European Journal of Nutrition & Food Safety

12(5): 101-111, 2020; Article no.EJNFS.53945
ISSN: 2347-5641

Sorghum Grains: Nutritional Composition, Functional Properties and Its Food Applications

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Authors' contributions

This work was carried out in collaboration among all authors. Author CRA designed the study. Author CNI wrote the protocol and wrote the first draft of the manuscript. Authors JEO and AAO managed the analyses of the study. Author AAO managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/EJNFS/2020/v12i530232
Editor(s):
(1) Dr. Hudson Nyambaka, Kenyatta University, Kenya.
(2) Dr. Dan-Cristian Vodnar, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Romania.
Reviewers:
(1) Kunle Ogungbemi, Nigerian Stored Products Research Institute, Nigeria.
(2) Attia Abd-Elfattah Yaseen, National Research Centre, Egypt.
(3) Zinat Suleiman Mohammed, Bauchi State University, Nigeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/53945

Review Article

Received 22 December 2019
Accepted 28 February 2020
Published 22 June 2020

ABSTRACT

This review work is on the composition, functional properties and food applications of sorghum grains. The review shows that this cereal grains is a rich source of carbohydrate and starch, with little of proteins, fat, vitamins and other nutrients. The functional properties of sorghum were also explored and the findings gotten from various authors shows that sorghum has good functional properties in terms of its bulk density, oil absorption capacity, water absorption capacity, least gelatinization temperature and host of others. The food applications of the grains such as sorghum ball "*Fura*", *tuwo*, gruel, alcoholic beverages such as *pito*, *burukutu* and non-alcoholic beverages such as "*kunu zaki*" were extensively explored to understand and appreciate the profound benefit of sorghum as a diversely rich and nutritious source of food especially in Africa.

Keywords: Sorghum; flour; kunu; cereal; grains.

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1. INTRODUCTION

Sorghum [*Sorghum bicolour* (L.) Moench] is an indigenous crop to Africa, and remain a basic staple food for many rural communities. Sorghum is mainly cultivated in drier areas with an average temperature of 25°C, especially on shallow and heavy clay soils with an annual production ranging from 100,000 tonnes (130 00 ha) to 180,000 tonnes (150 000 ha) in South Africa [1]. In recent years, there has been a shift in sorghum production from the drier western production areas to the wetter eastern areas. This change in production area has resulted in the identification and development of cultivars, which are more tolerant to lower temperatures [1]. During drought, it rolls its leaves to reduce water loss due to perspiration. If the drought continues, it becomes dormant instead of dying. The leaves are protected by a waxy cuticle to reduce evapo-transpiration.

Sorghum is the fifth most important cereal crop in the world after rice, wheat, corn and barley and it serves as the main cereal food for over 750 million people living in semi-arid tropical regions of Africa, Asia and Latin America [2]. In Senegal, as in many semi-arid countries of Africa and Asia, grains occupy an important place as food and feed. Sorghum grains are used by these people (especially farmers), who often do not have the means to feed themselves with other food sources rich in protein, vitamins and minerals. In these areas, they are intended for consumption as pasta, semolina, boiled and traditional beverages [3]. The increasing demand of the grain in West Africa especially Nigeria, Ghana and Burkina Faso has been attributed to its industrial applications in the production of bio-ethanol and fodder in animal feed as well as population growth [4].

Impairment to the grain is often characterized with the presence of a testa, seed coat and brownish coloration. In some sorghum genotypes the testa is sometimes partial, not visible or even missing while in others it is highly pigmented [5]. Phenolic compounds such as phenolic acids, flavonoids and tannins are the most widely represented and ubiquitous secondary metabolites present in sorghum grain [6,7,8]. These compounds play an important role in the defense mechanisms against insects and birds [4].

