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Beta-carotene retention, physical, phytochemical and storage characteristics of value added snacks from pigeon pea and yellow-fleshed cassava

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ABSTRACT

Yellow-fleshed cassava, an improved breed, has the ability to alleviate vitamin A deficiency and enhance some immune responses, but a dearth of protein makes it inadequate in the diet. In this study, a value-added snack was prepared by incorporating fermented pigeon pea (FPP) (0–45%) and yellow-fleshed cassava flours (YFCF) (55–100%), after which the pasting profile, β-carotene retention, proximate, phytochemical, color, sensory, and storage properties were evaluated. Incorporation of FPP reduced the peak viscosity (565.83–258.17 RVU) of the flour and the β-carotene (5.14–0.50 μg/g), phytate (0.66–0.32 mg/g) and color parameter L* (39.78–30.33) of the snack, while there were consequential increases in the protein (1.98–9.59%), total phenol (0.15–1.68 mg GAE/g), and brown index (60.22–69.67). All the supplemented snacks generally had higher taste and flavor ratings than unaugumented snacks (YFCF). The β-carotene retention and hardness of the snacks decreased during storage. The formulated snacks were shelf stable in polyethylene pouches for a period of 30 days at ambient conditions (30 ± 2 °C) without any marked loss of physicochemical, rancidity, and microbial qualities. Thus, nutrients enhanced, shelf stable and acceptable snacks were developed.

1. Introduction

Worldwide, snacks are generally regarded as important components of the human diet, with a total global production valued at $584.58 billion in 2022 (Parker, 2023), and are unique both in terms of consumption patterns (ready to prepare and eat) and ease of handling (Gat & Ananthanarayan, 2015). According to Olatoye et al. (2020), many studies on convenient foods have shown snacks to be reliable vehicles for conveying micronutrients (minerals, vitamins), bioactive compounds (phenolic compounds, flavonoids), dietary fibers, and essential amino acids into the body. Due to the recent reintroduction of food as a medicine earlier credited to Hippocrates, nutraceutical snacks have been associated with many health and therapeutic benefits, such as anti-anemic, antioxidant, anti-inflammatory, and protein energy malnutrition relief (Gat & Ananthanarayan, 2015). Miranda-Ramos et al. (2019) used the concept of chain reversal to describe the response of the modern-day food industry to consumers' preferences toward products with high organoleptic values (color, flavors, crispiness, taste, and acceptance) in addition to their contributions to health and wellness. Presently, these changes in the eating habits of consumers are propelling research into the development of new food products from blends of underutilized agricultural crops of synergetic capacity with a more efficient role and contribution to meals than individual crops (Olatoye et al., 2023). Moreover, the application of different unconventional proteinous flours, such as bambara, flaxseed, and pigeon pea (PP), in healthy snack formulations has gained continuous acceptance in recent years when compared with traditional gluten-based snacks due to numerous advantages, such as anti-celiac, anti-diabetic, and positive physiological functions, as well as the ability to diversify the diet for super-nutrient crops previously underutilized (Kaur et al., 2019). The Food and Agriculture Organization also listed human innovation reflection, diversification, and nourishing food preferences among the merits associated with the utilization of such crops (Eyinla et al., 2019). However, in addition to certain antinutrients that may inhibit the

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availability of desirable nutrients in the diet, low functional stability and beany flavor are often unacceptable to consumers and constitute hindrances to product quality, which could limit profit margins (Lawal et al., 2016). Fermentation technology has been used as an alternative technique to reduce toxic phenomena and undesirable aromas and improve the quality of nutrients in crops (Xiao et al., 2021). The consumption of processed PP could be elevated through fortification in cassava-based (gluten-free) convenient food products. Cassava flour has been successfully used as a gluten-free flour and a complete replacement for wheat flour in different snacks. However, it is limited in protein and vitamin content and has to be supplemented with protein-rich foods such as legumes for it to be nutritious. In the last few years, the effects of protein addition have been investigated in different snacks, such as extruded cassava-tiger nut (Adebowale et al., 2016), deep-fried cassava-soybean (Maziya-Dixon et al., 2017), cassava-cowpea chips (Olapade & Adegboye, 2018), etc. Little or no attention has been devoted to improving the vitamin contents. To attain sustainable healthy choices and overcome certain functional constraints, traditional cassava flour is now being increasingly replaced with yellow fleshed varieties, which is a rich source of carotenoids with potential to alleviate vitamin A deficiency, enhancement of some immune responses and potential for various food applications (Awoyale et al., 2018). However, beta-carotene cassava flour remains among the underexplored alternative flours for snack production, and its suitability for fermented pigeon pea (FPP) products has not been fully addressed in the literature despite the high protein and phytochemical contents of PP. Thus, the present study sought to investigate the quality attributes of novel gluten-free snacks made from blends of beta-carotene cassava and pigeon pea flours.

