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Improved Yam-Baobab-Tamarind flour blends: Its potential use in extrusion cooking

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ABSTRACT

This project was aimed at determining the physicochemical properties of water yam-baobab-tamarind flour composites and its potential use in extrusion cooking. Proximate and mineral composition of Baobab (B), Yam (Y), and Tamarind (T) were determined. Six blends of composite flours were formulated and colour and physicochemical properties were determined. Two of the flour blends were used as trial samples and extruded. Proximate composition of B, Y and T were comparable to similar literature reports, however, the mineral compositions were low. Moisture content, pH, water binding capacity, swelling power and bulk density values ranged from 3.01-5.61%, 3.90–5.39, 87.50–132.50%, 201.43–237.95% and 0.74–0.93 g/mL, respectively, for the flour blends. Peak, minimum, cooling end, final, breakdown and setback viscosities were in the range of 2.50–291.00bu, 2.20–289.50bu, 11.00- 455.00bu, 10–440bu, 0.00–20.50bu and 69.50–148.00bu, respectively, for flour blends. The addition of tamarind and baobab flours improved the swelling power, water binding capacity and peak viscosity of flour extrudates. Generally the L, a, and b values for extrudates were lower than the flour composites. However, the panelist preferred the appearance. The bulk density and expansion ratio of extruded snacks were low. Generally, panellists preferred extrudates with higher (40%) tamarind kernel powder substitution (E5). The extruded composite flour (E6) had low viscosity values. Incorporation of tamarind and baobab into water yam flour has great potential for development of extruded snacks.

Introduction

Yam (*Dioscorea spp.*) is an annual edible underground tuber native to warmer regions of both southern and northern hemispheres [39]. Ghana is the third largest producer of yams in the world, behind Nigeria and Cote d'Ivoire. In Ghana, yam constitutes about 13% of household food budget in urban centers [5]. Nutritionally, yam is a major staple providing food for

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millions of people in the world [5,8]. Yam is considered one of the country's main agricultural commodities including cocoa, cassava, banana and maize, as well as other cereals and fruits [26].

Over the years, yam has been consumed in forms such as *fufu* (pounded yam), *elubo, gbodo*, fried yam slices, yam balls, roasted and boiled slices [4]. Pounded yam is the most popular food form of yam in West Africa and is often reserved for special occasions in the urban areas [87]. The processing of yam traditionally depends [11] on the species, desired product quality and attributes.

In Ghana, varieties of yams are grown, but the white yams (*D. rotundata*), especially the *Pona* (sometimes *Puna*) variety, are preferred by both the domestic and export market. Water yam is next to *D. rotundata* in terms of volume of production and extent of utilization. *D. alata* species is the highest yielding among the yam species and can store relatively longer than other species (5–6 months) after harvest. Other popular varieties include *Dente, Asana* and *Serwaa*.

Yams have also been used as raw materials for starch industries and pharmaceutical companies [8,48]. Despite the numerous benefits, yams been highly perishable commodities are facing postharvest losses (10–60%) at various stages from production such as handling, marketing, distribution and processing and so require much attention due to lack of suitable raw materials, drying and storage equipment, poor quality of the processed product to pest infestation and physiological processes as a result of its high moisture content (50–80%) and high respiration rates [59]. Tuber processing is designed at obtaining products that are shelf stable, healthy and delicious [6,63]. CSIR- Crop Research Institute in Ghana has developed precooked vacuum-packaged yam from two varieties of Ghanaian yam (*Dioscorea rotundata)* [84].

One of the fastest growing sectors of the food industry is the snack industry. Scientists have also made efforts to incorporate oil seeds, fruits and vegetables to improve the nutritional content in ready-to-eat expanded snacks [18,50].

One of the promising technologies that could be employed in the surge for healthy shelf stable snack foods is extrusion cooking. Extrusion is a highly efficient process, which is versatile, minimizes cost, environmentally-friendly and provides high quality products. Singh et al. [80] has reported that extrusion also aids in the destruction of anti-nutritional factors, gelatinisation of starch, increased soluble dietary fibre and reduction of lipid oxidation. Over the years the most widespread source of ingredients is corn, tapioca, wheat, potato, rice, and oats. Some researchers have also used barley and other cereal sources such as rye, sorghum, millet, amaranth, and triticale [12,44].

Researchers have used other root and tubers such as yam and cocoyam to develop extruded snacks. Two flavoured extruded products were also developed by co-extruding yam grits (750 µm) obtained from white yam (*Dioscorea rotundata*) and Bambara groundnut flour (250 µm) [65]. There is an opportunity to expand processing facilities and increase the production of fresh yam into other value-added products. The main ingredient, usually cereal based has a percentage range of 50–80% depending on the objective of the investigation [18,78]. Research has also shown that high percentages of baobab in "heat subjected" food products not desirable sensorily [16]. The aim of this project was to assess the suitability of incorporating baobab pulp powder (B) and tamarind kernel powder (T) into yam flour (Y) for the development of an extruded snack. The extrudates were assessed for their physicochemical, sensory, colour and pasting properties.

Materials and methods

Source of materials

The baobab and tamarind fruits were obtained from the Upper East (Bolgatanga) and Upper West Region (Wa) of Ghana respectively. *Matches*, a variety of water Yam (*D. alata*), was obtained from the Kejetia market, Kumasi.

Sample preparation

Yam flour production

Yam flour was prepared by a method described by Adeola et al. [3] with little modification to the drying temperature, drying time, sodium metabisulphite solution concentration and inclusion of blanching to reduce browning. The yam tubers (46 kg) were washed with clean water to remove dirt, sand and unwanted particles. The yam tubers after peeling and slicing (0.05 mm thickness) were dipped in sodium metabisulphite solution (0.2%) for 3 min to prevent browning reaction and placed in a sieve to remove excess water. The samples were blanched with water (2.5 times the volume of sliced yams) for 10 min at 100 °C, oven dried at 65 °C for 12 h followed by milling using a hammer mill and the resulting yam flour was sieved (500 µm), packaged in transparent low density polythene bag and stored at low temperature (4° celcius) prior to analysis.

Tamarind kernel powder (TKP) preparation

The seeds were boiled for 10 min to remove the hard testa. The kernel was separated from the hard testa. The kernel obtained was grounded into fine powder and sieved through a 0.09 µm sieve to obtain a fine powder. The powder was packed in packaged in transparent low density polythene bag and stored at low temperature (4° celcius) prior to analysis.

Table 1
Flour blend composition.