2. NUTRITIONAL COMPOSITION OF 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% fibre. The germ, a rich source of oil (28% of the germ) also has high levels of protein (19%) and ash (10%) [9]. Although almost all the bran is cellulose and hemicellulose, appreciable quantities of starch are deposited in the

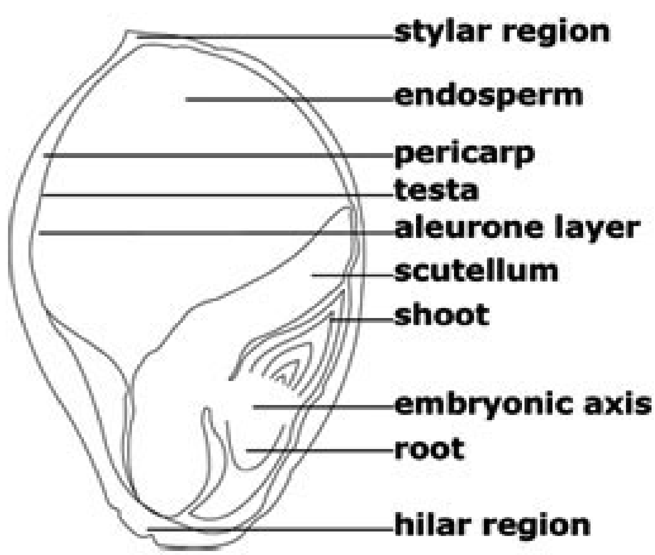

Fig. 1. Structure of sorghum grain

Table 1. Nutritional composition of sorghum

Constituents (%)	Range
Protein	4.40 - 21.10
Water soluble protein	0.30 – 0.90
Lysine	1.06 – 3.64
Starch	55.60 – 75.20
Amylose	21.20 – 30.20
Soluble sugar	0.70 - 4.20
Reducing sugar	0.05 – 0.53
Crude fibre	1.00 – 3.40
Fat	2.10 – 7.60
Ash	1.30 – 3.30
Minerals (mg/100 g)	
Calcium	11.00 – 586.00
Phosphorus	167.00 – 751.00
Iron	0.90 – 20.00
Vitamins (mg/100 g)	
Thiamine	0.24 – 0.54
Niacin	2.90 – 6.40
Riboflavin	0.10 – 0.20
Anti-nutritional factors	
Tannin (%)	0.1 – 7.22
Phytic Acid (mg/100 g) as Phytin Phosphate	875.00 – 2211.90

Source: Makokha et al. [16]

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 [10]. 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. The proximate composition and nutritional aspects of sorghum grain have been extensively reviewed. Lu et al. [11] found that sorghum grain protein varies from 4.4 to 21.1% with a mean value of 11.4%. Sorghum grain is known for its hardness compared to other food grains. The hardness of the grain is due to higher content of protein prolamin (3.6 to 5.1%) [12]. The lysine content ranges from 1.06 to 3.64% [12]. The protein fractionation studies in sorghum indicated that the distribution of albumin-globulin, prolamin and glutelin is about 15, 26 and 44% respectively of total nitrogen [13]. Starch is the major constituent of grain accounting for 56-75% of the total dry matter in the grain [9]. The total content of soluble sugars of sorghum grain ranged from 0.7 to 4.2% and the reducing sugars from 0.05 to 0.53% [14]. Fat content in sorghum grain varies from 2.1 to 7.6%, crude fibre from 1.0 to 3.4% and ash from 1.3 to 3.3% [13]. Another study on the physico-chemical characterization of sorghum accessions showed a wide variation in protein (7.99 to 17.8%), lipids (2.52 to 4.76%), starch (51.88 to 85%), and amylose (12.30 to 28.38%) content [10]. Linoleic acid (18:2) and oleic acid (18:1) were the major fatty acid constituents of sorghum lipids [10]. The grain is commonly eaten with the testa which retains the majority of the nutrients. The wide range in composition of mineral and trace elements indicated that sorghum is a good source of minerals. The mineral composition however is influenced by the environmental conditions [15].

3. FUNCTIONAL PROPERTIES OF SORGHUM

Functional properties are the fundamental physico-chemical properties that reflect the complex interaction between the composition, structure and molecular conformation of food components together with the nature of environment in which they are associated and measured [17,18]. Functional characteristics are required to evaluate and possibly help to predict how new proteins, fat, fibre and carbohydrates may behave in specific systems as well as demonstrate whether or not such protein can be used to stimulate or replace conventional protein [17,18].

