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Effect of some extrusion parameters on the nutrient composition and quality of a snack developed from cocoyam (*Xanthosoma sagittifolium)* flour

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There is increase in the use of cocoyam tubers for flour production which can be use for food and industrial purposes in Nigeria. Cocoyam (*Xanthosoma sagittifolium)* flour was cooked and extruded in a single screw extruder. A second order central composite response surface design was used in designing the experiment which generated 20 runs on selected process parameters including feed moisture (22, 24 and 26%), screw speed (60, 70 and 80rpm) and barrel temperature (200, 220 and 240°C) on the functional and physical properties (density, expansion, water absorption index (WAI), water solubility index (WSI) and hardness) of the extrudates. Furthermore, the nutritional compositions of the snacks were also determined. Increase in feed moisture content results in higher density, lower expansion, higher WAI, lower WSI and higher hardness in the extrudates while increase in barrel temperature decreases the density, WAI and hardness but led to increase in expansion and WSI in the extrudates. The nutrient value for the extruded snacks were protein (3.76%), fibre (6.41%), carbohydrate (79.50%), energy (343.03 kj/100 g), Ca (238.50 mg/100 g), Mg (113.71 mg/100 g), K (283.77 mg/100 g), Na (97.66 mg/100 g), P(161.23 mg/100 g), vitamin C (1.03 mg/100 g) and niacin (0.78 mg/100 g). This study has established that a nutritious and acceptable snack can be produced from cocoyam flour using extrusion cooking.

Key words: Cocoyam flour, single screw extrusion, functional, physical properties, nutritional composition.

INTRODUCTION

Cocoyam, a member of the Araceae family is an ancient crop and is one of the minor staple root crops commonly grown in the forest zone of Nigeria and Ghana (Ekanem and Osuji, 2006). Cocoyam contribute significant portion of carbohydrate content of the diet in many regions in developing countries and provide edible starchy storage

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Table 1. Coded levels for the response surface design.

Variables	Level				
	-α	-1	0	+1	+α
Feed moisture (%), X_1	20.32	22	24	26	27.68
Screw speed (rpm), X_2	58.32	60	70	80	81.68
Temperature (°C), X_3	198.32	200	220	240	241.68

α =1.682.

corms or cormels. Although cocoyam is less important than other tropical root crops such as yam, cassava and sweet potato, they are still a major staple in some parts of the tropics and subtropics (Ojinnaka et al., 2009). The world's leading producer of cocoyam is Nigeria producing an estimate of 3.7 million metric tonnes annually (Baruwa and Oke, 2012). The main nutrient supplied by cocoyam is dietary energy provided by the carbohydrates. Cocoyam is a good source of Na, K, P, Mg and Ca and is fairly rich in carotene, ascorbic acid, thiamine, riboflavin and nicotinic acid. The leaves contain beta-carotene, iron and folic acid (Eka, 1998; FAO, 1990). The problem of inherent nutritional hazard such as presence of acridity factors, oxalate and perishability of the tubers call for elaborate processing prior to consumption, thereby improving handling, convenience, palatability, storability and nutritional safety (Iwuoha and Kalu, 1995). Most processing methods are known to reduce the level of oxalate in cocoyam such as boiling, roasting, frying in oil, milling and conversion into 'fufu', soup thickeners, flour for baking, chips, beverage powder, porridge and specialty food for gastro-intestinal disorders (Iwuoha and Kalu, 1995).

Extrusion cooking is one of the most versatile and well established food processes and is used worldwide for the production of expanded snack foods, pastes, modified starch, flat breads, meat and cheese analogues, ready to eat cereal foods and porridge (Li and Lee, 2000; Thymi et al., 2005). The main purpose of extrusion is to increase the variety of foods in the diet, by producing a range of products with different shapes, textures, colours and flavours from basic ingredients (Fellows, 1999). It has been reported that small variations in processing conditions affect process variables as well as product quality, which can vary considerably depending on the extruder type, screw configuration, feed moisture, temperature profile in the barrel session, screw speed and feed rate (Ding et al., 2005).

Response surface methodology (RSM) is a statistical method for determining and simultaneously solving multivariate equation. It uses an experimental design such as central composite rotatable design (CCRD) to fit a first or second order polynomial by least significant techniques. An equation is used to describe how the test variables affect the response and to determine inter-relationship among the test variables in the response (Sobukola, 2007). The main objective of this research was to determine the effect of extrusion parameters on the physical, functional and nutritional composition of snacks developed from cocoyam flour.

