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Effect of feed moisture, variety and single screw extrusion on physicochemical properties and acceptability of grain sorghum

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Abstract

Four (4) cultivated varieties of sorghum were extruded in a single-screw extruder. Extrusion was done at 15, 20 and 25% feed moisture and a temperature of 130^{O}C at 140 rpm screw speed and 2 mm die diameter. The grain dimensions and proximate composition of the sorghum cultivars were determined using standard procedures. The water absorption index (WAI), water solubility index (WSI), bulk density (BD) and expansion ratio (ER) of the extrudates were also determined. The grain thickness, length, width, weight, volume and density varied from 2.26 to 2.87 mm, 4.16 to 4.99 mm, 3.57 to 4.18 mm, 24.57 to 42.56 g/100grains, 25.61 to 61.00 cm^3 and 0.709 to 0.942 g/cm^3 respectively. There was significant difference ($p \leq 0.05$) in grain thickness, length, width, volume and density respectively. The proximate composition of the sorghum varieties were; Carbohydrate 71.22 to 73.94%, protein 10.36 to 11.20%, moisture 10.67 to 11.64%, crude fat 2.34 to 4.51% and ash 1.85 to 2.41% respectively. The crude fibre content of the sorghum grains ranged from 2.0 to 2.4% with Chakalari white recording the lowest value while Kanoline had the highest value. The physical and functional properties of sorghum extrudates varied from 1.86 to 5.68 for expansion ratio and 0.134 to 1.114 g/cm^3 for bulk density. The water absorption index of the sorghum extrudates varied from 3.97 to 6.21 g H_2O/g sample while the WSI of the sorghum extrudates ranged from 3.7 to 9.07%. There was significant ($p<0.05$) variation in the grain dimensions, proximate composition, physical properties and water absorption behaviour of the sorghum varieties.

Keywords: grain dimension, expansion, extrusion, sorghum variety, water absorption

Introduction

Extrusion processing has become an increasingly popular procedure in the cereal, snack and pet food industries, which utilizes starchy and proteinacious raw materials. It exhibits several advantages, the principal one being that the ingredients undergo a number of unit operations, e.g. mixing, shearing, shaping, cooking, drying and texturization, in one energy efficient and rapid process (Stanley, 1986) [1]. The food processor is at a distinct advantage when working with fabricated foods, since it is possible, within technological limits, to adjust both the composition of starting material and duration of the process to maximize structure and quality.

Starch-based snack foods are a popular example of extruded materials. Studies on starch extrusion (Owusu-Ansah *et al*. 1982; 1983; 1984) [2, 3, 4] have shown that two major operations occurring during this process-heating in the presence of water and shearing – impart structure to the final product through the transformation of starch granules by the mechanism of gelatinization. It is known that the moisture content has a significant influence on the gelatinization process. Thus when corn starch was retorted at 120ºC for 1 hour at total moisture contents ranging from 13 to 60%, scanning electron micrographs showed that as the moisture level increased, starch granules exhibited swelling and eventually disintegrated (Owusuh-Ansah *et al*. 1983 and Stanley, 1986) [3, 1].

Starch-based ingredients are extruded at lower moistures than vegetable proteins. Low moisture extrusion in the range of 12 – 16% dry weight basis is practiced (Harper, 1986) [5] to make expanded snacks. Ready to eat (RTE) cereals are typically extruded at 25 – 42% moisture (Gbenyi *et al*. 2016a) [6]. During the extrusion process, the starch is partially hydrated and subjected to increasing shear while it is mechanically conveyed and heated. Gomez and Aguilera (1984) [7] described a process in which shear causes mechanical damage to the starch while the application of heat and moisture favours a loss in crystallinity. Lower moisture content causes increased viscosity and more mechanical damage. Amylopectin cannot align itself effectively in the streamlines of flow in the screw and die because of the bulkiness of the molecules resulting in its greater mechanical damage and reduced molecular size (Davidson *et al*. 1984) [8]. These damaged starches are characteristically less cohesive than gelatinized undamaged starch. Consequently, they expand less, predominantly in the longitudinal direction (Launay and Lisch, 1983) [9], creating products with smaller pores, softer textures, greater solubility, and a sticky character when eaten. High moisture extrudates have larger pore sizes and thicker cell walls. This is characteristics of extruded RTE cereal products, which hydrate more slowly than snack foods, retaining their desired crispness longer when consumed with milk.