2. Materials and methods

2.1. Materials

Two cultivars of pigeon pea (94^A NGB and 92^A NGB) were collected from the National Center for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Nigeria. Yellow-fleshed (β-carotene) cassava flour (YFCF) was purchased from the International Institute of Tropical Agriculture, Ibadan, Nigeria. The other ingredients utilized in this study (bow refined soybean oil, salt, seasoning, and granulated sugar) were purchased from Al-Barka Plaza, Bodija, Ibadan.

2.2. Methods

2.2.1. Production of pigeon pea flour

The flour produced was obtained from raw and FPP seed cultivars (94^A NGB and 92^A NGB). Fermentation was carried out for 48 h in water (at an atmospheric temperature of 30 °C ± 2 °C), after which the mixture was drained, dehulled, and oven-dried (at 60 °C for 48 h). The dried samples were hammer milled (3100, Hagerstern, Sweden), sieved (<150 μm), packaged in a Ziploc bag, and stored in a laboratory freezer (4 °C) for further analysis.

2.2.2. Fried snack preparation

Different deep fried (170 ± 5 °C for 5 ± 1 min) snack variants were made in three repetitions each. YFCF flour replaced with fermented 94^A NGB and 92^A NGB flours at 15%, 30%, and 45% were chosen to produce snacks, while the control was made from 100% YFCF. The recipe utilized fortified YFCF flour (60 g/100 g) and hot water (31/100 g). Salt, sugar, and other seasonings were based on 3 g/100 g. All the ingredients were thoroughly mixed to form dough, which was kneaded and molded into shapes prior to deep frying in vegetable oil. The fried samples were removed, drained, cooled to room temperature, and packaged in polyethylene pouches.

2.2.3. Microstructural observations

Microscopy images of both the fermented and unfermented pigeon pea flours were obtained by scanning electron microscopy (SEM) (3400NII, Hitachi, Tokyo, Japan). Briefly, the images were observed at various magnifications under a 3 kV acceleration voltage from samples that were previously secured to a load table with conductive double-sided tape and then sprayed with gold under vacuum conditions (Melroa et al., 2020; Gu et al., 2022).

2.2.4. Pasting

The pasting profiles of the flour samples were measured following the protocol (61–01.01) reported by the AACC (2000). Sample pastes were prepared in a pre-weighed canister using the initial moisture content of each flour to estimate the volume of water and flour mass. The canister containing the paste was inserted into a Rapid Visco Analyzer (Model 4500, Perten, Australia) and subjected to a heating and cooling cycle. The slurry was initially held at 50 °C for 1 min, heated to 95 °C for 5 min, and cooled to 50 °C for 2 min (Akinoso et al., 2021).

2.2.5. Nutritional content

The protein, lipid, ash, moisture, and crude fiber contents of the flour and fried snacks were measured by the Association of Official Analytical Chemists (AOAC, 2010). The summation of protein, lipids, ash, and crude fiber was subtracted from 100% to determine the carbohydrate content. The standard method outlined by Lawal et al. (2023) was used to determine the energy (kcal/100 g) value using a conversion factor of ((% carbohydrate + % protein) 17 + (% fatx37)) 0.239. Pro-vitamin A (β-carotene) was determined using the spectrophotometer (UV/VIS) method described by Peprah et al. (2020). Briefly, 1 g of flour was mixed with methanol (25 ml) and vacuum filtered into a flask, after which acetone (25 ml) was added to the residue to facilitate adequate extraction of carotenoids. The filtrate volume was recorded after the initial extraction. The filtrate was transferred into a separating funnel containing petroleum ether (20 ml) and distilled water. The inorganic liquid (colorless) was removed, and the remaining compound (yellow) was washed with distilled water until it became colorless. All the inorganic solvents were collected and discarded. The volume of the remaining organic solvent was recorded as a second extract. The absorbance was read at 450 nm using a UV–visible spectrophotometer (TI-1901, Beijing, Purkinje, China) against the control and is presented as μg/g.

