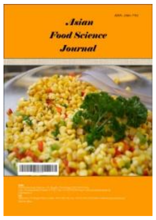

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Nutritional Composition, Functional Properties and Food Applications of Millet Grains

C. R. Abah[1*], C. N. Ishiwu[1], J. E. Obiegbuna[1] and A. A. Oladejo[2]

[1]*Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.*
[2]*Department of Applied Biochemistry, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.*

Authors' contributions

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

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ABSTRACT

Millet is an important nutritious ancient minor cereal food crop. This work reviews the composition, functional properties and food application of millet grains. The review shows that this cereal grains is a good source of carbohydrate and starch, with minute proteins, fat, vitamins and other nutrients. The functional properties of the cereal grains (Millet) was also evaluated and the findings gotten from various authors shows that the grains has a good functional properties in terms of their bulk density, oil absorption capacity, water absorption capacity, least gelatinization temperature and host of others. The pasting properties were also researched on and various authors attested to the potentiality of the grains in terms of the pasting properties. The food applications of the grains was not left out since the basic essence of this review is to see to the betterment of the livelihood of human, as such the various foods that can be produced from these grains were also looked into foods like millet ball "Fura", tuwo, gruel, alcoholic beverages (like pito, burukutu) and non-alcoholic beverages (like "kunu zaki") where all examined and conclusively the grains were rich sources of meals.

**Corresponding author: Email: rejoiceabah@gmail.com;*

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1. INTRODUCTION

The word 'millet' gets its origin from the French word "*mille*" which means thousand, with a handful of millet containing up to 1000 grains [1]. Millet belongs to the group of small-seeded species of cereal crops or grains which are annual plants [2]. The grain belongs to the family *Poaceae* which originated in Ethiopia and the sub-family *Chloridodeae* [3]. Different cultivars of millet grains exist: brown, light brown and white [4,5], with grain colour used as the distinct means of cultivar differentiation. The white cultivars have been developed mainly for the baking industry, the brown and light brown types used for porridge while the brown cultivar is utilized for brewing traditional opaque beer in Southern Africa [6].

The grain millet is a semi-arid region crop cultivated in dry areas with limited rainfall and can adapt to various agro-climatic conditions [7]. Period of cultivation of the grain ranges between February and August with harvest period set in June or January. Millet grains are cultivated in Nepal [8], Sri Lanka, Bhutan and the Himalayan regions of India. The grain is also cultivated in Taiwan, China, Japan (to a limited extent), as well as in South Carolina in the United States. About 55-60% of globally produced millet is cultivated in Africa [9] mainly in Ethiopia, Kenya, Nigeria, Malawi, Tanzania, Uganda, Zambia and Zimbabwe. The grain is widely cultivated in Africa using different names. The total annual production of all millets worldwide is approximately 4.5-5 million tons [10], with India alone producing about 2.5 million tons and some countries in Africa accounting for about 2 million tons of the grains. India is thus reported to be the largest producer of millet [2], contributing a total of 60% of the global production [6].

Millet grains are gluten-free, non-acid-forming [9], easy to digest with low glycemic index [11]. Its low glycemic index food property is reported to be a good choice for people with celiac disease (disease caused by gluten-containing cereal protein ingestion) and diabetes as consumption of the grain assist in the regulation of blood glucose level [12]. The grains consist of dietary fiber, carbohydrates, iron and calcium in high concentration when compared to other cereal grains. Millet grains also contain high amount of magnesium and phosphorus [13]. Krishnan et al. [14] reported that millet grains contain polyphenols and phytates which are known to influence the bioavailability of minerals. In addition to their nutritive value, several potential health benefits such as preventing cancer and cardiovascular diseases, reducing tumor incidence, lowering blood pressure, risk of heart disease, cholesterol and rate of fat absorption, delaying gastric emptying, and supplying gastrointestinal bulk have been reported for millet [13,15,16].

Millets are small-seeded with different varieties such as pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), kodo millet (*Paspalum setaceum*), proso millet (*Penicum miliaceum*), foxtail millet (*Setaria italic*), little millet (*Panicum sumatrense*), and barnyard millet (*Echinochloa utilis*). They are known as coarse cereals beside maize (*Zea mays*), sorghum (*Sorghum bicolor*), oats (*Avena sativa*), and barley (*Hordeum vulgare*) [17]. Millet is known as *ragi* and *mandia* in the Bastar region of Chhattisgarh and offers both nutritional and livelihood security for human beings and also feed security for diverse livestock populations in dry land regions of rural India [18].

