

EFFECT OF GERMINATION PERIOD ON SOME OF THE FUNCTIONAL AND ENGINEERING PROPERTIES OF SORGHUM FLOUR

ABSTRACT

Sorghum (red and white) were germinated for 24, 48, 72 and 96 h with the aim of determining the effect of germination on some of the functional and engineering properties of sorghum flour. The bulk density results for the red and white germinated sorghum are 0.620-0.673 g/cm³ and 0.477-0.620 g/cm³, respectively. Water **absorption capacity** values for the two samples are 116.630-125.970% and 81.643-98.293% while the oil **absorption capacity** ranged from 62.917 to 85.750% and 44.933 to 61.980%, respectively for the two samples. The **dispersibility test** for the two samples gave 85.667-87.333% and 83.000-84.667%. The **swelling power** at 55 °C are 2.537-2.673 and 2.700-3.257, at 75 °C, 3.620-4.680 and 3.853-4.560 and at 90 °C, 2.977-4.787 and 6.287-7.230, respectively for the two samples. For the engineering properties, the **specific heat capacity** ranged from 0.136 to 0.450 kJ/kgK and 0.122 to 0.139 kJ/kgK, **thermal conductivity**, from 0.547 to 1.674 W/mK and 1.012 to 1.236 W/mK and **thermal diffusivity** from 0.128 to 0.824 m²/s and 0.110 to 0.121 m²/s, respectively for red and white germinated sorghum flours. It can be concluded from this study that there were increases in the values of bulk density, WAC, OAC and dispersibility test of the two samples with the increase in germination period with the optimum germination period of 72 h. Engineering properties results indicated that germination had beneficial effect on the thermal conductivity of the germinated red sorghum and the thermal conductivity and specific heat capacity of the white germinated sorghum with 96 h having the best result for both samples.

Keywords: germination-time, sorghum-flour, functional, engineering.

1. INTRODUCTION

Sorghum (*Sorghum bicolor*) is in the subfamily Panicoideae and the tribe Andropogoneae (the tribe of big bluestem and sugarcane) being a flowering plant in the grass family is the fifth most important cereal after rice, wheat, maize and barley. It is a major source of proteins and calories in the diet of large segment of Africa populace and is mostly consumed by the poorer part of the population in many countries (Belton and Taylor, 2004). It is an important crop worldwide used for food (as grain and in sorghum syrup or sorghum molasses), animal fodder, production of alcoholic beverages, and biofuels which is important in the arid regions, where the grain is one of the staple food for the poor and rural people (Dillon *et al.*, 2007). Eight out of the 25 species are native of Australia, with some extending to Africa, Asia, Mesoamerica and certain islands in the Indian and pacific oceans (Dillon *et al.*, 2004). One of the species is grown for grain, while the others are used as fodder plants and it is either cultivated in warm climate worldwide or naturalized in pasture (BONAP, 2014). Although, sorghum as a food source has not been fully exploited due to its abundance in numerous phytochemicals (Cardoso *et al.*, 2017), but it represents an important ingredient in gluten free formulations (Marengo *et al.*, 2015). Traditionally, the technologies involved in the processing of sorghum include threshing, cleaning, washing, soaking, fermentation, and germination, wet and dry milling.

Germination is a phenomenon that occurs when a new plant is formed from a dry seed upon the inhibition of water, if the dry seed is not inactive and the conditions are favourable, it enters germination process. It is also a natural process that occurs during the growth of seed when they meet the minimum condition for growth and development (Sangronis *et al.*, 2006). It is also a processing method that improves the nutritional and functional properties of grains and legumes as well as digestibility according to Imtaiz and Burhan-Uddin (2012). The metabolic activity

involved in germination, as a result of reactivation of dormant enzyme results in the production of secondary and primary metabolites which improves the nutritional and functional properties of the grain (Bohoua and Yelakan 2007; Abbas and Nushara, 2008).

