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PROPERTIES OF EXTRUDATES FROM SORGHUM VARIETIES

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ABSTRACT

Extrusion cooking is a modern high-temperature short-time (HTST) processing technology, which is becoming popular in certain industries because it offers several advantages over other types of cooking processes. The objective of this study was to evaluate the extrusion performance of sorghum (*Sorghum bicolor*) varieties commonly grown in Uganda. Four varieties of sorghum namely, Seso1, Epuripur, Seso3 and Eyera were extruded with and without defatted soy-flour. Physical-chemical properties of the extrudates including, lateral expansion, bulk density, hardness, water absorption index, water solubility index, as well as proximate composition were determined. The extrudates exhibited 240-300% lateral expansion and 0.067-0.095 g cm^{-3} bulk density. The water absorption index was 6.4-7.9 g g^{-1} compared to 1.9-2.3 g g^{-1} of the control; while the water solubility index was 6.5-13% compared to 3.4-5.0%% of the control. Extrusion of all the varieties reduced the peak and final viscosity of the extrudates. There were no varietal differences with respect to lateral expansion, bulk density and hardness. However, the water absorption index for the varieties increased in the order, Eyera, Seso 3, Seso 1 and Epuripur; while the water solubility index for the varieties increased in the order, Seso 1, Seso 3, Eyera and Epuripur. Defatted soybean flour had no effect on the extrudate properties. The results suggest that the four sorghum varieties in this study can be used in the production of extruded puffed snacks, breakfast cereals and other food products.

Key Words: Bulk density, extrusion cooking, sorghum, soy-flour

RÉSUMÉ

La cuisson-extrusion est une technologie moderne de cuisson rapide à haute température qui devient de plus en plus populaire dans certaines industries parce qu'elle offre plusieurs avantages face à d'autres procédés de cuisson. L'objectif de cette étude était d'évaluer la performance de l'extrusion des variétés du sorgho (*Sorghum bicolor*) communément cultivées en Ouganda. Quatre variétés du sorgho dont Seso1, Epuripur, Seso3 et Eyera étaient extrudées avec et sans farine du soja dégraissée. Les propriétés physico-chimiques de l'extrudant incluant l'expansion latérale, la densité volumique, la dureté, l'indice d'absorption d'eau ainsi que la composition chimique étaient déterminées. Les extrudants ont manifesté 240-300% de l'expansion latérale et 0.067-0.095 g cm^{-3} de la densité volumique. L'indice d'absorption d'eau était de 6.4-7.9 g g^{-1} en comparaison avec 1.9-2.3 g g^{-1} dans le contrôle, pendant que l'indice de solubilité dans l'eau était de 6.5-13% contre 3.4-5.0% dans le contrôle. L'extrusion de toute les variétés a réduit l'apogée et la viscosité finale des extrudants. Il n'y avait pas de différences significatives entre les variétés au niveau de l'expansion latérale, la densité volumique et la dureté. Par ailleurs, l'indice d'absorption d'eau pour les variétés a augmenté dans l'ordre pour les variétés Eyera, Seso 3, Seso 1 et Epuripur; pendant que l'indice de solubilité dans l'eau pour les variétés a augmenté dans l'ordre pour les variétés Seso 1, Seso 3, Eyera et Epuripur. La farine degraissée de soja n'avait aucun effet sur les propriétés de l'extrudant. Ces résultats suggèrent que toutes les quatre variétés de sorgho dans cette étude peuvent être utilisées dans la production des collations , céréales pour petit déjeuner et autres produits alimentaires.

Mots Clés: Densité volumique, extrusion de cuisson, sorgho, farine de soja

INTRODUCTION

Extrusion cooking is a modern high-temperature short-time (HTST) processing technology, which is becoming popular in certain industries because it offers several advantages over other types of cooking processes, such as faster processing times and significant reduction in energy consumed, which consequently results in lower prices for the final products (Branèiæ *et al.,* 2006). The products of extrusion are important in the food and feed industries today. An extruder represents a very complex bioreactor in which, various types of food raw materials with different moisture contents and viscosities are treated, under high temperatures, short residence times, high pressures and very strong shear forces (Branèiæ *et al.,* 2006).

Extrusion typically involves mixing, mass kneading, heating, shearing, and lastly forcing the food material through a die appropriately designed to form and dry an expanded product under rapid fall in pressure (Akdogan, 1999). The extrudate formed has characteristic properties that are very different from the starting raw materials (Cai *et al.,* 1995).

