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Review Article

Nutritional, Functional and Bioactive Properties of Sorghum (*Sorghum Bicolor* I. Moench) with its Future Outlooks: A Review

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Abstract

In this paper the nutritional, functional, and bioactive properties of *Sorghum Bicolor* L. monarch with future outlooks is reviewed. Sorghum is the fifth most important cereal crop in the world after rice, wheat, corn, and barley. It is the main cereal food for over 750 million people living in semi-arid tropical regions of Africa, Asia, and Latin America. Sorghum grains are rich in energy and non-energy nutrients. Sorghum is an important source of minerals, vitamins, proteins, antioxidants, and energy. Sorghum has great functionality of foods with crucial characteristics of the food ingredients aside from its nutritional quality and features a great influence on its use. Sorghum is unique among the other cereal grains; sorghum has a high level of various set-in order bioactive properties which are not normal to the other cereal grains with the confirmed potential benefits to human health. Sorghum is a source of nutrients and the most prominent group of beneficial sorghum bioactive components are phenolic contents, phenolic acids, flavonoids, tannins (proanthocyanins) which is useful for human prevention from chronic disease and lowering parameters of certain non-communicable diseases.

Keywords: Bioactive properties; Functional; Future outlooks; Nutritional; *Sorghum Bicolor* I. monarch

Introduction

Sorghum is a versatile, drought-tolerant crop that is commonly produced in semi-arid regions of Africa, Asia, Australia, and North and South America. Sorghum grain is mainly used as a staple food in semi-arid regions of Africa, and to a much more limited extent in parts of India and Central America [1]. Sorghum is that the fifth most-produced cereal within the world and maybe a source of nutrients and bioactive compounds for the human diet. Sorghum is an excellent source of bioactive compounds that can promote benefits to human health. The results of *in vitro* and animal studies have shown that compounds isolated from sorghum, mainly phenolics, promote beneficial changes in parameters related to non-communicable diseases such as obesity, diabetes, dyslipidemia, cardiovascular disease, cancer, and hypertension.

The presence of flavones in sorghum extracts, such as luteolin, apigenin, and their D-methyl derivatives, which have estrogenic properties, could be responsible for the protective effect against colon cancer [2]. Nevertheless, the aforementioned biological potential of sorghum could be modified to a great extent due to different technologies applied before its intake [3]. In Western countries such as the United States, Australia, and Brazil, sorghum is developed and cultivated primarily for animal feeding [4]. However, due to its high nutritional and functional potential, several studies on sorghum for human consumption have been conducted in these countries.

Nevertheless, the overall use of sorghum as a food ingredient in these parts of the world remains fairly modest. In addition to sorghum's agronomic benefits; sorghum has pleasant attributes highly relevant to modern food use; especially given chronic diseases linked to excess calorie intake and poor diet are a growing concern globally. Sorghum is exclusive among major cereal grains therein its high levels of a various array of bioactive components not common to other cereals, with demonstrated potential to profit human health. While sorghum is one of the valuable cereal grains, the sorghums absence for its critical review about sorghum's nutritional, functional, and bioactive properties, I summarize the recent findings concerning the nutritional composition and health effects of sorghum to harmonize the parameters related to nutritionally, functional and bioactive properties of *sorghum bicolor* l. monarch. Potential human health and negative points of the recent studies and harmonizing the directions for future researches.

Literature Review

The chemical composition and nutritional value of sorghum

The chemical composition and nutritional value of the whole sorghum are alike to rice, corn, and wheat. The nutrient composition of sorghum indicates that it's an honest source of energy, protein, carbohydrate, vitamins, and minerals including trace elements. Sorghum grain contains 1.3% to 3.3% of ash and minerals such as phosphorus, potassium, and magnesium in varying quantities. Sorghum is additionally a crucial source of some minerals, particularly iron and zinc, but all except ragi are low in calcium. Iron (Fe) and Zinc (Zn) are essential trace elements in human nutrition and their deficiencies are major public health threats worldwide.

Sorghum nutritional quality is dictated mainly by its chemical

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composition and therefore the presence of anti-nutritional factors, like phytate. Phytate or Phytic acid is a principal storage form of phosphate ubiquitously distributed in plants particularly in cereal grains and in legumes. Martino and the US Department of Agriculture, suggested that the major components of sorghum are polysaccharides (starch and non-starch), followed by proteins and lipids. Sorghum is an important resource of minerals, vitamins, proteins, antioxidants, and energy (Table 1). Sorghum can act as an important grain to cope up with food security, nutritional security at a lower cost. The energy value of 100 g of sorghum grains differs between 296.1 kcal and 356.0 kcal.

Table 1: Comparative nutritional composition of sorghum, wheat, rice, and maize.