	Baobab Pulp Powder (BPP)	Tamarind Kernel Powder (TKP)	Yam Flour (YF)
F1(100Y)	0	0	100
F2(40T:60Y)	0	40	60
F3(40B:60Y)	40	0	60
F4(30B:10T:60Y)	30	10	60
F5(10B:30T:60Y)	10	30	60
F6(20B:20T:60Y)	20	20	60

BPP=Baobab Pulp Powder TKP=Tamarind Kernel Powder YF=Yam Flour.

Table 2
Flour composite formulation and extrusion parameters.

Formulations	Temp (°C)	Feed rate (g/min)	Screw speed (rpm)
F5(10B:30T:60Y)	200	300	1200
F6(20B:20T:60Y)	200	300	1200

*F=Formulation Y=Yam T=Tamarind B=Baobab.

Baobab pulp powder (BPP) preparation

The fruits of baobab was cleaned, shells of the fruits were opened to obtain pods, and then seeds were removed from the pods. The seeds were grounded using mortar and pestle to separate the pulp from the seeds. The mixture was sieved through a 0.09 µm sieve to obtain a fine powder. The powder was immediately packed in The powder was packed in packaged in transparent low density polythene bag and stored at low temperature (4° celcius) prior to analysis. [56].

Flour formulations

Six blends of composite flours in the proportions as shown in Table 1 were prepared for physicochemical, colour and pasting analysis.

Yam flour production. Yam flour (15 kg) was prepared by a method described by Adeola et al. [3] with little modification. The yam tubers (46 kg) were washed with clean water to remove dirt, sand and unwanted particles. The yam tubers after peeling and slicing (0.05 mm thickness) were flushed with sodium metabisulphite solution (0.2%) to prevent browning reaction and placed in a sieve to remove excess water. The samples were blanched for 10 min at 100 °C oven dried at 65 °C for 12 h followed by milling using a hammer mill and the yam flour was sieved (500 µm), The powder was packed in packaged in transparent low density polythene bag and stored at low temperature (4°C) prior to analysis.

Tamarind kernel powder (TKP) preparation. The seeds were boiled for 10 min to remove the hard testa. The kernel was separated from the hard testa. The kernel obtained was grounded, sieved through a 0.09 µm sieve to obtain a fine powder. The powder was packed in polyethylene bags sealed and stored in a dark cool place.

Baobab pulp powder (BPP) preparation. The fruits of baobab was cleaned, shells of the fruits were opened to obtain seeds, and then seeds were removed from the pods. The seeds were grounded using mortar and pestle to separate the pulp from the seeds. The mixture was sieved through a 0.09 µm sieve to obtain a fine powder. The powder was immediately packed in polyethylene bags sealed and stored in a dark cool place [56].

Extrusion of products

Composite formulation/preparation

The flour composites were prepared using the formulation as described in Table 4. The samples were mixed on dry basis using a laboratory blender (E8150 - Waring @ Variable Speed Blender) for 10 min at 10000 rpm. The flour composites were stored at 5 °C. The composites were extruded using a twin screw extruder (Clextral Extruder BC21, Germany) to determine the desired sensorial and textural characteristics of the extrudates using moisture feed rate of (70 l/hr, screw speed, 1200 rpm and temperature (200 °C).

Two formulations out of the six were selected, F5 (10B:30T:60Y) and F6 (20B:20T:60Y), for extrusion cooking trial. Table 2 shows the extrusion parameters selected for the trial work.

Physicochemical analysis

Determination of pasting properties

Forty grams of flour sample and 420 ml distilled water was mixed to form a slurry (8.8% Slurry) for pasting properties of flour samples using Brabender Visco amylograph (Viskograph-E, Brabender Instrument Inc. Duisburg, Germany) equipped with a 1000 cmg sensitivity cartridge. Pasting properties of flour after extrusion was characterized using rapid visco analyzer (RVA) as described by Delcour et al. [17]. Pasting Time, Pasting Temperature, Peak viscosity, Minimum Viscosity, set back, breakdown viscosity and final viscosity were also measured on flour samples after extrusion. Total running time was about 13 min and the viscosity values were recorded every 4 s by Thermocline Software as the temperature increased from 50 °C to 95 °C and cooled to 50 °C.

Water binding capacity (WBC)

This was determined using methods described by Beuchat [15] as cited in Amza et al. [8] with little modification to centrifuge speed and time. One gram sample was weighed into 25 ml graduated conical centrifuge tube and about 10 ml of water added. The suspensions were allowed to stand at room temperature (30 ± 2 °C) for 30mins and centrifuged at 2000 x g for 30 min. The volume of water on the sediment was measured and the water absorbed expressed as per cent water absorption based on the original sample weight.

Water binding capacity (grams of water per gram of flour) was calculated as

$$\%\ \text{Water Binding Capacity} = \frac{(\text{W2} - \text{W1})}{\text{W0}} \times 100$$

where W0 is the weight of the dry sample (g), W1 is the weight of the tube plus the dry sample (g), and W2 is the weight of the tube plus the sediment (g).

Determination of swelling power

This was determined with the method described by Leach et al. [47] with modification. Modification was made with water and flour quantities. One gram of the sample was mixed with 10 ml distilled water in a centrifuge tube and heated at 80 °C for 30 min. The mixture was continually shaken during the heating period. After heating, the suspension was centrifuged at 1500 x g for 15 min. The supernatant was decanted and the weight of the paste taken. The swelling power was calculated as:

$$\text{Swelling power} = \frac{\text{Weight of the paste}}{\text{Weight of dry sample}} \times 100$$

Determination of bulk density

The bulk density was determined by the method of Makinde and Ladipo [52] with little modification to flour quantities. Ten grams sample was weighed into 100 ml graduated measuring cylinder. The samples were packed by gently tapping the cylinder on the bench top 10 times from height of 5 cm. The volume of the sample was recorded.

$$\text{Bulk density}(\text{g/ml}) = \frac{\text{Weight of the sample}}{\text{Volume of the sample after tapping}}$$

Determination of pH

Five grams of yam flour was weighed and mixed with 50 ml of distilled water to obtain slurry. The pH was then determined using a Fisher Science Education pH (Model S90526, Singapore) meter by inserting the pH probe into the slurry and the reading is taken [9].

Determination of expansion ratio

Expansion ratio was determined using the method described by Kannadhason et al. [42]. The diameter of the extrudates was measured with Vernier calliper and then divided by the diameter of the die nozzle (5.0 mm) to determine its expansion ratio.

