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Review Article

Physical Measurements and Improvement Methods of Protein and Other Nutritional Quality Traits of Sorghum [*Sorghum bicolor* (L) Moench]

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Abstract: Sorghum [*Sorghum bicolor* (L) Moench] is the fifth most important cereal crop and is a primary food and feed crop in Africa, especially in the dry land regions. This crop is drought tolerant and can be grown in semi-arid conditions where maize, wheat, and rice cannot be grown because of water scarcity. The nutrient content of sorghum grain is generally similar to other cereal grains. However, studies have revealed poor protein quality of sorghum foods because sorghum protein is deficient in lysine. Besides being a staple food crop in the semi-arid regions of the world, sorghum is also used for feed, traditional beverages, fuel, construction material, confection (sweet sorghums), brooms, as well as for making sugar, syrup and molasses. Sorghum is basically composed of starch, which is more slowly digested than that of other cereals, has low digestibility proteins and unsaturated lipids, and is a source of some minerals and vitamins. Therefore exploration of the available genetic variation in landraces and improved cultivars for chemical and physical grain attributes and their association with end-uses, such as injera quality, would require the screening of germplasm for quality characteristics before subsequent inclusion in breeding programs.

Keywords: Anti-nutritional Factors, *Bio fortification*, Chemical Composition, Nutritional Value, Quality Traits

1. Introduction

Sorghum [*Sorghum bicolor* (L) Moench] is one of the important staple food crops serving over 400 million people in semi-arid tropics and ranks fifth in production among the world cereals. It is grown in the tropical and sub-tropical region of the world, between 400 N and 400 S latitude [1] and [2]. Due to its drought tolerance and adaptation to semi-arid, sub-tropical and tropical conditions, sorghum can still be produced where agricultural and environmental conditions are unfavorable for the production of other cereal crops. This is of particular importance as Global Warming and the growth of the world's population will require that more marginal lands be used for food production [3].

Over the continent as a whole, sorghum is the second most important cereal after maize occupying 22% of the total area planted to cereals [4]. Nearly all the sorghum grain produced in Ethiopia is used for human consumption. About 80% is used for making leavened bread *(injera)* and 10% is used to make home brewed beer *(telia)* [5]. The remainder goes into making stiff porridge *(genfo)*, unleavened bread *(kitta),* boiled whole grain *(nifro),* popped grain *(kollo)* and animal feed. Sorghum grain is eaten in a variety of forms that vary from region to region [6]. As stated by these authors, the most common traditional foods made from sorghum are thin and thick porridges and flatbreads. The nutrient content of sorghum grain is generally similar to other cereals. However, studies have revealed poor protein quality of sorghum foods because sorghum protein is deficient in lysine [7] and becomes less digestible after cooking into foods [8].

The great effort done to improve the lysine content of sorghum foods, such as that of [9] has shown that supplementation with synthetic essential amino acids may improve protein quality of sorghum diets. However, this practice is regarded as inefficient and impractical among populations where sorghum is the dietary staple as it may be too expensive for the poor to afford such amino acid supplements [10]. Furthermore, such an approach requires infrastructure, access to markets and healthcare systems for their success, often not available to people living in remote rural areas [11]. Compositing with lysine-rich legumes has been used to enhance the protein quality of sorghum food products. For example, [12] reported an improved protein quality of sorghum-soy blend used in the United States‟ Food for Peace Program. As the semi-arid tropics are characterized by unpredictable weather, limited and erratic rainfall and nutrient poor soils among other agricultural constraints [13], efforts to improve nutritional insufficiency should focus on indigenous crops which are accessible to the poor consumers in such environments.

Sorghum bicolor [14] In Ethiopia, sorghum is grown over a wide range of ecological zones due to its tremendous genetic diversity. It is a potential crop for sustainable production in moisture stress areas of the country. The crop is utilized in different forms where the grain is used for making *injera* (local flat bread) and preparing local drinks such as '*tella'* and '*areke'*. It is also consumed in boiled and roasted forms; the stalk is used for construction, fodder, fuel and fencing. The national cultivar release committee of Ethiopia has made it mandatory to include end-use quality data before a cultivar is proposed for release. For example evaluated sorghum cultivars from Ethiopia and internationally for *injera* making qualities are reported that sorghum cultivar differences existed for *injera* making and staling properties [5].

