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Proximate composition, provitamin A retention, and shelf life of extruded orange-fleshed sweet potato and bambara groundnut-based snacks

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Abstract

Evaluating the effect of processing on nutrient content and shelf life is important when developing new products. Six formulations of orange-fleshed sweet potato (OFSP) and bambara groundnut were extruded at a feed rate of 10.15 kg/hr, screw speed of 30 rpm and at 100 and 130 °C in first and second zones respectively. Proximate composition was determined using standard methods. Provitamin A was determined using high-performance liquid chromatography. An untrained panel ($n = 73$) was used to determine consumer acceptability. Shelf life was predicted by using peroxide values. Concentration of OFSP or bambara groundnut significantly ($p < .05$) affected proximate composition of the snacks. Moisture (4.79–8.34 g/100 g), carbohydrates (55.53–78.99 g/100 g) and provitamin (0.54–17.33 mg/100 g) contents increased with increase in proportion of OFSP. Protein (4.08–15.03 g/100 g), fat (4.20–12.74 g/100 g), fiber (5.29–6.46 g/100 g), ash (0.09–4.80 g/100 g), and energy (366.13–396.9 kcal/100 g) increased with increasing proportion of bambara groundnut in the formulation. Extrusion significantly ($p < .05$) reduced provitamin A content from 0.90–20.73 to 0.54–17.33 mg/100 g. Presence of OFSP improved provitamin A retention and consumer acceptability. Predicted shelf life (ranged from 118 to 150 days at room temperature) was inversely proportional to the concentration of bambara groundnut.

Practical applications

Vitamin A deficiency (VAD) is the leading cause of preventable blindness affecting many children and women of reproductive age globally. Provitamin A enriched foods can be developed from locally available provitamin A-rich foods and their consumption promoted to help prevent VAD. In this study, recipes incorporating orange-fleshed sweet potatoes and bambara groundnut were used to develop acceptable and shelf stable vitamin A enriched extruded snacks. The formulations and process used in this study can be adopted at commercial level to produce affordable snacks that can contribute towards reducing the burden of VAD. The results from this study can also be used in similar studies to develop nutrient enhanced extruded snacks.

1 | INTRODUCTION

Vitamin A deficiency (VAD) is the leading cause of preventable blindness affecting many children and women of reproductive age (Burri, 2011). Globally, 250,000,000 preschool children are vitamin A deficient; 250,000–500,000 of these become blind annually, while 125,000–250,000 die within a year of losing their sight (WHO, 2016). VAD increases the risk of disease and death from severe infections like diarrhea and measles (WHO, 2016). About 40% of preschool children in Sub-Saharan Africa and South-East Asia suffer from VAD (Burri, 2011). In Tanzania, 34% of preschool children and 37% of women have VAD (TNBS/ICFMacro, 2010). VAD prevention strategies include: vitamin A supplementation programmes, food fortification and promoting intake of provitamin A-rich foods (Burri, 2011). Vitamin A supplementation and fortification have been successfully adopted by a number of countries despite limitations of coverage and challenges with universal acceptability of fortified food vehicles. Promoting intake of provitamin A-rich foods is open to a diversity of foods and can be used to enhance the former strategies. Provitamin A-rich extruded snacks developed from locally available raw materials could be used to promote vitamin A intake since extruded snacks are very popular among young children.

Extrusion cooking is a high-temperature, short-time process in which starchy and/or proteinaceous food materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear (Singh, Gamlath, & Wakeling, 2007). Extrusion is a relatively easy process that is widely used to produce a variety of textured and shaped convenience products including: breakfast cereals, baby foods, soups, and ready-to-eat snacks among others (Brennan, Derbyshire, Tiwari, & Brennan, 2013; Singh et al., 2007). Extruded snacks are, however, predominantly prepared from high carbohydrate containing ingredients such as corn, rice, wheat, potato, and oats (Brennan et al., 2013). The snacks are thus energy dense with a limited content of protein and other nutrients such as vitamin A (Brennan et al., 2013; Riaz, Asif, & Ali, 2009). Consumers are, however, increasingly demanding for more nutritious snacks that are low in fat but rich in protein, fiber, minerals and vitamins (Brennan et al., 2013). Locally available raw materials such as orange-fleshed sweet potatoes (OFSPs) and bambara groundnuts can be used to produce vitamin A- and protein-enriched extruded snacks.