Amylose is less susceptible to mechanical damage than amylopectin in the flow environment within the extruder. Also higher temperatures are required to increase its solubility. Typically, high amylose products are denser, harder and less radially expanded when extruded. Reductions in shear and break strength for extrudates having increased amylase content were indicated by Faubion *et al.* (1982) [10].

A study by Sopade *et al*. (2008) [11] to investigate the effects of extrusion on functional and digestibility properties of sorghum (var. Buster) and triticale (var. Koslusko) using a twin screw extruder showed that, extrusion changed the pasting behavior of the sorghum suggesting the disruption of starch-protein interaction in the extrudates. In addition to the pasting behavior, extrusion affected other properties of the extrudates and the response of the extruder was dependent on the changes to moisture and screw speed at the maximum barrel set temperature of 140ºC. Sopade *et al*. (2008) [11] further stated that extrusion can yield products from sorghum with variable digestibility which can be described by digestion models with parameters that can significantly correlate with final properties and extrude response. Extruding sorghum at 30% moisture and 250 rpm could yield maximum starch digestion for optimum energy delivery from products.

According to Mahasukhonthachat *et al*. (2008) [12], extrusion increased (up to 150%) water absorption index (WAI) or water solubility index (WSI) of milled sorghum grain and the indices significantly depended on extrusion conditions. Extrusion moisture caused a decrease in WAI and WSI, while both indices increased with the screw speed. According to the workers, there was no significant relationship between the degree of gelatinization and WAI and WSI however, the molecular and structural changes that accompany starch gelatinization would be expected to enhance water-binding ability and water solubility. If gelatinization is accompanied by depolymerization of starch into low molecular weight materials, WSI may increase while WAI decreases. Water solubility index (WSI) has been reported to represent the extent of soluble starch released from the grain in excess of water (Doucet *et al*. 2009; White *et al.* 2008) [13, 14]. Extrusion of fine fractions resulted in the highest WSI compared to the coarse fraction, while it was intermediate for the medium sized fraction (3.25) and the unsieved ground material (3.46). The increase in WSI with decreasing particle size may be attributed to the greater specific surface area before extrusion, resulting in higher leaching of soluble starch derived molecules after extrusion dissolved in water during the WSI assay. In sorghum, extrusion temperature had no significant effect on the WSI.

Response surface methodology was used (Owusu – Ansah, *et al*. 1984) [4] to examine the effects of primary extrusion variables (temperature, moisture and screw speed) on starch gelatinization in a twin-screw extruder. It was found through the use of multiple linear regression that these variables accounted for more than 90% of the variation in gelatinization. Linear effects of temperature, moisture and screw speed were found to be significant, as was the interaction of the temperature and moisture content. According to Owusu-Ansah *et al*. (1984) [4], the response surfaces generated from these equations indicated that maximum gelatinization occurred at the minimum temperature (100º C) and at the maximum moisture content (23%), while minimum gelatinization was observed at the same temperature but at the lowest moisture content (10%). Increasing extrusion temperature at high feed moistures, however, produced and apparent decrease in gelatinization. Scanning electron microscopic examination of three extruded samples indicated that all the starch granules were completely gelatinized even at 100ºC. This anomalous reduction and gelatinization with increased extrusion temperature is considered to be a result of hydrolytic breakdown of the starch polymers which reduced the formation of the amylase-iodine complex. Chromatographic studies demonstrated the presence of maltose and other low molecular weight compounds in samples produced at high temperatures and moistures, thus strengthening the hydrolysis hypothesis.

Upon heating and working during the extrusion process, the macromolecules in food ingredients lose their native, organized tertiary structures and form a continuous viscous mass (Stanley, 1986, Owusu-Ansah *et al*. 1982, 1983, and 1984) [1, 2, 3, 4]. As it flows, it exposes bonding sites which lead to cross-linking and a reformed, expandable structure that creates the crunchy or chewy texture in fabricated foods. Vegetable protein and starch are the major components of textured food mixtures and deserve special attention as model systems.

Several authors (Danbaba *et al*. 2017, Gbenyi *et al*. 2016a, Filli *et al*. 2010 and Anuonye *et al*. 2010) [15, 6, 16, 17] have reported on the extrusion of composites of legumes and various cereals (sorghum, rice, millet or acha) to produce ready-to-eat foods. Although Nigeria is the largest producer of sorghum in Africa and third largest the world over (USDA, 2015) [18], sorghum is underutilized in modern food processing. Reasons for the underutilization include presence of polyphenols, phytates, poor starch and protein digestibility, poor amylolitic activity, absence of gluten among others. There is also, dearth of information on effect of extrusion on various sorghum cultivars native to Nigeria. Such information will help food processors in the choice of sorghum varieties that will best serve their processing needs. This work was designed to assess some physical, hydration properties and proximate composition of extruded sorghum varieties cultivated in Nigeria.