Functional properties explains how ingredients behaves during preparation and cooking and how they affect the finished food product in different ways such as how it looks, tastes and feels. These are also the interaction between the physiochemical characteristics and chemical component of food (Sibian *et al.*, 2017) associated with the nature of the environment which are measured (Kaur and Singh, 2005). These functional properties include: dextrinization, caramelization, water absorption capacity, bulk density, dispersibility, swelling power (capacity) and solubility index, water absorption index. Other functional properties include: emulsification, hydration (water binding), viscosity, foaming, solubility, gelation, cohesion and adhesion.

The engineering properties of food are very important, if not essential, in the process design and manufacture of food products. These engineering properties can be classified as (translucency), electrical (conductivity and permittivity), mechanical (structural, geometrical, and strength) properties. These properties of food show the design of processes and/or machines for characterization, handling and processing of the materials (Barbosa-Canovas *et al.*, 2009). The basic information on engineering properties is of great importance and helps in achieving efficient process and equipment development.

Studies have been carried out on the effect of germination on sorghum quality (Elkhalia and Bernhardt, 2010; Phattanakulkaewmorie *et al.*, 2011; Arouna, 2020). Meanwhile, there is lack of information on engineering properties of germinated sorghum flour. This study was therefore

carried out to investigate the effect of germination period on some of the functional and engineering properties of red and white sorghum flour.

2. MATERIALS AND METHODS

2.1 Materials

Sorghum grains (red and white) were purchased from a local market, Oshodi in Lagos. Other materials used include: tray, bowl, cabinet dryer, water, malting tray, muslin cloth, hammer mill, sieve, measuring cylinder, centrifuge, spatula, aluminum foil and weighing balance were obtained from Food Technology Laboratory, Federal Institute of Industrial Research Oshodi (FIRO).

2.2 Sample Preparation

The method of Ocheme (2007) was adopted for the germination of sorghum. Two thousand grams (2000 g) of both red sorghum and white sorghum grains was sorted and washed using tap water. The washed sorghum was soaked in 2.5 l of tap water for 12 h. At the end of the soaking, the water was decanted and drained off and the grain was evenly spread on the muslin cloth in a malting tray. It was covered with the same material in a dark secluded area and germinated for 24, 48, 72 and 96 h. Water was sprinkled on the germinated grain at 24 h interval to prevent it from drying out. At the end of the germination period, the grains were dried using a cabinet dryer at 60 °C for 4 h until constant weight was observed. The de-rooting and de-shooting was done manually by rubbing the grains between the palms and the grains were winnowed to separate the dried grind from its roots and shoots. It was milled using a hammer mill and packaged using a zip lock pack.

2.3 Functional Properties

Bulk density: Bulk density was carried out as described by the gravimetric method described by Okaka *et al.* (1991), with some modifications. The sample (3 g) was weighed and placed in a 25 cm³ measuring cylinder on a bench top and was tapped 10 times on a rubber laden table top to eliminate air space between the flour in the cylinder. The final volume of the sample was measured and expressed in g/cm³.

$$\text{Bulk density}(g) = \frac{\text{weight of the flour}(g)}{\text{volume occupied by the flour before tapping}}$$

Water and oil absorption capacities: Water absorption capacity was carried out as described by Lawal and Adebawale (2005), with some modifications. Two grams (2 g) of the sample was added to 10 cm³ of distilled water in a weighed 25 cm³ centrifuge tube. The sample was vortex for 1 min and allowed to stand for 30 min at 25 °C before being centrifuged at 4000 rpm for 25 min. The supernatant was decanted and the sediment together was weighed. For the oil absorption, 10 cm³ of refined vegetable oil was used in place of distilled water.

Dispersibility: The dispersibility of the flour was measured according to Kulkami *et al.* (1991) method with some modifications. Five grams (5 g) of each sample was suspended in 100 cm³ measuring cylinder and distilled water was added to reach the 50 cm³ mark. The set up was stirred vigorously with a glass rod and was allowed to settle for 3 h. The volume of settled particles was recorded and subtracted from 100.

$$\text{dispersibility} = 100 - \text{volume of settled particles}$$

Swelling capacity: The swelling capacity of the flour was determined as described by Li and Yeh (2001) and Adeboye and Singh (2008) with little modification. The swelling capacity depends on

size of particles, types of variety and types of processing method or unit operation. It is the quality criterion in some good formulations as bakery products. The sample, one gram (1 g) was weighed into the centrifuge tubes and 10 cm³ of distilled water was added. The tube was heated at 55, 75 and 90 °C for 30 min with occasional stirring using a water bath shaker. The supernatant was decanted carefully and sediment was weighed.