The sweet potato (*Ipomoea batatas*) is one of the important root and tuber crops produced in Africa. Over 7 million tons, about 5% of global production, of sweet potatoes are produced in Africa with most being produced in the East and Southern Africa region (Olapade & Ogunade, 2014). Sweet potatoes contains 63–70% moisture content, 18.86–29.86% carbohydrates, 0.71–9.84% protein, 0.14–2.8% crude fiber, 0.43–2.0% ash, and 1.1–2.0% fat (Rose & Vasanthakaalam, 2011; Ukom, Ojimelukwe, & Okpara, 2009). OFSP varieties are among the foods with the greatest potential of reducing VAD owing to their very high beta-carotene content and general acceptability as a food (Burri, 2011). The beta-carotene content of OFSP may range from 1,240 to 92,940 μg/100 g beta-carotene (Burri, 2011; Fonseca, Soares, Freire Junior, de Almeida, & Ascheri, 2008). It is estimated that daily consumption of 6–33 or 68–381 g/day of OFSP by children and lactating mothers respectively is sufficient to meet 100% of vitamin A requirements (Burri, 2011). OFSP has been used as an ingredient in infant foods to boost vitamin A content. OFSP is, however, low in protein and fat and has to be mixed with high protein and lipid containing ingredients such soy, fish powder, and soy bean oil to produce nutritionally adequate products (Amagloh & Coad, 2014).

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is widely distributed throughout the semi-arid zones of sub-Saharan Africa (Hillocks, Bennett, & Mponda, 2012). It grows well under extreme conditions of poor soils, low rainfall, pests and diseases thus making it important for ensuring food security and curbing malnutrition (Amarteifio, Tibe, & Njogu, 2006; Hillocks et al., 2012). Bambara groundnut is used in several recipes, especially in western Africa where it is consumed fresh, boiled, roasted, milled into a powder, and used to make balls, steamed pastes, porridges, flat cakes, or biscuits (Hillocks et al., 2012). Despite this, bambara has remained relatively underutilized because of its long cooking time and antinutritional factors such as trypsin inhibitors, oxalate and tannins (Hillocks et al., 2012). Its seeds contain 7.2–11.7% moisture, 54.5–69.3% carbohydrate, 17–24.6% protein, 10.3% crude fiber, 2.9–4.8% ash, and 1.4–7.85% lipids and 390 kcal/100 g (Hillocks et al., 2012; Okonkwo & Opra, 2010; Yao et al., 2015). Bambara groundnut is also a good source of fiber and minerals, such as calcium, potassium, magnesium, phosphorous, iron, magnesium, and phosphorous (Amarteifio et al., 2006; Hillocks et al., 2012). Bambara, just like other legumes, has a great potential for fortifying the protein, fat, and ash contents of extruded snacks (Adebowale, Adegunwa, Okunbolurin, & Bakare, 2016; Asare, Sefa-Dedeh, Afoakwa, Sakyi-Dawson, & Budu, 2012; Filli, Nkama, & Jideani, 2013; Oluwole, Awonorin, Henshaw, Elemo, & Ebuehi, 2013).

Evaluating nutrient content, retention of labile nutrients and shelf stability is very important in developing new nutritious extruded snacks. Retention of beta-carotene during extrusion may be influenced by extrusion conditions and formulation (Fonseca et al., 2008; Riaz et al., 2009; Singh et al., 2007). Similarly, oxidative rancidity, which is one of the spoilage characteristics of lipid containing extruded products, is influenced by formulation (Kocherla, Aparna, & Lakshmi, 2012; Shaviklo, Thorkelsson, Rafipour, & Sigurgisladottir, 2011). Although bambara groundnut has been used as an ingredient in extruded snacks, there is no report of its coextrusion with OFSP. Little is therefore known about how varying formulations of OFSP and bambara groundnut may influence nutrient content, provitamin A retention and shelf stability of OFSP and bambara extruded snacks. Therefore, the purpose of this study was to determine the effect of varying OFSP and bambara groundnut formulations on proximate composition, provitamin A retention, consumer acceptability, and shelf stability of extruded snacks.

2 | MATERIALS AND METHODS

2.1 | Raw materials

OFSP tubers of the Jewel variety were purchased from Ukiliguru Agricultural Research Institute (Mwanza, Tanzania). Bambara groundnuts were purchased from the main market in Morogoro, Tanzania. Analytical grade reagents were used for chemical analyses.