2. Materials and Methods

2.1 Procurement of raw materials

The sorghum varieties Chakalari red and Chakalari white were obtained from Maiduguri Monday Market. The improved sorghum varieties CSV400 and Kanoline-2 were procured from ICRISAT Research Institute Bagauda, Kano, Nigeria.

2.2 Sample preparation

2.2.1 Preparation of sorghum flour

All grains were cleaned using a laboratory aspirator (Vegvari Ferenc Type OB125, Hungary) to remove stalks, chaff, leaves and other foreign matter. They were then washed with clean water and sun dried. The sorghum samples were dehulled, sun-dried, and milled, using an attrition mill (Imex GX 160, Japan). This was then oven dried to a moisture content of 12%. The flour was packed in polythene bags and stored for further use.

2.2.2 Moisture adjustment of sorghum flours

The total moisture content of samples was adjusted to the desired level by adding the appropriate amount of water, mixing thoroughly, and allowing to equilibrate.

2.3 Physical analysis
2.3.1 Grain dimensions
One hundred kernels were randomly selected. The length and width of kernels was determined using micrometer screw-gauge.

2.3.2 1000 Kernel weight
One thousand kernel weight was determined according to the procedure described by Gomez *et al.* (1997).

2.3.3 1000 Kernel volume
The sample used for one thousand kernel weight was transferred into a measuring cylinder containing a known volume of water. The new volume resulting from the displacement of the grains by water was noted and the difference between the two readings taken as the grain volume. The density of the grains was calculated based on the volumes obtained from 1000 kernel weight and 1000 kernel volume.

2.3.4 Bulk density of grains
The bulk density of grain samples was determined using the procedure described by Banigo and Akpapunam (1987) [20].

2.3.5 Bulk density of extrudates
Bulk density of the extrudates was determined using the method of Qing-Bo *et al*. (2005) [21] as described by the following equation below:

$$\text{Bulk density} = \frac{4a^0}{\pi D^2 L}$$

Where:
a^o = Mass of extrudates
D = Diameter of extrudates
L = Length of extrudates

2.3.6 Expansion ratio (ER)
This was determined according to the procedures of Alvarez-Martinez *et al*. (1988) [22]. The following equation was used.

$$\text{Expansion ratio} = \frac{De}{D}$$

Where:
De = diameter of extrudate (mm)
D = diameter of the die (mm)

2.3.7 Water absorption index (WAI) and water solubility index (WSI)
This was determined according to the method of Beuchat (1977) [23]. One gram (1g) of sample was mixed with 10 mL distilled water for 30 sec in a centrifuge tube. The samples were allowed to stand at 25 ºC for 30 min and centrifuged (Model: Hettich Zentrifugen D-7200 Type 2008) at 55,000 x g for 30 min. The supernatant was decanted into an evaporating dish of known weight. Water absorption index was determined as the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The supernatant was dried to constant weight in an air oven at 100ºC. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.

$$WAI = \frac{Weight\ gain\ by\ gel}{Dry\ weight\ of\ extrudate}$$

$$WSI = \frac{Weight\ of\ dry\ solids\ in\ supernatant}{Dry\ weight\ of\ extrudate} x \frac{100}{1}$$

2.4 Extrusion of sorghum varieties
Four (4) different cultivated varieties of sorghum were extruded in a single-screw extruder (Model: Brabender Duisburg DCE-330), equipped with a variable speed DC drive unit and strain gauge type torque meter. Extrusion was done at 15, 20 and 25% feed moisture and a temperature of 130ºC, 140 rpm screw speed and 2 mm die diameter. The extruder was fed manually through a screw operated conical hopper using a plastic bowl. Five hundred grams (500 g) of each sample was fed into the extruder hopper. The hopper which is mounted vertically above the end of the extruder is equipped with a screw rotated at variable speed. Experimental samples were collected when steady state (constant torque and temperature) was achieved. Extrudates were kept on stainless steel work benches overnight to dry. They were then packaged in polythene bags the next day prior to analysis.