The allegedly "poor nutritional quality" of sorghum is detrimental to its use in foods and feed. Tannins and poor protein digestibility are major problems in the eyes of some. Besides the milling quality of sorghum is determined mainly by kernel shape, density, hardness, structure, and presence of a pigmented testa, pericarp thickness and color. The objective of sorghum improvement is mainly for direct enhancement of yield potential and stability. However, in the present market economy, product quality has become increasingly important. Breeding for improved quality, consideration is given to the physical and chemical characteristics of the product harvested that affect its nutritional value, processing and utilization. For example our ability to improve the nutritional quality of sorghum grain protein by classical plant breeding is limited by the low level of variation in the gene pool available for crossing. Exploration of the available genetic variation in landraces and improved cultivars for chemical and physical grain attributes and their association with end-uses, such as *injera* quality, would require the screening of germplasm for quality characteristics before subsequent inclusion in breeding programs. Therefore, the objective of this seminar is to discusses the major quality traits of sorghum and to Review potential methods that could be applied in sorghum breeding programs for quality traits

2. Literature Review

2.1. Structure of Sorghum Caryopsis

Structure of the grain has an important bearing on various processing and food quality traits. The structure of sorghum kernels varies significantly because of environmental and genetic factors. The sorghum caryopsis is composed of three distinct parts: outer layer (pericarp), storage tissue (endosperm) and embryo (germ) [15]

2.1.1. Pericarp

The pericarp constitutes 4.3% to 8.7% of the sorghum caryopsis reviewed by [16]. It has a thickness of 8 to 160 μm [17] varying within individual mature caryopses. It is subdivided into three tissues: epicarp, mesocarp and endocarp. The epicarp is covered with a thin layer of wax and is usually pigmented. The sorghum mesocarp contains starch granules, a characteristic unique to sorghum and pearl millet. The tube cells, which are part of the pericarp, conduct water during germination while, the cross cells form a layer that impedes moisture loss [16]. The pericarp contains approximately 5% to 8% of the grain protein.

Some sorghum cultivars have pigmented sub-coat (testa) [17] located between the pericarp and the endosperm. The pigmented testa contains tannins proanthocyanidins. Tannins protect the grain against insects, birds and fungal attack but condensed tannins are associated with nutritional disadvantages and reduced food quality [16].

2.1.2. Endosperm

The endosperm constitutes 82% to 87% of the sorghum grain [16]. It is composed of aleuronic layer, peripheral, and floury and corneous (horny, vitreous, glassy) areas. The aleuronic layer cells possess large amounts of proteins (protein bodies and enzymes), ash (phytic bodies), and oil (spherosomes). The peripheral region has several layers of dense cells containing more protein bodies and smaller starch granules than the corneous area. The peripheral and corneous areas affect processing and nutrient digestibility. The endosperm contains approximately 81% of sorghum protein reviewed by [16]. In normal sorghum cultivars, most of the proteins in the endosperm are prolamins (soluble in alcohol-water mixtures) as well as some limited amounts of glutelins (soluble in dilute acid and dilute alkali) [7].

In a review of biochemical basis and implications of hardness and grain strength in sorghum and maize, [18] noted that the protein bodies in the corneous endosperm contained more γ-prolamins, which seemed to be cross-linked by disulphide bonds, than in soft grains. These authors suggested that the amounts of α- and γ- prolamins relative to the total prolamins content may be essential for corneous texture, in which these prolamins are usually higher in hard grains than in soft grains. Furthermore, [19] investigated the role of cross-linking of sorghum storage proteins (kafirins) into larger polymeric groups in influencing grain hardness. These authors found that corneous endosperm had a greater level of kafirin crosslinking than did floury endosperm and that the cross-linking produced a larger molecular weight distribution than in the floury endosperm.

2.1.3. Germ (Embryo)

The germ is the living part of the sorghum grain. It consists of two main parts: embryonic axis and scutellum. The embryonic axis contains the new plant [20]. As explained by these authors, during germination and development the radicle forms the primary roots while the plumule forms the shoot. The scutellum is the cotyledon and has reserve nutrients: moderate quantity of oil, protein, enzymes, and minerals, doubling up as a link between endosperm and germ [16]. The germ contains approximately 15% of the protein in sorghum. It is rich in albumins (water-soluble) and globulins (soluble in dilute salt solution) which are rich in lysine and other essential amino acids [7].

2.2. Food Utilization

The proper sorghum cultivars can be processed into a wide variety of very acceptable commercial food products. These grains can be extruded to produce a great array of snacks, ready to eat breakfast foods, instant porridges and other products. The flakes of a waxy sorghum obtained by dry heat processing can be used to produce granola products with excellent texture and taste. Tortillas and tortilla chips have been produced from sorghum and pearl millet alone or with maize blends. The sorghum products have a bland flavor while pearl millet products have a unique strong flavor and color. The critical limitation is again cost efficient, reliable supplies of grain. Considerable progress to define grain quality has been made since the early 1970s [21].