MATERIALS AND METHODS

Preparation of flours

Cocoyam tubers (*Xanthosoma sagitifolium)* were purchased in Abeokuta, Ogun State. The processing of the tubers to flour as described by Idowu et al. (1996) was employed. Cocoyam tubers were selected, cleaned, hand peeled, washed and sliced into chips of 3-4 mm thickness. The chips were steeped for 12 h, rewashed and sulphited in 0.1% potassium metabisulphite solution for 3 h. The sulphited chips were dried in cabinet dryer at 60°C for 24 h, milled in attrition mill, and sieved (< 600μm) into flour. The cocoyam flour was stored in high density polyethylene films until processed.

Before extrusion, cocoyam flour (500 g) was pre-conditioned according to each moisture content (Table 1) by calculated amounts of water being incorporated into each sample. After that, the samples were sealed in high density polyethylene films and kept at ambient temperature for 12 h to reach homogeneous equilibrium moisture distribution.

Extrusion process

The cocoyam flours were cooked and extruded using a single screw extruder (model 1993 DD85G, 201132, IBG Monforts Gmbhi & Co, D-4050 Monchengladbach, Germany). The extruder was equipped with 254 mm barrel, a screw diameter of 200 mm and was fitted with a die nozzle of 4 mm diameter. The rehydrated samples were then extruded and the extrudates were cooled to room temperature and sealed in high density polyethylene films until measurements were taken.

Experimental design

A centre composite RSM design was used to show interactions of feed moisture, screw speed and temperature on the extrudates. This comprised of 20 runs, of which six were centre point and 14 for non-centre point (Stat-Ease, 2002).

Second order polynomial model was fitted to measure dependent variables (Y) such as bulk density (Y_1), expansion rate (Y_2), water absorption index (Y_3), water solubility index (Y_4), texture (Y_5). The following equation was used:

$$Y = \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_{11}X_1^2+\beta_{22}X_2^2+\beta_{33}X_3^2+\beta_{12}X_1X_2+\beta_{13}X_1X_3+\beta_{23}X_2X_3$$

Where, β_0, β_1-β_3, β_{11}-β_{33} and β_{12}-β_{23} are regression coefficients for interception, linear, quadratic and interaction coefficients, respectively, X_1-X_3 are coded independent variables and Y is the response (Myers and Montgomery, 1995).

An ANOVA test was carried out using Design Expert 6.0.8 (Stat-Ease Inc., Minneapolis, USA) to determine the significance at different levels (0.1, 1 and 5%) (Stat-Ease, 2002).

Physical and functional properties of the extrudates

Bulk density

The bulk density was calculated by measuring the actual dimen-

Table 2. Chemical composition of cocoyam flour.

Composition	g/100g
Moisture	5.38
Protein	3.92
Fat	0.28
Fibre	1.56
Sugar	1.79
Starch	73.28
Carbohydrate	86.78

sions of the extrudates according to the method described by Ding et al. (2005). The diameter and length of the extrudates were measured using Vernier caliper. The bulk density was then calculated using the following formula,

$$\text{Density (g/cm}^3\text{)} = \frac{4 \times M}{\pi \times D^2 \times L}$$

Where: M = Mass (g), D = diameter (cm), L = length (cm). Six replicates of extrudate were randomly selected and an average taken.

Expansion ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate according to Ding et al. (2005). Six replicates of extrudate were randomly selected and an average taken.

Water absorption index (WAI) and water solubility index (WSI)

The WAI and WSI were measured using the method of Ding et al. (2005). The extrudate samples were milled and sieved through 600 µm sieve. 2.5 g samples was dispersed in 25 ml distilled water, using glass rod to break up any lumps and then stirred for 30 min, centrifuged at 4000 rpm for 15 min. The supernatant was decanted into an evaporating dish of known weight and dried at 105°C until constant weight. The weight of the gel remaining in the centrifuge tube was noted. The results were expressed as the average of the two measurements.

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

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

Determinations were made in triplicate.

Hardness

The hardness was determined by using Erweka (Gmbh D 63150, TBH200, Heusenstamm / Germany) hardness tester fitted with a 2 mm cylinder probe. The samples were punctured by the probe to a distance of 6 mm and the hardness recorded.