The food property is characterized of the structure, quality, nutritional value and /or acceptability of a food product. A functional property of food is determined by physical, chemical and/or organoleptic properties of a food. Example of functional properties may include solubility, absorption, water retention, frothing ability, elasticity and absorptive capacity for fat and foreign particulars. Typical functional properties include pasting properties, emulsification, hydration (water binding), viscosity, foaming, solubility, gelation, cohesion and adhesion.

3.1 Water Absorption Capacity (WAC)

Water absorption capacity is the amount of water taken up by flour to achieve the desired consistency and create a quality end-product. Flour with high water absorption may have more hydrophilic constituents such as polysaccharides. Protein has both hydrophilic and hydrophobic nature and therefore they can interact with water in foods. Increase in the WAC has always been associated with increase in the amylose leaching and solubility, and loss of starch crystalline structure. Thilagavathi et al. [19], compared WAC of sorghum with wheat and soybeans flour and found out that it ranged from 74.08 to 76.83 ml/100 g, 74.08 to 78.83 ml/100 g and (58.17-60.02 ml/100 g) for sorghum, wheat and soybean flour respectively. The observed variation in different flours may be due to different protein concentration, their degree of interaction with water and conformational characteristics [20].

3.2 Oil Absorption Capacity (OAC)

OAC has been attributed to the physical entrapment of oil; this is important since oil acts as flavor retainer and increases the consumers' taste of food [21]. OAC of sorghum flour has been a wide research that has been conducted by various researchers at varying conditions and different results obtained. An increase in OAC of sorghum was recorded during the 3-day germination as reported by Maha et al. [22]. The highest increase in OAC was at the third day of germination (121.17%). Similar trends were observed by Obatolu and Cole [23] and Ghavidel and Prakash [24]. An increase in OAC could be attributed to a change in the protein quality upon grain germination and also its capacity to hold oil globules as the amount of lipophilic protein increase. Since the binding of the lipid depended on the surface availability of hydrophobic amino acids, the enhancement in oil absorption capacities of germinating samples could result from an increase in the availability of amino acids by unmasking non-polar residues from the interior protein molecules. A higher oil-binding capacity of sorghum flour suggested that the flour would be useful in formulation of foods which hold oil well [25].

3.3 Bulk Density

Bulk density is a measure of heaviness of flour and is generally affected by the particle size and the density of the flour. It is very important in determining the packaging requirement, material handling and application in wet processing in the food industry. Bulk density of sorghum subjected to germination for three days by Maha et al. [22] ranged from 0.83 g/cm^3 to 0.70 g/cm^3. An insignificant decrease in bulk density with an increase in germination time is consistent with the result of a previous study [26]. The decrease might be due to decreases in heaviness and also dispersibility of flour samples, bulk density is an indication of the relative volume of packaging material required. A higher bulk density is desirable for a greater ease of dispersibility and a reduction of paste thickness, which is an important factor in convalescent child feeding.

3.4 Foaming Capacity and Stability

The Forming capacity (FC) and foaming stability (FS) are determined by a loss of liquid resulting from destabilization that is measured as a volume decrease. Foaming formation is governed by three factors: transportation, penetration, and reorganization of the molecule at the air–water interface. Therefore, for good foaming, the protein should be capable of migrating at the air–water interface, unfolding and rearranging at the interface [27].

Yagoub and Abdalla, [28] presented results of FC which varied from 116.55% to 151.58%. They were in agreement with those of cowpea and millet flour as reported by Akubor [29] and Jayathilake et al. [30] respectively. An increase in FC might be initiated by a decrease in surface tension of the air and water interface, which consequently caused absorption of soluble protein molecules for hydrophobic interactions. The FC of a food materials depended on the surface active properties of its protein [26]. It has been observed that germination could improve the FS of sorghum flour as the FS was enhanced with increasing germination time. Furthermore, germination might have caused surface denaturation of the proteins and reduced the surface tension of the molecules, which gave an improved FS. Therefore, FS is an important property because the usefulness of whipping agents depends on their ability to maintain the whip as long as possible [31].

3.5 Gelatinization Temperature

Gelatinization temperature is the temperature at which starch molecules in a food substance lose their structure and leach out from the granules as swollen amylose and it affects the time required for the cooking of food substances [32].

