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PROCESSING AND UTILIZATION OF SORGHUM – A REVIEW PAPER

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Abstract

This paper deals with review of literature on physical and thermal properties of sorghum, existing technologies for processing of sorghum with hydrothermal treatments for flaking, nutritional and storage qualities. The various findings of the related work have been reviewed and presented in this paper. By suitable processing it might be feasible to produce completely new food products from sorghum such as flakes, pasta, vermicelli, semolina etc. by applying new hydrothermal technologies. In rural farming areas, one of the major limitations for starting small/medium scale production of sorghum flakes is that the sorghum flaking machinery is not available at a reasonable price.

Key words: Sorghum; Physical properties; Processing; Value addition; Products.

Introduction

Sorghum is used for the production of alcoholic beverages, food and fodder. It is heat and drought tolerant, and is especially effective in arid regions. It is a significant food crop in Central America, Africa and South Asia and is the "fifth most important cereal crop grown in the world". In the semiarid tropics of Asia and Africa, for millions of poor rural people, Sorghum is one of the most significant staple foods. It is a main source of protein, minerals, energy and vitamins for some of the impoverished regions of the world. For the grain threshing unit, its design and optimal performance are based on the physical properties of sorghum such as bulk density, diameter, surface area, weight. The shape and size of agricultural materials helps to understand the problem for separating grains from undesirable materials. To describe the shape of grain, the size of grains described by their sphericity and equivalent diameter is needed. For the appropriate heating equipment design, surface area is helpful in calculation of the rate of heat transfer. For heat transfer operations and seed mass to volume mathematical conversion, density is required. Degree of kernel filling is determined by the bulk density during growth. The degree of kernel serves as the quality indicator for baking quality, hardness tests and breakage susceptibility. It is also useful in dielectric mixture equations and determines the dielectric properties. Kernel shape, hardness, structure and density decide the sorghum milling quality. The most significant thermal properties dependent on moisture are thermal diffusivity, thermal conductivity and specific heat. These properties are useful for calculations of engineering design that involve grains and foods thermal processing.

Physical and Thermal Properties of Sorghum

Baig et al. (2019) determined the physical and thermal properties of sorghum grain (Mahalakshmi - 946) at a moisture content of 10.5 % (wb). The physical properties namely length, width, thickness, thousand grain weight, sphericity, mean geometrical diameter, surface area, particle density, bulk density, coefficient of static friction, angle of repose, porosity and thermal properties namely thermal conductivity, thermal diffusivity and volumetric specific heat were determined. The mean ± standard deviation values of sorghum grain for length, width, thickness, geometrical mean diameter, sphericity and surface area were found to be 4.21 ± 0.281 mm, 3.64 ± 0.254 mm, 2.32 ± 0.233 mm,3.29 ± 0.230 mm, 0.78 ± 0.031 and 34.10 ± 4.638 mm2 respectively. The mean ± S.D of thousand grain weight, bulk density, true density, porosity, angle of repose of sorghum were found to be 22.645 ± 0.004 g, 770 ± 1.0 kg/m3,1272.893 ± 22.386 kg/m3, 39.497 ± 0.992 % and 31.6220 ±1.0895°respectively. The mean ± SD coefficient of static friction values were found to be 0.512 ± 0.016, 0.479

