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Review On Breeding Sorghum (Sorghum Bicolor (L.) Moench) for Nutritional Quality Improvement

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Abstract: *Low nutritional quality and protein digestibility of the seed are the most important directions of genetic improvement of sorghum. in this review, i summarize breeding methods and efforts made for quality improvement of sorghum. today, grain quality became an important criterion in sorghum breeding. Sorghum is principal source of energy, proteins, vitamins, minerals, phytochemicals, and phenolic compounds beneficial to health. however, the nutritional quality of sorghum is poor mainly due to the predominance of storage proteins called kafirins. the protein content and the amino acid composition vary due to genotype and environmental conditions. sorghum contains high genetic variation for traits influencing grain quality .identification and effective characterization genes influencing quality would help sorghum breeders to develop new quality product. The studies shown us, no major antagonism between quality traits and yield, suggesting that it is possible to combine the desirable traits to breed for high yield varieties with satisfactory grain quality attributes. Attempts were made to improve sorghum grain quality, mineral content and kafrin digestibility through genetic engineering and mutation breeding but information on the use of classical breeding methods to improve sorghum grain quality is still limited.*

Keywords: *Biofotification, genetic variability, kafirin, mutation, quality trait.*

1. Introduction

Sorghum (Sorghum bicolor (L.) Moench) is a widely grown cereal crop in the semi-arid tropical regions of Africa, Asiaand Central America (Derese *et al*. 2018). According to (FAO, 2017), in semi-arid tropical regions of Africa and Asia. Sorghum is grown primarily for food and more than 80 % of global sorghum area (42.12 m ha) lies in developing countries. In developing countries, like sub-Saharan countries, sorghum is a main source of energy, minerals, proteins, vitamins, phytochemicals, and phenolic compounds which is beneficial to human health. Sorghum grain has been used to make baking flours, pop sorghum, alcoholic beverages, pet foods, and packaging materials (Udachan *et al*. 2012; Zhu 2014).

These various products can require different grain characteristics and thus can alter crop ideotype. However, the nutritional quality of sorghum is poor mainly due to the predominance of storage proteins called Kafirins. Today, grain quality improvement in cereal crops continues to be an important area of research as cereals represent the largest constituent of global food supplies (Gilland, 2002). Global malnutrition crisis has shifted emphasis toward improving the grain quality of staple cereal crops and ensuring food security (Rosegrant and Cline 2003).

Identifying genes influencing sorghum grain composition would help manipulate grain texture and quality to promote new product development (Bean *et al*. 2016). Unlocking the network of genes regulating grain quality traits will help facilitate the manipulation of protein content, quality, mineral content and protein digestibility for plant breeders. Sorghum contains high phenotypic variation for traits influencing grain quality. Identifying genes influencing nutritional quality traits would help sorghum breeders to manipulate grain quality to develop new quality product and the exploitation of the genetic variability requires effective characterization of the germplasm.Thus, the main objectives of this paper were to review breeding approaches used for nutritional quality improvement of sorghum and to explore breeding efforts made for quality improvement in case of sorghum.

2. Nutritional Composition And Utilization Of Sorghum

The preferred grain composition of sorghum is varies depending on end-use. Generally, sorghum is a main source of energy, proteins, vitamins and minerals for people in the semi-arid tropics of the world.

Gierend, and Swamikannu, (2016), reported that, sorghum is the major energy source for more than 300 million people who live in the semiarid tropics of the world. Sorghum is a good energy source and it is about 70% starch. Proteins are the main constituents of sorghum after starch, making up to 12% dry weight of sorghum grain (Ng'uni *et al.,* 2012).t is a good source of the β-complex vitamins and some varieties contain β carotene which can be converted to vitamin A by the human body.