Nutrient	Units/100g	Sorghum	Wheat	Rice	Maize
Energy	kcal	339	342	360	365
Protein	g	11.3	11.31	6.61	9.42
Carbohydrate	g	74.6	75.9	74.26	72.56
Fat	g	3.3	1.71	0.58	4.74
Fiber	g	2.7	12.2	7.3	----
Thiamin	mg	0.237	0.387	0.385	0.07
Riboflavin	mg	0.142	0.108	0.201	0.048
Niacin	mg	2.972	4.371	3.622	0.145
Pantothenate	mg	1.25	0.954	0.424	1.342
Vitamin B6	mg	0.59	0.368	0.622	0.145
Folate	µg	0.02	38	19	9
Vitamin B12	mg	0	0	0	0
Vitamin A	IU	16	9	214	N/a
Vitamin E	mg	1.2	1.01	0.49	n/a
Vitamin C	mg	2	0	0	0
Vitamin D	µg	n/a	0	0	0
Calcium	mg	28	32	7	9
Iron	mg	4.4	4.56	2.71	0.81
Magnesium	mg	0.19	93	127	35
Phosphate	mg	287	355	210	108
Potassium	mg	350	432	287	86
Sodium	mg	6	2	35	2
Zinc	mg	1.54	3.33	2.21	1.16
Copper	mg	1.08	0.363	0.314	0.11
Manganese	mg	1.63	3.821	0.485	1.1

The source is taken from United Sorghum Checkoff Program and Lindsay, John, "Sorghum: An Ancient, Healthy and Nutritious Old-World Cereal" (2010). INTSORMIL Scientific Publications.

Starch in sorghum grain: Sorghum grain is a good source of starch, containing approximately 71% of dry whole-grain weight [5]. The starch is encapsulated in granules that are located predominantly in the endosperm (storage tissue), although uniquely some are present in the pericarp (outer layer of grain). Sorghum starch consists of both amylose and amylopectin polysaccharides (branched polymers of glucose), with very low percentages of amylose present within the starch of waxy sorghum varieties compared with 24% to 33% in non-waxy sorghum starch [6].

Sorghum starch granules are enmeshed in a strong protein matrix in the endosperm, 1 a unique structural aspect of sorghum grain [7]. Disulfide-bond cross-linking involving kafirins in the protein matrix forms a protective network around the starch granules, reducing starch digestibility [8]. Non-Starch Polysaccharides (NSP) can lower the availability and glycemic index of starch by the complex formation and restricting access for digestive enzymes [9]. Polysaccharides can also bind to dietary lipids and reduce their uptake into the body, a factor that has been observed in the ability of high-fiber diets to lower blood lipid levels with potentially beneficial consequences for the incidence of cardiovascular disease.

Polysaccharides: The content and composition of starch, the major polysaccharide of sorghum is affected by the genetic characteristics and growing conditions or environment of the grain [10]. In some variety's starches range between 32.1 g/100 g and 72.5 g/100 g and is composed mainly of amylopectin (81.0% to 96.5%) and amylose (3.5% to 19.0%). The quantity of amylose and amylopectin affects the rheological properties (like gelatinization, retrogradation, and gelling) and digestibility of the sorghum starch [11,12].

Sorghum has the lowest starch digestibility among cereals due to the strong relationship between the starch granules and proteins and tannins [13]. Overall starch granules are slowly digestible (30.0% to 66.2%) and the rest is rapidly digestible (15.3% to 26.6%) or resistant (16.7% to 43.2%) [14]. The non-starch polysaccharides of sorghum (6.0% to 15.0%/100 g) include insoluble fibers (75.0% to 90.0%), mainly arabinoxylans and soluble fibers (10.0% to 25.0%).

Proteins: According to Afify and Martino sorghum proteins are classified as prolamins and non-prolamins. Prolamins correspond on average to 79% (77% to 82%) of the total proteins (7 g to 15 g/100 g) and the remainder is albumins, globulins, and glutelins. Kafirins are the major prolamins of the sorghum and contain three major classes: α-kafirins (66% to 84%), β-kafirins (8% to 13%), and γ-kafirins (9% to 21%) [15]. Sorghum kafirins are stored in the endoplasmic reticulum in spherical protein forms the β and γ-kafirins are located in the peripheral protein bodies region while α and δ-kafirins are encapsulated in the inner region and that conformation determines the digestibility of sorghum proteins. The overall digestibility of sorghum proteins particularly after being cooked is lower than cereals like wheat and maize. According to Belton, the kafirins of sorghum are hardy to peptidase due to the formation of intramolecular disulfide bonds and this is the main reason for the low digestibility.

Even so, in varieties rich in tannins the complexation of the kafirins with this phenolic compound can decrease the protein digestibility by up to 50% [8]. In addition, the opposite exogenous factors (interaction of the proteins with non-protein components such as starch, non-starch polysaccharides, phytic acid, and lipids) and endogenous factors (nature and organization of proteins inside the grain) contribute to this low digestibility.