2.5 Proximate composition of samples
The moisture, crude fat, crude protein, total ash and crude fibre of samples were carried out using the methods in Egan *et al*. (1981) [24]. The per cent carbohydrate was determined by subtracting the known amounts of moisture, crude fat, crude protein and ash from 100. The difference was reported as the per cent carbohydrate (Egan *et al*. 1981) [24]. Calorific values of the extrudates were estimated using the Atwater factors of 4 Calories for carbohydrate and protein and 9 calories for crude fat.

2.5.1 Sensory evaluation
The nine-point hedonic scale described by Larmond (1977) [25] was used to assess the acceptability of extrudates from the sorghum varieties. The highest score (9) was described as "like extremely" while the least score (1) was described as "dislike extremely". Results of the evaluation were subjected to statistical analysis using analysis of variance. Mean scores were separated using Least Significant Difference (LSD).

2.6 Statistical analysis
STATISTIX 9.0 Statistical Analysis Software was used in the statistical analysis of data. Results were subjected to Analysis of Variance (ANOVA). Mean scores were separated using Least Significant Difference (LSD).

3. Results and Discussion
3.1 The grain dimensions
The grain dimensions of the sorghum varieties are presented in Table 1. The grain thickness of the cultivars ranged from 2.26 to 2.87 mm. The lowest thickness was observed from Chakalari Red while the highest thickness was observed from Kanoline variety. There was significant difference ($p \leq 0.05$) in grain thickness among cultivars. The length of the grains varied from 4.16 to 4.99 mm. The ICSV400 variety had the lowest grain length while Chakalari Red had the highest gain length. There was significant ($p<0.05$) variation in grain length of the sorghum cultivars. The grain width of the cultivars ranged from 3.57 to 4.18 mm. The lowest grain width was observed from ICSV400 while Chakalari Red had the highest grain width. There was significant ($p<0.05$) variation in the grain width of the cultivars. The grain weight of the cultivars varied from 24.57 to 42.56 g/100 grains. The ICSV400 was significantly ($p<0.05$) lower in grain weight. Kanoline 2 had the highest grain weight. The grain volume of

the cultivars ranged from 25.61 to 61.00 cm^3 while the density of the grains varied from 0.709 to 0.942 g/cm^3. Kanoline 2 had the highest volume while ICSV400 had the highest lowest. There was significant difference ($p \leq 0.05$) in grain volume among the sorghum cultivars. The data on sorghum grain dimensions is useful in the design and fabrication of cleaning and milling equipment.

Table 1: Grain dimensions of the four varieties of sorghum[1]

Cultivar	Thickness	Length	Width	Weight	Volume	Density
Chakalari White	2.30b	4.44b	4.08a	34.22c	49.12b	0.719b
Chakalari Red	2.26b	4.99a	4.18a	35.01b	48.21b	0.738b
Kanoline 2	2.87a	4.87a	4.13a	42.56a	61.00a	0.709b
ICSV400	2.28b	4.16b	3.57b	24.57d	25.61c	0.942a
Std error	0.10	0.18	0.17	0.38	1.08	0.02
Critical value	0.21	0.36	0.34	0.78	2.20	0.034

[1]Any two means in a column not accompanied by the same letters are significantly ($p<0.05$) different.

3.2 Proximate composition of sorghum flours

The proximate composition of the various sorghum cultivars is presented in Table 2. Carbohydrate content of the sorghum flours varied from 71.22 to 73.94%. The lowest carbohydrate content was recorded by Kanoline 2 while the highest carbohydrate content was observed from Chakalari White. The protein content of the flours ranged from 10.36 to 11.20%. Kanoline 2 had the lowest protein content while Chakalari white had the highest protein content. The moisture content of the flours varied from 10.67 to 11.64%. There was significant ($p<0.05$) difference in the moisture content of the sorghum flours. The crude fat content of the flours ranged from 2.34 to 4.51%. Chakalari white flour had the lowest fat content while Kanoline 2 had the highest fat content. The ash content of the sorghum flours ranged from 1.85 to 2.41%. Crude fibre ranged from 2 to 2.4% with chakalari white recording the lowest value while Kanoline had the highest value. There was ($p<0.05$) significant difference in the fibre content of the extrudates.