It is excellent sources of health promoting constituents including polyphenols and bioactive lipids. Sorghum contains inadequate levels of some essential amino acids, particularly tryptophan , lysine,threonine, and methionine and the majority of amino acids within sorghum grains are stored in protein bodies, called kafirins, which are similar to zeins in maize. The concentration of the mineral elements and protein content in sorghum varies due to genotypic and environmental influences and genotype by environment interactions. Nevertheless, the nutritional quality of sorghum is poor compared to maize, this is mainly due to the predominance of storage proteins. These storage proteins are extremely low in the essential amino acids. Many literature's indicated that the variation in grain color, shape and size as well as stalk thickness juiciness, sugar content and color often influence the use of the crop. The white, large grains with corneous endosperm are usually preferred for human consumption. Nutritive value is increased if the endosperm is yellow with carotene and xanthophylls (Ng'uni *et al*., 2012). The red varieties are preferred for making beer, especially in Africa. The white grained varieties are usually preferred four bread making, however it is vulnerable to attack by birds during the dough stage of maturity, while the darker varieties are not (Ng'uni *et al*., 2012).

In many parts of the world it is utilized in different forms. For-instant, in Ethiopia, the nutritive value of sorghum-based food is usually enhanced through its combination with locally grown edible oil crops (Geleta *et al*., 2002). In developed countries, like the USA, sorghum can also be used as a main ingredient in production of gluten-free beer. In the southern US, sorghum syrup is used as a sweet condiment usually for biscuits, corn bread, pancakes, hot cereals or baked beans (Delserone, 2007). As an Arab cuisine, the milled grain is often cooked to make couscous, porridges, soups and cakes. Sorghum can also be popped in the same manner as popcorn, although the popped kernels are smaller than popcorn.A currently, it is as a source of ethanol and for making alcoholic beverages. In China it is the most important ingredient for the production of distilled beverages such as maotai and kaoliang.

2.1 Genetic resource for quality improvement

Sorghum has a huge range of genetic resources with much of the genetic variability available in the African regions for quality improvement. The identification and characterization of trait-specific germplasm from large ex situ collections is key to successful introgression of new variability into the crop improvement programs (Upadhyaya, H.D, *et al*. 2014). Landraces and wild relatives of cultivated sorghum from the centers of diversity have been rich sources of traits to improve food and industrial products. A significant variability has been reported for protein content as well as essential amino acid levels such as lysine, methionine, argentine, aspartic acid, threonine, serine, glutamic acid, proline, tryptophan, histidine, glycine, alanine, cystine, valine, methionine, isoleucine, tyrosine, and phenylalanine (Nanda and Rao, 1 975a, 1975b).

The two high-lysine Ethiopian lines, IS 1 1758 and IS 11 167, have exceptionally high lysine contents have been identified. However, their acceptance is limited due to many problems associated with their opaque kernel, reduced grain yield, slow drying in the field, increased susceptibility to molds and insects, and the tendency of the seed to crack when mechanically harvested. Similarly, the chemically induced high-lysine strain p-721 Q has soft kernel and floury endosperm with reduced yielding ability. In addition, lines having vitreous kernels with good food grain and processing properties have been identified and are available for breeding programs at Purdue University. Sorghum germplasm with high protein digestibility as higher than maize or other staple cereals have been identified the mutation breeding rough research. In addition, (Axtell, 2001) reported that lines having vitreous kernels with good food grain and processing properties have been identified and are available for breeding programs at Purdue University.

2.2. Correlation Among Traits

Since 18^{th}, sorghum breeders have attempted to combine productivity and desired grain traits in the new varieties (Kayode *et al*., 2005). Many studies shown us, it is possible to combine the desirable traits to breed for high yield varieties with satisfactory grain quality attributes. No major antagonism was detected between grain quality traits and grain yield, suggesting that it is possible to combine the favorable alleles of both categories to breed for productive varieties with satisfactory grain quality attributes. A positive correlation between grain yield and grain starch content has been found in sorghum (Murray et al., 2008).

A number of genetic studies have been conducted on important agronomic traits using mapping populations and detection of quantitative traits loci (QTLs)Mace and Jordan (2011), including grain quality traits (Boyles *et al.*, 2017; Rhodes *et al.*, 2017). An association mapping study between grain quality traits and specific one gene involved in synthesis pathways of starch and grain storage proteins was also conducted (De Alencar *et al.*, 2010). The sequencing of the sorghum genome (Paterson et al, 2009) permitted the large development of Single Nucleotide Polymorphism (SNP) markers and the production of high density genetic maps, enabling whole genome association mapping studies (Morris *et al*., 2013a; Murray et al., 2009), including some on grain quality traits (Boyles *et al.*, 2017; Sukumaran *et al.*, 2012).