2.2 | Preparation of OFSP and bambara groundnut flours

OFSP tubers were washed with portable water to remove dirt and then peeled using a kitchen knife. The tubers were chipped to approximately 0.2–0.4 cm wide, 2–5 cm long, and 0.1–0.3 cm thick using a chipping machine (Model CH, Intermech Engineering, Morogoro, Tanzania). Bambara groundnuts were sorted and washed with portable water. Drying of the chips and nuts was carried out for 24 hr in a walk-in solar drier. The dried chips and bambara groundnuts were milled into flour using a commercial hammer mill (Model CH, Intermech Engineering, Morogoro, Tanzania) having a screen of 0.8 mm. The moisture contents of OFSP and bambara groundnut flours were 8.34 ± 0.05 and 5.43 ± 0.24 g/100 g, respectively, as determined by the oven drying method (AOAC, 1995).

TABLE 1 Formulation of orange fleshed sweet potato (OFSP) and bambara groundnut (BN) composite flours for extruded snack production

Code of composite flour formulation[a]	Amount of ingredient in the formulation (g)					Adjusted moisture content (%)
	OFSP	Bambara groundnut	Sugar	Salt	Cooking oil	
100% OFSP	100	0	3	2	3	14
80% OFSP	80	20	3	2	3	14
60% OFSP	60	40	3	2	3	14
40% OFSP	40	60	3	2	3	14
20% OFSP	20	80	3	2	3	14
100% BN	0	100	3	2	3	14

[a]The composite flour used in formulating the extruded snacks was composed of orange fleshed sweet potato (OFSP) and bambara groundnut (BN).

2.3 | Extrusion of OFSP–bambara groundnut based snacks

Composite OFSP and bambara groundnut flours for preparation of the snacks were prepared by substitution as shown in Table 1. Prior to extrusion, 3 g sugar, 2 g salt, and 3 g cooking oil were added per 100 g of composite flour. Moisture content was adjusted to 14 g/100 g by adding distilled water and allowing the mixture to equilibrate for 4 hr at room temperature (Hazarika, Borah, & Mahanta, 2013; Oluwole et al., 2013). Extrusion was carried out using a corotating twin screw extruder with *L*/*D* ratio of 16:1 and screw diameter of 60 mm (Model Js-60D, China). Extrusion conditions were: feeding rate of 10.15 kg/hr, screw speed of 30 rpm and barrel temperatures of 100 and 130°C in first and second zones respectively. After extrusion, the samples were collected, cooled to room temperature under natural convection conditions, sealed in polyethylene bags, and stored at −18°C prior to analysis. Samples for shelf life estimation were stored in the dark at room temperature.

2.4 | Proximate composition of OFSP–bambara groundnut extruded snacks

Moisture content was determined by the oven drying method (AOAC, 1995). Crude protein was determined by the Kjedahl method (AOAC, 1995). Fat content was determined by solvent extraction (AOAC, 1995). Ash content was determined by the dry ashing method (AOAC, 1995). Crude fiber was determined using dilute acid and alkali hydrolysis (AOAC, 1995). The carbohydrate content was determined by difference (FAO, 2003).

2.5 | Provitamin a retention

Provitamin A content was determined using high-performance liquid chromatography (Rodriguez-Amaya & Kimura, 2004). Percentage retention of provitamin A was calculated by considering the amount of provitamin A before and after extrusion on dry matter basis.

2.6 | Evaluation of consumer acceptability

An untrained panel of consumers ($n = 73$) aged 20–39 years was used to determine the consumer acceptability of OFSP–bambara ground nut extruded snacks. The panelists ranked the acceptability of different attributes of the snacks using a 9-point hedonic scale (9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely) described by Lawless and Heymann (2010). The samples were coded with three-digit random numbers using statistical random tables and served to the panelists in a randomized order. Distilled water was provided for rinsing the palate.

2.7 | Estimation of shelf life of OFSP–bambara groundnut extruded snacks

Shelf life at room temperature was estimated by measuring the peroxide value (AOAC, 1995) of the snacks during storage. Portions of the extruded snacks (50 g each) were individually packed and sealed in transparent polyethylene bags and stored in the dark at room temperature. Transparent packaging was used to facilitate observation of visible product changes. Sampling for analysis of peroxide value was done at time = 0, 14, 28, 42, and 56 days for samples stored at room temperature. Peroxide values were plotted against time and linear regression used to determine the point at which a critical peroxide value of 10 meq/kg (Bureau of Indian Standards, 1989) would be obtained under conditions of fluctuating room temperature storage.