Gelatinization temperature of all the flour samples investigated by Iwe et al. [33], ranged from 29.00 to 74.000°C and it fell within the range (<75°C) reported by ARSO [34]. There is a significant variation between the flour varieties in their gelatinization temperatures. According to Chandra and Samsher, [35], flour which has a higher starch content takes lower temperature for gelatinization and those with lower starch content takes higher temperature to gelatinize.

3.6 Least Gelation Concentration

Least gelation concentration results of Maha et al. [22], conducted on germinating sorghum varied from 12% to 16%. Gelation capacity enhanced with an increase in germination time. Non-germinating sorghum flour had the lowest gelation capacity, while that of 3-day germinating had the highest gelation capacity. The LGC for germinating sorghum flours was 16%, 14% and 12% at day 0, day 2 and 3 of germination, respectively.

The results indicated that LGC of germinating sorghum flours were best at a concentration of 12% (w/v). Improvement in gelation capacity following an increase in flour concentration mainly resulted from a decrease in thermo-dynamic affinity of proteins for the solution, which increased the interactions of different proteins [31]. The above data is consistent to those reported by Udensi and Okoronkwo [26] for mucuna bean protein of 16–20%. However, Ocheme and Chinma [36] stated that 8% LGC for germinating millet flour. These differences might be linked to the relative ratio of different constituents of proteins, carbohydrates and lipids [37]. Also, a variation in LGC of this study could come from the aggregation of denatured protein molecules, which increased the protein concentration or solubility and caused intermolecular contacts during heating [23]. This observation also indicated that amylase released during germination would have interacted with the starch component of the flour, and led to an increase in its gelation property. Thus, it is recommended to use sorghum flour derived at 3-day germination of grains to achieve a good quality of gel-forming or firming agent.

3.7 Pasting Properties

Pasting properties are important in predicting the behaviour of flours during and after cooking. The difference in Peak viscosity observed in the samples is an indication of various degrees of starch gelatinization and difference in amylose content of the blends. Sanni et al. [38] noted that high peak viscosity is closely associated with the high starch damage which in turn enhances viscosity.

Bhupender et al. [39] did a research on the pasting properties on sorghum from different cultivars using RVA. Starches from different cultivars displayed a significant variation in all their pasting parameters. The starch suspensions showed gradual increase in viscosity with increase in temperature. The increase in viscosity with temperature may be attributed to the removal of water from the exuded amylose by the granules as they swell. Peak Viscosity is an indicator of water binding capacity and ease with which the starch granules are disintegrated and often correlated with final product quality [40]. Peak viscosity (PV) of different starch samples was observed to be in the range from 1665 to 1998 cP,. Breakdown viscosity (BV) of starch from different sorghum cultivars differed ranged from 414 to 769 cP. The breakdown is caused by disintegration of gelatinized starch granules structure during continued stirring and heating, thus, indicating the shear thinning property of starch [41]. A low breakdown value suggests the stability of starches under hot conditions. Amylose content is believed to have a marked influence on the breakdown viscosity (measure of susceptibility of cooked starch granule to disintegration) and the setback viscosity (measure of recrystallization of gelatinized starch during cooling) [42]. Lower level of amylose to reinforce the molecular network within the granules resulted in greater breakdown viscosity. High amylose content has also been suggested as the major factor contributing to the non-existense of a peak, a high stability during heating, and a high setback during cooling [43].

4. FOOD APPLICATION OF SORGHUM

4.1 Tuwo Production

Tuwo is a local delicacy of the Northern part of Nigeria; it is made from almost all types of cereals which include wheat, millet, fonio, rice, maize and sorghum as the case may be and the choice of the producer. *Tuwo* is a solid food which is made in forms of balls or swallows; it is made from the flour produced from any of the above mentioned grains [44]. According to Odusola et al. [45], *tuwo* is produced by getting the needed grains (sorghum or maize), sorted, dehulled, winnowed and mill into smooth flour and then sieve appropriately, water will then be heated in the pot to boil, little portion of the flour is used to make a slurry in a cold water and then transferred into the boiling water and allowed to boil together properly. After which the sieved flour of the millet is poured gradually into the pot containing the boiled water and the boiled slurry and stir until a desired thickness is obtained, the food is allowed to heat for additional ten to fifteen minutes and then stirred to desired constituency after which it is ready to be served with any desired soup.