Millets are not placed as a single important commodity in the North American and European food basket at the present time, but their importance as an ingredient in multigrain and gluten-free cereal products has been highlighted. However, in many African and Asian areas, millets serve as a major food component and various traditional foods and beverages, such as bread (fermented or unfermented), porridges, and snack foods are made of millet, specifically among the non-affluent segments in their respective societies [19]. Millet grains, before consumption and for preparing of food, are usually processed by commonly used traditional processing techniques include decorticating, malting, fermentation, roasting, flaking, and grinding to improve their edible, nutritional, and sensory properties. Processing of millet grains comprises both the traditional and modern methods. The modern methods of processing can be employed in the manufacture of value-added products such as soaked, cooked, malted, fermented, popped or puffed, extruded and multi-grain flour. Traditional methods of millet processing also include a method of spreading and drying the grains in the sun for a period of one week. Upon drying, the grains are stored in a bag and later used for the processing and manufacture of different food products [20]. Dried millet grains can be stored for more than 5-10 years, but a major hurdle is that the grains are very tiny and not easy to handle. The grains are resistant to diseases and insects but are easily invaded by fungal disease [21]. Despite its usefulness and health beneficial properties, there is little research and innovation on millet grains/flours as compared to conventional cereal grains such as maize, sorghum, rice and wheat.

2. NUTRITIONAL COMPOSITION OF MILLET

Nutritional quality of food is a key element in maintaining human overall physical well-being because nutritional well-being is a sustainable force for health and development and maximization of human genetic potential. Therefore, for solving the problem of deep-rooted food insecurity and malnutrition, dietary quality should be taken into consideration [22].

In addition to the cultivating advantages of millet, they were found to have high nutritive value and comparable to that of major cereals such as wheat and rice [23]. Millet proteins are good sources of essential amino acids except lysine and threonine but are relatively high in methionine. Millets are also rich sources of phytochemicals and micronutrients [24,25]. For example, pearl millet was found significantly rich in resistant starch, soluble and insoluble dietary fibers, minerals, and antioxidants [26]. It contains about 92.5% dry matter, 2.1% ash, 2.8% crude fiber, 7.8% crude fat, 13.6% crude protein, and 63.2% starch [27]. Also, foxtail millet protein characterization showed that its protein concentrate is a potential functional food ingredient and the essential amino acid pattern suggests possible use as a supplementary protein source to most cereals because it is rich in lysine [28]. Finger mill*et al*so is known to have several potential health benefits and some of the health benefits are attributed to its polyphenol contents [29]. It has a carbohydrate content of 81.5%, protein 9.8%, crude fiber 4.3%, and mineral 2.7% that is comparable to other cereals and millets [30]. Its crude fiber and mineral contents are markedly higher than those of wheat (1.2% fiber, 1.5% minerals) and rice (0.2% fiber, 0.6% minerals); its protein is relatively better balanced; it contains more lysine, threonine, and valine than other millets [31]. In addition, black finger millet contains 8.71 mg/g dry weight fatty acid and 8.47 g/g dry weight protein [32]. Kodo millet and little millet were also reported to have 37% to 38% of dietary fiber, which is the highest among the cereals; and the fat has higher polyunsaturated fatty acids [33]. The protein content of proso millet (11.6% of dry matter) was found to be comparable with that of wheat with significant higher content of leucine, isoleucine, and methionine [34]. Thus, the presence of all the required nutrients in millets makes them suitable for large-scale utilization in the manufacture of food products such as baby foods, snack foods, and dietary food and, increasingly, more millet products have entered into the daily lives of people, including millet porridge, millet wine, and millet nutrition powder from both grain and flour form [35,36].

3. FUNCTIONAL PROPERTIES OF MILLET

Cereal grains contain 60 to 70% starch and are excellent energy rich food for human. Doctors recommended cereals as the first food to be added to infant diets and a healthy diet for adults should have most of its calories in the form of complex carbohydrates such as cereals grain starch. Cereals and millets form the staple food of diets in about 75% of the countries of the world [37].

Cereals are an excellent source of vitamin and minerals including fat soluble vitamin E, which is an essential antioxidant. The cereal grains are an easy protein source as required by Recommended Daily Allowance (RDA) but unfortunately they lack the essential amino acid lysine and therefore they must not be used as the sole source of dietary protein [38]. Cereal grains contain about 58 to 72% carbohydrates, 8 to 13% protein, 2 to 5% fat, and 2 to 11% indigestible fibre. They also contain 300 to 350 kcal/100 g of the grain. Carbohydrates are present in the form of digestible starches and sugars. The operations of milling generally remove much of the indigestible fibre and fat from the grains when they are to be consumed for human food.

Functional properties are the fundamental physico-chemical properties that reflect the complex interaction between the composition, structure, molecular conformation and physico-chemical properties of food components together with the nature of environment in which these are associated and measured [39,40]. 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 [39,40].

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 its physical, chemical, and/or organoleptic properties. Example of such functional properties may include solubility, absorption, and water retention, frothing ability, elasticity and absorptive capacity for fat and foreign particulars, 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. [41], compared WAC of various types of millet 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 millet, 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 [42].

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 [43]. OAC of millet flour has been a wide research that has been conducted by various researchers at varying conditions and different results obtained. The oil absorption capacity according to Amir et al. [44], on finger millet flour was found to be 1.93 g/g and that of pearl millet flour is 1.60 g/g. There is an advantage for best organoleptic characteristics of meal that high water and oil absorption capacity of the flour can positively influence the flavor, moisture and fat content in food [45].