2.8 | Statistical analysis

Means for provitamin A in unextruded and extruded samples were compared using the Student's *t*-test ($p < .05$). Means of proximate composition, percentage provitamin A retention, and consumer acceptability were analyzed using one-way analysis of variance to test for significant differences ($p < .05$). Means were separated using Tukey's honest significant difference ($p < .05$). Linear regression of peroxide values was used to estimate the shelf life of the extruded snacks. Data were analyzed using the R statistical package (Version 3.0.0; R Development Core Team, Vienna, Austria).

TABLE 2 Effect of formulation on the proximate composition of orange fleshed sweet potato (OFSP) and bambara groundnut extruded snacks

Composite flour for formulation*	Proximate composition (g/100 g DM)							
	Moisture	Protein	Fat	Fiber	Ash	CHO	Energy (kcal)	Provitamin A (mg/100 g DM)
100% OFSP	8.34 ± 0.50^{d}	4.08 ± 0.26^{a}	4.20 ± 0.092^{a}	5.29 ± 0.03^{ab}	0.09 ± 0.02^{a}	78.00 ± 0.67^{f}	366.13 ± 2.43^{a}	17.33 ± 0.48^{e}
80% OFSP	5.16 ± 0.20^{a}	6.94 ± 0.09^{b}	5.91 ± 0.04^{b}	5.42 ± 0.09^{a}	2.31 ± 0.31^{b}	72.35 ± 0.56^{e}	370.37 ± 2.23^{a}	8.04 ± 0.20^{d}
60% OFSP	6.60 ± 0.29^{bc}	8.06 ± 0.09^{c}	7.48 ± 0.09^{c}	5.81 ± 0.17^{b}	4.51 ± 0.13^{b}	67.53 ± 0.77^{d}	369.71 ± 1.90^{a}	9.16 ± 0.09^{c}
40% OFSP	6.72 ± 0.12^{c}	9.58 ± 0.39^{d}	8.42 ± 0.13^{d}	6.75 ± 0.06^{c}	4.66 ± 0.04^{b}	63.87 ± 0.61^{c}	369.63 ± 0.23^{a}	4.07 ± 0.19^{b}
20% OFSP	4.74 ± 0.38^{a}	12.93 ± 0.31^{e}	9.91 ± 0.12^{e}	6.45 ± 0.00^{c}	4.48 ± 0.06^{b}	61.50 ± 0.10^{b}	386.90 ± 1.90^{b}	3.81 ± 0.23^{b}
100% BN	5.43 ± 0.24^{ab}	15.03 ± 0.34^{f}	12.74 ± 0.02^{f}	6.46 ± 0.31^{c}	4.80 ± 0.26^{b}	55.53 ± 0.15^{a}	396.94 ± 0.90^{c}	0.54 ± 0.05^{a}

Values are mean ± *SD* ($n = 2$). Mean values with different superscripts (a, b, c, d, e, and f) along the column are significantly different ($p < .05$).
*The composite flour used in formulating the extruded snacks was composed of orange fleshed sweet potato (OFSP) and bambara groundnut (BN).
CHO, carbohydrates.

3 | RESULTS

3.1 | Proximate composition of OFSP–bambara groundnut extruded snacks

Generally, varying the concentration of OFSP or bambara groundnut in the formulation significantly ($p < .05$) affected the proximate composition of the extruded snacks (Table 2). Moisture (4.79–8.34 g/100 g), carbohydrate (55.53–78.99 g/100 g), and provitamin (0.54–17.33 mg/100 g) contents of the snacks increased with increase in the proportion of OFSP in the formulation. Conversely, protein (4.08–15.03 g/100 g), fat (4.20–12.74 g/100 g), fiber (5.29–6.46 g/100g), ash (0.09–4.80 g/100 g), and energy (366.13–396.9 kcal/100 g) increased with increasing proportion of bambara groundnut in the formulation.

3.2 | Effect of extrusion and formulation on provitamin A retention in OFSP–bambara groundnut extruded snacks

Extrusion significantly ($p < .05$) reduced the provitamin A content of all snack formulations (Figure 1). Losses ranged from 13.5 to 40.44% and these increased with increase in proportion of bambara groundnut in the formulation. With respect to effects of formulation, significant ($p < .05$) reduction in provitamin A retention was only observed in the formulation containing 100% bambara groundnut.

3.3 | Effect of formulation on consumer acceptability of OFSP–bambara groundnut extruded snacks

Variations in the formulation of the OFSP–bambara groundnut significantly ($p < .05$) affected their mean acceptability scores (Table 3). Acceptability scores of the snacks ranged between 5 (neither like nor dislike) to 7 (like moderately). Snacks made from 100% bambara groundnut flour were liked the list but addition of OFSP significantly improved their acceptability scores.