Sorghum (*Sorghum bicolor* L. Moench) is major food and cash crop in Africa (Rohrbach, 2003; Ebiyau *et al*., 2005) with over 90 million people directly dependant on it in the east and central Africa region alone. However, in most of the communities that depend on sorghum, little or no value addition processing is done on this crop. The little processing that is done involves milling, malting and fermentation with rudimentary traditional technologies to produce, flours, traditional alcoholic and non-alcoholic beverages and pre-ferments. Extrusion is a relatively new technology in Africa that is not widely used.

Nonetheless, extrusion technology provides more opportunities for producing and marketing new value added products from soghum. Early research done on extrusion of sorghum showed both successes and challenges (Anderson *et al*., 1969; Pelembe *et al*., 2002). As such, most of the work done on sorghum extrusion has been on sorghum composites. On the other hand, sorghum breeding programmes have continued to release high yielding elite sorghum varieties. However, such elite varieties have not been evaluated for extrusion purposes. The objective of this work was to evaluate the extrusion performance of sorghum varieties commonly grown in Uganda for products like breakfast cereals and snack foods.

MATERIALS AND METHODS

Samples and sample treatment. One hundred kg each, of four sorghum varieties namely, Epuripur, SESO 3 SESO1 (improved varieties) and Eyera (local variety) were obtained from National Semi-Arid Resources Research Institute (NaSARRI), in Uganda. The samples were manually cleaned and sorted to get rid of chaff, foreign matter and any broken, shriveled and/or moulded grains. Defatted soy-flour packed in sealed polyethylene bags was obtained from a local supplier (SESACO Uganda Ltd).

The sorghum grain varieties were individually milled into flour using a commercial hammer mill. The flour from each sorghum variety was then individually mixed with defatted soy-flour at 0, 3 and 6% (w/w) proportions. The control samples were un-extruded flours from the respective sorghum varieties to which no soy-flour was added. Treatment samples were identified by sorghum variety name and level of defatted soy flour added.

Extrusion process. Prior to extrusion, 30 kg of the mixed flour were individually thoroughly mixed with 3% potable tap-water (w/w) in order to condition the flour for proper extrusion. Extrusion was done in a co-rotatory intermeshing twin screw extruder, at temperatures: 60 ^{o}C (heater area I), 130 ^{o}C (heater area II) and 150 ^{o}C (heater area III); Screw frequency: 35Hz; Filler frequency: 30Hz and Cutter frequency: 50Hz. The residence time for sorghum flour samples in the extruder was about 5 seconds. Preliminary experiments (results not shown) exhibited these conditions as the optimum extrusion conditions for sorghum. Extrudates were collected, dried and packaged in polyethylene bags, and kept for further analysis. All treatments were extruded in triplicates and each analysis was done in duplicate.

Laboratory analyses

Diameter of extrudates. Ten extrudates were selected at random from each of the triplicate extrudate samples. Using a vernier caliper, the diameter of the extrudates was measured at three positions along the length of each of the selected samples. The average of the 3 x 10 readings was taken as the extrudate diameter for subsequent statistical analysis.

Lateral expansion of extrudates. The ratio of diameter of extrudates to the diameter of die was taken as a measure of lateral expansion of the extrudates (Ibanoglu *et al*., 2006). The percent Lateral Expansion (LE) was calculated using the mean of the measured diameters with the following equation:

$$LE = \frac{\text{Diameter of extrudate - Diameter of extruder}}{\text{Diameter of extruder die}} \times 100$$

Bulk density of extrudates. Bulk density (BD) measured in g cm^{-3} (Stojceska *et al*., 2008) was calculated using:

$$BD = \frac{4 \times m}{\pi \times d^2 \times L}$$

Where:

m = mass (g), L = length (cm) and d = diameter (cm) of extrudates.

Hardness of extrudates. Hardness of the sorghum grains was determined using a penetrometer (AFG series, T.W.L Force Systems, Stubbington, United Kingdom). The probe was attached onto the penetrometer and then the gauge fitted onto the strand. The penetrometer was allowed to stabilise for 20 minutes and it was then zeroed by pressing the reset button. Each sample was placed in between the probe and the stand using a lever. The probe was then gently lowered to press against the sorghum extrudate and the reading on the gauge was recorded in degrees and then converted to mm (1° = 0.01 mm) using a conversion table supplied with the instrument. The higher the measured degrees the softer the sample.