Colour determination

The colour of the flour samples was measured with a Minolta CR-310 (Minolta Camera Co. Ltd, Osaka, Japan) tristimulus colorimeter, recording L, “a” and “b” values. L represented lightness (with 0= darkness/ blackness to 100= perfect/brightness); a corresponds to the extent of green colour (in the range from negative= green to positive = redness); b represents blue in the range from negative=blue to positive=yellow. Chroma (C) is the saturation or vividness of color. As chromaticity increases, a color becomes more intense; as it decreases, a color becomes duller. Hue angle (h) is the basic unit of color and can be interpreted, for example, as 0 = red and 90 = yellow. Both chroma and hue are derived from a and b using the following equations: metric chroma: $C = (a)^2 + (b)^2$, metric hue angle: h = tan–1 (b/a) (degrees) and colour intensity is measured as: $E = \sqrt{L^2 + a^2 + b^2}$. The colorimeter was calibrated against a standard white reference tile. Samples were placed in a clear glass Petri dish (10 replicates), and colour measurements were done in triplicate [89].

Table 3a
Moisture and water binding capacity of composite flour blends.

Composite flours	pH	Moisture (%)	Bulk density (g/cm3)	WBC (%)	Swelling power (g/100 g)
F1(100Y)	5.26±0.02[a]	5.51±0.21[a]	0.93±0.05[a]	87.50±3.54[a]	201.43±2.33[a]
F2(40T:60Y)	5.39±0.06[b]	5.61±0.11[a]	0.87±0.03[a]	112.50±3.53[b]	213.7 ± 4.88[a]
F3(40B:60Y)	3.90±0.06[c]	3.01±0.11[b]	0.74±0.04[b]	132.50±3.54[c]	214.63±7.31[a]
F4(30B:10T:60Y)	3.91±0.01[cd]	3.08±0.03[b]	0.77±0.02[b]	111.50±3.53[b]	221.51±2.09[b]
F5(10B:30T:60Y)	5.29±0.01[e]	4.28±0.08[c]	0.82±0.03[a]	107.50 ±5.30[b]	222.66±1.96[b]
F6(20B:20T:60Y)	4.21±0.02[f]	4.02±0.10[c]	0.80±0.05[b]	123.80±1.77[c]	237.95±9.41[b]
Baobab pulp powder	3.36±0.04	9.54 ± 0.23	0.61± 0.03	189.0 ± 1.76	–
Tamarind Kernel Powder	6.56±0.02	2.68 ± 0.03	0.74 ±0.04	136.31 ± 5.35	–

*Analysis was done in triplicates *Y=Yam T=Tamarind B=Baobab.
*Means with the same superscripts within the column are not significantly different (p>0.05).

Sensory evaluation of extrudates

A method described by [53] was used for the consumer acceptance tests to evaluate the overall acceptance of the two extruded snacks. The sensory assessments were conducted in Food Science and Technology laboratory. The panel of 30 members consisted of students from the department of Food Science and Technology. The panellists were naive to the project objectives. Samples were coded using random three-digit numbers and served with the order of presentation counter-balanced. Panellists were provided with a glass of water and, instructed to rinse and swallow water between samples. They were given written instructions and asked to evaluate their liking for aroma, texture, shape, crunchiness, puffiness and taste of the extruded products using nine-point hedonic scale, wherein 1 = Dislike extremely, 2 = Dislike very much, 3 = Dislike moderately, 4= Dislike slightly, 5 = neither like nor like, 6 = Like slightly, 7 = Like moderately, 8 = Like very much, and 9= Like extremely. Panellists were then asked to assess their overall preference for the two extrudates using the scale, 1= most preferred and 2= least preferred. The extrudate that had the highest percentage for preference was considered the most preferred extrudate in terms of overall acceptability.

Statistical analysis

Quantitative data were expressed as means and standard deviation (SD) of at least 2 measurements. Each experimental set was analysed using Statistical Package for Social Sciences (SPSS) version 11.5 (SPSS Inc., Chicago, IL, USA). Least Significant Difference (LSD) test was used to determine the differences of means. P values <0.05 were regarded as significant.

Results and discussion

Physicochemical characteristics on composite flours and trial extrudates

Table 3a and 3.1b show the physicochemical analysis of flour composites. Flour composites have been coded F1 to F6 whiles the trial extrudates have been coded E5 and E6.

Moisture

Moisture contents of flour composites were within the range of 3.01–5.61% (Table 3a) F4 and F2. Samples with tamarind kernel powder (TKP) substitutions had higher moisture contents than those substituted with baobab pulp powder (BPP). This can be explained by the fact that the moisture content of TKP was higher than that of BPP as seen in Table 3a and this influenced the overall moisture content after substitution. There were significant differences (p<0.05) among moisture contents of flour blends.

Moisture contents of composite flours (F5 and F6) were generally higher than the extrudates (E5 and E6). This is basically because there was moisture loss during when the flours were subjected to heat (200 °C) within a short time during extrusion cooking. There were significant differences (p<0.05) between moisture contents of extrudates.

The low moisture content of flour blends and extrudates indicates that they may have a long shelf life during storage [29,38,69].

Water binding capacity (WBC)

The WBC of flour samples varied between 87.50- 132.50% (Table 3a). Thirty percent tamarind (F5) showed the highest WBC of 132.50% whiles 100% yam flour (F1) had the least WBC of 87.50%. There were significant differences (p<0.05) within flour composites. In the development of ready-to-eat foods water binding capacity is an imperative functional feature since high water absorption capacity may guarantee product cohesiveness [1]. Particle size, protein content and protein denaturation of foods greatly affects water binding capacity of flours. Addy [1] reported that the water binding capacity values of yam flour varieties ranged from 215.20 - 232.45%. A range between 159.7% and 202.0% was reported by Baah et al. [10] for

Table 3b
Moisture and water binding capacity of trial extrudates.

Extrudates	Moisture (%)	pH	Swelling power (ml/100 g)	Bulk density (g/cm^3)	Expansion Ratio	WBC (%)
E5(10B:30T:60Y)	1.12±0.03^a	4.83±0.06^a	359.94±5.17^b	0.24±0.02^a	4.15±0.15^a	85.00±7.00^b
E6(20B:20T:60Y)	2.03±0.07^b	4.91±0.11^a	261.08±1.93^a	0.19±0.01^b	3.45±0.19^b	62.50±3.54^a

* Analysis was done in triplicates *Y=Yam T=Tamarind B=Baobab.
*Means with the same superscripts within the column are not significantly different ($p>0.05$).

D. alata however these values are quite higher than what was observed in this study. Water binding capacity of *D. alata* flour (100% Y) was 87.50%. This may be because of the difference in source of materials and variety/cultivar of *D. alata*.

Tamarindus indica is a legume known to have high jellose and protein content. Jellose in tamarind seeds has a gelling ability, which makes it suitable as a stabilizer and thickener in food products [25]. The proteins also have both hydrophilic and hydrophobic properties thereby can interact with water and oil in food [25]. However in Table 3a, 40% baobab (F3) had higher WBC, 189.0%, than 40% tamarind (F2) with 136.31%, even though they had equal level of substitution. This means that baobab improves WBC in flours than tamarind kernel powders because the sugars and pectin in baobab may be absorbing more water than the proteins and jellose in tamarind.