The plant stem and foliage are used for green chop, hay, silage, and pasture. In some areas, the stem is used for hut making. The grain plays a dominant role in the traditional beer brewing, at household and industrial levels [22]. Grain sorghum is used to make products such as potable alcohol, malt, beer, liquids, gruels, starch, adhesives, core binders for metal casting, ore refining, and grits as packaging materials. Grains are a rich and cheap source of starch and have applications in the food, pharmaceutical, textile, and paper industries. Malt drinks and malt cocoa-based weaning food and baby food industries are popular in Nigeria [23].

2.3. Food Quality

The quality of grain sorghum is determined by visual quality, nutritional quality (including whole grain, protein and starch digestibility; nutrient bio-availability), and anti-nutritional factors such as tannins, processing characteristics, cooking quality and consumer acceptability [24]. The mature sorghum kernel (dry weight) is composed of the embryo (10%), the pericarp (8%) and the endosperm (80%). Sorghum is an important source of minerals that are located in the pericarp, aleuronic layer, and germ, is a good source of K and an adequate source of Mg, Fe, Zn, and Cu [25]. Sorghum is also a good source of vitamins, especially the B vitamins (thiamin, riboflavin, pyridoxine), and the lipo-soluble vitamins A, D, E and K [26]. Among the B group vitamins, concentrations of thiamin, riboflavin and niacin in sorghum were comparable to those in maize. Wide variations have been observed in the values reported, particularly for niacin [24].

2.4. Chemical Composition of Sorghum Grain

2.4.1. Carbohydrates

Carbohydrates are sugars and starches, which provide energy for humans and animals, and cellulose which make up many plant structures. The quality and quantity of carbohydrates present in sorghum are significantly important quality parameters that can influence consumer acceptance of the end product. Starch is the most abundant chemical component, while soluble sugars and crude fiber are low [27].

2.4.2. Protein Quality

The second major component of sorghum and millet grains is protein. Sorghum is mainly utilized in developing countries where cereals are a staple food crops. This might cause unbalanced diet, since sorghum and most other cereal grains, when examined for albumin, glutelins and globulin proteins are limiting essential amino acids, particularly lysine, tryptophan and threonine. The quality of a protein depends primarily on its essential amino acid composition. The average protein content of sorghum is usually variable ranged from 11 to 12% [28] and [29] reported that the protein content varies from 6 to 25%. The protein content and its amino acid composition in sorghum varies due to genotype and environmental conditions at which the crop is grown (water availability, soil fertility, temperatures and environmental conditions during grain development) [7], [30] that affect the grain composition. Sorghum proteins are located in the endosperm (80%), germ (16%), and pericarp (3%), [7]. Kafirins, or prolamins, and glutelins comprise the major protein fractions in sorghum.

In several cereal grains, including sorghum, an inverse correlation has been observed between grain yield and protein content [30]. Moreover, the protein content of the grain is significantly and inversely correlated with its weight and starch content. Likewise, the ash content and protein content of the sorghum grain are positively correlated with each other. Grain protein and its amino acid composition in sorghum differ with the environmental conditions [31].

2.4.3. Starch Quality

In spite of the botanical source, starch is structurally composed of two high molecular weight homopolysaccharides known as amylose, a straight chain and amylopectin, a branched chain polymer of glucose which are held together by hydrogen bonds and are arranged radically in spherical granules [32]. Sorghum is among the primary source of carbohydrates in tropics and semi-arid tropics of India and sub-Saharan Africa [33]. Amylose content in sorghum grain is genotype dependent. Waxy sorghums contain very low levels of amylose (level < 1%). The average starch content in sorghum varies from 56-73 percent of which 70-80% is amylopectin and the remaining 20-30 percent is amylose. Waxy sorghums or glutinous sorghum varieties contain very low or no amylose and the starch is 100% amylopectin [34]. In sugary sorghums, the amylose content of starch is about 5-15% higher than in normal sorghums and they contain exceptionally high levels of water soluble polysaccharides i.e. 29.1% [35]. The digestibility of isolated starch of sorghum cultivars ranged from 33 to 48 percent as against 53 to 58 percent for corn starches [36].