Regardless of the reduction in protein digestibility of sorghum after cooking in wet heat, processing such as fermentation and germination may increase the digestibility up to 2 times. However, mainly the recent efforts to improve the protein digestibility of sorghum and the objective is to reduce the number of kafirins particularly β and γ forms and to increase the glutenins and albumins [16]. The genetically modified sorghum varieties have *in vitro* digestibility from which its ranges are almost 23% to 102% higher than control varieties.

The α-kafirins are the final proteins to be digested in the intestine due to their high abundance the indigestibility reduces their nutritive value. The β and γ-kafirins are full of cysteine, which forms disulfide bonds and therefore is assumed to block the availability of α-kafirins to hydrolytic enzymes [7]. Hence, the higher digestibility in modified varieties can be attributed to increased enzyme vulnerability of the major storage protein α-kafirin as changes in protein body morphology as well as to the reduction disulfide bonds formation between β and γ kafirins.

Commonly, sorghum proteins are rich in glutamic acid and non-polar amino acids (alanine, leucine, and proline) and have lysine as the major limiting amino acid. Besides, they may be deficient in another five essential amino acids (cysteine, methionine, isoleucine, valine, and threonine) [17]. However, varieties obtained through breeding programs have 52% to 115% more lysine than conventional varieties.

An increased lysine content can be attributed to decreased levels of kafirin proteins and increased levels of lysine-rich, non-kafirin proteins in the grain endosperm [18]. Unlike the main prolamins of wheat, rye, and barley the kafirins do not trigger an allergic response or an autoimmune reaction in humans. According to Pontieri et al. [19], besides the qualitative evidence based on the type of proteins found in sorghum and there is genetic evidence that has characteristics that do not allow the expression of toxic peptides related to gliad in. Therefore, sorghum is considered an effective safe cereal for consumption by people with celiac disease.

Lipids: The fat content in sorghum which ranges (3.20 g/100 g to 3.90 g/100 g) is high compared to other common cereals wheat, rice, and maize with around 83% to 88% of unsaturated fatty acids. Different fatty acids are present mainly linolenic acids1.4% to 2.8%, palmitic 12.4% to 16.0%, oleic 32.2% to 42.0% and linoleic 45.6% to 51.1%. Sorghum has a reduced lipid content of 10.24 g to 3.07 g/100 g), which is mainly composed of unsaturated fatty acids (83% to 88%). In most of the varieties of sorghum, the Poly Unsaturated Fatty Acids (PUFA) are higher than Mono Unsaturated Fatty Acids (MUFA). The majority of fatty acids of sorghum are linoleic (45.6% to 51.1%), oleic (32.2% to 42.0%), palmitic (12.4% to 16.0%), and linolenic acids (1.4% to 2.8%).

Minerals and vitamins: Sorghum is a source of minerals like phosphorus, potassium, and zinc in which their contents vary according to the place of cultivation. And interms of vitamins, sorghum is an excellent source of fat-soluble vitamins (D, E, and K) and B-complex vitamins (thiamine, riboflavin, and pyridoxine), except B12.

According to Afify as well as Kruger the bioavailability of most of the minerals of sorghum is still identified little. Though it is known that zinc availability differs between 9.7% and 17.1%, and iron availability ranges from 6.6% to 15.7%. Some studies have shown to increase the content and bioavailability of iron and zinc through fortification, biofortification, and genetic improvement of sorghum.

The information on the vitamin content of sorghum is unusual, however, it is worth noting that it. The information on the vitamin content of sorghum is unusual, however, it is worth noting that it is a source of some B-complex vitamins like thiamine, riboflavin, and pyridoxine, and fat-soluble vitamins (D, E, and K) (Table 2) [20].

Functional properties of sorghum

The functionality of foods is the characteristics of the food ingredients aside from its nutritional quality, and features a great influence on its use and application, how they affect the finished product in terms of how it tastes, looks, and feels [11]. Functional properties include Swelling Capacity SC, Water Absorption Capacity WAC, Oil Absorption Capacity OAC, Emulsion capacity EA, Emulsion Stability ES, Foam Capacity FC, Foam Stability FS, Gelatinization Temperature GT, Least Gelatinization Concentration LGC, and Bulk Density BD.

Bulk density: The bulk density of treated and untreated sorghum flours and their blends. The range of the bulk density is 0.5341 g and 0.72 g. And the least bulk density is 0.5341 g while the highest bulk density is 0.7267 g. Proposed that the low bulk density of the blends

Table 2: Average content of minerals (mg/100) in sorghum grown in Brazil, the United States, and Ethiopia.