Water Absorption Index (WAI) and Water Solubility Index (WSI). WAI and WSI were determined using the method developed for cereals (Stojceska *et al*., 2008; Yagci and Gogus, 2008). The extrudate samples were ground into a fine flour and suspended in water at room temperature (approximately 25 °C) for 30 minutes, and gently stirred during the period. The samples in water were centrifuged at 6000 rpm for 10 minutes. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. WAI and WSI were calculated using the following formulae:

$$WAI\ (g/g) = \frac{\text{Weight of wet gel - Dry weight of extrudate}}{\text{Dry weight of extrudate}}$$

$$WSI\ (\%) = \frac{\text{Weight of dry solid in the supernatant}}{\text{Dry weight of extrudate}} \times 100$$

Determination of proximate composition

Moisture content. Moisture content was determined using the method recommended by AOAC (1996). About 2 g of sample was taken onto a preconditioned Petri-dish and dried in a hot air oven at 100 °C for about 18 hours. The dry sample was cooled in a dessicator for about 30 minutes and reweighed. The loss in weight was taken as moisture content of the sample and calculated as percentage of the total.

Crude fat analysis. The fatty material or crude fat in foods was determined by extraction of the dried food with Petroleum ether. The Soxhlet extraction method was used as described by AOAC (1996). About 3 g of the sample was mixed with about 40 ml of extraction solvent (Petroleum Ether) The extracted oil was weighed and expressed as a percent of the original sample weight.

Dietary fibre. Fibre was determined using the method described by Kirk and Sawyer (1991). About 1 g of the oven dried sample was taken for analysis. Total fiber content was weighed and expressed as a percent of the original sample weight

Ash content. Ash content was determined by the method described by AOAC (1996). About 3 g of the sample were taken for analysis. The ash extract expressed as a percent of the original sample weight

Crude protein. The Kjeldahl technique was used as described by Kirk and Sawyer (1991) for crude protein determination. About 0.2 g were measured from each sample for analysis. Protein content was calculated using the cereals' nitrogen conversion factor of 6.25.

Data analysis. Data were subjected to Analysis of variance (ANOVA) using the Statistical Package for Social Scientists (SPSS) computer software. Where significant differences were detected, the Least Significant Difference method was used to separate the means at $P < 0.05$.

RESULTS AND DISCUSSION

Physical properties of extrudate. Table 1 shows the physical properties of sorghum extrudates with and without soy-flour. Lateral expansion of extrudates ranged from about 240 in Eyera to 300% in Epuripur. However, there was no significant difference ($P>0.05$) among the expansion rates of extrudates from the different sorghum varieties. The expansion rates obtained in this work were higher than the 175-189% reported by Zamre *et al*. (2012) for sorghum based extruded products. This difference can be attributed to differences in varieties. According to Chinnaswamy and Hanna (1988), higher starch contents favour

TABLE 1. Physical properties of extrudates of four commonly grown sorghum varieties obtained from germplasm in Uganda

Sample	Diameter (cm)	Lateral expansion (%)	Bulk density (g cm^{-3})	Hardness (mm)
Seso1 + 0% Soy	1.58 (0.05)	284.11 (11.06)	0.077 (0.00)	1.78 (0.23)
Seso1 + 3% soy	1.61 (0.08)	292.60 (20.18)	0.078 (0.00)	1.84 (0.71)
Seso1 + 6% soy	1.47 (0.03)	256.76 (16.76)	0.090 (0.00)	1.78 (0.31)
LSD (0.05)	0.10	27.18	0.01	0.08
Epuripur + 0% Soy	1.55 (0.16)	275.91 (11.95)	0.069 (0.01)	1.42 (0.29)
Epuripur + 3% soy	1.46 (0.13)	255.47 (20.68)	0.073 (0.01)	1.74 (0.54)
Epuripur + 6% soy	1.65 (0.12)	301.22 (28.08)	0.067 (0.01)	1.04 (0.32)
LSD (0.05)	0.27	46.7	0.008	0.81
Seso3 + 0% soy	1.58 (0.06)	283.94 (9.81)	0.083 (0.01)	1.44 (0.35)
Seso3 + 3% soy	1.52 (0.06)	270.07 (9.64)	0.085 (0.00)	1.24 (0.43)
Seso3 + 6% soy	1.44 (0.05)	249.88 (7.46)	0.095 (0.01)	1.04 (0.41)
LSD (0.05)	0.07	18.20	0.009	0.5
Eyera + 0% soy	1.54 (0.05)	273.72 (9.42)	0.079 (0.01)	1.48 (0.53)
Eyera + 3% soy	1.47 (0.04)	256.94 (5.13)	0.081 (0.01)	1.34 (0.67)
Eyera + 6% soy	1.40 (0.14)	239.66 (3.07)	0.085 (0.01)	1.82 (0.25)
LSD (0.05)	0.17	17.00	0.008	0.46

Values in parenthesis ( ) are the standard deviation of the mean expansion of extrudates. The expansion recorded in this study seems to be higher due to starch content for the varieties tested in this study compared to those in literature. Other factors that could have contributed to the difference include formulation and extrusion conditions such as initial moisture content of the feed, the barrel and die temperatures, screw speed and feed rate.