Nutrient composition of the extruded snack

Chemical composition

Moisture, protein, ash, fat and fibre contents were determined using AOAC (2000). Total sugar and starch contents were determined by the procedure described by Kayisu et al. (1981). Carbohydrate was estimated by difference and the energy were calculated using the Atwater factors of 4 X proteins, 4 X carbohydrates and 9 X fats. The samples were analyzed in triplicate.

Mineral analysis

Mineral elements were determined using AOAC (2000) methods. One gram of the sample was first digested with 20 ml of acid mixture (650 ml concentrated HNO_3; 80 ml per chloric acid (PCA); 20 ml concentrated H_2SO_4) aliquots of the diluted clear digest was used in atomic absorption spectrophotometer for determination of Ca, Mg, Zn, Cu, S and Fe. Flame analyzer was used for determination of K and Na using filters that match the different elements. Phosphorus (P) was determined by converting phosphate into phosphorus molybdate blue pigment and assayed at 7000 nm.

Vitamin analysis

Vitamin C, thiamine, riboflavin and niacin were determined using the method described by AOAC (2000).

Statistical analysis

The data obtained from the nutritional composition were subjected to One-Way-Anova [ANOVA] and the means of values were separated by Duncan Multiple Range Test using SPSS 16.0.

RESULTS AND DISCUSSION

Chemical composition of cocoyam flour used for extrusion is shown in Table 2. It contained moisture (5.38%), protein (3.92%), fat (0.28%), fiber (1.56%), sugar (1.79%), starch (73.28%) and carbohydrate (86.78%).

Effect of extrusion parameters on bulk density

The effect of extrusion parameters on extrudates density is shown in 3-D surface plot (Figure 1). It was observed that increase in feed moisture leads to increase in extrudates density at all temperature levels. However, increase in barrel temperature causes a decrease in the density of the extrudates. Asare et al. (2004) reported that bulk density has been linked with the expansion ratio in describing the degree of puffing in extrudates. Increase in feed moisture during extrusion of cocoyam flour could probably be due to a reduction in the elasticity of the

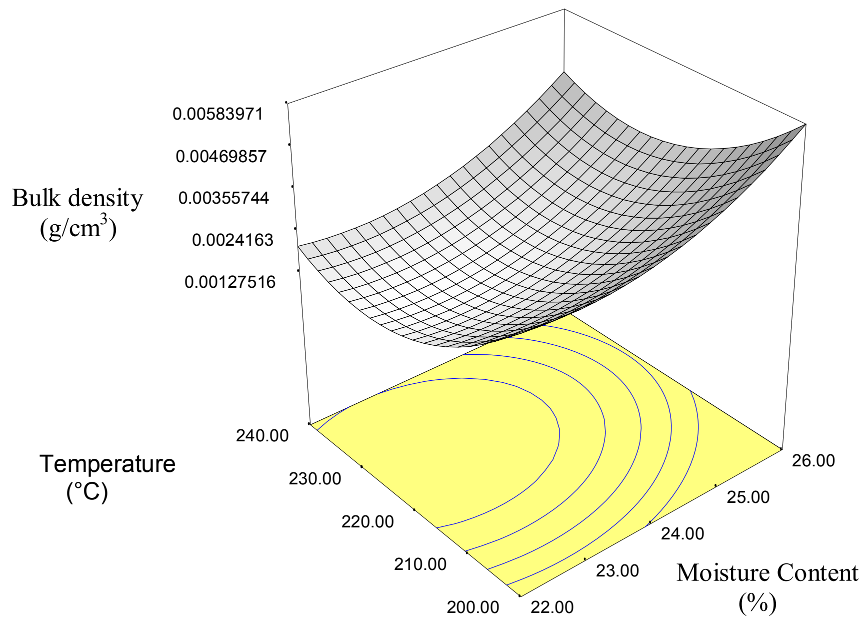

Figure 1. Effect of moisture content and barrel temperature at constant screw speed on the bulk density of cocoyam extrudates.