Minerals	Brazil[1] (n=8)	United States[2] (n=1)	Ethiopia[3] (n=31)
Calcium	10.7	28	31.13
Iron	1.64	4.4	6.14
Potassium	-	350	188.8
Manganese	0.06	-	1.58
Sodium	nd	6	23
Potassium	217.87	287	289.34
Zinc	1.65	-	2.24
Magnesium	102.77	-	116.8
Copper	0.51	-	-
Sulfur	79.2	-	-
Aluminum	nd	-	-
Cadmium	nd	-	-
Chrome	nd	-	-
Lead	nd	-	-

[1]Martino et al. [20]; [2]US Department of Agriculture [21]; [3]Shegro et al. [22]; nd: not detected; -: not analyzed

could be an advantage in the formulation of baby foods where high nutrient density to low bulk is desired. High nutrient density is a desirable characteristic in flour that can be used as a base for infant food formulations had reported a similar reduction in bulk density.

Rightly observed that food flours are cohesive meaning that their inter-particle attractive forces are significantly higher relative to the particle on weight, interaction and concerning the powders, the additive effects and characteristics of individual particles comprising a powder system may be different from those of the powder or flour in bulk [1].

Water absorption capacity: The water absorption capacity ranged between 7.00 g/g to 8.50 g/g. The highest water capacity is 8.50 g/g while the least water absorption capacity is 7.0 g. The pregelatinized flour and their blends absorbed more water 7 g/g to 8 g/g than the sprouted samples with absorbed between 7.00 g/g to 7.50 g/g of water. The untreated samples also absorbed 7.00 g/g to 8.5 g/g water. The treated and untreated samples did not differ (p>0.05) significantly.

Mepba reported that an increase in water absorption for wheat flour blends while reported 130% water absorption for soy-flour, 227.3% and 196.1% respectively for two commercial soy protein concentrates namely is a pro & promo-soy. The results were higher than the values obtained by who observed water absorption capacity of 2.73 g/g for Great Northern bean and also obtained 2.6 g/g for Nigeria red groundnut. Also, the absorption capacity of the composite flour was high probably due to the cooling or drying process which caused some starch gelatinization and increased the porosity of the corneous endosperm fragments. High water capacity is related to the extent of gelatinization.

Oil absorption capacity: The trend of the oil absorption capacity is different from those of the water absorption capacity. The range of the oil absorption capacity is 2.66 g/g to 3.23 g/g. The untreated samples showed a marginally high oil absorption capacity between 2.66 g/g to 3.23 g/g. The pregelatinized flour and their composites showed high oil absorption capacity, which ranged between 2.66 g/g to 3.04 g/g while the value in the sprouted samples ranged from 2.85 g/g to 3.25 g/g.

The oil absorption ability of the sprouted samples did not differ (p>0.05) significantly from the pregelatinized and untreated samples. The oil absorption capacity of the blends increased progressively as the level of pigeon pea flour is increased. Similar results were obtained by the high fat or oil absorption capacity in these flours is probably due to the lipase during the absorption of the flours. The flour blends which absorption of oil would be suitable in formulating certain food products such as cakes, breakfast cereals, and some others.

Bioactive properties of sorghum

According to Althwab, Morais, and Awaki stated that sorghum is solely among the other cereal grains in that sorghum has a high level of a various array of bioactive properties not normal to the other cereal grains with the verified potential benefit to human health. As Girard and Awika [23] suggested the most prominent group of beneficial sorghum bioactive components are the polyphenols, especially the flavonoids. In addition, sorghum is exclusively high in bioactive lipids (especially policosanols and phytosterols), mostly as components of waxes located on the grain pericarp [24]. As well the bioactive compounds, sorghum endosperm has also commonly a slower starch digesting profile compared to other cereal grains, the properties that have been proved to modulate postprandial blood glucose response in humans.

Sorghum is considered unique among the other major cereal grains which have a high level of a different array of bioactive components which is not common to the other cereals with confirmed potential to benefit human health. Sorghum has a bioactive compound like the other cereal grains are mainly within the bran fraction (pericarp, testa, and aleurone tissues). The compounds co-exist through the ample cell wall polysaccharides in cereal bran and contribute significantly to the health benefits attributed to whole grain consumption.

Sorghum like other cereal grains the bioactive compounds are mainly located in the bran fraction (pericarp, testa, and aleurone tissues). The compounds co-exist with the abundant cell wall polysaccharides in cereal bran and contribute significantly to the health benefits attributed to whole grain intake. Therefore, food processing methods that remove the bran can severely reduce the health benefits derived from cereal grains Sorghum has more diverse and/or higher levels of both polyphenols and bioactive lipids than the other major cereal grains.

Phenolic contents of sorghum grains: Khan found that the phenolic compounds within the sorghum are compared to rice, wheat, barley, maize, rye, and oats. Most of the phenolic classes are available in most of the sorghum varieties, but the major classes are phenolic acids, flavonoids, and condensed tannins. The phenolic compounds in some sorghum grain varieties are more abundant and diverse than in any other cereal grain [25]. Sorghum grain varieties that have a pigmented testa and thick pericarps have the highest levels of phenolic compounds.