The quality of cooked sorghum has been strongly associated with the total and soluble amylose content of the grain and also the soluble protein content [37]. The swelling power of starch and its solubility significantly influenced the cooking quality of sorghum Subramanian. Plasticity of sorghum flour dough mostly arises from the gelatinization of starch when the dough is prepared in hot or boiling water. The stickiness of the cooked flour is a function of the starch gelatinization. Porridge prepared from hard endosperm of sorghum is less sticky than that prepared from grains with a larger proportion of floury endosperm [38].

2.4.4. Soluble Sugars

According to [39] soluble sugar content of the caryopsis changes during development but the maximum can be 5.2%. At maturity, the average soluble sugar content ranges from 0.8 to 4.2% with sucrose being 75% of the sugars [40] and [41]. Mature caryopsis contains 2.2 to 3.8% soluble sugars, 0.9 to 2.5% free reducing sugars, and 1.3 to 1.4% non-reducing sugars [42]. Glucose ranges from 0.6 to 1.8% and fructose from 0.3 to 0.7%. High lysine and sugary cultivars contain more soluble sugars than normal sorghums [40] and [39] reported that the high-lysine sorghum lines IS11167 and IS11758 from Ethiopia comprised of the highest percentages of total soluble sugars (5.2 and 4.4%, respectively). During germination, sugars accumulate in the endosperm after the second day with maximum concentration occurring after eight days [16].

2.5. Malting Quality of Sorghum

Antinutrients are commonly removed by decortication, malting, fermentation, roasting, flaking, and grinding. In Ethiopia and elsewhere, barley is the preferred grain for malting in modern brewing industries. However, intensive cultivation of barley in tropical areas, including Ethiopia, is limited. Most of the cultivated areas in Ethiopia are characterized by a warm and dry climate and are not suitable for barley production [43]. The Authors revealed that pockets of areas in the highlands where barley is normally grown have frequently suffered from infestations by biotic agents that have limited the production of this crop. As a result, local brewery industries have increased the import of malt barley and at present 67% of the barley used by local breweries is imported. Sorghum is increasingly becoming popular for lager beer production.

Sorghum has been malted for centuries and is used for the production of baby food and traditional alcoholic and nonalcoholic beverages. During 2002, about 55% of the sorghum used by the South African consumer was in the form of malt, this makes the malt industry the largest consumer of sorghum in South Africa. The malting process commences with a 24 h soaking or 'steeping' process in order for the grain to absorb water. Steeping leads to leaching losses of grain components, but also initiates germination [44]. At least 90% of sorghum grains should germinate in order to produce good quality malt during malting; endogenous amylases are mobilized to hydrolyse starch into fermentable sugars that are utilized by yeasts during brewing [45].

2.6. Anti-nutritional Factors and Mycotoxins in Sorghum

The anti-nutritional factors present in sorghum grain are polyphenols, tannins and phytic acid which greatly reduce the bioavailability of minerals. Polyphenols are the secondary metabolites produced and they inhibit the digestibility of proteins as they bind the proteins present in grain and make them unavailable for the intestinal absorption [46]. As to author sorghum grain contains polyphenols and phenolic acids which are generally associated with grain pigmentation. Polyphenols (tannins) also interfere with bio-availability of other major nutrient.

The tannin content of the grain ranges from 0.10 to 7.22%. In white sorghum, flavone 3-ols or flavone 4-ols (monomers of polyphenols) are present in very low quantity. In sorghum, as in other cereals and oil seeds, phytic acid is the major storage from of phosphorous. Phytic acid ranged from 875.1 to 2211.9 mg/100 g in sorghum. Phytic acid forms insoluble compounds with mineral elements including Ca, Fe, Mg and S. Fermentation resulted in a mean decrease of phytic acid of 64.8% after 96 hours and 39.0% after 72 hours in sorghum grain. Malting also resulted in a mean decrease of 23.9 and 45.3% after 72 and 96 hours, respectively [47]. Reduction in antinutrients during plant growth and development is therefore a promising strategy to improve the bioavailability of minerals from nutrient-rich sorghum.

2.7. Approaches to Improving the Protein Quality of Sorghum Foods

Nutritional security is the key to improve the health status of the world's population as mankind is primarily dependent on plant-based diets. Plants are the major source of nutrients essential for normal growth and development [48]. Sorghum improvement programs in the sorghum growing countries of the world have generated a range of segregating materials by crossing between lines possessing good agronomic characters, disease and pest resistance. However, there is often no clear-cut direction to assist sorghum breeders to select for grain quality for a particular end-use. Researchers have taken different approaches to generate relationships between sorghum grain characteristics and quality attribute of food products. Those related to flat breads from sorghum will be discussed, as they are relevant to *injera*

2.7.1. Food Compositing

Sorghum can be combined with suitable protein sources such as the lysine-rich legumes to provide the level of protein required in formulation for optimum nutrition reviewed by [49]. This is referred to as food compositing. One such legume is cowpea, which is an important local legume in sub-Saharan Africa and is a relatively inexpensive source of legume protein. When composited sorghum with cowpea, they produced a protein-rich extruded instant porridge. Composite food products for children containing sorghum and quality protein sources like soya meal served as thin porridge or gruel are common as formulations of high protein complete foods. [50].