2.4 Engineering Properties

Specific Heat Capacity: This method was carried out according to Choi and Okos (1986). It was carried out by the use of a Tempos Thermal Analyzer. Certain amount of the sample was poured into the container to the brim and a node was inserted into it. The machine read the specific heat capacity and it was recorded. It was allowed to cool for 15 min before the next experiment was carried out.

Thermal Conductivity: The method of Choi and Okos (2003) was used to determine the thermal conductivity of flour and thermal conductivity, k , was expressed in W/mK. It was carried out by the use of a Tempos Thermal Analyzer. Certain amount of the sample was poured into the container to the brim and a node was inserted into it. The machine read the specific heat capacity and it was recorded. It was allowed to cool for 15 min before the next experiment was carried out.

Thermal Diffusivity: This is done by using the formula of Lide and David (2009). Thermal diffusivity (α) is the thermal conductivity (k) divided by bulk density (ρ) and specific heat capacity (C_p) at constant pressure and the SI is m²/s. The thermal diffusivity will be calculated using:

$$\alpha = k/\rho C_p$$

It was carried out by the use of a Tempos Thermal Analyzer. Certain amount of the sample was poured into the container to the brim and a node was inserted into it. The machine read the specific heat capacity and it was recorded. It was allowed to cool for 15 min before the next experiment was carried out.

3. RESULTS AND DISCUSSION

3.1 Functional Properties

The functional properties of germinated red and white sorghum flour are as shown in Tables 1 and 2, respectively. The bulk density of red germinated sorghum flour ranged from 0.62 to 0.67 g/cm³ with the sample germinated at 24 h having the lowest bulk density while sample germinated at 72 h had the highest value while the bulk density for germinated white sorghum flour ranged from 0.48 to 0.62 g/cm³. There was an increase in the bulk density of the two flour sample from 24 h to 72 h and it started reducing when it got to 96 h for the two samples. This reduction may be due to the change that occurred during germination which led to the breakdown of complex compound such as starch, fat and protein. The bulk density of a food material affects its mouthfeel as well as the type of packaging material used (Awoyale *et al.*, 2020; Awuchi *et al.*, 2019) that is increase in bulk density requires lesser package requirement.

Bulk density can be affected by different factors such as preparation, treatment and storage of grains. Lower bulk density might be as a result of softening of grain during soaking which produced smaller flour particle after milling (Siddiqua *et al.*, 2019). The bulk density of material is affected by the particle size and density of the food. There were a significant difference ($p < 0.05$) in the bulk density of the red germinated sorghum samples and there were no significant difference between the 48 and 96 h sample of the germinated white sorghum flour, but there were significant difference between samples 24 and 72 h.

The water absorption capacity of red germinated sorghum flour ranged from 116.63 to 125.97% with sample germinated at 72 h having the lowest water absorption capacity while sample germinated at 96 h had the highest value. There was stability between 24 and 48 h, a reduction at 72 h and an increase at 96 h. The WAC for the white germinated sorghum flour ranged from 81.64-98.29%. There was an increase between 24 and 48 h and stability occurred between 72 and 96 h. The increase might be due to the fact that there was a production of compounds with good water absorption capacity such as soluble sugars (Ocheme *et al.*, 2015). The increase may also be due to change in the quality of protein upon germination and also the breakdown of polysaccharide molecules which increases the site for the interaction with water and holding water (Elkhalifa and Bernhardt, 2010).