The phenolic compounds in sorghum grain exhibit high antioxidant activity through their ability to scavenge free radicals. The degree of antioxidant activity is correlated to the content of phenolic compounds in a specific sorghum cultivar, and this, in turn, is influenced by its genotype and growing environment [26]. Levels of phenolic compounds and the activity of enzymes that synthesize or catabolize phenols in sorghum grain strongly influence food product properties such as flavor and color and are therefore important determinants of sorghum for food use [27].

Phenolic acids: Phenolic acids are defined as aromatic secondary metabolites found in plants. Chiremba reported that sorghum grain contains 13.5 mg/g to 479.40 mg/g of phenolic acids categorized as hydroxybenzoic acid derivatives and hydroxycinnamic acid derivatives. The phenolic acids present in sorghum are mainly bound to arabinoxylan chains or lignin which cannot be hydrolyzed by in vivo digestive enzymes accounting for reduced bioavailability is decreased. Barros et al. [13] stated that studies have proved that fermentation with specific probiotics and cooking processes can improve the bioavailability of phenolic acids.

Phenolic acids are representing the simplest phenolic compound containing a single aromatic ring with hydroxyl and methoxyl replaced groups and are derivatives of cinnamic acid and hydroxybenzoic acid [28]. Phenolic acids are spread widely throughout the plant kingdom and are estimated to contribute to one-third of the total phenolic compound consumed within the diet.

The major phenolic acids identified in sorghum grain include protocatechuic, gestisic, caffeic, cinnamic, ferulic, sinapic, salicylic, and p-coumaric acid [29]. Ferulic and p-coumaric acids have been reported in the sorghum stalks [30]. Vanillic-hydroxybenzoic and gallic acids have also been identified in the sorghum grain [31]. P-coumaric, o-coumaric, and p-hydroxybenzoic acids have been identified in the leaf sheaths and leaves of sorghum varieties.

According to Wood head and Cooper-Driver, in the leaves, these compounds have been reported to inhibit locust migratory feeding indicating the importance of these compounds to plant defense against insects. In sorghum, like the other cereals, phenolic compounds are concentrated in the outer layers of the grain (pericarp, testa, and aleurone), where it is likely to find more than 90% of the phenolic compound's total content.

Kang stated that sorghum is a source of phenolic acids, glyceride esters (caffeoylglycerols), flavonoids (flavanones, flavanols, flavanonols, and flavan-3-ol derivatives), phenyl propane, glycerides, dicaffeoyl spermidine, and reduced tannins (flavan-3-ols and/or flavan-3,4-diols). Luthria and Liu [32] stated that phenolic acids found in sorghum can be classified as derivatives of benzoic acid like Gallic, p-hydroxybenzoic, syringic, and protocatechuic acids and/or derivatives of cinnamic acid-like p-coumaric, caffeic, chlorogenic, ferulic, and synaptic acids. Luthria and Liu [32] mentioned that sorghum has flavonoids which consist mainly in 3-deoxyanthocyanidins, and also is possible to find flavones and flavanones.

The major proportions of flavonoids in the sorghum with black and brown pericarp are highly accessible because approximately 80% are found in a free form, whereas in sorghum with white and red pericarp, the proportions of free flavonoids are 26% and 26% to 41% respective. Sorghum with black pericarp is a source of 3-deoxyanthocyanidins, mostly in the free form whereas brown pericarp is a source of flavones, dihydroflavonol, and flavanone in the free form. The tannins found in sorghum structurally are oligomer or polymers of phenolic compounds and they are heterogeneous molecules that are generally composed of flavan-3-ol and 3, 4-diols, which can establish the interactions with proteins, carbohydrates, lipids, and metals. Dykes et al. [33] found tannins in sorghum with pigmented testa and a chalky red, chalky brownish-red, or black appearance in concentrations between 10 mg/g and 68 mg/g (Table 3).

Flavonoids: Flavonoids are a set of bioactive compounds which have several health benefits. Dykes et al. [34] stated that flavonoids are located in the outer layer which provides the color to the grain, and flavonoid quantity along with nature is dependent on the thickness of

Table 3: The main content of phenolic compounds in sorghum and some other cereals.