2.7.2. Biofortification

Biofortification is the process used to increase the amounts of nutrients in food crops through conventional breeding or targeted genetic engineering. Itis a food-based approach to overcome the nutrient starvation by delivering nutrient-dense crops at the door steps of poor populations [51]. [52] reviewed the progress made in the nutritional fortification of cereals. Biofortification of staple crops is proved to be an economically feasible approach to combat micronutrient malnutrition. The authors, pointed out that effective biofortification of a cereal, such as sorghum, can reach the poor in rural areas, has low recurrent costs, is sustainable in the long term, and in the case of genetic improvement, it only requires an up-front investment. [53] Pointed out that, it may be essential to link nutrition to a commercial driver such as yield to develop commercial varieties of crops with enhanced nutrition. In the case of crop lines biofortified for mineral nutrients, yield increases can go hand in hand with nutritional quality.

Unlike the continual financial outlays required for traditional supplementation and fortification programs, a one-time investment in plant breeding can yield micronutrient-rich plants for farmers. It is this multiplier aspect of biofortification across time and distance that makes it so cost-effective. Early attempts to improve sorghum protein quality focused on the identification of high lysine mutants. For example, two mutants were identified in sorghum, *hl* gene in an Ethiopian line [35]. In another work, *P721 opaque* gene was induced by chemical mutagen diethyl sulphate [54], following identification of similar lines in maize (Both sorghum lines are low in prolamins. However, as noted by these authors, such lines are associated with deleterious effects on seed weight and yield. Sorghums with easier-to-digest proteins have been identified It is believed that the improved protein digestibility is caused by more invaginations in the protein bodies. Theauthors also indicates that, the change in structure of protein bodies locates the highly cross-linked γ-kafirins to the base of the folds, improves accessibility to the major storage protein α-kafirin by proteolytic enzymes, and increases surface area for enzyme activity. All these modifications probably increase their protein digestibility [55]. Moreover, biofortification provides a feasible means of reaching malnourished rural populations who may have limited access to commercially marketed fortified foods and supplements.

2.7.3. Supplementation

Supplementation involves the addition of synthetic essential amino acids to improve the protein quality of sorghum diets [52]. The practice is however, considered inefficient and impractical among populations where sorghum is the staple food because economically disadvantaged households that cannot afford to buy fortified food products [10].

2.7.4. Processing

Digestibility of sorghum protein was also improved after processing of the grain, a thin fermented porridge used as baby food in the Sudan. Nitrogen retention was improved in normal home-pounded and winnowed sorghum with reduced fibre content Indigenous sorghum consumers of Africa and Asia have developed traditional processes that make the sorghum palatable, digestible, and a good source of ingredients for food [56]. The traditional sorghum processing methods that improve protein quality were discussed earlier in section 2.2. They include fermentation and malting of sorghum [3].

3. Summary and Conclusion

Sorghum is a gluten free cereal used as whole grain and it is a source of energy, protein, vitamins, minerals, and nutraceuticals such as antioxidant phenolic and cholesterol-lowering waxes. In addition sorghum grain is utilized for human diets also used for livestock feed, fuel, construction materials and an increasing number of industrial products. This diversity of uses increases the complexity of breeding for improved quality. Grain quality varies amongdifferent types of sorghum and their cultivated environments. Genetic improvement of grain quality can help sorghum to adapt to varying demands for end-use products.

So far many sorghum improvement programs focused mainly for direct enhancement of yield potential and stability. However, in the present market economy, product quality has become increasingly important. Breeding for improved quality, consideration is given to the physical and chemical characteristics of the product harvested that affect its nutritional value, processing and utilization. The tannin sorghums (brown sorghums) have significant levels of condensed tannins with resistance to birds and grain molding. However, the tannin sorghums have high antioxidant activities and may be a very important source of nutraceuticals. Sorghum proteins likely provide a greater role in the functionality and quality of sorghum foods than has previously been thought. Generally reduction in antinutrients during plant growth and development is therefore a promising strategy to improve the bioavailability of minerals from nutrient-rich sorghum.

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