Addition of defatted soy-flour at 6% decreased lateral expansion and increased bulk density in Seso1 Seso3 and Eyera ($P<0.05$). A similar trend of decreasing expansion was reported in sorghum extrudates containing increasing amounts of cowpea flour (Pelembe *et al.,* 2002). Chinnaswamy and Hanna (1988) noted that the expanded volume of cereal flour decreases with increasing amounts of protein and lipid; but increases with starch content. Although addition of soy-flour is nutritionally desirable since it increases the protein content of the extrudates, its reduction of the expansion is detrimental for products like puffed snacks that are sold by volume.

The hardness recorded for extrudates in this work (Table 1) suggests that the extrudates were in the lower intermediate and brittle range, which is desirable for puffed snack food. Both sorghum variety and addition of soy-flour had no significant effect on hardness of the extrudates. Hardness of a product is closely correlated with bite forces during mastication of any food (Mioche and Payron, 1995). The lower intermediate and brittle range suggests that the consumer would use relatively low force to crunch and bite the extrudates. This implies high desirability for puffed sorghum snack foods.

Table 2 presents the WAI and WSI of sorghums extruded with and without soy-flour. The extrudates had WAI and WSI 2-3 times higher than the control flour, implying that the extrudates would easily absorb moisture and get solublised. With respect to storage, these results suggest that the extrudates would have to be packed and stored in air tight packages to avoid moisture absorption to maintain the brittle texture. Anderson *et al.* (1969) reported a similar increase in WAI and WSI for sorghum extrudates obtained from varieties of Texas-Oklahoma areas in The USA. The higher WAI and WSI of the extrudates than the control flour was possibly due to the dextrinisation and depolymerisation of starch at extrustion temperatures, reducing molecular weight of amylose and amylopectin chains (Anderson *et al*., 1969; Gujska and Khan, 1990; Balandran-Quintana *et al*., 1998). Soy-flour reduced WAI in Seso1 and Eyera varieties, suggesting a soy-flour-sorghum variety interaction, which can be taken advantage of should a processor require a product with lower WAI.

TABLE 2. Water absorption index and water solubility index of extrudates from four commonly grown sorghum varieties obtained from the germplasm in Uganda

Sample	Water absorption index ($g\ g^{-1}$)	Water solubility index (%)
Seso1 CTRL	1.87 (0.06)	3.86 (0.29)
Seso1 + 0% soy	7.14 (0.17)	7.53 (0.85)
Seso1 + 3% soy	7.03 (0.19)	7.24 (0.53)
Seso1 + 6% soy	6.65 (0.16)	6.48 (0.07)
LSD (0.05)	0.36	0.73
Epuripur CTRL	2.03 (0.12)	4.02 (0.21)
Epuripur + 0% soy	7.16 (0.88)	11.91 (1.41)
Epuripur + 3% soy	7.90 (0.23)	11.03 (0.42)
Epuripur + 6% soy	7.42 (0.28)	12.23 (1.27)
LSD (0.05)	0.94	1.50
Seso3 CTRL	2.14 (0.16)	3.36 (0.22)
Seso3 + 0% soy	7.35 (0.33)	7.68 (0.89)
Seso3 + 3% soy	7.36 (0.08)	8.84 (0.60)
Seso3 + 6% soy	7.20 (0.27)	9.10 (0.68)
LSD (0.05)	0.37	1.45
Eyera CTRL	2.28 (0.17)	5.11 (0.34)
Eyera + 0% soy	7.87 (0.34)	11.75 (0.95)
Eyera + 3% soy	6.57 (0.36)	11.26 (0.63)
Eyera + 6% soy	6.39 (0.34)	13.70 (2.20)
LSD (0.05)	1.50	2.51

Values in parenthesis ( ) are the standard deviation of the mean

Proximate composition of extrudates. Table 3 shows the proximate composition of sorghum extrudates, with and without soy-flour. Extrusion resulted in decreased moisture, fat and fiber contents of the extrudates. The decrease in