Cereal	Food matrix	Extraction method	Total phenols
Sorghum	Tannin grain	acidified methanol	16.5-29.6
	Non-tannin black grain	acidified methanol	18.2
	Non-tannin red grain	Acidified methanol	11.8
	Non-tannin white grain	Acidified methanol	8.1
	Red grain	Aqueous acetone method extraction	5.0-7.3
	White grain	Aqueous acetone extract	1
	Red bran	Aqueous acetone ethanol extraction	20.0-62.5
Rice	Black bran	ethanol extraction	23.4
	Brown bran	ethanol extraction	7
	white bran	ethanol aqueous acetone extraction	3.1-5.0
	black grain	methanol extraction	3.1
	whole-grain	methanol extraction	0.5
	white grain	methanol extraction	0.2
	Bran	ethanol extraction	6
Wheat	bran	ethanol extraction	3.9
Barley	grain	methanol extraction	0.5
Oat	bran	ethanol extraction	0.8
Corn	black grain	ethanol extraction + alkaline hydrolysis	4.6
	Yellow grain	ethanol extraction + alkaline hydrolysis	5.5
	Blue grain	ethanol extraction + alkaline hydrolysis	3.4
	White grain	ethanol extraction + alkaline hydrolysis	1.7

the pericarp. Ross and Kasum stated that flavonoids are the second main class of sorghum phenolics and represent the largest class of phenolics in the plant kingdom. Flavonoids can be divided into six main subclasses based on C-ring substitutions; flavanones, flavanols, flavones, catechins, anthocyanidins, and is flavones.

Bröhan et al. [31] suggested that Anthocyanidins, flavones, flavanones, and flavanols have been previously identified in the sorghum. Bröhan, Kwon, and Kim identified that Apigenin, luteolin, and tricin in the grain the stem of sorghum are flavones while certain flavonoids are abundant throughout the sorghum plant, the flavanones naringenin and eriodictyol have only been recognized in the grain [34].

Tannins (proanthocyanins): Tannins are these secondary metabolites distributed throughout the plant for defensive purposes against predators and pathogens because of their defense mechanism [14]. The number of tannins in dark grains is always high compared to pale grains and is also affected by the environment. Dykes et al. [33] that sorghum tannin ranges from 0.2 mg/g to 48.0 mg/g and a huge variation in the tannin content might be due to cultivars effect, as well as environmental factors. Wu et al. [35] tannins are mainly existed in a condensed form and are composed of oligomers or polymers of catechins. Tannins can inhibit the activity of some digestive enzymes, and thus negatively affect protein digestibility and cellulose hydrolysis. Polymeric tannins have strong interaction with amylose granules, and thus forming the resistant starch [36-42].

Kaufman suggested that tannins are the secondary metabolites found in many species which are phenolic compounds that often act as a protection mechanism against pathogens and predators [43-45]. Sorghum varieties have pigmented testa which is absent in the other cereals, such as rice, wheat, and maize. The tannins in sorghum differ as to the sort, content, and distribution of the individual oligomers and polymers [46-48]. And they are categorized as type I (no significant levels), type II (tannins that are extractable only in acidified methanol), and type III (tannins that are extractable in methanol and acidified methanol) [48,49].

Awika and Rooney [22], Wu et al. [33] stated that almost all of the tannins in sorghum are reduced and constituted by oligomers or polymers of catechins (flavan 3-ols and/or flavan-3,4-diols). Almost all of the tannins in sorghum are reduced and constituted by oligomers or polymers of catechins (flavan 3-ols and/or flavan-3,4-diols) [49].

Conclusion and Recommendation

The nutritional, techno-functional, and bioactive properties of *Sorghum Bicolor* L. Monarch with future perspectives is discussed in this review. Nutritionally sorghum is an important resource of minerals, vitamins, proteins, antioxidants, and energy. Sorghum is one of the most versatile crops, capable of growing well under contrasting climatic conditions. And its chemical composition and nutritional value are alike to rice, corn, and wheat. Functional properties of sorghum include bulk density, Water absorption capacity, Oil absorption capacity, and so on. Sorghum has a bioactive property like the other cereal grains are mainly within the bran fraction (pericarp, testa, and aleurone tissues). Sorghum is an excellent source of bioactive compounds that can promote benefits to human health. Future research may address the effects of sorghum consumption which may help drive the typical move from sorghum as a low-value food to a potentially health-promoting, highly valued human grain food. There is a need for continuity in research, to obtain and utilize generated techno-functional and bioactive compounds. Nutritionists and Dietitians are recommended to update their databases with values obtained in the researches about sorghum's nutritional facts.

References

1. Althea S, Carr TP, Weller CL, Dweikat IM, Schlegel V. Advances in grain sorghum and its co-products as a human health-promoting dietary system. Food Res Int. 2015;77:349-59.

2. Yang L, Allred KF, Geera B, Allred CD, Awika JM. Sorghum phenolics demonstrate estrogenic action and induce apoptosis in nonmalignant colonocytes. Nutr Cancer. 2012;64(3):419-27.

3. Chávez DWH, Ascheri JLR, Carvalho CWP, Godoy RLD, Pacheco S. Sorghum and roasted coffee blends as a novel extruded product: Bioactive compounds and antioxidant capacity. J Funct Foods. 2017;29:93-103.

4. Taleon V, Dykes L, Rooney WL, Rooney LW. Effect of genotype and environment on flavonoid concentration and profile of black sorghum grains. J Cereal Sci. 2012; 56(2):470-75.