There were no significant difference in the water absorption capacity of the samples 24 and 48 h germinated red sorghum flour, 72 and 98 h were significantly different for germinated red sorghum flour. A significant difference in the water absorption capacity of the samples 24 and 48 h germinated white sorghum flour was observed, so also, 72 and 96 h germinated white sorghum flours were significantly different. The increase in water absorption capacity observed is in agreement with the report of Gernah *et al.* (2011) who reported an increase in the water bounding capacities of maize as a result of malting. There was a similar result gotten by Ocheme and Chidinma (2008) for the germination of millet flour. Water absorption capacity is the ability of a product to associate with water under a condition where water is limiting. Proteins are mainly responsible for high water intake and to a lesser extent, starch and cellulose at room temperature (Afoakwa, 1996). Water absorption capacity is important in foods where water is imbibed without the dissolution of protein, thus increasing their viscosity and body thickening (Seena and Sridhar, 2005). Higher value water absorption capacity helps to improve softness,

bulkiness, consistency of the product and reduce viscosity (Oyarekua and Adeyeye, 2009). Flours with good water absorption capacities are useful for baking (Ocheme *et al.*, 2015).

The oil absorption capacity for red germinated sorghum flour range from 62.92 to 82.04% with 24 h sample having the lowest oil absorption capacity while 96 h have the highest value while the OAC for white germinated sorghum flour ranged from 44.93 to 61.98%. Oil absorption capacity is the ability of food or food ingredient to absorb oil or fat. The ability of protein to bind fat is important, since fats acts as flavour retainer and increase mouth feel of foods, improves palatability, extends shelf life of bakery products, meat extenders, doughnuts, pan cakes, baked goods and soup mixes (Oluwalana *et al.*, 2011).

Germination of grain improves the oil absorption capacity as a result of the entrapment of oil related to the non-polar side chains of proteins (Giani and Bekebain, 1992). It was observed in this study that the OAC of germinated red sorghum flour was not constant while there was an increase in the OAC of white germinated sorghum flour increased from 24 h to 72 h, this increase is in line with the earlier work of Ocheme *et al.* (2015) and also in line with the earlier work of Imtaiz *et al.* (2011). Food with good oil absorption capacity can be used as meat replacers and extenders. There were significant differences ($p < 0.05$) in the oil absorption capacity for the two samples of flour.

There were a significant difference ($p < 0.05$) in the results of swelling capacity. The ranges of results are 2.64-2.67 at 55 °C with 24 h having the lowest swelling power and 96 h having the highest swelling power, 4.26-4.68 at 75 °C with 24 h having the highest swelling power and 96 h having the lowest swelling power and 3.57-4.79 at 90 °C with 24 h having the highest swelling power and 48 h having the lowest swelling power for the germinated red sorghum samples.

While for the germinated white sorghum samples, the results ranged from 3.07 to 3.26 at 55 °C with 96 h having the highest swelling power and 48 h having the lowest swelling power, 4.18 to 4.56 at 75 °C with 96 h having the highest swelling power and 48 h having the lowest swelling power and 6.29 to 7.23 at 90 °C with 24 h having the highest swelling power and 96 h having the lowest swelling power. There was an increase in the swelling power of the red germinated sorghum flour at 55 and 75 °C and a decrease at 90 °C and there was a variance in the swelling power at 55 and 75 °C and a total reduction at 90 °C. Swelling power depends on the nature of the material and the type of treatment used. Biopolymers of starch contribute to the development of these characteristics. Swelling power can also be related to water absorption index of starch-based flour during heating.

The dispersibility of germinated red sorghum ranged from 86.00 to 87.33% with 96 h having the highest value and 48 h and 72 h having the lowest value; that of germinated white sorghum flour ranged from 83.00 to 84.33% with 48 and 72 h having the highest value and 96 h having the lowest value. The ability of flours to go into dispersion without formation of lumps is a very important property especially in instant cold or hot mixes (Ikegwu and Okoli, 2011). The higher the dispersibility the more easy it is to reconstitute giving fine consistency dough during mixing (Adebowale *et al.*, 2008). The results gotten are in line with the previous work of Adebowale *et al.* (2012) on the functional properties and biscuit making potentials of sorghum- wheat flour composite. For the red germinated sorghum flour, there were no significant difference between 48 h and 72 h germinated red sorghum and there were a significant difference between the 24 h and 96 h germinated red sorghum. For the white germinated sorghum flour there were no significant difference between the 48 h and the 72 h sample but there were significant difference between the 24 h and 96 h germinated samples.