4.2 Sorghum Ball Production "*Fura*"

Fura is a staple food for the Fulanis and Hausas. The single most important cereal grain for *fura* production is sorghum or its twin grain millet [46]. In tropical Africa, cereal grains are milled and used to produce thick porridges which are known by various names in different parts of the continent. In West Africa particularly in Nigeria, Ghana and Burkina Faso, one such thick porridge is called '*fura'* - a semi- solid dumpling cereal meal. *Fura* is produced mainly from moist sorghum flour, blended with spices, compressed into balls and boiled for 30 minutes. While still hot, the cooked dough is worked in the mortar with the pestle (with addition of hot water) until a smooth, slightly elastic, cohesive lump (*fura*) is formed. The *fura* dough is rolled into 25–30 g balls by hand and dusted with flour. The *fura* is made into porridge by crumbling the *fura* balls into fermented whole milk (kindrimo) or fermented skimmed milk (*nono*). Sugar may be added to taste; the mixture is called '*fura da nono*' in Nigeria; a popular mid-day meal. *Fura* is produced at home both for family and commercial consumption. The producers of *fura* still use the modern method to dehull the grain and to reduce the dehulled grain into flour unlike the formal traditional methods of using mortar and pestle. *Fura* is typically distributed with minimum packaging. Processors and retailers of *fura* are primarily concerned with reducing waste and having a container for their food. *Fura* has a limited shelf-life of one day at ambient temperature [47]. Usually, a day after production, it shows visible mold growth on the surface. Its short shelf-life has always been a major deterrent to large-scale production. Thus, improving its processing, packaging and storage life are of interest before food manufacturers can think of large scale production.

4.3 Gruel Production

Sorghum has been used for gruel production or as breakfast meals which are in turn produced into pap, "*ogi*", "*akamu*" etc and are taken with any other desired snacks for adequate nourishment [48].

In the production of the gruels, the raw sorghum is graded, washed and soaked for 72 hours and the water decanted, some producers change the water daily that is after 24 hours while others leave it for that period of 72 hours fermentation. The fermented grains are then washed and wet milled in a clean grinding machine. The grain slurry is then filtered with muslin cloths and the filterate is allowed to sediment and the water decanted. Then the slurry or gruel can be cooked and made into pap, *ogi*, *akamu*, *kwokwo* and host of others dependant on the choice of the producers [45].

4.4 Local Alcoholic Beverage Production

In times past, barley has been the sole cereal that is used in the production of alcoholic beverages in Western part of Africa and in Nigeria inclusive; this practice has left us in the dependant stage of life, adding no dividend to the economy of the country. Rather it takes from it to expand and enrich others and growing us in the rank of a dependent nation. Recent research works have strived to break that barrier of over dependency by introducing other means of using home grown grains in the production or manufacture of some of this alcoholic beers and beverages, of which sorghum is part of this innovations. Alcoholic beverages are divided into three (3) general classes: beers, wines and spirits. Alcoholic beverages that have lower alcohol content (beer and wine) are produced by fermentation of sugar- or starch containing plant materials. Beverages of higher alcohol content (spirits) are produced by fermentation followed by distillation. The major local alcoholic beverages produced in Nigeria are *Burukutu*, palmwine, *pito* and *Ogogoro*. *Burukutu* beer is a traditional cereal-based fermented beverage. Cereals are important in many parts of the world as food sources, and starches from them differ in physicochemical properties and molecular structures [49]. The main chemical component of sorghum grain is starch [50]. The basic characteristics of *Burukutu* include a sour taste due to the presence of lactic acid, a pH of 3.3 to 3.5 and an opaque colour because of suspended solids and yeast. It contains vitamins, iron, manganese, magnesium, potassium and calcium and also contains about 26.7 g of starch and 5.9 g of protein per liter [51]. The local beverage is known as *Techoukoutou* in Benin or Togo, *Dolo* in Burkina-Faso, *Pito* in Ghana, *Burukutu* or *Otika* in Nigeria, *Bilibili* in Tchad, *Mtama* in Tanzania, *Kigage* in Rwanda [51,52]. The manufacturing processes are very variable and dependent on the geographical location. Generally the production process of cereals involves, malting, steeping, germination, milling, mashing, boiling, fermentation and maturation.