5. Serna-Saldivar S, Rooney LW. Structure and chemistry of sorghum and millets. In: Dendy DAV, editors. Sorghum and Millets Chemistry and Technology. St Paul, Minnesota, USA: American Association of Cereal Chemists Inc; 1995.p. 69-124.

6. Taylor JRN, Emmambux MN. Review: Developments in our understanding of sorghum polysaccharides and their health benefits. Cereal Chem. 2010;87(4):263-71.

7. Duodu, KG, Taylor JRN, Belton PS, Hamaker BR. Factors affecting sorghum protein

digestibility. J Cereal Sci. 2003;38(2):117-31.

8. Taylor J, Bean SR, Ioerger BP, Taylor JRN. Preferential binding of sorghum tannins with γ-kafirin and the influence of tannin binding on kafirin digestibility and biodegradation. J Cereal Sci. 2007;46(1):22-31.
9. Ramsden L. Grains other than cereals, non-starch polysaccharides. Reference Module in Food Science 2016.
10. Hill H, Lee LS, Henry RJ. Variation in sorghum starch synthesis genes associated with differences in starch phenotype. Food Chem. 2012;131(1):175-83.
11. Sang Y, Bean S, Seib PA, Pedersen J, Shi YC. The structure and functional properties of sorghum starches differing in amylose content. J Agri Food Chem. 2008;56(15):6680-5.
12. Singh H, Sodhi NS, Singh N. Characterization of starches separated from sorghum cultivars grown in India. Food Chem. 2010;119(1):95-100.
13. Barros F, Awika JM, Rooney LW. Interaction of tannins and other sorghum phenolic compounds with starch and effects on in vitro starch digestibility. J Agri Food Chem. 2012;60(46):11609-617.
14. Mkandawire NL, Kaufman RC, Bean SR, Weller CL, Jackson DS, Rose DJ. Effects of sorghum (Sorghum bicolor (L.) Moench) tannins on α-amylase activity and in vitro digestibility of starch in raw and processed flours. J agri food chem. 2013;61(18):4448-54.
15. Mokrane H, Amoura H, Belhaneche-Bensemra N, Courtin CM, Delcour JA, Nadjemi B. Assessment of Algerian sorghum protein quality [Sorghum bicolor (L.) Moench] using amino acid analysis and in vitro pepsin digestibility. Food Chem. 2010;121(3):719-23.
16. Goodall M. An investigation into the functionality of kafirin from a high digestible, high-lysine sorghum in a composite dough and bread system. 2012.
17. Moraes EA, Queiroz VAV, Shaffert RE, Costa NMB, Nelson JD, Ribeiro SMR, et al. In vivo protein quality of new sorghum genotypes for human consumption. Food Chem. 2012;134(3):1549-55.
18. Shewry PR. Improving the protein content and composition of cereal grain. J Cereal Sci. 2007;46(3):239-50.
19. Pontieri P, Mamone, G, De Caro S, Tuinstra MR, Roemer E, Okot J, et al. Sorghum, healthy and gluten-free food for celiac patients as demonstrated by the genome, biochemical, and immunochemical analyses. J Agri Food Che. 2013;61(10):2565-71.
20. Cardoso LM, Montini TA, Pinheiro SS, Pinheiro-Sant'Ana HM, Martino HSD, Moreira AVB, et al. Effects of processing with dry heat and wet heat on the antioxidant profile of sorghum. Food Chem. 2014;152:210-7.
21. US Department of Agriculture, ARS. USDA National Nutrient Database for Standard Reference (25th ed.). Washington DC; 2012.
22. Shergo GA, Shargie NG, Biljon AV, Labuschagne M. Diversity in starch, protein, and mineral composition of sorghum landrace accessions from Ethiopia. J Crop Sci Biotechnol. 2012;15(4):275-80.
23. Girard AL, Awika JM. Sorghum polyphenols and other bioactive components as functional and health-promoting food ingredients. J Cereal Sci. 2018;84:112-24.
24. Awika JM, Rooney LW. Sorghum phytochemicals and their potential impact on human health. Phytochemistry. 2004;65(9):1199-221.
25. Awika JM, Rooney LW, Waniska RD. Properties of 3-deoxyanthocyanins from sorghum. J Agri Food Chem. 2004;52(14):4388-94.
26. Dykes L, Rooney LW, Waniska R, Rooney WL. Phenolic compounds and antioxidant activity of sorghum grains of varying genotypes. J Agric Food Chem. 2005;53(17):6813-18.
27. Dicko MH, Gruppen H, Traoré AS, Voragen AGJ, van Berkel WJH. Review: Sorghum grain as human food in Africa: Relevance content of starch and amylase activities. Afr J Biotechnol. 2006;5(5):384-95.