± 0.012, 0.453 ± 0.012, 0.412 ± 0.011 and 0.392 ± 0.011 for Mild Steel, Galvanized Iron, Aluminium, Stainless Steel and Perspex surface material respectively. The mean ± S.D values of thermal conductivity, volumetric specific heat capacity and thermal diffusivity were 0.157 ± 0.015 W/mK,1.222 ± 0.13 MJ/m3K and 0.129 ± 0.009 mm2/s respectively. Chang (2013) determined the bulk densities and thermal conductivities of sorghum using the line heat source method at ambient temperature. The moisture contents of the grain samples ranged from 11% to 18% (wb) from 0.160 to 0.184 W/mK for grain sorghum. Thermal conductivity of each type of grain increased linearly with the bulk density at a constant moisture content. Simonyan et al. (2007) reported that the average diameter of sorghum grain calculated by arithmetic mean, geometric mean and equivalent diameter methods were 3.32 and 3.31 mm, 3.31 and 4.20 mm, 4.16 and 4.18 mm at 8.89 and 16.50% (wb) respectively. The projected area, particle density, mean mass, bulk density and volume for sorghum grain are 4.66 mm2, 1.02 g/ cm3, 0.044 g, 568.5 g/ cm3 and 0.091 cm3 at 8.89% (wb) respectively.The sphericity of sorghum grain was normally distributed about 0.92. Mwithiga and Sifuna (2006) reported that the kernel strength, angle of repose, porosity, true density, bulk density, 1000 grain mass, sphericity and geometric mean diameter at the moisture content of 13.64% (db) were found to be 87.89 N, 30.43°, 53.44%, 1264 kg/m3, 588.4 kg/m3, 33.91 g, 0.737, 3.94 mm and for Kari-mtama, 59.64 N, 24.41°, 36.86%, 1087 kg/m3, 686.33 kg/m3, 20.89 g, 0.733, 3.33 mm for Serena and 48.66 N, 20.11°, 33.31%, 1138 kg/m3, 757.61 kg/m3, 19.66 g, 0.789, 3.15 mm for Seredo respectively. Sphericity remained fairly unaltered but the geometric mean diameter increased with moisture content linearly for all the three types of sorghum. Within the experimental testing range (13.64% to 21.95% (db), both the angle of repose and 1000 grain mass increased linearly with moisture content while true density and bulk density decreased linearly with increase in moisture content. Ndirika and Mohammed (2005) determined some selected physical properties of sorghum; For the two types of sorghum (short kaura and farafara), comparative evaluation on the properties shows that only the difference in the means of angle of repose (grain to glass) and a thousand kernel weight (TKW) are the parameters that are statistically important at 5 percent level of significance.

. Lee et al. (2002) studied the effects of kernel size on grain sorghum [Sorghum bicolor (L.) Moench] quality in an experiment designed to separate effects of kernel size from seed lot. The study utilized three sieve fractions of varying kernel diameter (>3.35, >2.80 and >2.36 mm) from six seed lots. Chemical composition, physical characteristics, milling characteristics, pasting properties, and cooking qualities were determined for each kernel size fraction.. Kernel size effects on Rapid Visco Analyzer (RVA) properties were not consistent. These results suggest that within the sorghum seed lots studied, an increase in kernel size is associated with an increase in sorghum quality as defined by the parameters measured in this study.

Existing Technologies for Processing of Sorghum

Baig et al. 2018 conducted 40 experiments by a combination of treatments to sorghum grain, namely, soaking time for 12, 18, 24, 30 and 36 h, machine roasting tepemratures at 200, 210 and 220 °C, open pan roasting at 125±2 °C with machine parameters, namely, speed of rollers at 60 rpm and 80 rpm and gap between the rollers at 0.1 mm. The highest yield of 93.27 % percent flakes was obtained 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed and lowest yield of 59.30 % for 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed. It was also observed that the yield obtained for different treatments was more at 60 rpm roller speed than at 80 rpm. It was observed that a moisture content of 9.20 % (wb) for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the highest and a lowest moisture content of 7.08 % (wb) for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed. It was observed that a bulk density of 0.352 g/ ml for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the highest and a bulk density of 0.317 g/ml for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the lowest. It was observed that the water absorption capacity of 106.607 g/100 g for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the highest and the water absorption capacity of 52.477 g/100 g for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the lowest. It was observed that a thickness of 0.947 mm for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the highest and a thickness of 0.757 mm for flakes processed by 24 h soaking, open pan roasting at