2.2.6. Determination of phytochemicals and antinutritional factors

DPPH was evaluated according to the colorimetric method reported by Tang et al. (2015), with Trolox serving as the standard. A UV–visible spectrophotometer (517 nm) was used to determine the absorbance against a negative control. The result was expressed as mg GAE/g of dry sample. For total phenol content, samples extracted from an appropriate dilution were oxidized with 2.5 ml and neutralized with 2.0 ml of 10% Folin-Ciocalteu's reagent (v/v) and 7.5% Na_2CO_3. The solution was incubated at 45 °C for 40 min. The absorbance was read at 765 nm against blank distilled water in a UV–visible spectrophotometer (TI-1901, Beijing, Purkinje, China), and the results were expressed as gallic acid equivalents (Tang et al., 2015). The phytate content was determined with the aid of a spectrophotometer, and the results were expressed as mg/g of sample (AACC, 2000). Trypsin content evaluation was carried out using BAPA solution as the synthetic substrate, and the results are expressed as mg/g of sample (Gat & Ananthanarayan, 2015). For the oxalate content, a UV–visible spectrophotometer (7305, Jenway, Scientific, UK) was used. The procedure 915.03 published by AOAC (2010) was utilized for alkaline titration in the evaluation of hydrocyanic acid (HCN).

2.2.7. Color

The lightness (L*), redness (a*), and yellowness (b*) of the snack samples were measured using a Hunter Lab colorimeter. The Brown index was obtained by subtracting lightness from 100 (Lawal & Akinoso, 2019).

2.2.8. Sensory

Sensory evaluation was carried out in the sensory laboratory (which has adequate lighting from fluorescent light) on the same day as snack production, and 30-member semi-trained panelists were selected randomly from those accustomed to eating fried snacks. All the panelists were seated in individual booths after a detailed explanation of the study requirements, without any coercion to participate, and served with coded (three-digit numbers) products in transparent plastic for quality (color, flavor, crispiness, taste, and acceptance) evaluation using a 9-point hedonic preference scale (9 = like extremely, 5 = neither like nor dislike, and 1 = dislike extremely) as described by Olatoye et al. (2020). Each of the trained panelists received portable water for cleansing and rinsing their palates between each sample. Appropriate protocols for protecting the rights and privacy of all participants were utilized during the execution of this study, and the selected panelists declared their interest in the research consent form.

2.2.9. Storage

Different samples of well-packaged fried snacks in polyethylene pouches were kept on the shelf at ambient conditions (30 ± 2 °C) for a period of 40 days. The pro-vitamin A carotenoid concentration, hardness, moisture content, free fatty acid content, and microbial qualities of the stored samples were evaluated at ten-day intervals for four consecutive periods (Raja et al., 2014).

2.2.9.1. Determination of free fatty acid (FFA) and peroxide value (PV). An automated process (Soxtec System HT2) was used to extract the oil from the snack samples using hexane. For FFA determination, diethyl ether (25 ml) was mixed with 25 ml of alcohol and 1 ml of phenolphthalein solution (1%) and carefully neutralized with 0.1 M sodium hydroxide. About 1 g of the extracted oil was dissolved in the mixed neutral solvent and titrated with aqueous 0.1 M sodium hydroxide, shaking constantly until a pink color that persisted for 15 s was obtained. The results were calculated and expressed as a percentage of oleic acid. The peroxide value (PV) of the extracted oil was measured by the titrimetric method, and the results were expressed as the equivalent of O_2/kg (AOAC, 2010).

2.2.9.2. Microbial analysis. The snack samples were stored for 0–40 days, and during that time, microbiological studies were performed to determine the total plate counts (TPC) and yeast and mold counts. After homogenizing the samples (1 g) aseptically with saline (0.85% NaCl), they were serially diluted (1:10) as required. In order to count TPC, homogenate (1 ml) was spread out on plate count agar and incubated at 37 °C for 48 h. Meanwhile, the counts of yeast and mold were obtained from incubated plates at 27 °C for 72 h. The results were depicted as log colony-forming units per gram (log cfu/g) (AOAC, 2010).

2.2.10. Statistical analysis

All the data obtained were statistically analyzed, and the results are presented as the means ± standard deviations. The differences among the means were computed from the analysis of variance (ANOVA) using the Duncan test available in Minitab 16.0 software (Minitab, Inc., State College, PA, USA) to identify a significant relationship ($p < 0.05$) between the treatments.