Breeding ideotype of sorghum varieties is challenging as it requires measuring and assembling a large range of traits not always positively genetically correlated (Guindo, D, *et.al*, 2019). Many QTLs with moderate effect were detected for grain attributes associated to quality, without showing antagonism between grain quality and yield (Guindo, D, *et.al*, 2019). Although grain number appears to have a stronger influence on grain yield, increasing grain weight in sorghum without sacrificing grain number would also increase yield and has other beneficial implications, such as improved grain quality and processing (Lee *et al*., 2002). One hypothesis for this relationship is a higher rate of starch biosynthesis within the endosperm could increase sink strength of the grain and drive photo assimilate production.

3. Breeding Methods and Strategies to Improve Sorghum Quality

Different breeding approaches have been employed with the purpose of improving quality of protein in sorghum. These breeding approaches includes; convectional breeding, molecular breeding, biotechnological approaches and mutation breeding are most common breeding methods available for quality improvement. Breeding for plant compositional traits to enhance nutritional quality or to meet an industrial need are major plant breeding goals. Breeders need to identify the quality traits associated with these uses and have produced cultivars with enhanced expression of these traits. Genetic variability within cultivated plant species is precious genetic resources that allow us to increase qualityproduct (Geleta & Ortiz, 2013).

3.1 Molecular and Biotechnological Approaches

Traditionally, breeders used to classify sorghum gene pool based on morphological characters. Recently, biotechnology has provided ways of improving crops with special reference to sorghum. This is through the use of various techniques such as molecular markers, gene identification and cloning, in vitro protocols for efficient plant regeneration, genetic engineering and gene transfer technology to introduce desirable traits into sorghum genomes and genomics, and germplasm databases (O'Kennedy *et al*., 2006). The genetic improvement has been made easily accessible through the use of easily assayable molecular DNA genetics of DNA markers that enable accurate identification of genotype without the confounding effect of environment, thereby increasing heritability.

3.2 Biofotification (Genetic Transformation Of Sorghum)

The combined use of recombinant DNA technology, gene transfer methods and has led to the efficient production of transgenic in a wide array of crop plants. Unlike conventional plant breeding, in transgenesis, only the cloned genes of agronomic importance are introduced into the plants without linkage drag from the donor. Sorghum grain is characterized by its high starch, protein, micronutrients, and crude fiber but low in fat (Kumar *et al.,* 2015). The enhancement of grain nutrients (biofortification), either agronomically (application of mineral fertilizers) or genetically (breeding), is viewed the most promising and cost-effective approach to combat malnutrition and related health problems (Cakmak, 2007).

Compared to all other major food crops, sorghum transformation is in its infancy, with much technical progress yet to be achieved (Seetharama *et al.* 2003).At ICRISAT, sorghum transformation has been achieved and efforts are continuing to develop procedures for Agro bacterium-mediated transformation. Numerous researches published up to date clearly demonstrate that genetic engineering techniques are quite promising for enrichment of cereal grain with essential amino acids, i.e. lysine, tryptophan, methionine, and micronutrients. Biofotification of sorghum grain through genetic strategies is a powerful approach for changing the nutrient balance in the human diet on a large scale.

The use of biotechnological tools to address the problem of improving the digestibility of kafirins requires reliable methods of introducing genetic constructs into genome of different of sorghum lines and reliable methods of plant regeneration from transformed cells. In spite of numerous reports on obtaining transgenic sorghum plants by using micro bombardment technique, Agro bacterium-mediated genetic transformation, pollen-mediated transformation, genetic transformation of sorghum for a long time was a serious problem (Do PT, Zhang ZJ,2015) However, as a result of intensive research in recent years, significant progress has been made in this area.

To date, the methods of introducing transgenes into the genome of sorghum, both by micro projectile transformation (Liu G, Godwin ID, 2012) and through Agro bacterium mediated genetic transformation were significantly improved. This medium increased the frequency of obtaining transgenic sorghum plants in micro projectile transformation (Liu G, Godwin ID, 2012) and in experiments on Agro bacterium-mediated genetic transformation. (Kumar T, *et.al., 2012*), increased level of copper ions in the medium for plant regeneration greatly stimulates plant regeneration in sorghum tissue culture, which also contributed to the increase rate of transgenic plants.(Liu G, Godwin ID, 2012) recently, using these modifications of nutrient media (Do *et al*.,2016) reported on significant increase of frequency of transgenic sorghum plants (up to 14%) in experiments.