125±2 °C and 60 rpm roller speed gave the lowest. Based on the highest yield and lowest bulk density of flakes, it can be concluded that 36 h soaking time, pan roasting at 125±2 °C, roller flaking at 60 rpm and with 0.1 mm gap between the rollers were the process and machine parameters optimized. Vijaya et al. (2016) conducted studies on sorghum-based extruded products. Sorghum blends with broken rice and green gram in the proportion of (7:2:1, 6:3:1 and 5:4:1), barrel temperatures (110, 120 and 140 oC) and Extruder barrel screw speed (150, 200 and 250 rpm) were optimized at feed moisture content of 12%wb. It was found that increase in temperature reduced expansion ratio. The screw speed had negligible effect. The expansion ratio was higher for sample prepared at 110 oC and 150 rpm. The bulk density was lower for sample with higher expansion ratio. The samples with higher expansion ratio and lower bulk density values were selected for sensory evaluation. Ready –to-eat snack was developed using blends of sorghum, broken rice and green gram at 12% moisture content. Chavan et al. (2015) undertook a study with an objective to standardize procedures for preparation of flakes from sorghum, to identify the best genotype for preparation of flakes and to study the nutritional quality parameters of flakes and their products. Ten varieties and five hybrids were used for preparation of flakes and their products. A process standardized for flakes preparation using flaking machine. The flakes Phule Maulee gave higher level of crude fiber content (3.12%). The amino acid profile of sorghum grain and flakes showed very minor differences in the content due to the processing. The new genotypes of rabi sorghum showed comparable results for the mineral with that of hybrids. The mineral content of flakes was changed due to the soaking and roasting treatment while processing the grains. The organoleptic properties of the Chiwada and Poha prepared from sorghum flakes were judged on the basis of colour and appearance, texture, flavour, taste and overall acceptability of the product using semi- trained judges and 1 to 9 hedonic scale. TNAU (2013) developed a method of flaking of sorghum in which pearled grain was soaked for 2 h in water, steamed (pressure cooked for 15 min), dried at 70 °C for 1 h in a cabinet drier and pressed between rotating rollers having a specific clearance which determines the flake thickness. The flakes thus obtained were subjected to drying for 45 min in solar drier, graded and packed. Dayakara rao (2012) processed sorghum flakes by soaking sorghum grain in water for overnight at room temperature, air drying for 3 h, roasting at 200 °C for 5 min in a roaster, flaking in edge runner, sieving, cooling and packing. The flakes resemble rice flakes and the output is 50% to 60%.

Processing of Sorghum for Production of Flakes

Lazaro et al. (2014) developed a low cost pedal operated sorghum dehuller for dehulling tempered grain and tested for its performance using two sorghum varieties (Dionje and Jumbo). The use of short tempering duration (10 to 15 min) followed by a short resting period (5 to 10 min) to ensure that all the tempering moisture was absorbed into the grain before the grain was introduced into the dehuller thus eliminating the clogging problem usually associated with conventional abrasive dehullers. This facilitated the removal of the seed coat from the endosperm. The obtained results showed that the developed dehuller was able to achieve high dehulling efficiency (90.1 for Jumbo and 83.4% for Dionje) and high recovery levels compared to conventional abrasive dehullers (45.6 for Jumbo and 40.3% for Dionje). The quality of the dehulled grain was also much higher as indicated by the low ash content, low crude fibre content and superior colour of the flour obtained from the grain dehulled in the developed dehuller compared to flour from grain dehulled using conventional abrasive dehullers Accordingly, the developed pedal operated dehuller could be very appropriate for small scale sorghum farmers and consumers in the rural areas. Mbaeyi and Onweluzo (2010) studied the effect of sprouting and pre-gelatinization on the physicochemical properties of sorghum-pigeon pea composite blend used for the production of breakfast cereal. Sprouted (96 h) and pregelatinized (78 °C) sorghum grains were milled and blended with graded proportion of pigeon-pea and used in formulating flaked breakfast cereal. A commercial ready-to-serve breakfast cereal served as product control. The flour blends and formulated products were subjected to the physicochemical quality analyses using standard methods. Results of the amylose content of the pregelatinized sample showed higher ($p<0.05$) amylose content than the sprouted samples. The sorghum samples used for the study showed pre gelatinization temperature range of 68 °C and time of 10 min, respectively. Pre gelatinization treatment increased the amylose content.