Table 1: Functional Properties of Germinated Red Sorghum

Germination Period (h)	Bulk Density (g/cm ³)	Water Absorption Capacity (%)	Oil Absorption Capacity (%)	Dispersibility (%)	Swelling Power		
					Temperature		
					55 °C	75 °C	90 °C
24	0.62 ^a	119.96 ^b	62.92 ^a	86.00 ^b	2.64 ^b	4.68 ^c	4.79 ^b
48	0.63 ^b	119.97 ^b	85.75 ^d	85.67 ^a	2.54 ^a	3.62 ^a	3.10 ^a
72	0.67 ^d	116.63 ^a	76.53 ^b	85.67 ^a	2.54 ^a	3.74 ^{ab}	2.98 ^a
96	0.64 ^c	125.97 ^c	82.04 ^c	87.33 ^c	2.67 ^c	4.26 ^{bc}	3.57 ^a

Values represent means of triplicate reading, follow by different lowercase letter
Means within the same row with different alphabets are significantly different ($p \leq 0.05$)

Table 2: Functional Properties of Germinated White Sorghum Flour

Germination Period (h)	Bulk density (g/cm ³)	Water Absorption Capacity (%)	Oil Absorption Capacity (%)	Dispersibility (%)	Swelling Power		
					Temperature		
					55 °C	75 °C	90 °C
24	0.48 ^a	81.64 ^a	44.93 ^a	84.33 ^c	3.07 ^b	4.18 ^{ab}	7.23 ^c
48	0.53 ^{ab}	98.29 ^c	54.23 ^b	84.67 ^b	2.70 ^a	3.85 ^a	6.89 ^{bc}
72	0.62 ^b	89.99 ^b	61.98 ^d	84.67 ^b	3.15 ^c	4.23 ^{ab}	6.67 ^b
96	0.58 ^{ab}	89.99 ^b	57.10 ^c	83.00 ^b	3.26 ^d	4.56 ^b	6.29 ^a

Values represent means of triplicate reading, follow by different lowercase letter
Means within the same row with different alphabets are significantly different ($p \leq 0.05$)

3.2 Engineering Properties

The engineering properties of the flour range are shown in Tables 3.3 and 3.4, respectively. The specific heat capacity of the red germinated sorghum flour ranged from 0.14 to 0.24 (kJ/kgK) with 24 h having the lowest value and 96 h having the highest value and ranged from 0.13 to 0.14 (kJ/kgK) for the white germinated sorghum flour with 48 h having the lowest value and 96 h having the highest value. There were significant difference ($p < 0.05$) between the samples of red germinated sorghum flour and there were no significant variation for 24 and 72 h germinated

white sorghum flour but 48 and 96 h were significantly ($p < 0.05$) different. Specific heat capacity is the measure of the amount of heat energy required to change the temperature of 1 kg of a material by 1 K. It gives the indication of how much energy is needed to cool and heat an object or food substance by a given amount. It also gives us information as to how long the heating or cooling process will take under a given specific supply as well as the cost implication. Specific heat capacity also finds application in heat conduction, convection and radiation, length and volume expansions, phase changes, etc. The sample with the highest specific heat capacity is cost effective and shows that it will not consume much energy and it will not take a longer time to heat up or cool down.

The thermal conductivity of the red germinated sorghum flour ranged from 1.07 to 1.67 W/mK with 48 h having the lowest value and 96 h having the highest value. The thermal conductivity of the white germinated sorghum flour ranged 1.09 to 1.24 W/mK with 48 h having the lowest value and 96 h having the highest value. There were significant differences ($p < 0.05$) among the samples. Thermal conductivity refers to characteristics or ability of a material to transfer and conduct heat. It can be used to predict heat flux in soe operations like cooking, baking, drying etc (Ramesh, 2000). The results of thermal conductivity obtained in this study proved that the flour has a good baking property. Knowledge of the product properties, including thermal conductivity as a function of processing conditions is needed in order to predict the water and temperature distribution in the product during baking. In baking process, baking products under go physical, chemical and biochemical changes that results in expansion of bulk volume, evaporation of water, formation of porous structure, denaturation of protein, gelatinization of starch, formation of crust and browning reactions. During such processes, ovens are powered by gas, electricity, firewood, charcoal or microwaves to generate the required heat. It occurs through molecular

agitation and contact, and does not result in the bulk movement of the solid itself. Heat moves along a temperature gradient, from an area with a high temperature and high molecular energy to an area with lower temperature and lower molecular energy.