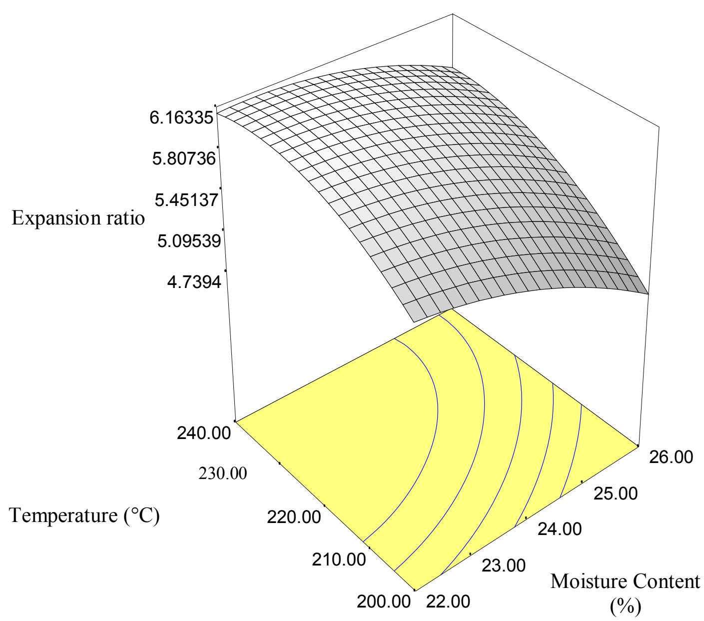

Figure 2. Effect of moisture content and barrel temperature at constant screw speed on the expansion ratio of cocoyam extrudates.

dough through plasticization of the melt, causing reduction in gelatinization and increase in the density of the extrudates. Increase in screw speed was observed in extrudates with lower density. Higher screw speed could have lowered the melting viscosity and increase the elasticity of the dough which results in reduction in the density of the extrudates (Ding et al., 2005).

Effect of extrusion parameters on expansion

The effect of extrusion parameters on the expansion of extrudate is shown in 3-D surface plot (Figure 2). Increase in feed moisture content caused decrease in the expansion ratio of the extrudates while increase in barrel temperature led to increase in the expansion ratio of the

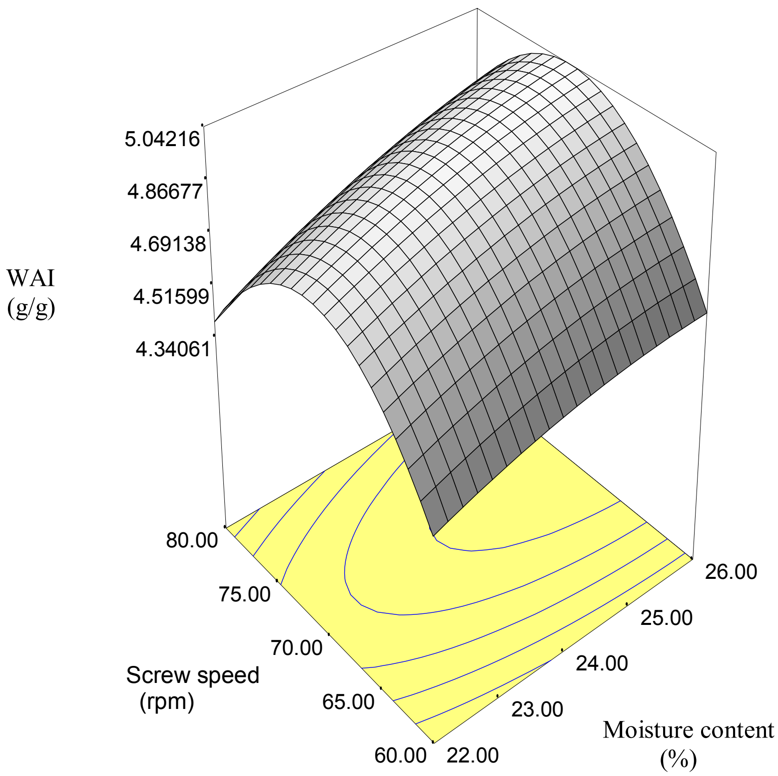

Figure 3. Effect of moisture content and screw speed at constant barrel temperature on the water absorption index of the cocoyam extrudates.

extrudates. Feed moisture content has been reported to have a highly significant effect on the radial expansion ratio. The radial expansion decreased with an increase in feed moisture content and it is most dependent on the melt elasticity (Launay and Lisch, 1983). Increase in feed moisture content during extrusion could have also lead to changes in the amylopectin networks and in the melting rheology characteristics leading to greater elastic effect and changes in product density and expansion.