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. According to Amir et al. [44], the bulk density of pearl millet and finger millet flours ranged from 0.67 g/ml to 0.54 g/ml. The differences in the values of bulk density between these flours are likely due to varietal differences. Krishnan et al. [46] found a bulk density of 0.5 g/ml,0.50 g/ml and 0.6g/ml in native, malted and hydrothermally treated finger millet seed coat.

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 [47].

Yagoub and Abdalla, [48] 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 [49] and Jayathilake et al. [50] 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 [51].

3.5 Gelatinization Temperature

Gelatinization temperature of all the flour samples investigated by Iwe et al. [52], ranged from 29.00 to 74.00°C and it fell within the range (<75ºC) reported by ARSO [53]. There is a significant variation between the flour varieties in their gelatinization temperatures. 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 [54]. According to Chandra and Samsher, [55], a flour which has a higher starch content takes lower temperature for gelatinization and those with lower starch content takes higher temperature to gelatinize.

3.7 Pasting Properties

Pasting properties are important in predicting the behavior 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. [56] noted that high peak viscosity is closely associated with the high starch damage which in turn enhances viscosity.

Bhupender et al. [57] did a research on the pasting properties of starches from different pearl millet cultivars measured 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 [58]. 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 pearl millet 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 [59]. 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) [60]. 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 [61,62]. Setback viscosity of pearl millet starches ranged from 627 to 1064 cP. Final viscosity indicates the ability of the starch to form a viscous paste. Final viscosity of pearl millet starches ranged from 1931 to 2476 cP. A higher final viscosity relates to the high resistance to shear. Increase in final viscosity might be due to the aggregation of the amylose molecules. Pasting temperature of starch suspensions ranged from 88.1 to 90.2ºC. Stability ratio explains the resistance of a starch paste to viscosity breakdown as shear is applied.

4. FOOD APPLICATION OF MILLET

4.1 Tuwo Production

Tuwo is a local delicacy of the Northern part of Nigeria; it is made from millet, maize or 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 [63]. According to Odusola et al. [64], tuwo is produced by getting millet, the grain is then sorted, dehulled, winnowed and mill into smooth flour and then sieve appropriately, water will be heated in the pot to boil, little portion of the flour is used to make a slurry in a cold water and its then transferred in to the boiling water and is allowed to boil together properly. After which the sieved flour of the millet is pour 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 it's then stirred and it's ready to be served with any desired soup.

4.2 Millet Ball Production “Fura”

Fura is a staple food for the Fulanis and Hausas. The single most important cereal grain for fura production is millet or its twin grain sorghum [65]. In tropical Africa, millet 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 [66]. Fura is produced mainly from moist millet 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 24 fermented skim milk (nono) [66]. Sugar may be added to taste, the mixture is called ‘fura da nono' in Nigeria. It is 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 on like the formal traditional methods of mortar and pestle thing. 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 [66]. Usually, a day after production, fura shows visible mold growth on the surface. The short shelf-life has always been a major deterrent to large-scale production. Thus, improving the processing, packaging and storage life of fura are of interest before food manufacturers can think of large scale production.

4.3 Greul Production

Millet 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 and some the gruels are been enriched with other food products like soybeans, ginger and host of other [67].

In the production of the gruels, the raw millet 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 [64].

4.4 Local Alcoholic Beverage Production

In many times past barley has been the sole cereal grains that are used in the production of alcoholic beverages in Western part of Africa and 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 has strive 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 millet 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 [68]. Millet is an important cereal crops grown in Nigeria with starch as its main chemical component. 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 26.7g of starch and 5.9g of protein per liter [69]. 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 [70,71]. 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

Millet 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 [72]. It serves as breakfast drink, appetizer, weaning food and is also medicinal [73]. 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 is 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 [74]. The major important cereals which are used in the preparation of kunu are millet, maize, guinea corn and rice. 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 particularly, vitamin B [75]. Kunu is widely accepted as food drink in some urban centres 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 [75]. 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 [76]. Spoilage of this product from observation occurs from improper handling, constant fermentation of the ingredients especially the carbohydrates and enzymatic action on the substrates [75]. 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, flavoring and some other types of sweet syrup [77]. The CO_2 when introduced increases the acidity level of the drink, thereby keeping some micro-organisms from growing. Thrive of microbes in a drink is what usually reduces the shelf-life of the product [78]. Carbonated millet 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 50Cl costs an average price of N100.00 and these 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 and consumption. It is being prepared from our 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, millet grain 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 35ºC and subsequently added to the remaining half slurry. Adequate amount of water will be added to the mixture, stirred and left to settle. After which, the mixture will be sieved using a muslin cloth and the filtrate sweetened with granulated sugar and mixed properly to obtain the freshly processed millet beverage. The product will be bottled in plastic bottles.

5. CONCLUSION

In this study the composition, functional properties and food application of millet was extensively examined. The review work showed high nutritional composition of this cereal grains (millet). The behavioral pattern was also discussed when used industrially which portrays their functional capabilities. The review showed that the product processes wide food applications as 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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