3.4 | Effect of formulation on estimated shelf life of OFSP–bambara groundnut extruded snacks

Figure 2 shows the regression equations for peroxide values (PV) of the OFSP–bambara-based extruded snacks while Table 4 shows the estimated

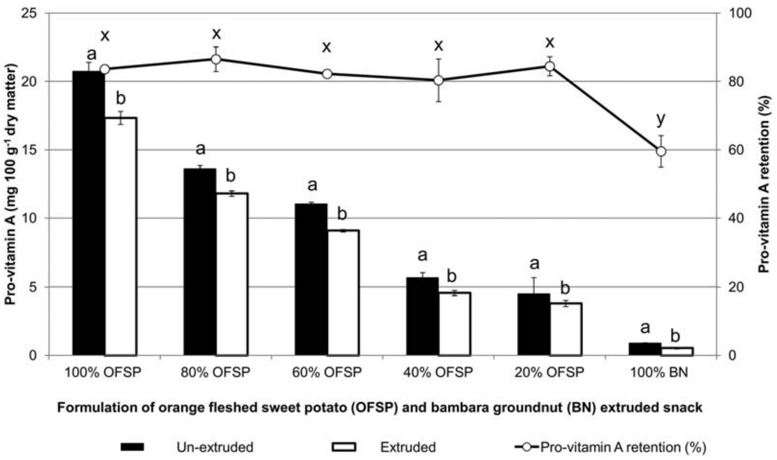

FIGURE 1 The effect of extrusion and formulation on provitamin A retention in orange fleshed sweet potato (OFSP) and bambara (BN) extruded snacks. Values are expressed as mean ± *SD* ($n = 3$). Error bars represent *SD*. Bars with different letters (a and b) for the same product group and points on the line for provitamin retention with different letters (x and y) are significantly different ($p < .05$)

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TABLE 3 Acceptability scores for extruded formulated snacks

Code of composite flour formulation*	Acceptability scores				
	Aroma	Color	Taste	Texture	Overall acceptability
100% OFSP	6.67 ± 1.44^{b}	7.29 ± 1.35^{c}	7.08 ± 1.44^{c}	6.68 ± 1.73^{c}	6.96 ± 1.39^{c}
80% OFSP	$6.1 \pm 9\ 1.24^{ab}$	6.71 ± 31^{bc}	6.45 ± 1.47^{ab}	6.55 ± 1.50^{c}	6.62 ± 1.39^{bc}
60% OFSP	6.61 ± 1.23^{b}	7.16 ± 1.39^{c}	6.69 ± 1.40^{bc}	6.33 ± 1.75^{bc}	6.66 ± 1.44^{bc}
40% OFSP	6.45 ± 1.23^{b}	6.51 ± 1.44^{b}	6.36 ± 1.51^{ab}	5.82 ± 1.62^{ab}	6.38 ± 1.24^{ab}
20% OFSP	6.34 ± 1.33^{b}	$7.01 \pm 1.45b^{c}$	6.51 ± 1.69^{ac}	6.58 ± 1.42^{c}	6.66 ± 1.39^{bc}
100% BN	5.81 ± 1.55^{a}	5.39 ± 1.79^{a}	5.69 ± 1.78^{a}	5.66 ± 2.00^{a}	5.88 ± 1.76^{a}

Values are mean ± *SD* ($n = 2$). Mean values with different superscripts along the columns are significantly different ($p < .05$).
*The composite flour used in formulating the extruded snacks was composed of orange fleshed sweet potato (OFSP) and bambara groundnut (BN).

shelf life at fluctuating room temperatures (temperatures in the laboratory varied between 24 and 26 °C at noon and 19 and 20 °C in the early morning). PV generally increased during storage from 2.45 to 6.40 meq/kg but did not reach the critical value of 10 meq/kg in any of the samples.

The estimated shelf life using linear regression and based on a critical value of 10 meq/kg ranged from 118 to 150 days. Estimated shelf life decreased with increasing proportion of bambara groundnut in the formulation (Table 4).