3. Results and discussion

3.1. Pasting properties

The pasting properties of cassava, raw, and fermented pigeon pea flours at different substitution levels are shown in Table 1. Although the pasting time (4.23 min) and temperature (72.88 °C) of cassava flour were significantly lower than those of raw and fermented pigeon pea flours, the other pasting properties (peak, through, break, final, and set viscosities) were significantly ($p \leq 0.05$) greater for cassava flour. The higher viscosities exhibited by cassava flour could be due to its highly homogenous, ordered structure and low amylose content (Olatoye et al., 2020). Previous studies had attributed the higher peak viscosity of flours to weak molecular interactions between starch granules, which stimulated their susceptibility to disintegration and thus lowered the pasting temperature and time (Arici et al., 2016; Akinoso et al., 2021). Additionally, the viscosity of the raw pigeon pea flour of both cultivars was also considerably ($p \leq 0.05$) higher than that of the fermented pigeon pea flour (FPP) at the peak (66.42–78.31 RVA), trough (65.12–71.24 RVA), and final (71.08–87.35 RVA). The differences in viscosity can possibly be explained by the disintegration of the intact raw pigeon pea starch granules (Fig. 1) by the activities of fermentative microorganisms. (Olapade & Adegboye, 2018). In general, the peak (471.92–258.17 RVA), trough (253.75–182.38 RVA), break (230.33–60.46 RVA), final (362.42–248.54 RVA), and setback (116.83–52.96 RVA) viscosities of the flour blends decreased significantly ($p \leq 0.05$) with an increase in the fermented 94^{A} NGB and 92^{A} NGB pigeon pea flours in the order C15FPP>C30FPP>C45FPP. The decrease in viscosities of flour blends is due to a significant reduction in cassava-rich starch content during enrichment with FPP. According to Arici et al. (2016), pasting properties are an appropriate parameter for predicting flour suitability for value-added products such as snacks, noodles, and weaning foods.

3.2. Morphology and nutritional composition of flours and snacks

The morphologies of the raw and fermented pigeon peas flours determined by scanning electron microscopy were different between the two samples regardless of the cultivar (Fig. 1), and differences related to starch and other particles that participate in the physical, textural, rheological, and organoleptic traits of foods can be viewed at various ranges (Melroa et al., 2020). Both raw flours of each cultivar showed

Table 1
Pasting properties of the flours.

Samples	Peak (RVA)	Trough (RVA)	Break (RVA)	Final (RVA)	Set (RVA)	Time (min)	Temperature (°C)
FloursYFCF	565.83 ± 21.33^{a}	258 ± 14.46^{a}	307.83 ± 17.62^{a}	387.75 ± 10.22^{a}	129.75 ± 11.11^{a}	4.23 ± 0.51^{c}	72.88 ± 4.27^{b}
R94^{A} NGB	78.31 ± 5.76^{g}	71.24 ± 4.37^{e}	7.07 ± 0.11^{h}	87.35 ± 4.21^{f}	16.11 ± 37.15^{h}	6.82 ± 1.21^{a}	89.17 ± 2.52^{a}
R92^{A} NGB	66.42 ± 4.28^{h}	65.12 ± 5.63^{f}	1.25 ± 0.24^{j}	71.08 ± 3.48^{g}	5.96 ± 2.31^{i}	7.00 ± 1.35^{a}	90.41 ± 3.67^{a}
F94^{A} NGB	70.67 ± 4.12^{h}	66.47 ± 6.07^{f}	4.20 ± 0.36^{i}	82.08 ± 3.63^{g}	15.61 ± 1.12^{h}	6.90 ± 0.62^{a}	90.02 ± 3.40^{a}
F92^{A} NGB	55.50 ± 3.82^{i}	54.88 ± 6.33^{g}	0.63 ± 0.12^{j}	59.96 ± 3.16^{h}	5.08 ± 0.24^{i}	6.93 ± 0.12^{a}	90.39 ± 4.25^{a}
C15F94^{A}	471.92 ± 17.10^{b}	253.75 ± 11.04^{a}	218.17 ± 8.15^{c}	362.42 ± 9.72^{b}	108.67 ± 5.16^{c}	4.80 ± 0.34^{bc}	73.8 ± 2.61^{b}
C30F94^{A}	343.08 ± 12.25^{d}	211.88 ± 13.41^{c}	135 ± 7.35^{d}	300.67 ± 8.35^{c}	92.54 ± 4.34^{d}	4.67 ± 0.16^{bc}	73.43 ± 3.07^{b}
C45F94^{A}	258.17 ± 11.92^{f}	182.38 ± 12.05^{g}	75.79 ± 4.32^{f}	248.54 ± 7.70^{e}	66.17 ± 3.06^{f}	4.70 ± 0.33^{bc}	73.38 ± 3.72^{b}
C15F92^{A}	468.21 ± 16.34^{c}	237.88 ± 13.12^{b}	230.33 ± 11.74^{b}	354.75 ± 8.26^{b}	116.83 ± 2.93^{b}	4.30 ± 0.24^{c}	73.4 ± 4.20^{b}
C30F92^{A}	318.67 ± 10.75^{e}	213.75 ± 11.18^{c}	104.92 ± 8.05^{e}	286.21 ± 6.04^{d}	72.46 ± 2.35^{e}	5.07 ± 0.15^{bc}	75.03 ± 4.41^{b}
C45F92^{A}	258.92 ± 12.45^{f}	198.46 ± 9.63^{d}	60.46 ± 3.34^{g}	251.42 ± 5.61^{e}	52.96 ± 3.5^{g}	5.50 ± 0.11^{b}	76.03 ± 2.86^{b}