The thermal diffusivity of the red germinated sorghum flour ranged from 0.13 to 0.14 m²/s with 96 h having the lowest value and 48 h having the highest value. The thermal diffusivity of the white germinated sorghum flour ranged from 0.11 to 0.13 m²/s with 72 h having the lowest value and 24 h having the highest value. There were significant differences (p<0.05) in the samples. Thermal diffusivity is a measure of the rate of heat transfer of a material from the hot side to the cold side. It is a physical property because it is a combination physical property such as conductivity, density and specific heat capacity and it plays an important role in influencing the movement and behavior of heat. A material with high density is composed of atoms or molecules tightly packed together. So a material of high density will determine how fast heat can be transferred by limiting the speed and distance that heat can travel through the object. Thermal diffusivity determines how rapidly heat will flow within the material or the rates of temperature spread. It measures the rate at which heat disperses throughout an object or body. A material that conducts heat efficiently must be able to have effective heat diffusion properties in order to facilitate heat transfer.

Table 3: Engineering Properties of Germinated Red Sorghum Flour

Germination Time (h)	Specific Heat Capacity (kJ/kgK)	Thermal Conductivity (W/mK)	Thermal Diffusivity (m ² /s)
24	0.14 ^b	1.07 ^b	0.13 ^a
48	0.45 ^a	0.55 ^a	0.82 ^d
72	0.19 ^c	1.14 ^c	0.17 ^c
96	0.24 ^d	1.67 ^d	0.14 ^b

Values represent means of triplicate reading, follow by different lowercase letter

Means within the same row with different alphabets are significantly different ($p \leq 0.05$)

Table 4: Engineering Properties of Germinated White Sorghum Flour

Germination Time (h)	Specific Heat Capacity (kJ/kgK)	Thermal Conductivity (W/mK)	Thermal Diffusivity (m ² /s)
24	0.13 ^b	1.09 ^b	0.12 ^b
48	0.12 ^a	1.01 ^a	0.12 ^b
72	0.13 ^b	1.17 ^c	0.11 ^a
96	0.14 ^c	1.24 ^d	0.11 ^a

Values represent means of triplicate reading, follow by different lowercase letter
Means within the same row with different alphabets are significantly different ($p \leq 0.05$)

4. Conclusion

Functional properties are important in determining food material behaviour among other functions. It can be concluded from this study that germination had beneficial properties on bulk density, WAC, dispersibility test and OAC of the two samples with flour germinated at 72, 48 and 96 h having the best results. Engineering properties are also important in food processing in determining the most effective and efficient process design, machines, controls and structure among other functions. It can be concluded from this study that germination had beneficial effect on the thermal conductivity of the germinated red sorghum and the thermal conductivity and specific heat capacity of the white germinated sorghum with 96 h having the best result for both samples.

References

- Abbas, T.E.E. and Mushara, N.A. (2008). The effect of germination of low-tannin sorghum grains on its nutrient contents and broiler chicks' performance. *Pakistan Journal of Nutrition*, 7(3): 470-474.
- Adebowale, A.A., Sanni L.O. and Onitilo M.O. (2008). Chemical composition and pasting properties of tapioca grits from different cassava varieties and roasting methods. *African Journal of Food Science*, 2: 77-82.
- Adebowale, A.A., Sanni, L.O. and Awonorin, S.O. (2012). Effect of texture modifiers on the physiochemical and sensory properties of dried fufu. *Food Science Technology International*, 119(5): 373-382.
- Adeboye, O.C. and Singh, V. (2008). Physico-chemical properties of flours and starches of two cowpea varieties (*Vigna unguiculata* (L.) Walp). *Innovative Food Science and Emerging Technologies*, 9: 92-100.
- Afoawka, E.O. (1996). Chemical composition and quality changes occurring in millet after harvest. *Food Chemistry*, 75: 85-91.
- Arouna, N., Gabriele, M. and Pucci, L. (2020). The impact of germination on sorghum nutraceutical properties. *Foods*, 9, 1218; doi:10.3390/foods9091218
- Awoyale, W., Oyedele, H. and Maziya-Dixon, B. (2020). The functional and pasting properties of unripe plantain flour, and the sensory attributes of the cooked paste (*amala*) as affected by packaging materials and storage periods. *Cogent Food and Agriculture*, 6(1): 1-20