McDonough et al. (1998) studied steam flaking characteristics of sorghum hybrids and lines with differing endosperm characteristics. Commercial and food-type sorghum hybrids with differing kernel and endosperm characteristics were grown under comparable conditions and steam flaked in each of three years. The raw-grain kernel characteristics and proximate analyses were homogenous over the three year period. The waxy hybrid produced large, translucent, durable flakes that had significantly higher enzyme-susceptible starch values for all years compared to the other varieties. Flakes with lower amylose contents (waxy endosperm) were positively correlated with percent whole flakes ($r2 = 0.509$), flake diameter ($r2 = 0.846$), and enzyme-susceptible starches ($r2 = 0.564$) and negatively correlated with higher flake fragility ($r2 = –0.647$), test weight ($r2 = –0.626$), and flake breakage ($r2 = –0.560$). The heterowaxy flakes had a good appearance and were generally comparable in quality to the nonwaxy commercial and experimental hybrids. Heterowaxy sorghum hybrids with good grain yields can provide improved quality grain and flakes without sacrificing agronomic performance and yields. No difference in flaking performance was detectable among the kernels with different pericarp colors; flakes from the white food-type sorghums had excellent appearance. Nontempered control samples were inferior in quality to all conditioned treatments.

McDonough et al. (1997) studied the structural characteristics of steam-flaked sorghum. Sorghum undergoes structural changes during tempering, steam cooking, and flaking at various tempering moisture levels. Physical properties of flakes, digestibility, birefringence, scanning electron microscopy (SEM), and environmental SEM (ESEM) were used to evaluate the quality of steam-flaked sorghum from grain containing 11% to 23% water. As moisture levels increased, the flakes became stronger (57–69% whole flakes) and less dusty (9% to 4% fines). The steaming process prepared the grain for flaking by heating and softening the kernels. Tempering allowed extra water to penetrate inside the kernel endosperm. The starch granules were more intact and less tightly packed into the flake. Good quality flakes were translucent, thin, and strong, with little chalkiness, and low levels of dust and fines. The starch granules were much larger in diameter, and the relative level of gelatinization, evident by the presence of starch granules with collapsed centers, was much higher. Anderson (1994) studied the effects of tempering and steaming on flaking of sorghum. Seven improved sorghum hybrids and two commercial hybrids were tempered and steam flaked. The flakes were evaluated for hardness, bulk density, flake durability, in vitro digestibilities, starch properties, and other physical/chemical properties. The flakes from the waxy grain were large, more resistant to breakage, and attractive in appearance. The waxy flakes also had the most unique starch pasting properties. Overall, the waxy flakes had the highest quality. The white food type sorghums produced flakes with superior appearance to commercial red and white sorghums. The floury sorghum produced inferior flakes high in fragility and low in test weight. The hard food type sorghum produced small, uniform flakes that were very hard.. The in vitro digestibility and enzyme susceptible starch values had a great deal of variability and there were no significant differences found between flakes prepared from the varieties. The pasting properties of the different sorghum flakes were significantly affected by tempering and endosperm type. This suggests that it may be possible to utilize starch viscosity changes to monitor steam flaking. The flake breakage and durability tests appeared to be good quality control tests for steam flaking. Frederick et al. (1972) processed Barley and Sorghum grain with various combinations of moisture, heat and pressure. Percent starch digestion was determined by incubating ground samples of the processed grain with a buffered homogenate of bovine pancreas for 30 min at 40 °C. Addition of water to the grain by soaking or by steaming at atmospheric pressure did not greatly improve enzymatic starch degradation of barley or sorghum grain. Application of pressure to the grains (with hydraulic press or roller mill) increased in vitro starch digestibility over untreated grains. The pressure response was greater with moist grains than with dry grains. Enzymatic starch degradation was greatest for processing treatments involving application of moisture, heat and pressure. Starch digestibility of pressure cooked grains was increased at each increment of steam pressure from 1.4 to 7.0 kg/cm2. Flaking the grains after steam processing or pressure cooking markedly improved enzymatic starch degradation. The optimum cooking pressure for both grains (with flat flaking) appeared to be 4.2 kg/cm2. The critical pressure (with a hydraulic press) for improving enzymatic starch degradation of dry, steamed, and soaked sorghum grain occurred at 140 kg/cm2 with the pressure plates at room temperature. Increased pressures to 1,400 kg/cm2 did not improve digestion. When the pressure plates were preheated to 98°C, the critical pressure remained at 140 kg/cm2 for dry sorghum grain, but starch degradation was improved in the steamed and soaked grains at both 35 and 140 kg/ cm2.