Larrea et al. [46] indicated that water binding capacity increases after extrusion (Table 3b), but with this study it was not the case for the trial samples (E5, E6). Extrudates had lower (85.00%, 62.50%) WBC than the flour blends (107.50%, 123.80%). This may indicate that product composition affect the WBC of products after extrusion. The extrusion cooking led to loss of hydration capacity in extrudates [28]. The low WBC values after extrusion could also be because molecules engaged a lot of water during extrusion and so their capacity to bind to extra water after extrusion reduced [19].

As a result of this, if extrudates should be milled into flour for food products such as baby foods, breakfast meal, pudding or porridges, syneresis may occur during retorting or freezing after heating unless product composition and extrusion parameters are altered [23,62].

Acidity and alkalinity

pH of composite flours was within the range of 3.90 to 5.39. There were significant differences in pH in composite flours ($p<0.05$). One hundred percent yam flour (F1) had a pH of 5.26 which is quite lower than the 7.27, 6.53, 6.40 and 6.15 reported for *D. alata* by Sarpong [75], Harijono et al. [37], Obadina et al. [61], Onwuka and Ihuma [66], respectively. The differences could be attributed to varietal and flour preparation differences.

The amount of hydrogen ions in a particular solution gives an indication of the acidity or alkalinity. This parameter termed pH is vital in the assessment of eating quality since it contributes to taste and also determines the products susceptibility to the growth of microorganisms [60,62]. pH of the feed material may influence, colour, texture, nutritional content, enzyme activity, volatile compounds, viscosity, solubility and ultimately the final characteristics of the extruded product when altered because pH influences the activity of proteins [24].

Yam flour only had a pH of 5.26 (Table 3a) but upon substitution with 40% of baobab pulp (F3) and 30% baobab pulp (F4) the pH decreased to 3.90 and 3.91 respectively. As shown in Table 3a, TKP had a pH of 6.56 whiles baobab had a pH 3.36 which was close to results stated by Patel et al. [67] and Ndabikunze et al. [56] with values of 3.4 for baobab pulp and 6–7 for tamarind respectively. Lower pH of baobab (3.36) could be due to the presence of ascorbic acids [16], however the high temperature (200 °C) during extrusion may have destroyed some of the ascorbic acids which caused a slight increase in pH of 20% baobab/20% tamarind (E6) [72]

A pH value of 4.0 to 5.8 has been recommended for baked bread in order to extend shelf life. In this trial experiment, extrudates (E5 and E6) had pH values of 4.83 and 4.91 respectively. It can be concluded that the extrudates are safe for consumption and would have a good shelf life due to the low moisture level as well as the pH: yeasts and moulds prefer pH within a range of 5–6.

Swelling power

Swelling power of samples ranged from 201.43 to 237.95 g/100 g (Table 3a). There were significant differences in the swelling power of flour composites. This was due to the differences in the water binding capacities of the flour composites. Swelling power shows the hydration ability of starch granules and also indication of hydrogen bonding and association within the granules of starches [37]. Water binding capacity is an indicator of the swelling power of flours. Results from Table 3a shows that generally a blend of TKP and BPP gave higher values than for single substitutions of either tamarind or baobab. This could be as result of the synergistic effects and a phenomenon known as phase separation of pectin from baobab and jellose from tamarind. This phenomenon is generally due to excluded volume effects and water distribution between the phases [85].

Generally the swelling power of extrudates increased (Table 3b). 10% baobab and 20% baobab had swelling powers of 222.66% and 237% before extrusion and 359.94% and 261.08% respectively after extrusion. Extrusion cooking might have had an impact on the degree of exposure to the internal structure of the gelling polysaccharides and proteins in the extrudates, specifically their action to water as reported by Kafilat [41]. From the results extrusion improved the swelling power of flour samples. This implies that in order to incorporate any of the flour blends as a thickener or bulking agent in food formulations

Table 4
Sensory characteristics of trial extrudates.

	Aroma	Taste	Shape	Texture	Crunchiness	Colour	Puffiness
E5(10B:30T:60Y)	6.16[a]	4.92[a]	5.96[a]	6.40[a]	6.66[a]	6.24[a]	6.48[a]
E6(20B:20T:60Y)	5.96[a]	4.60[a]	5.36[a]	6.44[a]	6.04[a]	5.52[a]	5.92[a]

*Hedonic rating: 1= "Dislike Extremely", 9= "Like extremely"; the higher the value the higher the attribute. *Y=Yam; T=Tamarind; B=Baobab.
*Analysis was done in duplicates, *Means with the same superscripts within the column are not significantly different ($p<0.05$).

or products, subjecting it to some level of extrusion cooking before application is an advisable alternative because gels are known to boost the body, texture and cohesiveness of a food product [86].

Bulk density

The results show that there were significant differences ($P \leq 0.05$) between the flour blends. The bulk density of the flour blends with tamarind flour only (F2) having higher bulk densities as compared to those substituted with baobab flour only (F3). From Table 3a, TKP had higher bulk density (0.74 g/cm^3) than BPP (0.61 g/cm^3). However yam flour only (F1) had the highest bulk density of 0.93 g/cm^3.

Generally, the composite flours had higher bulk densities than the extrudates as shown in Table 3b. Fletcher et al. [30] as seen in Gui et al. [35] found that increased temperature in barrel during extrusion results in an increased degree of superheated water which encourages bubble formation and a decrease in melt viscosity, thus leading to the material being fully cooked and hence allows for more expansion and reduced density.

Low bulk density of extrudates (0.19– 0.24 g/cm^3) could also have been influenced by the structure of the starch polymers, loose structure of the starch polymers [64] and may be the jellose and pectin structure change after subjection to heat leading to expansion and increased porosity of the products. The bulk density of the extrudates is a determining factor to its packaging requirement and material handling in the food industries [43]. Bulk density could be a good indicator of the amount of space required for a given mass of the extrudates in packaging it.

Sensory evaluation and expansion ratio of extrudates

Sensory evaluation results (aroma, taste, shape, texture, colour, puffiness) of trial extrudates are shown in Table 4.

Sensory evaluation is a very important element in the food industry used on the basis that using equipment to measure certain attributes of food can only identify a part of the overall characteristic or attribute of a specified food product. The results of the preference test using a 9-point hedonic scale where 9=Like extremely, 5= like nor dislike and 1= Dislike extremely are presented in Table 4.