Values (mean ± standard deviation) with different superscripts in the same column differ significantly ($p \leq 0.05$). YFCF and YFCF100: yellow-fleshed cassava flour and snacks; R94^{A} NGB and F94^{A} NGB: R92^{A} NGB and F94^{A} NGB: raw and fermented cultivars of pigeon pea; C15F94^{A}, C30F94^{A} C45F94^{A}, C15F92^{A} C30F92^{A} C45F92^{A}: flour and snacks containing cassava and fermented pigeon pea cultivars (85: 15, 70:30, 55:45).

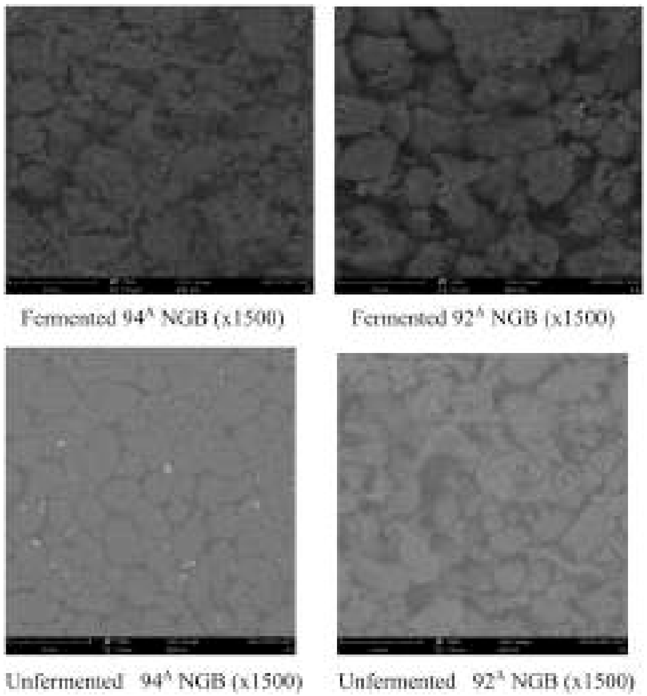

Fig. 1. SEM images of the raw and fermented flours.

similar smooth surface particles entrapped in the firmed envelope cell wall, while those of the fermented flour particles were enhanced, and starch granules were loosely distributed after disintegration by the fermentation process, which may have propelled the appealing appearance and smother texture of FPP (Gu et al., 2022).

The proximate compositions of the different raw materials and their blends were significantly different ($p \leq 0.05$) among the raw flours and snacks (Table 2). The dry matter content ranged from 87.51 to 91.99%. A sample of C45F94^{A} snack had the highest value, while 92^{A} NGB pigeon pea had the lowest. Among the snacks, dry matter content showed direct variation with the incorporation of pigeon pea, and there were significant differences ($p \leq 0.05$) between FPP at 45% and 15% flour incorporation, regardless of the cultivar. The values were within the range (90.79–91.37%) reported by Olatoye et al. (2020) for aidan-flavored snacks. It seems clear that the addition of pigeon pea flour is responsible for the general increase in the dry matter content of the snacks, which is in agreement with the findings of Adegunwa et al. (2015) on an indigenous kokoro produced from blends of maize and pigeon pea flour. Although the moisture contents were higher in flours (11.50–12.38%) than snacks (8.21–9.43%), but the values of the latter were within the acceptable range (<10%) for shelf-stable snack items during storage (Oyeyinka et al., 2017). Perhaps this trend was a consequence of an increase in dry matter content. Raw and fermented flours of PP showed high protein contents (16.31–18.57%), which is highly dependent on the cultivars. Among the snacks produced, those made from 45% fermented 92^{A} NGB pigeon pea flour had the highest ($p \leq 0.05$) protein content (9.59%), while those fermented with 15% substituted 94^{A} NGB PP flour had the lowest (3.40%). An increase in FPP caused a significant ($p \leq 0.05$) increase in the protein content of the snacks, which was expected. This is due to the fact that tubers, like cassava, are deficient in sulfur amino acids, and the protein in FPP balances the nutrients in cassava, enhancing the snacks' nutritional value. These findings are consistent with the reports of Olapade and Adegboye (2018) on the increasing trend in protein content (3.22–10.27%) in fried chips produced from composite flour of cassava and cowpea. The range (1.15–4.95%) of fiber observed varied greatly ($p \leq 0.05$) between the composite flour and the snacks, and the lowest fiber content (1.15%) was attributed to 100% cassava flour. The highest crude fiber value of snacks (1.60%) from the cultivar 94^{A} NGB-YFCF blended at the 45% level fell within the range of 1.37–1.66% reported by Olapade and Adegboye (2018) for cassava-cowpea-based chips. This result was a consequence of an increase in FPP content, which contains significantly more crude fiber content than the control. The special ability of fiber to promote bowel movement, aid bulk addition to food, and prevent diseases such as colon cancer and irritable bowel syndrome makes it important in food products (Lawal & Akinoso, 2019; Miranda-Ramos

