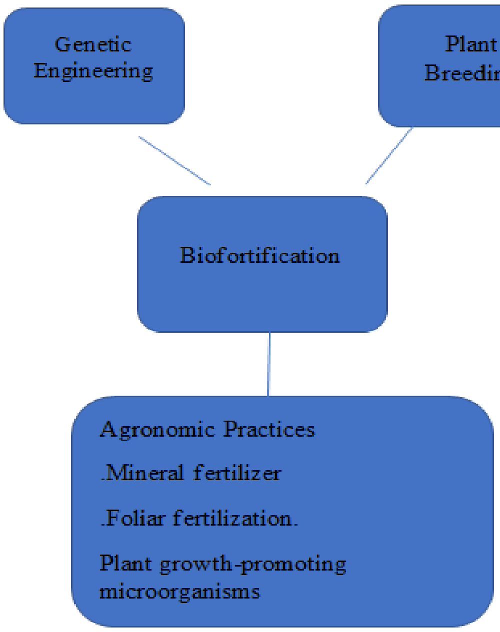

Figure 1: Techniques of nutrient enhancement in crops.

Structure and composition of grain *Sorghum*

The composition of *Sorghum* grain and its parts is generally similar to that of corn, except for lower oil content. The grain contains 8 to 12% protein, 65 to 76% starch with approximately 2% fiber. The germ, a rich source of oil (28% of the germ) also has high levels of protein (19%) and ash (10%). It is a gluten free and safe food for celiac patients or people with known gluten allergies. The slow digestibility of *Sorghum* starch makes it a food option for diabetics. The different varieties of *Sorghum* grains are defined by color, including red, orange, bronze, brown, white, and black. In addition to these botanical varieties, *Sorghum* can be processed into many different formats. *Sorghum* flour can be used in bread and pastries, liquefied *Sorghum* as a syrup, pearled *Sorghum* as a hot grain, and popped *Sorghum* as a popcorn like snack.

Although almost all the bran is cellulose and hemicellulose, appreciable quantities of starch are deposited in the mesocarp tissue of this fraction. Bran lipid consists mostly of wax rather than oil. The composition of *Sorghum* grain from different sources may vary because of many factors, including the nature of the hybrid, soil and climatic conditions, and manner of crop management. Older grain *Sorghum* varieties differed considerably in kernel size and relative amounts of grain parts. With the newer hybrids and wider use of irrigation, the grains are larger and are better filled with starch, and have lower protein content [33].

Sorghum crop has the following health benefits as

- Antioxidants in *Sorghum* can help combat cell damage, reducing inflammation.
- The slow digestibility of starch makes it a good food option for diabetic patients.
- Gluten free and makes it suitable for celiac patients.
- Allergy free.
- Controls blood pressure.
- It promotes weight loss.

Sorghum grain is composed of three main components, the pericarp, endosperm, and germ (Figure 2) [34]. Naturally, the amounts of these components will vary, but a general composition of a *Sorghum* grain has been reported to be 3 to 6% pericarp, 84 to 90% endosperm, and 5 to 10% germ [35]. The composition of these tissues varies substantially, the pericarp consists of multiple layers, including the epicarp, mesocarp, and endocarp [36]. *Sorghum* is unique in that it is the only cereal to have starch granules present in the pericarp. Pericarp thickness is variable, is not of uniform thickness within a single grain, and is related to the amount of starch in the mesocarp. The outer layer of the pericarp is covered with wax, as is shown in Figure 2. The endosperm in cereal grains is composed of the aleurone layer and "starchy endosperm". In *sorghum*, the starchy endosperm has been divided into the peripheral, vitreous (or corneous), and opaque (or floury) endosperm. The aleurone layer contains both protein and lipid bodies along with inclusion bodies possibly containing phytic.

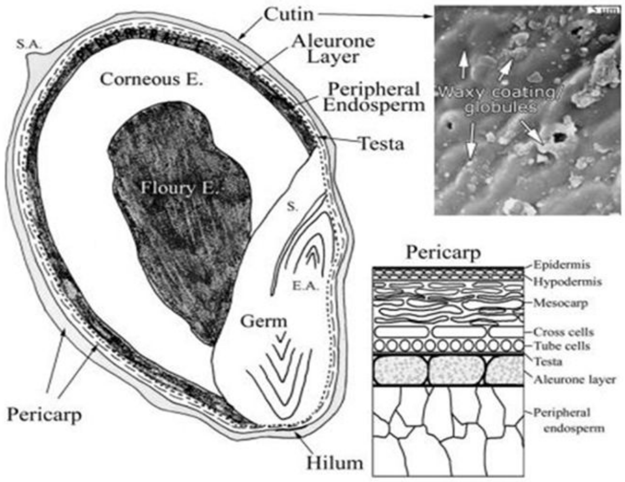

Figure 2: Structure of the *Sorghum* grain.

The peripheral endosperm lies beneath the aleurone layer and is characterized by a dense cell layer with high protein concentration and small starch granules [37]. Mature seeds of *Sorghum* are composed of a seed coat or pericarp (8% of dry weight), embryo or germ (10%), and endosperm (80%). The pericarp consists of the epidermis, subcutaneous tissue, starchy mesocarp, and underlying intersecting and tubular cells. Pericarp thickness is controlled by a single gene (z), which under homozygous recessive conditions results in a thicker pericarp associated with mild dissection. If a seed coat is present, it is located below the pericarp and is controlled by two co-dominant (b1 and b2) genes [38]. The aleurone layer just below the pericarp forms part of the endosperm but is removed along with the pericarp as bran when the grain is peeled. The highest concentrations of Fe and Zn are found in the aleurone layer and embryo (particularly in the scutellum), with low concentrations in the starchy endosperm [39]. Therefore, dehulling of *Sorghum* grains, which is common practice in West and Central Africa, dramatically reduces Fe and Zn concentrations [40]. The embryo contains a scutellum, hypocotyl, germ and radicle (small root) and is rich in structural proteins, lipids and minerals.