- Awuchi, C. G., Igwe, V. S. and Echeta, C. K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research (Sciences, Technology and Engineering)*, 5(11): 139 – 160
- Barbosa-Canovas G.V., Mawson, R., Corradini, M.G. and Bermudez-Aguirre, D. (2009). Modelling the inactivation of *Listeria innocua* in raw whole milk treated under thermo-sonication. *Innovative Food Science and Emerging Technologies* 10(2): 172-178.
- Belton, P. S. and Taylor, J. R. N. (2004). Sorghum and millets: Protein sources for Africa. *Trends in Food Science and Technology*, 15: 94-98
- Bohoua, G.L. and Yelakan, C.K.K. (2007). Effect of germinated sorghum flour on the performance of laying hens (Warren). *International Journal of Poultry Science*, 6(2): 122-124.
- BONAP (2014). Sorghum. County-level distribution maps from the North American Plant Atlas (NAPA). Biota of North American Program. Retrieved 4th September, 2016.
- Cardoso, L.D.M., Pinheiro, S.S., Martino, H.S.D. and Pinheiro-Sant'Ana, H.M. (2017). Sorghum (*Sorghum bicolor* L.): Nutrients, bioactive compounds, and potential impact on human health. *Critical Reviews in Food Science Nutrition*, 57: 372–390
- Choi, Y. and Okos, M.R. (1986). Effects of temperature and composition on thermal properties of foods. In M. Le Maguer and P. Jelen (Eds). *Food Engineering and Process Applications*, volume 1, pp. 269-312. New York: Elsevier Applied Science Publishers.

- Choi, Y. and Okos, M.R. (2003). Thermal conductivity of foods. In D.R. Helman (Ed.), *Encyclopedia of Agricultural, Food and Biological Engineering*. New York: Marcel Dekker, Inc. pp. 1004-1010.
- Dillon, S. L., Lawrence, P. K., Henry, R. J., Ross, L. , Price, H. J. and Johnston, J. S. (2004). *Sorghum laxiflorum* and *S. macrospermum*, the Australian native species most closely related to the cultivated *S. bicolor* based on ITS1 and ndhF sequence analysis of 25 Sorghum species. *Plant Systematics and Evolution*, 249: 233–246
- Dillon, S.L., Shapter, F.M., Henry, R.J., Cordeiro, G. and Liz Izquierdo, I. (2007). Domestication to crop improvement: Genetic resources for sorghum and *Saccharum* (*Andropogoneae*). *Annals of Botany* 100(5): 975-989.
- Elkhalifa, A.E.O. and Bernhardt, R. (2010). Influence of grain germination on the functional properties of sorghum flour. *Food Chemistry*, 121: 387-392.
- Gernah, D.I., Ariahu, C.C and Igbian, E.K. (2011). Effects of malting and lactic acid fermentation on some chemical and functional properties of maize (*Zea mays*). *American Journal of Food Technology*, 6: 404-412.
- Giani, G.H. and Bekebain, M.I. (1992). Preliminary studies on grain quality evaluation for finger millet as a food and beverage use in southern African region. In: *Advances in small millets*. Rilry KW., Gupta SC, Seetharam A, Mushong, JN New Delhi, India, Oxford and IBH Publishing. pp. 289-296.