Table 2
Nutritional composition of flours and snacks.

Samples	Dry matter	Moisture (%)	Protein (%)	Fiber (%)	Fat (%)	Ash (%)	Carbohydrate (%)	β-carotene (μg/g)	Energy (kcal/100 g)
FlourYFCF	88.50 ± 0.24^{d}	11.50 ± 0.76^{b}	2.12 ± 0.27^{h}	1.15 ± 0.05^{f}	0.30 ± 0.00^{e}	1.39 ± 0.04^{f}	83.54 ± 3.01^{a}	5.14 ± 1.35^{a}	350.70 ± 1.55^{c}
R94^{A} NGB	87.64 ± 0.16^{d}	12.36 ± 1.04^{a}	16.31 ± 2.22^{b}	4.46 ± 0.23^{b}	2.18 ± 0.01^{d}	2.97 ± 0.10^{b}	61.72 ± 2.50^{de}	0.99 ± 0.04^{b}	336.32 ± 1.80^{e}
R92^{A} NGB	87.51 ± 0.25^{d}	12.49 ± 1.02^{a}	18.11 ± 1.63^{ab}	2.83 ± 0.17^{d}	1.96 ± 0.03^{d}	3.25 ± 0.11^{a}	61.36 ± 2.14^{de}	0.83 ± 0.03^{c}	340.23 ± 1.25^{d}
F94^{A} NGB	87.70 ± 0.43^{d}	12.30 ± 0.96^{a}	16.77 ± 1.50^{b}	4.85 ± 0.51^{a}	2.00 ± 0.04^{d}	2.85 ± 0.12^{c}	61.23 ± 1.36^{de}	0.67 ± 0.02^{d}	334.61 ± 1.65^{e}
F92^{A} NGB	87.62 ± 0.17^{d}	12.38 ± 0.43^{a}	18.59 ± 1.31^{a}	3.94 ± 0.34^{c}	1.85 ± 0.02^{d}	3.14 ± 0.00^{a}	60.10 ± 1.25^{e}	0.52 ± 0.00^{e}	336.09 ± 1.67^{e}
SnacksC15F94^{A}	90.63 ± 0.24^{c}	9.37 ± 0.60^{c}	3.40 ± 0.70^{g}	1.43 ± 0.17^{ef}	18.60 ± 1.14^{c}	1.47 ± 0.17^{d-f}	65.73 ± 1.45^{c}	0.74 ± 0.04^{c}	447.19 ± 2.64^{b}
C30F94^{A}	90.79 ± .0.12^{c}	9.21 ± 1.37^{c}	5.75 ± 1.11^{f}	1.56 ± 0.15^{de}	19.12 ± 0.88^{b}	1.51 ± 0.15^{de}	62.85 ± 1.38^{d}	0.69 ± 0.07^{d}	447.81 ± 3.15^{b}
C45F94^{A}	91.99 ± 0.10^{a}	8.01 ± 0.71^{d}	8.76 ± 1.04^{d}	1.60 ± 0.00^{de}	19.85 ± 1.21^{a}	1.55 ± 0.00^{d}	60.23 ± 1.41^{g}	0.56 ± 0.00^{e}	450.33 ± 3.17^{a}
C15F92^{A}	90.57 ± 0.15^{c}	9.43 ± 0.09^{c}	4.65 ± 1.21^{fg}	1.49 ± 0.02^{d-f}	18.59 ± 0.09^{c}	1.44 ± 0.02^{d-f}	64.40 ± 1.71^{cd}	0.69 ± 0.05^{d}	447.27 ± 2.57^{b}
C30F92^{A}	90.68 ± 0.04^{c}	9.32 ± 0.47^{c}	7.17 ± 1.44^{e}	1.53 ± 0.00^{de}	19.00 ± 1.23^{b}	1.47 ± 0.00^{de}	61.51 ± 1.64^{de}	0.62 ± 0.00^{d}	447.89 ± 1.99^{b}
C45F92^{A}	91.79 ± 0.10^{a}	8.21 ± 0.88^{d}	9.59 ± 1.36^{c}	1.59 ± 0.04^{de}	19.54 ± 0.33^{a}	1.50 ± 0.04^{d-f}	59.57 ± 1.38^{e}	0.50 ± 0.09^{e}	449.78 ± 2.03^{ab}
YFCF100	91.14 ± 0.11^{b}	8.86 ± 0.49^{c}	1.98 ± 1.35^{i}	1.44 ± 0.02^{ef}	18.58 ± 0.17^{c}	1.10 ± 0.02^{g}	68.04 ± 1.43^{b}	0.79 ± 0.00^{c}	448.81 ± 1.95^{ab}