Effect of extrusion parameters on WAI and WSI

The effect of extrusion parameters on the WAI and WSI of the extrudates are presented in 3-D surface plot (Figures 3 and 4). Increase in feed moisture content significantly increased the WAI of the extrudates. WAI also increased with increase in screw speed. Increase in barrel temperature was observed to cause a significant decrease in WAI. Increasing feed moisture content was observed to result in a significant decrease in WSI of the extrudates. However, increase in barrel temperature was observed to cause a significant increase in WSI of extrudates. The WAI measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion (Mason and Hoseney, 1986). WSI is often used as an indicator of degradation of molecular components (Kirby et al., 1988), and measures the degree of starch conversion during extrusion which is the amount of soluble polysaccharide released from starch component after extrusion. During the extrusion of the cocoyam flour, water is absorbed and bound to the starch molecule with a resulting change in the starch granule structure. Barrel temperature and feed moisture was observed to have the greatest effect on gelatinization. The maximum gelatinization occurs at low moisture and high temperature or vice versa (Ding et al., 2005). Decrease in WAI could probably be due to dextrinization, which also could have led to increase in WSI.

Effect of extrusion parameters on hardness

The effect of extrusion parameters on the hardness of the extrudates is shown in 3-D surface plot (Figure 5). An Increase in feed moisture content caused an increase in the hardness of the extrudates, while increase in screw speed and barrel temperature resulted in a decrease in hardness of the extrudates. The hardness is the average force required for a probe to penetrate the extrudate. The hardness of the extrudates increased as the feed moisture content increase which could be due to reduced expansion caused by the increase in moisture content

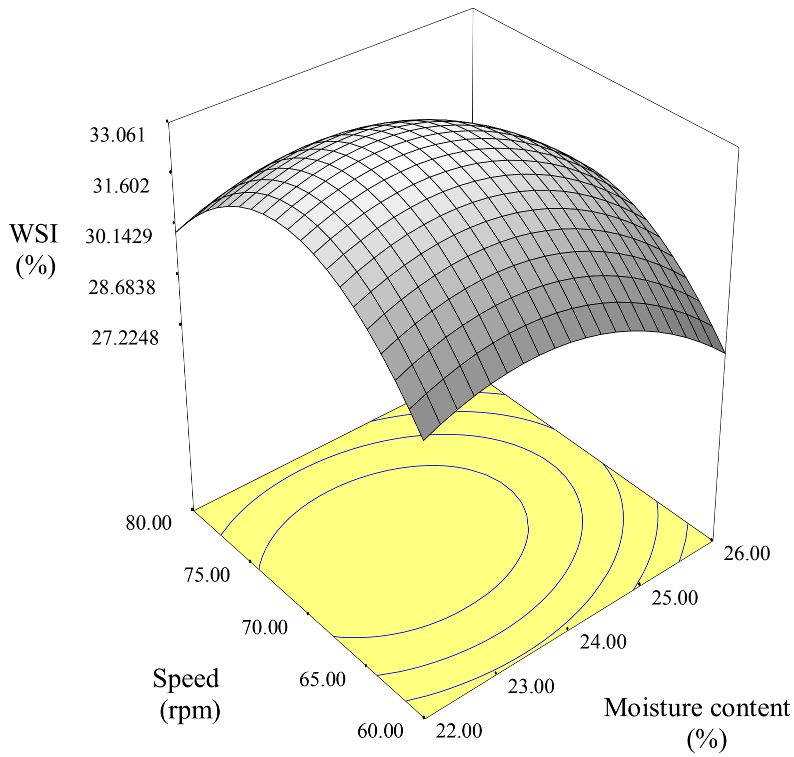

Figure 4. Effect of moisture content and screw speed at constant barrel temperature on the water solubility index of cocoyam extrudates.