Puffiness

Extrudates had expansion ratios of 4.15 and 3.45 for 10% baobab (E5) and 20% baobab (E6) respectively (Table 3b). It has been shown by Balasubramanian et al. [14] and Alavi et al. [7] that heating of ingredients to a temperature above 100 °C will result in direct expanded snacks hence puffing was expected in the extrudates as flour mixtures were extruded at a temperature of 200 °C. In the process of extrusion, there was a rapid pressure loss as the steam vaporized from water, thus, causing stretching and expansion of the starch/jellose/pectin matrix, which allowed the products to have a low density and light texture [22,35]. In spite of the fact that high puffing is good, when the air cell wall is too thin the extrudates will break easily [54]. Some of the sensory panellists complained about the thinness and large air cells of the extrudates because some easily crushed when pressed with fingers. These results show that consumers desired some level of puffiness in the samples however the expansion should not lead to easy breakage of extrudates. Thus expansion should be within a certain limit because too much of it counteracts product's preference.

Aroma

Ten percent baobab (E5) had an insignificantly higher preference value of 6.16 while 20% baobab/tamarind extrudates (E6) had a value of 5.96 (Table 4). Generally, the aroma of extrudates was liked slightly by consumers. Higher tamarind substitution (20% tamarind, E5) had preferable aroma due to its seed oil which is said to be appetizing and has culinary pre-eminence ([55] cited in El-Siddig [25]). Aroma is an essential attribute in consumer's opinion of food and purchasing assessment. It is evident from the results obtained that inclusion of tamarind and baobab had an impact on the aroma of the extrudates. The high temperature (200 °C) also affected the taste of the extrudates.

Enhancement of flavour is due to the secondary compounds that contribute to non-enzymatic browning reactions, causative to development of new flavours complex molecules [71]. Eleven consumers out of fifty stated that the extrudates had a distinct aroma. Six of eleven said the aroma was like that of cocoa and five said it was coffee-like.

Table 5a
Colour characteristics of composite flours.

Sample code	L	a	b	Hue angle	ΔC	ΔE
F1 (100Y)	85.73± 0.21[a]	0.20± 0.01[a]	8.25± 0.05[a]	88.37±1.06[a]		
F2(40T:60Y)	85.49± 0.06[b]	−0.26± 0.02[b]	10.68±0.29[b]	88.60±0.38[a]	2.64±0.02[b]	2.26±0.02[a]
F3(40B:60Y)	85.20± 0.09[c]	−0.21± 0.08[b]	11.03±0.13[c]	88.89±−0.39[b]	2.82± 0.13[c]	2.87±0.13[b]
F4(30B:10T:60Y)	85.08±0.09[cd]	−0.28± 0.03[b]	11.85±0.12[d]	88.63±0.05[a]	3.64±0.12[a]	3.69±0.13[c]
F5(10B:30T:60Y)	84.67± 0.03[e]	−0.17± 0.04[c]	10.83±0.06[bc]	89.10±0.25[b]	2.61±0.06[b]	2.82±0.05[b]
F6(20B:20T:60Y)	84.94± 0.08[d]	−0.28± 0.04[b]	10.92±0.31[bc]	88.53±0.25[a]	2.89±0.10[bc]	3.01±0.12[d]

*Y=Yam T=Tamarind B=Baobab.
* L=lightness a=(negative=green; positive=redness) b=(negative=blue; positive=yellow).
Chroma (C)=saturation or vividness of color; Hue angle (H)=basic unit of color; E=colour intensity.
*Analysis was done in triplicates, *Means with the same superscripts within the column are not significantly different ($p<0.05$).

Taste

It was observed from Table 6a that the extrudates with higher percentage (20%) of tamarind had a preferred taste even though the taste was generally slightly disliked by the consumers principally because the BPP has an astringent taste that contributed to the undesirable taste when it was subjected to high heat. The taste could be attributed to the presence of citric acids and tannins in the baobab pulp [34,83].

Extrusion processing variables like screw speed cooking temperature and moisture level have huge impact on the taste of extrudates. A harsh condition (high temperature and screw speed) during food extrusion causes different degrees of granular and molecular changes in the sample flours which may affect the taste of extrudates [32]. However, the taste of food is minimally affected by processing but is largely determined by the formulation used for a particular food. It may be inferred from the study that the taste of extrudates was mainly affected by the products composition aside the extrusion parameters used [27].

Shape

Most of the extrudates assumed cylindrical shapes because the shape of the die was circular. Ten percent baobab (E5) was preferred to 20% baobab/20% tamarind (E6) with preference values of 5.96 and 5.36 respectively. The die, rotating knife and the speed of rotation of the knife largely affects the shape of extrudates. Results of expansion ratio as shown in Table 3b indicates that extrudates had varying circular sizes.

Texture and crunchiness

In terms of texture 20% baobab/ tamarind (E6) was preferred (6.44) to 10% baobab (E5) which had a score of 6.40 (Table 4). In this study the textural attribute was hardness. The results show that the sample composition and extrusion parameters had effect on the texture of extrudates [31] even though it was not significant ($p<0.05$).

Crunchiness of food products gives an indication of their freshness. Duizer [22] reported on the connection that auditory sensations have with the perception of texture. These attributes are perceived by sounds or noises produced during mastication. Research done by Szczesniak [82] cited in Spence [81] shows that crisp and crunchy foods demonstrate evidence of a crunchy sound. The disparity between the two sensations is that crispy food has a higher pitch and is louder than the ones derived from crunchy foods [81,88].

Higher tamarind seed kernel substitution (30% tamarind, E5) may have inferred a desired crunchiness in 30% tamarind (E5) with preference value of 6.66. However consumers indicated that the texture of these extrudates could be improved. A higher screw speed may reduce the hardness and fracturability by increasing the cooking temperature that generally leads to a higher expansion ratio of extruded product. Riaz et al. [73] found that a soft texture product resulted from a fine granulation and a coarse meal led to a hard product.

Overall acceptability

A higher percentage, 63.3% (19 panelists), preferred E5 whiles only 36.7% (11 panelists) preferred E6. This shows that the E5 was much more acceptable to the panelists (Figs. 1 and 2).

Colour characteristics of composite flours and extrudates

The L, a, b values of the yam based flour composites and extrudates are shown in Tables 5a and 5b respectively.

Statistically there were significant differences between the mean values of colour measurements for flour samples as well as the extrudates ($p \le 0.05$).

The change in the degree of lightness, yellowness or redness after extrusion could be attributed to the effects of extrusion cooking which causes non-enzymatic browning, pigment destruction reactions and chemical reactions between amino acids and reducing sugars (maillards reaction) in the presence of heat [68]. Caramel colour formed during the extrusion is common to brown breads and buns during production [33].