Values (mean ± standard deviation) with different superscripts in the same column differ significantly ($p \leq 0.05$). YFCF and YFCF100: yellow- fleshed cassava flour and snacks; R94^{A} NGB and F94^{A} NGB: R92^{A} NGB and F94^{A} NGB: raw and fermented pigeon pea cultivars; C15F94^{A}, C30F94^{A}, C45F94^{A}, C15F92^{A}, C30F92^{A} C45F92^{A}: flour and snacks containing cassava and fermented pea cultivars (85:15, 70:30, 55:45).

et al., 2019). The fat contents of the flours and.

composite snacks were significantly different ($p \leq 0.05$) and varied from 0.30 to 19.85%, with YFCF and C45F94^A flours having the lowest and highest values, respectively. Among the snacks, the fat content increased significantly ($p \leq 0.05$) as the substitution level of FPP increased from 0 to 45%, irrespective of the pigeon pea cultivar. There is a possibility that the hydrophilic area of flour influences the absorption of fat when snacks are deep-fried (Oyeyinka et al., 2017). The ash content of the cassava flour was 1.39 ± 0.04, and upon incorporation of FPP (2.85–3.14%), these values recorded for snacks slightly increased (1.44–1.55%). An earlier study of fried snacks produced from cassava flour enriched with cowpea indicated that the addition of cowpea to cassava flour improved the ash content of the snacks from 0.24 to 1.53% (Olapade & Adegboye, 2018). Miranda-Ramos et al. (2019) observed a similar trend of increasing ash content (1.70–4.0%) in bread fortified with partially amaranth flour, which could be regarded as a reflection of the higher mineral content of formulated composite snacks. This could be attributed to the increase in FPP content, which contains significantly more ash than the control. The carbohydrate content of the snacks decreased significantly ($p \leq 0.05$) as a result of the replacement of cassava flour with protein-rich FPP. The substitution of fermented 94^A NGB and 92^A NGB pigeon pea flours contributed between 3.40% and 12.45% more carbohydrate reduction than the control snack. Notably, a similar trend of carbohydrate content (61.65–64.32%) was observed in snack bar formulations with up to 20% replacement with common bean flour (Ramírez-Jiménez et al., 2018). The β-carotene content in flour and snacks ranged from 0.50 μg/g to 5.14 μg/g (Table 2). There was a significant ($p \leq 0.05$) decrease in the β-carotene content of raw 94^A NGB and 92^A NGB flour samples after the fermentation process, both of which were 32.32% and 37.35%, respectively, lower than the content in fermented flours. This could be due to the activities of microorganisms that degraded β-carotene during the fermentation of pigeon pea. Further, the frying process influenced the β-carotene content profoundly, with a downward tendency upon thermal processing. The β-carotene content of raw YFCF flour was 5.14 μg/g, while that of the fried YFCF100 snack was 0.79 μg/g (representing 15.37% β-carotene retention). Among the snacks, fermented 92^A NG flour at 45% incorporation had the lowest value (0.50 μg/g), which is equivalent to 9.73% β-carotene retention. The trend also showed a decrease in retention (15.37–9.73%) with the incorporation of pigeon pea flours, similar to the observations of Honi et al., (2017, pp. 13415) (sweet potato and bambara groundnut snack) and Awoyale et al. (2018) (cassava-wheat composite flour and bread), who reported degradation of β-carotene content greater than 40% and 90%, respectively. The mechanism of β-carotene degradation during food processing involves the interaction of carotenoids with light (photodegradation), heat (thermal degradation), air (autooxidation), and free radicals (singlet oxidation) (Honi et al., 2017, pp. 13415). According to Peprah et al. (2020), isomerization and degradation of pure β-carotene to a lighter color (13-cis-carotene) and volatile (epoxides, apocarotenals, apocarotenones, and di-cis isomers) compounds are the main factors responsible for the decreased retention of pro-vitamin A carotenoids during the thermal processing of food products.