Table 2: Proximate composition of sorghum flours (%)

Cultivar	Carbohydrate	Protein	Moisture	Crude fat	Crude fibre	Ash
Chakalari White	73.94a	11.20a	10.67c	2.34c	2.0c	1.85c
Chakalari Red	73.31a	10.87b	11.49b	2.40c	2.2b	1.93c
Kanoline 2	71.22b	10.36c	11.50b	4.51a	2.4a	2.41a
ICSV400	72.16c	10.51c	11.64a	3.46b	2.0c	2.23b

3.3 Physical and functional properties of the sorghum extrudates

3.3.1 Expansion ratio (ER)

The physical and functional properties of the extrudates are presented in Table 3. In extrusion cooking, expansion is the primary quality parameter associated with product crispness, water absorption, water solubility, and crunchiness. During extrusion cooking of biopolymers, the viscoelastic material is forced through the die so that the sudden pressure drop causes part of the water to vaporize, giving an expanded porous structure (Sawant *et al*. 2013) [26]. Expansion ratio of the sorghum extrudates varied from 1.86 to 5.68 with Chakalari Red extruded at 15% moisture showing the lowest ER while Chakalari White had the highest expansion ratio. The ER of Kanoline 2 and ICSV400 progressively increased as the feed moisture was increased. The ER for Chakalari Red and Chakalari White however increased with the feed moisture up to 20% and then began to decline as the feed moisture was increased to 25%. This may be explained by the varietal differences in the grains. A high ER is desirable in the production of expanded snacks (Jadhav and Annapure, 2013) [27].

3.3.2 Bulk density (BD)

Bulk density measures the heaviness of a food material (Oladele and Aina, 2007) [28]. The bulk density of the sorghum extrudates varied from 0.134 to 1.114 g/cm^3. Chakalari White extruded at 20% feed moisture had the lowest bulk density while Chakalari White extruded at 15% feed moisture had the highest bulk density. There was ($p<0.05$) significant difference in the bulk density of the extrudates. Bulk density is inversely related to expansion ratio. The more expanded the extrudate, the less the bulk density. There was significant ($p \leq 0.05$) variation in the bulk density of the extrudates of the various sorghum cultivars which could be due to both varietal differences and the variation in the feed moisture.

3.3.3 Water absorption index (WAI)

WAI and WSI are indices that are important in explaining the degree of gelatinization (cooking) (Kebede *et al*., 2010) [29]. The water absorption index of the sorghum extrudates varied from 3.97 to 6.21 g H_2O/g sample. The Chakalari White extruded at 15% moisture had the lowest WAI while Chakalari Red extruded at 20% feed moisture had the highest WAI value. There was significant ($p<0.05$) difference in the WAI of the sorghum extrudates. The values reported in this work are similar to the findings by Gbenyi *et al.* (2016a) [6]. The WAI of the extrudates increased with increase in feed moisture up to a maximum at 20% similar observations were made by Anderson *et al*. (1969) [30]. According to Mahasukhonthachat *et al*. (2008) [12], extrusion increased (up to 150%) water absorption index (WAI) or water solubility index (WSI) of milled sorghum grain and the indices significantly depended on extrusion conditions.

3.3.4 Water solubility index

Water solubility index (WSI) has been reported to represent the extent of soluble starch released from the grain in excess of water (Doucet *et al*. 2009; White *et al.* 2008) [13, 14]. The WSI of the various sorghum extrudates ranged from 3.70 to 9.07%. Kanoline 2 extruded at 15% moisture had the lowest

WSI value while Chakalari White extruded at 20% feed moisture had the highest WSI. There was significant ($p<0.05$) difference in the WSI of the various sorghum extrudates. This may be because of the varietal differences and the variation in the feed moisture. The water solubility index increased with increase in feed moisture.

Table 3: Physical and water absorption properties of extrudates from four sorghum varieties

Cultivar	Feed Moisture	Expansion Ratio	Bulk Density	WAI	WSI
Chakalari White	15	1.96^{e}	1.114^{a}	3.97^{e}	5.34^{cd}
Chakalari White	20	5.68^{a}	0.134^{d}	5.60^{b}	9.07^{a}
Chakalari White	25	4.40^{d}	0.184^{cd}	5.20^{c}	6.77^{bc}
Chakalari Red	15	1.86^{e}	1.050^{a}	4.40^{d}	5.07^{cd}
Chakalari Red	20	5.20^{b}	0.148^{cd}	6.21^{a}	7.92^{ab}
Chakalari Red	25	4.70^{cd}	0.208^{cd}	5.42^{bc}	6.28^{bc}
Kanoline 2	15	1.86^{e}	1.070^{a}	4.15^{dc}	3.70^{d}
Kanoline 2	20	4.80^{bcd}	0.186^{cd}	5.54^{bc}	6.04^{bc}
Kanoline 2	25	4.98^{bc}	0.258^{c}	5.22^{c}	6.80^{bc}
ICSV400	15	1.88^{e}	0.868^{b}	5.31^{bc}	6.32^{bc}
ICSV400	20	4.72^{cd}	0.220^{cd}	5.24^{c}	6.50^{bc}
ICSV400	25	4.86^{bcd}	0.222^{cd}	5.24^{c}	6.78^{bc}