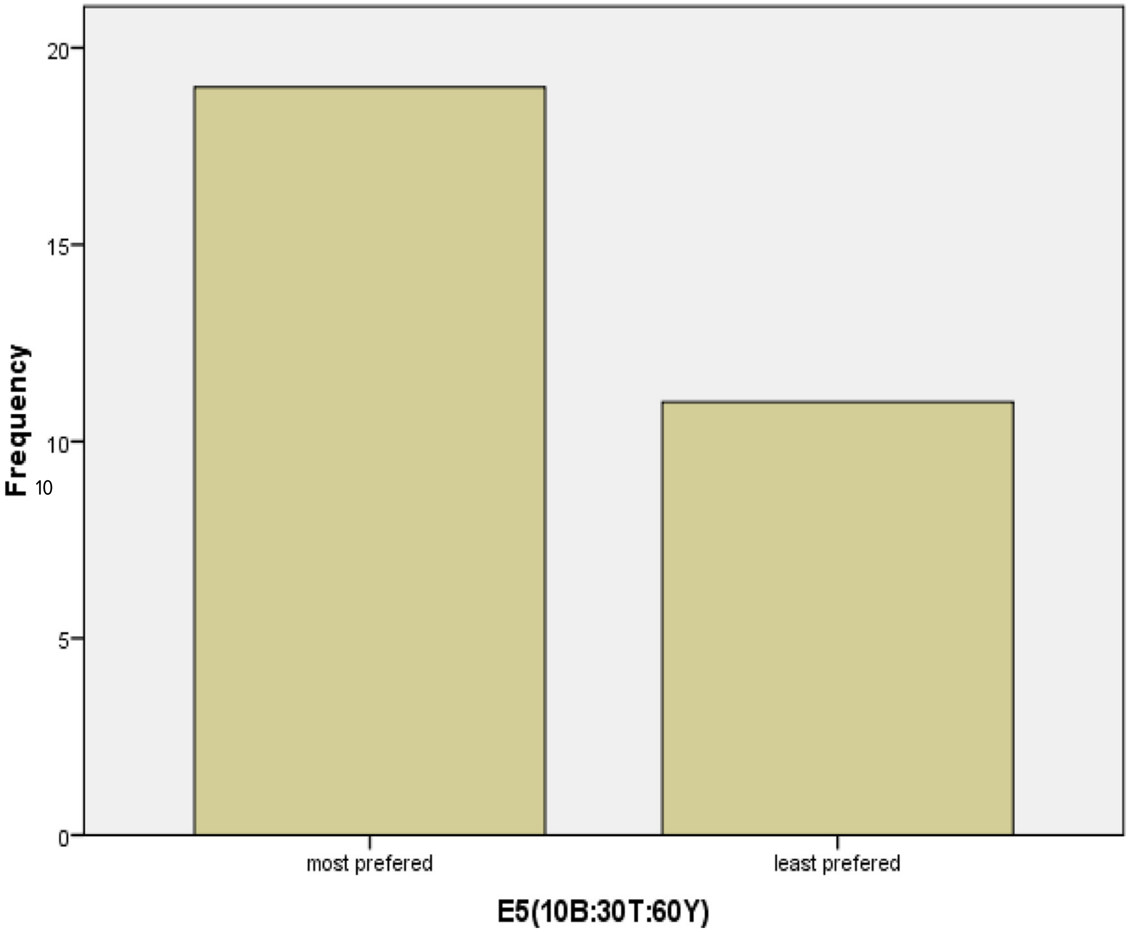

Fig. 1. Frequency of preference for E5 (10B: 30T: 60Y).

Table 5b
Colour characteristics of trial extrudates.

Sample code	L	a	b	Hue angle
E5(10B:30T:60Y)	63.72±0.08^a	3.83±0.05^a	13.63± 0.56^a	74.31±0.63^a
E6(20B:20T:60Y)	63.11±0.17^a	4.18±0.03^b	13.88±2.23^a	72.98±−2.02^b

*Y=Yam T=Tamarind B=Baobab.
* L=lightness a=(negative=green; positive=redness) b=(negative=blue; positive=yellow).
Hue angle (H)=basic unit of colour.
*Analysis was done in triplicates, *Means with the same superscripts within the column are not significantly different ($p<0.05$).

The hue angle (H) of composite flours (F2-F6) ranged from (88.53- 88. 89) as compared to the control sample (F1) which was 88.37. Results from Table 5a and 3.3b also there were significant differences ($p \leq 0.05$) between the mean hue values of both flour samples and extrudates. Hue is the colour from the rainbow or spectrum of colours and so the value of hue gives an idea of the colour of the product. Despite the fact that there were some variations in lightness, red/greenness, yellow/blueness, intensity and saturation of colour for extrudates, the closeness of preference for colour during sensory evaluation is evident in the statistical results of hue shown in Table 4.

Pasting characteristics of extrudates and composite flours

Results of the pasting properties of flour composites and extrudates have been summarized in Tables 6a and 6b respectively. There were significant differences ($p<0.05$) in the viscosities of flour blends.