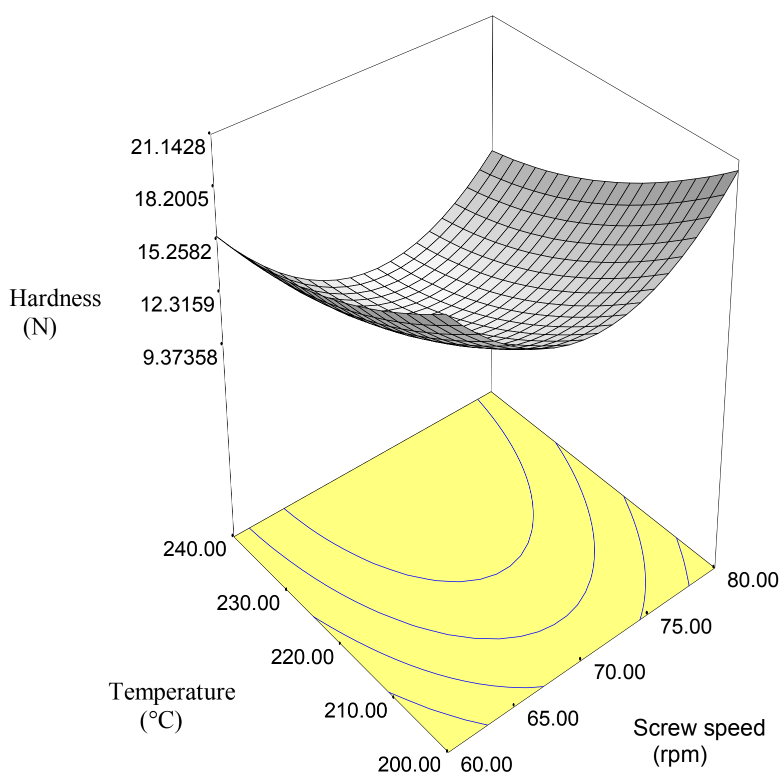

Figure 5. Effect of screw speed and barrel temperature at constant moisture on the hardness of cocoyam extrudates.

Table 3. Significant coefficients of regression equation for the responses

Coefficient	Bulk Density (g/cm^3)	Expansion Ratio	WAI (g/g)	WSI (%)	Hardness (N)
β_0	0.307**	-48.609*	-45.840**	-853.758***	851.298*
β_1	-0.009**	1.105*	0.236*	20.952**	-34.042**
β_2	-0.000	0.515	0.545	3.895	-6.812
β_3	-0.001**	0.207*	0.265**	4.441***	-1.771*
β_{11}	0.000*	-0.036	-0.010	-0.392***	0.648*
β_{22}	0.000	-0.003	-0.003**	-0.027***	0.049*
β_{33}	0.000*	-0.000	-0.000*	-0.009***	0.003
β_{12}	-0.000	-0.001	0.002	0.000	0.015
β_{13}	-0.000	0.002	0.000	-0.012	0.016
β_{23}	-0.000	0.000	-0.000	-0.000	-0.002
R^2	0.883	0.767	0.859	0.975	0.828

***Significant at the 0.1%; **Significant at the 1%; *Significant at the 5% .

Table 4. Chemical composition of extruded cocoyam snacks.

Parameters	Expanded cocoyam snack *
Moisture (%)	6.68±0.08
Protein (%)	3.76±0.01
Ash (%)	2.54±0.04
Fat (%)	1.11±0.03
Fibre (%)	6.41±0.01
Carbohydrate (%)	79.50±0.02
Energy (kj/100g)	343.03±0.33
Total sugar (%)	19.25±0.05
Starch (%)	17.33±0.05
pH	5.60±0.05
TTA (%)	0.39±0.01

*Each value represents the mean of triplicate determinations ± standard deviation

Table 5. Mineral and vitamin contents (mg/100g) of cocoyam snacks.

Parameter	Expanded cocoyam snack from Tannia*
Ca	238.50±1.87
Mg	113.71±1.48
K	283.77±2.69
Zn	7.51±0.09
Cu	7.85±0.23
Na	97.66±0.89
S	3.35±0.25
Fe	25.53±0.88
P	161.23±2.96
Vitamin C	1.03 ±0.01
Thiamine	ND
Riboflavin	ND
Niacin	0.78±0.04

*Each value represents the mean of triplicate determinations ± standard deviation.

(Lui et al., 2000). An increase in temperature resulted in a decrease in hardness which could be due to reduction in melting viscosity favouring bubble growth, increased expansion and lower density gave a softer extrudate. An increase in screw speed could also have lowered the melting viscosity of the mix resulting in a less dense and softer extrudates.