4.5 Local Non-alcoholic Beverage Production

Sorghum drink (*Kunu* or *Kunun-zaki*) is a non-alcoholic, non-carbonated and refreshing cereal beverage popular in Northern Nigeria and is becoming widely consumed in the South [53]. It serves as breakfast drink, appetizer and weaning food [53]. *Kunu*, is a nutritious non-alcoholic drink that is produced from various cereal grains such as millet, sorghum, maize and rice. *Kunu* is a drink that has found great appeal in the northern part of Nigeria, its consumption spread over every class of personality and it is consumed either as a food supplement or thirst quencher. *Kunu* is cheaply available and serve as an alternative to carbonated drinks products which have little or no nutritional benefits to its consumers. *Kunu* is one of the complex mixtures which contain macromolecules such as protein, carbohydrates and lipids [54]. During the preparation of *kunu*, the ingredients needed are ginger (*Zingiber officimals*), alligator pepper (*Afromonium melegueta*), red pepper (*Capsicum species*), black pepper (*Piper guineense*) and *kakandoru* or *eru*. All these ingredients perform one function or the other in the course of the preparation. The most abundant constituents of *kunu* is water and it acts as the medium in which all other constituents are dissolved and contain only traces amount of in-organic substances. The high nutritive value of *kunu* is attributed to the presence of protein, carbohydrates and in particular, vitamin B [55]. *Kunu* is taken after meal as a supplement or to quench thirst. It is widely accepted as food drink in some urban centers especially in the Hausa land. The quality and quantity of the products depend largely on the quality of the ingredients and handling technique in the course of production by the producer. The product could be obtained quantitatively after 2 days and it could be stored for another 3 days when refrigerated [55]. It has however been reported that, if *kunu* is kept overnight in hot season without being refrigerated, its quality begins to deteriorate and this may lead to the spoilage which when consume could constitute danger to health [56]. Spoilage of this product from observation occurs from improper handling, constant fermentation of the ingredients, especially the carbohydrates and enzymatic action on the substrates [55]. Hence there is need for proper formulation and carbonation of the product. Carbonated drinks are desired and preferred because of it sharp, unique and refreshing taste. Carbonated drinks are non-alcoholic beverages that consist of CO_2, water, flavouring and some other types of sweet syrup [57]. The CO_2 when introduced increases the acidity level of the drink, thereby keeping some micro-organisms from growing. The thrive of microbes in a drink is what usually reduces the shelf-life of the product [58]. Carbonated sorghum beverages (kunu) are expected to make a lot of difference when compared to other available carbonated drinks because of it nutritive values among many other properties which include:

i. Its ability to aid digestion and absorption of components into the body system.
ii. Boosting the immune system of the body against microbial attack.

Currently in Nigeria, carbonated drinks are very expensive to buy. A bottle of 50 cl costs an average price of N100.00. The carbonated drinks have little or no nutritive value because they contained high concentration of sugar and artificial concentrates. *Kunu* however seem to be highly nutritious with relatively low cost of production. It is being prepared from local cereals which are very common and are part of our stable food substances. The problem facing the satisfaction derived from *kunu* comes from its fast deterioration due to microbial activities causing its spoilage.

To produce kunu, cereal grains of choice will be cleaned and steeped in twice its volume of water for 24 h. Thereafter the steeped grains will be washed and spices added. The spices added will include ginger, red pepper, cloves and black pepper. The steeped millet grains and spices will then be wet milled in a grinding machine and sieved to remove the shafts after which the supernatant will be decanted from the slurry. The slurry will be divided into two equal halves with one half added to boiling water while stirring for 5 minutes, cooled to a temperature of 35°C and subsequently added to the remaining half slurry. Adequate amount of water will be added to the mixture, stirred and left to settle. The mixture will be sieved using a muslin cloth and the filtrate sweetened with granulated sugar. The product is mixed properly and bottled in plastic bottles.

5. CONCLUSION

In this study, the composition, functional properties and food application of sorghum was extensively examined. The review work showed high nutritional composition of this cereal grains (sorghum). The behavioral pattern was also discussed when used industrially which portrays their functional capabilities. The review showed that the product possess wide food applications and also serve as good functional abilities that could help to promote human health. However, research needs to focus on improving its shelf-life for industrial production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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