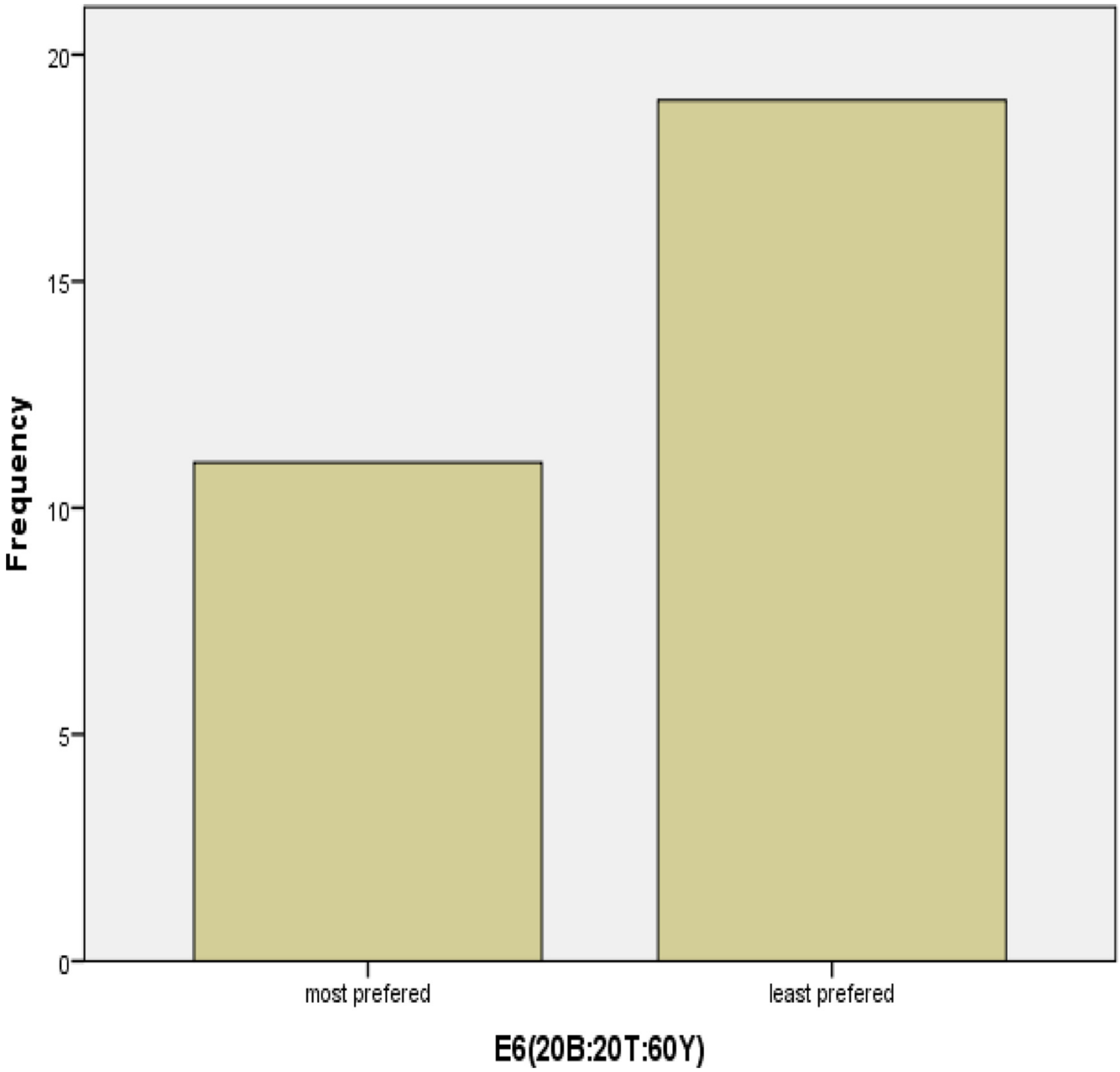

Fig. 2. Frequency of preference for E6 (20B: 20T: 60Y).

Pasting temperature (PT) and pasting time (Ptime)

There were significant differences ($p<0.05$) in pasting time and temperature for flour blends. Forty percent tamarind (F2) and 40% baobab (F3) flour composites had the highest pasting time while 30% baobab (F4) and 20% baobab (F6) flour composites had the shortest pasting time. According to Seetharaman et al. [77], flours with higher pasting temperatures may have granules that have a relatively higher resistance to swelling. Shimelis et al. [79] also indicated that pasting temperature is one of the pasting properties which present an indication of the minimum temperature needed for sample cooking, energy costs involved and other components stability. The extrudates need minimal temperature within a very short time to be cooked.

The pasting temperature and time of the trial extrudates, 20% tamarind/baobab, was 50.30bu and 0.08 min respectively (Table 6b). This suggests that extrudates had lower resistance to swelling due to weaker associative forces within the granules.

Peak viscosity (PV)

Peak viscosity values were significant ($p<0.05$) in flour blends. Viscosity measurement is necessary to predict the starch or polysaccharide structural changes that occur during cooking as well as the extent of starch change (conversion).

Trial extrudate (E6) had lower PV value (14.67bu) as shown in Table 4 which connotes degradation and gelatinization of starch/ jellose/ pectin. This effect results from the depolymerization and molecular entanglement which occurred when samples were subjected to high heat during extrusion cooking [36].

Table 6a
Pasting properties of flour composites.

Composite Flours	F1(100Y)	F2(40T:60Y)	F3(40B:60Y)	F4(30B:10T:60Y)	F6(20B:20T:60Y)
Ptemp (°C)	80.60±1.41[a]	76.45±2.05[b]	80.75±0.35[a]	50.15±0.07[c]	80.75±2.76[a]
Ptime (min)	21.54±1.22[a]	25.21±0.30[b]	21.59±0.58[a]	0.08±0.00[c]	19.68±0.34[d]
PV (bu)	282.00±4.24[a]	291.00±1.41[b]	145.50±0.71[c]	2.50±0.71[d]	166.00±2.83[e]
MV (bu)	264.00±5.66[a]	289.50±2.12[b]	138.00±1.41[c]	2.50±0.71[d]	164.00±4.24[e]
End of cooling (bu)	197.50±3.54[a]	455.00±1.41[b]	131.50±0.71[c]	11.00±1.41[d]	212.00±4.24[e]
FV (bu)	174.00±4.24[a]	440.00±2.83[b]	122.50±3.54[c]	10.00±1.41[d]	192.00±2.83[e]
BV (bu)	20.50±2.12[a]	1.50±0.71[b]	6.50±0.71[c]	0.00±0.00[b]	2.50±0.71[b]
SBV (bu)	−69.50±3.54[e]	148.00±2.83[b]	−7.00±1.41[a]	8.00±1.41[c]	47.50±2.12[d]

*Ptemp=Pasting Temperature; Ptime=Peak Time; PV=Peak Viscosity; MV=Minimum Viscosity; FV=Final Viscosity; BV=Breakdown Viscosity; SBV=Setback Viscosity; Y=Yam; T=Tamarind; B=Baobab.
*Analysis was done in triplicates.
*Means with the same superscripts within the column are not significantly different ($p>0.05$).

Table 6b
Pasting properties of extrudates.

Extrudates	Ptemp (°C)	Ptime (min)	PV (bu)	MV (bu)	FV (bu)	BV (bu)	SBV (bu)
E6 (20B:20T:60Y)	50.30±0.02	0.08±0.01	14.67±0.79	5.33±0.58	14.33±2.08	7.67±1.53	8.33±1.15

*Y=Yam; T=Tamarind; B=Baobab; Ptemp=Pasting Temperature; Ptime=Peak Time PV=Peak Viscosity; MV=Minimum Viscosity; FV=Final Viscosity; BV=Breakdown Viscosity; SBV=Setback Viscosity.
*Analysis was done in tripliclate.

Peak viscosity of 40% tamarind (F2) flour composite was higher than 100% yam flour (F1) whiles 40% baobab pulp substitute (F3) had lower in peak viscosity than 100% yam flour. This may be as a result of the fact that jellose in tamarind may have influenced the higher values for peak viscosity. This is supported by work done by Lineback and Ke [49] who reported that legume starches (tamarind in this case) have higher viscosity than cereal starches. This also may imply that jellose may have been more resistant to swelling and rupture towards shear stress and heat.