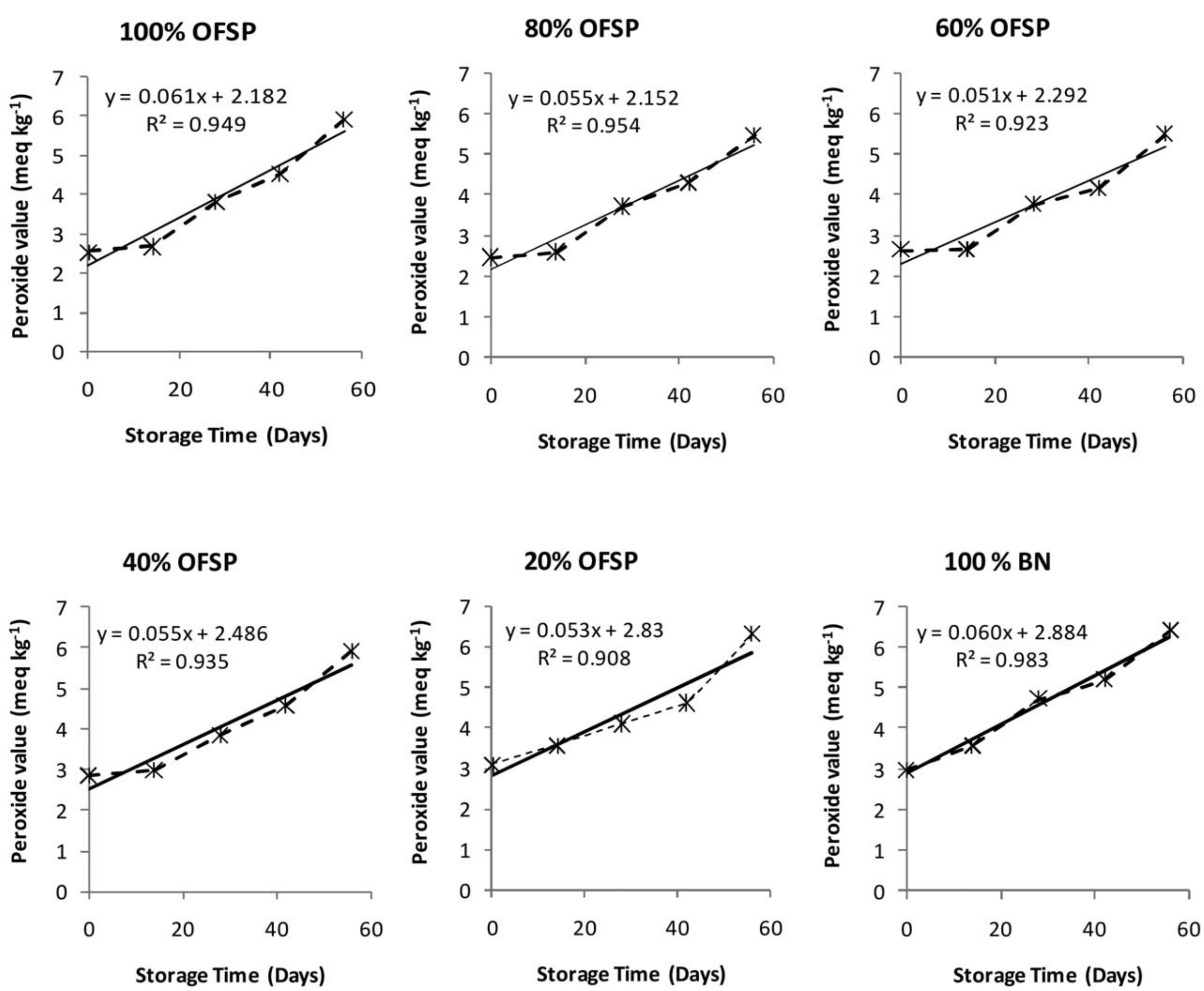

FIGURE 2 Linear regression plots of changes in peroxide value during room temperature storage (19–26 °C) of orange fleshed sweet potato and bambara groundnut extruded snacks of different formulations. Values are expressed as mean ± *SD* ($n = 3$). The composite flour used in formulating the extruded snacks was composed of orange fleshed sweet potato (OFSP) and bambara groundnut (BN)

TABLE 4 Regression equations and R^2 values for lipid oxidation based on peroxide values and the predicted shelf life of OFSP–bambara extruded snacks using the linear model

Code of composite flour formulation[a]	Linear model	R^2	Predicted shelf life (days)
100% OFSP	$y = 0.0514x + 2.292$	0.9231	150
80% OFSP	$y = 0.0551x + 2.152$	0.9546	142
60% OFSP	$y = 0.055x + 2.486$	0.9351	137
40% OFSP	$y = 0.0536x + 2.83$	0.9085	134
20% OFSP	$y = 0.0611x + 2.182$	0.9493	128
100% BN	$y = 0.0604x + 2.884$	0.9836	118

[a]The composite flour used in formulating the extruded snacks was composed of orange fleshed sweet potato (OFSP) and bambara groundnut (BN).