Sorghum was genetically transformed with the use of Agro bacterium to improve nutritional quality (Zhao *et al*., 2000). Because sorghum is low in lysine, a high-lysine gene HT12 was inserted into the sorghum gene using Agro bacterium vector together with a herbicide resistant gene bar. Ultimately, increased levels (40-60%) of lysine were observed in hemizygous sorghum grains (Zhao *et al*., 2002). This implicates that an improved lysine transgenic variety can benefit communities by eradicating malnutrition. Furthermore, Africa Biofortified Sorghum (ABS) project developed improved sorghum lines through the process of genetic engineering techniques (Africa Biofortified Sorghum Project, 2009). (Da Silva *et al*, 2011) transformed sorghum lines to suppress synthesis of various kafirin sub-classes (alpha, gamma and delta-kafirins) or backcrossed into transgenic lines with improved protein quality. The transgenic lines had high protein digestibility, improved amino acid score, and protein digestibility corrected amino acid score in contrast to untransformed sorghum lines.

3.3 Mutation Breeding

Mutation breeding plays an important role since it can increase genetic variation of important crops (Soeranto *et al.*, 2020).Researchers attempted to improve sorghum nutritional quality based on the identification of high lysine mutants. By selecting desired mutant genotypes, the plant breeder can advance his or her germplasm by progressing lines with good adaptability, high productivity and quality under adverse conditions. Two mutants were identified in sorghum, the hl gene in an Ethiopian line (Singh and Axtell, 1973) and the P721 opaque gene which was induced with the chemical mutagen diethyl sulphate (Axtell *et al*., 1979). Studies show that the lines contain ‘‘low prolamin’’ in which the proportion of kafirin is reduced by 50% with compensatory increases in other more lysine-rich proteins and free amino acids. The lysine content was enhanced by 40-60%. The challenge of protein improvement is the association with negative effects on seed weight and yield. (Oria *et al*, 2000) reported the identification of a novel line with high protein digestibility from a cross involving the high lysine P721 opaque mutant. Sorghum lines from the African Centre for Crop Improvement, and breeding lines from other sources were mutagenised with gamma irradiation and cyclotron to improve agronomic and nutritional traits.

4. Summary and Conclusion

Sorghum is a globally important food security crop, particularly in arid and semiarid environments. Nutritionally, sorghum is the main source of energy, proteins, vitamins and minerals. Scientists have been made many efforts to increase nutritional quality of sorghum including protein content but it has proved difficult to incorporate the high lysine phenotype into high yielder varieties. This due to negative correlation between grain yield and protein content as well protein quality in cereals including sorghum. The identification of naturally high lysine Ethiopian sorghum mutants from the world sorghum collection and the recent identification of a sorghum line with high protein digestibility levels surpassing that of maize facilitated the prospects for combining high nutritional quality and grain yield.

Different approaches have been employed with the purpose of improving quality of protein in sorghum for the society to have a balanced diet which includes conventional plant breeding, Molecular and biotechnological approaches and mutation breeding**.** But our ability to improve the nutritional quality of sorghum grain by classical plant breeding is limited by the low level of variation in the gene pool available for crossing. However, Molecular and biotechnological approaches are the most promising approaches for nutritional quality improvement in the future. Genetic engineering can offers an opportunity to overcome this limitation genetic variability available for quality improvement by introducing wild type or mutant genes from other organisms. Currently, mutation breeding is also the major promising approach.

Generally, a little progress has been made in breeding sorghum for nutritional quality traits. This is due to breeders have always concentrated on improving yield, and in more recent years stability of yield. Identifying genes influencing nutritional quality traits would help sorghum breeders to manipulate grain quality to develop new quality product. In the future efforts to genetically improve sorghum for food quality should include important traits such as high protein content, digestibility and quality to ensure sorghum becomes and remains a competitive food crop.

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