3.4 Sensory evaluation

The primary consideration for selecting and eating a food commodity is the product's palatability or eating quality. Other quality parameters such as nutrition and wholesomeness are secondary (Meiselman and MacFie, 1996, Lawless and Heymann, 1998) [30, 31]. The results of sensory evaluation of the sorghum extrudates are presented in Table 4. The scores for the colour of the extrudates ranged from 4.5 to 8.4. The extrudates from Kanoline 2 extruded at 20% feed moisture and ICSV400 extruded at 15% moisture, had the lowest score for colour while extrudates from Chakalari red, extruded at 15% moisture, had the highest scores for colour which was the most acceptable to the judges. The scores for the flavour of extrudates varied from 5.3 to 8.4. The lowest scores for flavour were from Kanoline 2 extruded at 25% feed moisture and ICSV400 extruded at 25% moisture, while the highest scores were from Chakalari white extruded 20% feed moisture, which was adjudged the most acceptable product. The crunchiness of the extrudates ranged from 5.3 to 8.4 with Chakalari white and Chakalari red, both extruded at 20% moisture having the highest scores. The overall acceptability scores varied from 5.2 to 8.3 with Chakalari white extruded at 20% moisture having the highest scores. Extrudates from Chakalari white were found most acceptable to the judges. Gbenyi *et al.* (2016b) [32] reported a good overall acceptability (10.46 on a 15 point scale) when sorghum-soybean flour blends were extruded. The findings in this work indicate sorghum as a good potential for the production of ready to eat snacks, breakfast cereals and related products using extrusion technology

Table 4: Sensory evaluation of sorghum extrudates[1]

Cultivar	Feed moisture	Colour	Flavour	Crunchiness	Overall acceptability
Chakalari white	15	7.5±0.14b	8.2±0.08a	8.3±0.41a	8.1±0.23a
Chakalari white	20	7.3±0.33b	8.4±0.23a	8.4±0.32a	8.3±0.11a
Chakalari white	25	8.2±0.26a	7.3±0.22b	7.1±0.25b	7.6±0.17b
Chakalari red	15	8.4±0.22a	8.1±0.17a	8.2±0.30a	8.2±0.28a
Chakalari red	20	8.2±0.32a	8.1±0.20a	8.4±0.08a	7.5±0.12b
Chakalari red	25	7.5±0.06b	7.5±0.13b	8.1±0.21a	8.1±0.34a
Kanoline 2	15	5.7±0.34c	5.5±0.30c	6.5±0.05c	7.7±0.06b
Kanoline 2	20	4.5±0.08d	5.5±0.15c	6.6±0.06c	6.4±0.22c
Kanoline 2	25	5.6±0.24c	5.3±0.09c	6.2±0.33cd	5.2±0.13de
ICSV400	15	4.5±0.11d	5.6±0.18c	6.2±0.14cd	6.7±0.24c
ICSV400	20	4.8±0.12d	5.4±0.33c	5.3±0.23d	5.3±0.17d
ICSV400	25	5.6±0.06c	5.3±0.07c	5.4±0.05d	5.6±0.08d

[1]Any two means in a column not accompanied by the same letters are significantly ($p<0.05$) different.

4. Conclusion

There was significant ($p<0.05$) variation in the grain dimensions, proximate composition, physical properties and water absorption behaviour of the sorghum varieties. Chakalari red was significantly higher in length and width while Kanoline 2 was significantly ($p<0.05$) higher in thickness, weight and volume than the other grain varieties. The expansion ratio of the extrudates was found to generally increase as the feed moisture was increased from 15 to 25% while the bulk density of extrudates generally decreased as the feed moisture was increased from 15 to 25%. This information could be useful in the fabrication of cleaning and milling equipment and also in the selection of sorghum varieties for the production of extruded snacks or breakfast cereals.

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