The peak viscosity is related to the water binding capacity of starch/jellose/pectin in samples. The peak viscosity indicates the ability of starch to swell freely before their physical breakdown [40]. Samples substituted with baobab/tamarind had higher WBC values than 100% yam flour (Table 4.4 and Table 4.5). The comparatively high peak viscosity exhibited by tamarind substituted flours is suggestive that they may be suitable for products requiring high gel strength and viscosity (puddings, purees, smoothies, porrigde).

Other factors which could have affected the peak viscosity are the size and shape of the starch granules, ionic charge on the starch, kind and degree of crystallinity within the granules, presence or absence of fat and protein and perhaps, molecular size and degree of branching of the starch fractions [76,79]. However these characteristics were not measured in this study.

The trial extruded product (20% tamarind/baobab), E6, had low PV (14.67bu). This may be attributed to the protein denaturation, modification of the conformation of the proteins and also starch-protein interactions which generates structures with lower ability for interaction with water and consequently low viscosity [45]. The low values for peak viscosity of extrudates means that the samples have been pre-cooked and if milled into flour, could be reconstituted easily with warm water (60^{0}C) or they could be taken as ready to eat snacks [58].

Minimum viscosity (MV)

The minimum viscosity which measures the ability of paste to resist breakdown during cooling were significantly higher ($p<0.05$) for flour samples than extrudates. Minimum viscosity is also termed as trough viscosity. MV values were in the range of 2.50bu to 289bu for flour composites (3.2a). Forty percent tamarind (F2) had the highest (289bu) MV whiles 30% baobab had the least (2.5bu) amongst flour composites. A higher breakdown viscosity value indicates lower ability of the sample to withstand heating and shear stress during cooking [2]. The results show that twenty percent baobab (F6) and 40% baobab (F3) substituted flours had the ability to withstand heating and shear stress better than tamarind substituted flours and 100% yam flour (F1). This implies samples with higher MV easily breakdown when subjected to heat and consequently syneresis and retrogradation may occur easily if the gelatinization temperature is exceeded.

Final viscosity (FV)

The mean final viscosity (FV) values for flour composites had significant differences ($p<0.05$). Composite flours had mean FV values within a range of 10bu for 30% baobab (F3) to 440bu for 40% tamarind (Table 4).

The most commonly used parameter to determine starch-based samples quality is final viscosity [21]. FV is a measure of starch re-association after cooling which depends on modifications that occur in the structure of granules and molecules during extrusion and pre-treatment processes. It could give an indirect clue of how much resistant starch are formed via retrogradation of starch [51]. It also indicates the ability to form viscous paste or gel after cooling and less stable of starch paste commonly accompanied with high value of breakdown.

Samples with higher tamarind substitution had higher FV than those with baobab substitutions. This means that highly substituted tamarind flour samples had an increase in starch/jellose content as well as the extent of re-association tendency of these gelling polysaccharides. However, the extrudates had low FV value (14.33bu) because during cooling the starch and the protein may have produced a weaker and less stable gel [51]. The final viscosity indicates the ability of the extrudates to easily form a viscous paste when milled into flour.

Breakdown viscosity (BV)

Break down viscosity mean values were generally low for either flour samples or extrudates. Composite flours had mean BV values within a range of 0.00bu for 30% baobab (F3) baobab to 2.50bu for 100% yam flour (F1) (Table 4). Extrudates (E6) had mean BV value of 7.67bu (Table 4).

One hundred percent yam flour (F1) had high break down viscosity (20.50bu) but as tamarind or baobab was added the breakdown viscosity decreased (0.00–6.50bu). The results show that TKP has the potential to reduce breakdown viscosity than BPP. However for the trial extrudates, there was an increase in BV value.

The breakdown is a measure of the extent of disintegration [57]. It indicates the starch's tendency for disintegration. The higher breakdown of viscosity indicates substantial disruption or weakening of the bonding forces (hydrogen bonds) in the starch granules during heating [13].

Low values of breakdown viscosity suggest that during the pasting process which involves mechanical shearing and heating, the composites were more resistant to the swelling and disintegration. This also indicates that swollen granules of the composite samples had good stability against the mechanical shearing [2].

Setback viscosity (SBV)

The setback viscosity values (measure of syneresis of starch upon cooling of the cooked starch pastes) of flour composites were in the range of −7.00 to 148bu. The higher the setback value, the lower the retrogradation during cooling of the products made from the flour. Setback values varied significantly ($p<0.05$) for flour composites.

Results from Table 4 shows that addition of TKP increased setback viscosity of flour composites. It may indicate that TKP minimized the starch chain re-association to occur readily during the cooling stage, and caused increased viscosity during cooking [70].

Trial extrudates, 20% tamarind/baobab (E6) had a decrease in setback viscosity with a value of 8.33bu. This may have been reduced by temperature [20]. Low setback values indicate high rates of starch retrogradation and syneresis, by re-arrangement of the stretched amylose molecules into a low energetic level forming new entanglements amongst them. The setback viscosity shows the syneresis of starch upon the cooling of the cooked starch pastes [74].

Conclusion

It has been shown from this study that flour blends with tamarind kernel powder (TKP) and baobab pulp powder (BPP) have improved physiochemical and pasting properties. The flour blends could be used in varying food formulations such as drinks, puddings, sauces, ice-creams, pastries and yoghurts for the reason that they could serve thickening and stabilizing functions (high WBC and swelling power).

D. alata (water yam) has a promising future in the snack industry using the technology of extrusion cooking. With the increasing surge for healthy snacks, supplementation of water yam with legumes such as *Tamarindus indica* and fruits such as *Adansonia digitata* will provide extruded healthy snacks that can equally compete with extruded cereal snacks on the market.

Sensory evaluation performed on extrudates revealed that consumers would prefer highly substituted yam flour with TKP to BPP. In terms of overall acceptability panellists preferred E5 (10B:30T:60Y) to E6 (20B:20T:60Y). Finally, the results for pasting and physicochemical after extrusion show that the extrudates are ready to be eaten with low moisture values.

Contributors

Zeenatu Suglo Adams was the student on the study. She was a part of the team that generated the concept for the study, carried out experiments and was involved in data analysis and write-up as well.

Dr. Faustina D. Wireko-Manu was a Supervisor on the study. She was part of the team that generated the concept for the study, guided experiments, reviewed results generated and write-up.

Dr. Jacob Agbenorhevi was a member of the team contributing to shaping up the study, supervising the experiments and assisting in data analysis and its subsequent explanations.

Professor Ibok Oduro was a Supervisor on the team giving professional advice to the development of the concept for the study, reviewing results and write-up.

Declaration of Competing Interest

None.

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