Quality of Sorghum Flakes

Mkandawire et al. (2015) studied composition, in vitro digestibility, and sensory evaluation of extruded whole grain sorghum breakfast cereals. Two sorghum genotypes (red, tannin; white, non-tannin), were evaluated for their potential use in breakfast cereals. Two levels of whole grain sorghum flour (550 g/kg dry mix or 700 g/kg dry mix) were processed per genotype using a pilot-scale, twin screw extruder. A whole grain oat-based cereal was used as a reference. White sorghum cereals (WSC) had significantly ($p < 0.05$) higher starch, brightness (L^*), and yellowness (b^*) than red sorghum cereals (RSC). RSC had higher protein and bulk density than the WSC. Cereals made with 700 g sorghum flour/kg were smaller and denser with lower water solubility and absorption indices than those made with 550 g/kg. In vitro protein digestibility of the RSC (43-58%) was significantly reduced compared with the WSC (69-73%) and the reference sample (72%). WSC with 700 g sorghum flour/kg contained significantly more resistant starch than the RSC cereals and the oat reference (208 g/kg starch versus 81-147 g/kg starch, respectively). Overall acceptability and texture of sorghum cereals did not differ significantly from the oat reference, although appearance and aroma liking were significantly reduced. Therefore, non-tannin sorghum has potential to be used in the breakfast cereal industry with minimal impact on nutritional profile and sensory properties. Sajjanar et al. (2010) made an attempt to test sorghum varieties of northern dry zone of Karnataka for flaking. To make sorghum viable in the food sector, either commonly grown jowar needs to be subjected for standardization of food processing or special grain type varieties with suitable flour texture can directly be made into use for commercialization. Therefore, to identify the suitable variety for good flaking two farmers' varieties of Rabi sorghum viz., Atharga Kempu Jola (Kadabina jola with property of high gelatinization of starch), Sakkari Mukkari Jola (Seetani Jola with sweet grain) were tested along with popular roti making variety M35-1. Flakes of these varieties were evaluated for flake yield and quality parameters. Colour and size of the flakes were observed visually and recorded. It revealed that Atharga Kempu Jola recorded high values for flake length, breadth and volume compared to other varieties. The flakes of Atharga Kempu Jola and M35-1 were elliptical, however, those of Sakkri Mukkri Jola were round in shape. The flakes of Atharga Kempu Jola were thin, with uniform shape and slightly elongated compared to M35-1. It also has attractive red colour unlike off white colour in M35-1 and dull colour in Sakkri Mukkri Jola. Organoleptic evaluation of flakes samples was carried out using five point scale by 25 semi trained panel members. Atharga Kempu Jola flakes scored high compared to other two varieties. Comparatively high grain yield, flake yield (%) and flakes quality recorded by variety Atharga Kempu Jola indicated its suitability for commercial exploitation in flaking. McNeill et al. (1975) conducted experiments to ascertain chemical and physical properties of carbohydrates from dry-ground, steam flaked reconstituted and micronized sorghum grain, and to relate these factors to differences in in vivo digestibility. There were differences in carbohydrate profiles and carbohydrate solubilities of differently processed grains. Starch granules of micronized and steam flaked grains were completely gelatinized and extensively swelled. Starch in steam flaked grain was most susceptible to enzyme action. The effect of method of processing upon solubility of protein matrix encapsulating the starch granules in the endosperm seems to be major factor affecting efficiency of utilization. Processing method which produces a change in the organization of sorghum grain kernel to release starch granules from the protein matrix offer promises of increasing utilization.

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