Genetics and breeding

The main goal of biofortification is to biofortify *Sorghum* and use genetic approaches to improve its nutritional quality to significantly increase the concentration of iron and zinc in the grain. Genetic variation is important to any plant breeding program. Genetic and environmental factors in *Sorghum* significantly influence differences in grain Fe and Zn concentrations between red, white, pink, and yellow grains [41].

Research showed that there is a significant difference in the concentration of Fe and Zn among the different *Sorghum* accessions. According to Poquette [42] in the first major effort to assess the variability for grain Fe and Zn, as well as β-carotene and phytate concentration in *Sorghum*, a total of 84 diverse *Sorghum* lines involving parental lines of popular hybrids, cultivars, yellow endosperm lines, high protein digestible lines, high-lysine lines, and waxy lines were assessed. The result showed that there is a slight difference between phenotypic and genotypic coefficient of variation for iron and zinc concentrations and high heritability's for micronutrients. Significant genetic differences were observed for Fe, Zn, and phytate concentrations and for agronomic and grain traits among different accessions. Wolter [43] had reported a range of 25–115 ppm for grain Fe and 15–65 ppm for Zn contents among the 79 *Sorghum* cultivars.

DISCUSSION

Gene action and heterosis for Fe and Zn

The development of breeding strategies for traits of interest in hybrid performance is important to identify the relationship between parental line and hybrid performance. Parental selection in the hybridization program needs evidence on combining ability and level of heterosis to develop improved hybrid

According to Gaddameedi a study conducted in Line Tester mating design involving seven parents. A total of 12 new hybrids were developed by mating three lines with four testers at two locations. The study aimed at developing suitable breeding strategy and improving breeding products using gene action, heterosis and combining ability analysis for improving the grain Iron (Fe) and Zinc (Zn) concentration and grain yield in *Sorghum* and the following results were obtained.

Parents were significant in traits, Fe and Zn concentration studies ($P<0.01$). The contribution of P x E interactions to variability was small compared to that due to genetic differences between parental strains. The average parental performance of the two environments showed a large variation in Fe and a small variation in Zn.

The variance due to SCA was higher than variance due GCA for Fe and Zn density. The result indicated that the variances in Fe and Zn concentrations is due to non-additive gene actions. The same result was reported by Mohammed [45]. According to the study, for Fe and Zn, there were significant positive and moderate correlations between parents mean scores and the hybrid performance itself. As the concentration of either of the two nutrients increases, so does the other. To develop hybrids with high grain iron and zinc levels in *Sorghum*, both parents need to be improved for these micronutrients. It is possible to combine high grain iron and zinc high grain yields [46].

Genetic control/QTL and genes for Fe and Zn concentration

Understanding trait inheritance is critical for developing an appropriate breeding strategy for its improvement. In most crops, when contrasting parents were crossed and the F2 population from such crosses were analyzed for grain Fe and Zn concentrations, they showed continuous variation indicating that grain Fe and Zn are multigenic traits, thereby implying that simple selection methods are not effective in their improvement. Complex traits such as grain Fe and Zn, grain yield and quality, and host plant resistance to pathogens and pests are likely controlled by many genes [47]. Understanding the genetic basis of Fe and Zn accumulation in grains and mapping genes or Quantitative Trait Loci (QTL) controlling them will provide the means for developing a sound plant breeding strategy through marker assisted selection.

Various QTLs have been identified for grain Fe and Zn concentrations in rice; Zn concentrations in wheat and barley and Fe and Zn concentration in the kernel of maize [48-58]. QTLs for Fe and Zn concentrations have not been reported for a long time in sorghum, but ongoing efforts to identify them have been successful. The recent release of the first biofortified *Sorghum* variety in India; the work is the first report on QTL mapping utilizing high-density of DArT and DArTseq markers for identifying QTLs for grain Fe and Zn in *Sorghum.* Overall, this study identified a total of 11QTLs (individual) and 3QTLs (across) environments controlling both the traits [59-61]. QTLs that are co-located and stable across environments, with common markers provides opportunity for early generation testing for enhancing grain Fe and Zn in *Sorghum* [62].

CONCLUSION

Micronutrient malnutrition is primarily due to low bioavailability of minerals and vitamins, leading to diseases that interfere with healthy living. For this; increasing micronutrient concentrations through biofortification of common food crops such as *Sorghum* is a cost effective and sustainable solution to combat micronutrient deficiencies, especially in developing countries.

Evidence of QTLs controlling Fe and Zn concentrations in *Sorghum* has enabled the development of robust plant breeding strategies through marker assisted breeding. Genetic variability exists in elite *Sorghum* lines for grain iron and zinc concentrations and agronomic traits that can be exploited to improve these traits. The greater variability in SCA than in GCA for cereal Fe and Zn concentrations indicates the importance of non-additive gene effects in enhancing nutritional traits. The hybrids displayed heterosis not only in terms of agronomic traits, but also in grain iron concentrations, suggesting that micronutrient improvements within populations are likely to be highly effective. Although both parents need to be improved to improve grain Zn concentration, there is plenty of room to exploit heterosis to increase grain Fe concentration in *Sorghum*. Experiments suggest that there is great variability in grain Fe and Zn, and traits associated with yield can be utilized in advanced breeding lines as future parents.

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