TABLE 3. Proximate composition of the extrudates and control flour samples of sorghum varieties obtained from Uganda

Sample	Moisture (%)	Crude fat (%)	Dietary fiber (%)	Ash (%)	Protein (%)
Seso1 CTRL	10.88 (0.29)	3.75 (0.03)	5.18 (0.01)	1.51 (0.06)	8.79 (0.69)
Seso1 + 0% soy	4.36 (0.11)	1.14 (0.09)	2.78 (0.37)	1.86 (0.06)	10.47 (0.81)
Seso1 + 3% soy	4.56 (0.34)	1.25 (0.19)	2.44 (0.04)	2.00 (0.13)	13.50 (0.04)
Seso1 + 6% soy	4.51 (1.47)	1.41 (0.17)	2.85 (1.12)	2.23 (0.19)	18.04 (0.42)
LSD (0.05)	1.20	0.96	1.10	0.34	1.60
Epuripur CTRL	13.90 (0.38)	3.80 (0.11)	8.16 (0.37)	1.68 (0.12)	11.11 (0.06)
Epuripur + 0% soy	5.36 (0.71)	1.39 (0.06)	2.43 (0.40)	2.66 (0.50)	13.40 (0.11)
Epuripur + 3% soy	5.13 (0.46)	1.42 (0.11)	2.31 (0.17)	2.66 (0.05)	16.67 (1.12)
Epuripur + 6% soy	5.38 (0.40)	1.25 (0.03)	2.88 (0.38)	2.26 (0.02)	19.57 (0.20)
LSD (0.05)	1.36	0.50	1.20	0.89	2.25
Seso3 CTRL	10.66 (0.01)	3.30 (0.21)	9.30 (0.07)	1.88 (0.10)	9.54 (0.40)
Seso3 + 0% soy	5.49 (0.36)	0.75 (0.01)	6.00 (0.30)	1.67 (0.12)	12.57 (0.10)
Seso3 + 3% soy	5.20 (0.31)	0.79 (0.35)	5.75 (0.48)	1.91 (0.05)	15.68 (1.84)
Seso3 + 6% soy	4.91 (1.00)	1.21 (0.52)	5.45 (0.74)	1.97 (0.15)	19.18 (1.20)
LSD (0.05)	1.07	0.58	0.92	0.73	2.94
Eyera CTRL	10.22 (0.43)	3.17 (0.15)	8.83 (0.83)	1.81 (0.29)	8.98 (0.01)
Eyera + 0% soy	5.17 (0.43)	0.83 (0.02)	6.38 (0.05)	1.93 (0.12)	10.49 (0.45)
Eyera + 3% soy	4.72 (1.23)	0.91 (0.03)	6.33 (0.75)	2.17 (0.11)	12.60 (0.44)
Eyera + 6% soy	5.52 (1.54)	0.80 (0.13)	7.24 (0.57)	2.40 (0.41)	18.29 (1.65)
LSD 0.05	2.30	0.94	1.13	0.95	1.10

Values in parenthesis ( ) are the standard deviation of the mean

moisture content is expected since the extrudates are released from a high pressure and temperature to a low pressure and temperature zone resulting in product expansion and easy evaporation of moisture. The composition of the sorghum samples was in agreement with that of other researchers (Dendy, 1995), suggesting that while there may be soil and climatic variations, the nutrient composition of the sorghums remained fairly the same.

The reduction in fat and fibre contents could be attributed to high shear, pressure and temperature conditions of extrusion resulting in breakdown of fibre and lipid polymeraisation, and interaction with other nutrient components (Belitz *et al*., 2009). Addition of soy-flour increased the protein content of extrudates; but had no effect on other nutrient components. This was expected since soy-flour contained more protein than the sorghum. Pelembe *et al*. (2002) reported similar increases in protein content of sorghum composite flours with increasing cowpea content. It is, thus, possible to increase the protein content of extruded cereal products to meet specific consumer nutrient needs. However, as stated earlier increasing protein content may have undesirable effects on other physic-chemical properties of extrudates, especially products that are sold by volume.

CONCLUSION

Extrusion provides the basis for use of sorghum in value added food products hitherto dominated by other cereals. Interactions between variety, soy-flour content and extrusion occur for some properties suggesting that different product formulations may behave differently when subjected to extrusion. Thus, use of sorghums in extruded products would require testing the extrusion performance of different formulations so as to achieve the desired nutritional and product quality properties.

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