28. Sikwese FE, Duodu KG. Antioxidant effect of a crude phenolic extract from sorghum bran in sunflower oil in the presence of ferric ions. Food Chem. 2007;104(1):324-31.
29. Waniska RD, Poe JH, Bandyopadhyay R. Effects of growth conditions on grain molding and phenols in sorghum caryopsis. J Cereal Sci.1989;10(3):217-25.
30. Billa E, Koullas DP, Monties B, Koukios EG. Structure and composition of sweet sorghum stalk components. Industrial Crops and Products. 1997;6(3-4):297-302.
31. Bröhan M, Jerkovic V, Collin S. Potentiality of red sorghum for producing stilbenoid-enriched beers with high antioxidant activity. J Agri food chem. 2011;59(8):4088-94.
32. Luthria DL, Liu K. Localization of phenolic acids and antioxidant activity in sorghum kernels. J Functional Foods. 2013;5(4):1751-60.
33. Dykes L, Hoffmann L, Portillo-Rodriguez O, Rooney WL, Rooney LW. Prediction of total phenols, condensed tannins, and 3-deoxyanthocyanidins in sorghum grain using near-infrared (NIR) spectroscopy. J Cereal Sci. 2014;60(1):138-42.
34. Dykes L, Seitz LM, Rooney WL, Rooney LW. Flavonoid composition of red sorghum genotypes. Food Chem. 2009;116(1):313-17.
35. Wu Y, Li X, Xiang W, Zhu C, Li Z, Wu Y, et al. presence of tannins in sorghum grains is conditioned by different natural alleles of Tannin1. Proc Natl Acad Sci USA. 2012;109(26):10281-6.
36. Amoako DB, Awika JM. Polymeric tannins significantly alter properties and in vitro 802 digestibility of partially gelatinized intact starch granule. Food Chem. 2016;208:10-17.
37. Awika JM. Chapter 3 - Sorghum: Its Unique Nutritional and Health-Promoting Attributes. Gluten-Free Ancient Grains. 2017:21-54.
38. Awika JM, Dykes L, Gu LW, Rooney LW, Prior RL. Processing of sorghum (Sorghum bicolor) and sorghum products alters procyanidin oligomer and polymer distribution and content. J Agri Food Chem. 2003;51(8):5516-21.
39. Cardoso LdM, Pinheiro SS, Martino HSD, Pinheiro-Sant'Ana HM. Sorghum (Sorghum bicolor L.): Nutrients, bioactive compounds, and potential impact on human health. Crit rev food sci nutr. 2017;57(2):372-90.
40. Ezeogu LI, Duodu KG, Emmanbux MN, Taylor JRN. Influence of cooking conditions on the protein matrix of sorghum and maize endosperm flours. Cereal Chem. 2008;85(3):397-402.
41. Geera B. Ojwang LO, Awika JM. New highly stable dimeric 3-deoxyanthocyanidin pigments from sorghum bicolor leaf sheath. J Food Sci. 2012;77(5):C566-72.
42. Girard AL, Bean SR, Tilley M, Adrianos SL, Awika JM. Interaction mechanisms of condensed tannins (proanthocyanidins) with wheat gluten proteins. Food Chem. 2018;245:1154-62.
43. Grootboom AW, Mkhonza NL, Mbambo Z, O'Kennedy MM, Da Silva LS, Taylor J, et al. Co-suppression of synthesis of major α-kafirin sub-class together with γ-kafirin-1 and γ-kafirin-2 required substantially improved protein digestibility in transgenic sorghum. Plant Cell Rep. 2014;33(3):521-37.
44. Luckemeyer TJ, Luckemeyer T, Hesteande B, Miller RK, Kerth CR, Awika J, et al. Sorghum bran addition in bratwurst, pre-cooked pork patties, and pre-cooked turkey patties. Meat Sci. 2015:101:118.
45. Moraes ÉA, Natal DIG, Queiroz VAV, Schaffert RE, Cecon PR, Paula SD. Sorghum genotype may reduce the low-grade inflammatory response and oxidative stress and maintain jejunum morphology of rats fed a hyperlipidic diet. Food Res Int. 2012;49(1):553-9.
46. Rooney LW, Pflugfelder RL. Factors affecting starch digestibility with special emphasis on sorghum and corn. J Anim Sci. 1986;63(5):1607-23.
47. Salazar-López NJ, González-Aguilar G, Rouzaud-Sández O, Robles-Sánchez M. Technologies applied to sorghum (*Sorghum bicolor* L. Moench): changes in phenolic compounds and antioxidant capacity. Food Sci Technol. 2018;38(3):369-82.
48. Selle PH, Truong HH, Liu SY. Kafirin in sorghum. Feed grain partnership. Sorghum Tech Note. 6-14.
49. Wu L, Huang Z, Qin P, Ren G. Effects of processing on phytochemical profiles and biological activities for the production of sorghum tea. Food Res Int. 2013;53(2):678-85.