4 | DISCUSSION

The objective of this study was to develop shelf stable snacks with enhanced provitamin A and protein contents using OFSP and bambara groundnut both of which are locally available ingredients from Tanzania. The effect of varying OFSP and bambara ground nut formulations on proximate composition, vitamin A retention, consumer acceptability, and shelf stability of extruded snacks was evaluated. The study also determined the effect of extrusion processing on the retention of vitamin A in the snacks.

4.1 | Proximate composition and provitamin A content of OFSP–bambara groundnut extruded snacks

Four studies on extruded snacks containing bambara groundnut and yams (Oluwole et al., 2013); bambara groundnut and rice (Adebowale et al., 2016); corn flour, rice flour, egg powder, or cheese powder (Kocherla et al., 2012); and rice flour, yam, and sweet potato (Hazarika et al., 2013) were reviewed for nutrition composition of extruded snacks. The snacks contained 1.8–12.1% moisture, 44.6–85.18% carbohydrates, 5.3–24.46% protein, 0.19–3.13% fat, 0.26–1.38% fiber, 0.09–2.49% ash, and 244.6–411 kcal/100 g. None of the four studies cited above determined the provitamin A content of the snacks. The moisture, carbohydrate, protein and energy content of the OFSP + bambara groundnut extruded snacks developed in this study were within the ranges noted above. However, fat, fiber, and ash contents were higher than for the other extruded snacks (Adebowale et al., 2016; Hazarika et al., 2013; Kocherla et al., 2012; Oluwole et al., 2013). The proportions of bambara groundnut used in this study (up to 100%) were much higher than 25 and 50% used by Oluwole et al. (2013) and Adebowale et al. (2016), respectively. The foregoing observation, coupled by the fact that bambara ground nut contains higher amounts of fat, ash, and fiber than OFSP (Hillocks et al., 2012; Okonkwo & Opra, 2010; Rose & Vasanthakaalam, 2011; Ukom et al., 2009; Yao et al., 2015), explains why higher levels of these components were observed in this study moreover as the concentration of bambara groundnut in the formulation increased.

An increase in protein content observed with increasing bambara groundnut content in the formulation is attributed to the fact that the latter has a higher protein content than OFSP (Hillocks et al., 2012; Rose & Vasanthakaalam, 2011; Ukom et al., 2009). Protein content in extruded snacks increases as the proportion of a high protein ingredient in the formulation is increased (Adebowale et al., 2016; Kocherla et al., 2012). Bambara groundnut can therefore be strategically incorporated in extruded foods to help boost the protein, mineral, fiber, and lipid contents.

The amounts of provitamin A in the extruded snacks (0.54–17.33 mg/100 g) are equivalent to 45–1,444 μg RE/100 g based on a conversion factor of 12 μg beta-carotene: 1 RE (Burri, 2011). Based on the recommended vitamin A intake of 450 μg RE per day for a 4–6-year-old child (Burri, 2011), consuming between 31 g (snack containing 100% OFSP) and 1,000 g (snack containing 100% bambara groundnut) of the snacks developed in this study would be sufficient to meet the vitamin A requirements. It is evident that including OFSP in bambara groundnut extruded snacks greatly boosts their provitamin A content and thus also reduces the quantity of snacks required to meet the recommended daily intake.

4.2 | Effect of extrusion and formulation on provitamin A retention

Provitamin A losses observed in this study (13.5–40.44%), at 100–130 °C, are relatively close to losses of 25.2–30% reported to occur during extrusion at 80–145 °C (Riaz et al., 2009). Provitamin A losses during extrusion are due to the fact that vitamin A and related carotenoid compounds are unstable in the presence of light, oxygen and heat and all these conditions can be encountered during extrusion (Riaz et al., 2009; Singh et al., 2007). However, the major factors affecting vitamin A retention during extrusion include: barrel temperature, screw speed, feed moisture content, die diameter and throughput (Riaz et al., 2009; Singh et al., 2007). Singh et al. (2007) suggest that thermal destruction is the major cause of vitamin A losses during extrusion while Emin, Mayer-Miebach, and Schuchmann (2012) observed that mechanical stresses generated in the process are more important. What is clear though is that extrusion does lead to provitamin A losses and it is important to consider optimizing extrusion conditions to maximize provitamin A retention.