- Ikegwu, O. and Okoli E.C. (2011). Effect of toasting temperature and time on the functional properties of *Brachystegia eurycoma* flour. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 10(1): 1821-1828.
- Imtaiz, H., and Burhan-Uddin, M. (2012). Optimization effect of germination on functional properties of wheat flour by response surface methodology. *International Research Journal of Plant Science*, 3(3): 31-37.
- Imtaiz, H. Burhanddin, M. and Gulzar, M.A. (2011). Evaluation of weaning foods formulated from germinated wheat and mungbean from Bangladesh. *African Journal of Food Science*, 5(17): 897-903.
- Kaur, M. and Singh, N. (2005). Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L) cultivars. *Food Chemistry*, 91: 403-411.
- Kulkarni, K.D., Kulkarni, D.N. and Ingle, U.M. (1991) Sorghum malt based weaning formulations, preparation, functional properties and nutritive value. *Food and Nutrition Bulletin*, 13: 322-327.
- Lawal, O.S. and Adebowale, K.O. (2005). Physico-chemical characteristics and thermal properties of chemically modified jack bean (*Canavalia ensiformis*) starch. *Carbohydrate Polymer*, 60(3): 331-341.
- Li, J.Y. and Yeh, A.I. (2001). Relationships between thermal, rheological characteristics and swelling power for various starches. *Journal of Food Engineering*, 50: 141-148.
- Lide, A. and David, R. (2009). CRC Handbook of Chemistry and Physics. 90th eds. Boca Raton, Florida: CRC Press. pp. 2-65. ISBN 978-1-4200-9084-0.

- Marengo, M., Bonomi F., Marti, A., Pagani, M.A., Elkhailifa, A.E.O. and Iamentti, S. (2015). Molecular features of fermented and sprouted sorghum flours relate to their suitability as components of enriched gluten-free pasta. *LWT Food Science Technology*, 78: 296-302
- Nwanekezi, E.C. and Ukagu, J.C. (1999). Determination of engineering properties of some Nigerian fruits and vegetables. *Nigeria Food Journal*, 17: 55-60.
- Ocheme, O. B., Adedeji, O. E., Lawal, G. and Zakari, U. M. (2015). Effect of germination on functional properties and degree of starch gelatinization of sorghum flour. *Journal of Food Research*, 4(2): 159-165.
- Ocheme, O.B. (2007). Effect of storage of millet on the quality and acceptability of millet flour porridge (*Enyiokwolla*). *Journal of Food Technology*, 5(3): 215-219.
- Ocheme, O.B., and Chidinma, C.E. (2008). Effects of soaking and germination on some physico-chemical properties of millet flour for porridge production. *Journal of Food Technology*, 6(5), 185-188.
- Okaka, J.C., Onilade P.A. and Ozo, O.N. (1991). Quality evaluation of sundried yam chips. *Tropical Science*, 31: 265-275.
- Oluwalana, I.B., Oluwamukomi, M.O., Akinbowale, O.F. (2011). Physicochemical and sensory properties of wheat-cassava composite biscuit enriched with soy flour. *African Journal of Food Science*, 5(2): 50-56.
- Oyarekua, M.A. and Adeyeye, E.I. (2009), Comparative evaluation of nutritional quality, functional properties and amino acid profile of co-fermented maize/cowpea and sorghum cowpea *ogi* as infant complementary food. *Asian Journal Clinical Nutrition*, 1(1): 31-39.

- Phattanakulkaewmorie, N., Paseephol, T. and Moongngarm, A. (2011). Chemical compositions and physico-chemical properties of malted sorghum flour and characteristics of gluten free bread. *World Academy of Science, Engineering and Technology*, 57: 9-27.
- Ramesh, M. N. (2000). Effect of cooking and drying on the thermal conductivity of rice. *International Journal of Food Properties*, 3(1): 77-92.
- Sangronis, E., Rodriguez, M., Cava, R. and Torres, A. (2006). Protein quality of germinated *Phaseolus vulgaris*. *European Food Research and Technology*, 222: 144-148.
- Seena, S. and Sridhar, K.R. (2005). Physicochemical, functional and cooking properties of under explored legumes, *Canavalia* of the Southwest coast of India. *Food Research International*, 38: 803–814.
- Sibian, M.S., Saxena, D.C. and Riar, C.S. (2017). Effect of germination on chemical, functional and nutritional characteristics of wheat, brown rice and triticale: a comparative study. *Journal of the Science of Food and Agriculture*, 97(13): 4643-4651.
- Siddiqua, A., Ali, M.S. and Ahmed, S. (2019). Functional properties of germinated and non-germinated cereals: A comparative study. *Bangladesh Journal of Science and Industrial Research*. 54(4): 393-390.