Effect of extrusion parameters on the nutrient composition of extruded cocoyam snack

The nutrient composition of the extruded cocoyam snack is shown in Tables 4 and 5. Extrusion cooking, like other food processing methods could have desirable and undesirable effects on the nutritional value of the extruded snacks. The food components that play an important role in the extrusion cooking processes are starch and proteins. During extrusion cooking, starch granules are disrupted and melted at low moisture contents, swelled and gelatinized at high moistures (Ilo et al., 2000). In both cases, starch conversion led to the loss of crystalline structure to form an amorphous phase, which in extrusion cooking of starch materials resulted in a fluid mass with starch biopolymers in the continuous phase. This help to retain the gases released during the expansion process at the extruder, enabling the formation of expanded foam structures. The amount of polymer which is found in the continuous phase determines the extensibility of bubble cell walls in the foam and the overall expansion of extrudates at the die (Ilo et al., 2000). Riaz (2000) reported that within the extruder barrel, unique chemical transformations occur. Different five chemical or physicochemical changes can occur during extrusion cooking such as binding, cleavage, loss of native conformation, recombination of fragments and thermal degradation. During extrusion cooking of the flour, there was a decrease in starch content and an increase in sugar content, this might be due to gelatinization of starch that occurs at lower moisture levels (Qu and Wang, 1994). This agrees with the report of Hsieh et al. (1993) that during extrusion cooking, starch resulted into the production of maltodextrins and sugar. Proteins act as 'filler' in starch extrudates and are dispersed in the continuous phase of the extrusion melt, modifying the flow behaviour and characteristics of the cooled extrudates. Protein materials hydrate the mixing stage of the process and become soft viscoelastic doughs during formation of the extrusion melt. The shearing forces generated in the extruder cause breakage of the protein into small particles of roughly cylindrical and globular shapes and tend to reduce the extensibility of the starch polymer foam during its expansion at the die exit, reducing the degree of expansion (Brennan, 2006). Proteins are denatured by extrusion cooking process. Proteins are made of amino acids which are known as the building blocks of protein. Amino acids are held together by primary bonds whereas the molecules are held together by secondary bonds. The cooking action of the extruder breaks down the secondary bonds but does not create sufficient heat to destroy the amino acids or the primary bonds (INSTA-PRO, 2011). There was a decrease in protein content due to extrusion cooking which could have been due to denaturation of protein. Denaturation of protein has been reported to improve nutritional quality by making the molecules more accessible to proteases and more digestible (Brennan, 2006). It has been reported that most enzyme activities were lost within the extruder unless they were stable to heat and shear (Della Valle et al., 1994). Denaturation and loss of solubility was reported to be affected by increased barrel temperature (Della Valle et al., 1994). Area (1992) reported that during extrusion, disulfide bonds were broken and may re-form. Electrostatics and hydrophobic interactions favor formation of insoluble aggregates. The creation of new peptide bonds during extrusion was controversial and high molecular weight proteins can dissociate into smaller sub-units.

The exposure of enzyme susceptible sites improves digestibility. Maillard reactions may also occur particularly at higher barrel temperatures and lower feed moisture at which the flour was treated. Free sugars might be produced to react with lysine and other amino acids with free terminal amines. The starch and dietary fiber fragments as well as sucrose hydrolysis products were available for maillard reactions (Bates et al., 1994). The degree of fat complexing during extrusion depends on starch content in process material. This facilitates the formation of starch-lipid complexes. The presence of starch and protein in raw material favours the formation of starch-lipid and lipid-protein complexes (Sobota et al., 2010).

Most of the minerals and vitamins differ greatly in composition and stability, and also it varies during extrusion cooking. Minimizing temperature and shear within the extruder protects most vitamins. The water soluble vitamin most susceptible to thermal processing is thiamine. Thiamine stability during extrusion is highly variable as evidenced by Killeit (1994). He reported that losses ranged between 5-100%.

Conclusion

The functional and physical properties of cocoyam extrudates on single screw extrusion process were dependent on the process variables. The feed moisture and barrel temperature had significant effect on the extrudates properties, with feed moisture having the greatest influence. The high starch content of cocoyam flour makes it a great potential as a food ingredient in extruded products and can be successfully used in preparation of high quality snacks.

Conflict of Interests

The author(s) did not declare any conflict of interests.

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