Besides processing conditions, provitamin A retention in extruded products is also influenced by factors such as cultivar and formulation of the matrix (Fonseca et al., 2008). For example a loss of about 60.7% beta-carotene was reported in cream varieties of sweet potatoes while OFSP lost 20.8–27.9% and much lower losses (2.6–16.2%) were observed in sweet potato co-extruded with rice (Fonseca et al., 2008). It is assumed that proteins and lipid in the food matrix may form a protective lipid–protein network around the beta-carotenoids thus minimizing thermal degradation (Fonseca et al., 2008). A higher retention of provitamin A would thus have been expected in samples containing more bambara groundnut since bambara contains more protein and lipids than OFSP. Since this was not observed in this study, we assume that OFSP could be having inherent protective mechanisms that minimize beta-carotene degradation during processing. Lago-Vanzela, Do Nascimento, Fontes, Mauro, and Kimura (2013) reported an improvement in carotenoid retention during drying of pumpkin slices coated with native or modified cassava and maize starch coatings. This may imply that starch, which is actually in higher concentrations in sweet potato compared to bambara ground nut, could also offer some protection against thermal destruction of provitamin A.

4.3 | Consumer acceptability of OFSP–bambara ground nut extruded snacks

The consumer acceptability of extruded snacks largely depends on their organoleptic properties: texture, color, aroma, and taste (Dehghan-Shoar, Hardacre, & Brennan, 2010). Higher acceptability scores for snacks containing OFSP compared to those with plain bambara ground nut can be attributed to the fact that increasing amounts of OFSP in the formulations were associated with increase in yellow color and sugars from OFSP. Plain bambara ground nut containing snacks on the other hand less inherent sugars and a lighter color. OFSP can thus be used in snack formulations to boost the acceptability of relatively bland ingredients.

4.4 | Predicted shelf life of the extruded snacks

The predicted shelf life of snacks developed in this study ranged from 118 to 150 days but was in the range of 60–180 days reported for different extruded snacks (Kocherla et al., 2012; Oluwole et al., 2013; Shaviklo et al., 2011; Sumathi, Ushakumari, & Malleshi, 2007). The shelf life of extruded products varies depending on composition and storage conditions. Extruded snacks containing bambara groundnut and yam were stable over 140 days of storage under refrigeration and at room temperature (Oluwole et al., 2013). Snacks containing corn flour, rice flour and egg albumin or cheese powder developed rancid odors after 60 days of storage at 37 ± 4 °C (Kocherla et al., 2012). The short shelf life of snacks could be attributed to storage at relatively elevated temperatures. Corn and fish extruded snacks stored at 27 °C developed rancid odors after about 180 days with peroxide values increasing from 0.0 to 2.8 meq/kg (Shaviklo et al., 2011).

Extruded products are generally susceptible to lipid oxidation due to their low moisture content, increased surface area resulting from expansion and presence of iron, a catalyst for oxidation from wearing of screws (Barden, 2014; Camire, 2001; Ekwenye, 2006). The extent of lipid oxidation in extruded snacks can be determined by using the peroxide value. A maximum peroxide value of 10 meq/kg is recommended for ready to eat snacks and these snacks should also be free of rancid odors (Bureau of Indian Standards, 1989). In this study, peroxide values of the bambara groundnut extruded snacks did not reach the maximum recommended value of 10 meq/kg during ambient temperature storage for two months. Furthermore, the extruded snacks did not develop rancid odors indicating that their shelf life at the ambient temperatures of 19–26 °C exceeds 2 months. Differences in the predicted shelf life of the formulations can be attributed to the differences in lipid content which ranged from 4.2% in 100% OFSP to 12.74% in 100% bambara groundnut based snacks. Increasing the content of bambara in the formulations elevates the lipid content thus increasing the susceptibility to oxidation.

5 | CONCLUSIONS

This study illustrates that locally available raw materials can be co-extruded to produce nutritious, acceptable and shelf stable snacks. In this case co-extrusion of OFSP and bambara ground nut produced provitamin A and protein enriched snacks. Increasing OFSP in the formulation resulted in higher acceeamounts of provitamin A and carbohydrate content, while increasing amounts of bambara groundnut boosted the protein, fiber, ash, fat, and energy contents. OFSP can also be used to improve the acceptability of extruded snacks containing relatively bland and dull colored ingredients such as bambara ground nut. Extrusion significantly reduced provitamin A content but the amounts retained in the coextruded snack combinations would be sufficient to meet vitamin A requirements. Predicted shelf life was inversely proportional to the concentration of bambara groundnut.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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