3.3. Metabolized energy

The total energy content estimated for the snacks varied between 447.19 and 450.33 kcal/100 g (Table 2). Notably, the 45% FPP treatment had a greater effect on both cultivars than the control treatment, and the differences were significant ($p < 0.05$). This increase in fat content could be attributed to the greater fat content of pigeon pea than of cassava flour. Variation in metabolized energy was also reported by Krystyjan et al. (2015) from biscuits developed from bee pollen and wheat flour. The observed values ranged from 474 to 486 Kcal/100 g. The authors underscore carbohydrate content as the main composition responsible for the differences reported. Additionally, Kaur et al. (2019) suggested that replacing wheat flour with flaxseed flour results in a significant increase (364.92 to 543.69 kcal) in metabolized energy. As a result of the differences in incorporation in this study, composite snacks produced, like other snack items, may provide dependable energy for the body.

3.4. Phytochemical and antinutritional properties

The total phenolic content (TPC) and DPPH radical scavenging activity of the composite flours and snacks varied between 0.03–12.57 mg GAE/g and 9.5–14.34%, respectively (Table 3). The incorporation of FPP (0–45%) significantly ($p \leq 0.05$) increased the TPC (0.03–1.68 mg GAE/g) and DPPH (9.51–17.46%) contents of the snacks. Similar patterns of positive influences of TPC (0.21–8.62 mg GAE/g) and DPPH (1.70–27.7%) were reported for cassava pasta containing different substitution levels of amaranth flours (Stuijvenberg et al., 2021). Additionally, the TPC and total antioxidant concentrations reported by different authors ranged from 1.42–4.84 mg GAE/g and 12.86–42.49 mmolTx/kg (Krystyjan et al., 2015) and from 0.05–0.45 mg GAE/g and 10.24–44.16% (Kaur et al., 2019), respectively. These variations are attributed to the variability in genetics and the geographical and botanical origins of various crops. Arici et al. (2016) highlighted that additional phenolics freed from the thermal decomposition of cellular constituents during processing, such as frying, drying, and products of the Maillard reaction from incorporated proteins in composite flours (amino-carbonyl interactions), are associated with increased antioxidant activities in food products. The antinutrient contents (phytate, trypsin inhibitor, oxalate, and HCN) of the plants are shown in Table 3. Generally, the antinutrient content of the pigeon pea (94^A NGB and 92^A NGB) flours decreased significantly ($p < 0.05$) after 48 h of fermentation, with a lower amount recorded for 94^A NGB; this could be a result of genetics. Fermentation is a well-known low-cost processing method for reducing the amount of nutrients in food through the action of microorganisms (Oyeyinka et al., 2017). With the exception of HCN (0.14–4.27 mg/kg), all the other antinutrients in the pigeon pea flours decreased significantly ($p < 0.05$). The phytate content (0.21–0.66 mg/g) decreased slightly with the incorporation of FPP, and there was a significant difference ($p < 0.05$) between the control and C45F94^A samples. Various research efforts have shown that while phytate concentrations > 4 mg/100 g can reduce zinc and iron absorption approximately 5-fold, HCN concentrations > 50 mg/kg in the diet can lead to acute toxicity through the activation of cytochrome oxidase in the mitochondria of cells by binding to iron in enzymes, thus blocking the synthesis of ATP (Peprah et al., 2020). Additionally, the concentration of the trypsin inhibitor (0.88–4.70 mg/g) was approximately 2-fold greater in the 45% FPP snacks than in the control, suggesting that the cassava flour contained less of these antinutrients. The oxalate content (0.97–3.30 mg/g) of the snacks increased slightly with the incorporation of FPP. A higher level of oxalate in food can bind to the calcium present in food during the formation of calcium oxalate, which has also been implicated in kidney stone formation (Adegunwa et al., 2015). The various antinutrient levels in flour and snacks are within the threshold level recommended for food by the Food and Agriculture Organization (Olatoye et al., 2020).

3.5. Color of the snacks

The color characteristics of the snack samples are depicted in Table 4. The L* parameter, which is an indicator of snack lightness, varied between 30.33 and 39.78. Importantly, the value decreases significantly ($p < 0.05$) with increasing pigeon pea flour content, which is in agreement with the trend observed for the yellowness as depicted by color parameter b* (10.62–15.41). The sample C45F92^A had the least yellowness (10.62). The color parameter a* (redness of the sample) and brown index (60.22–69.67) of the snacks, by contrast, significantly increased among the snacks containing different levels of pigeon pea flour. This is an indication that snacks with more pigeon pea flour are

Table 3
Phytochemical and antinutrient compositions of flours and snacks.

Samples	DPPH	Total phenol	Phytate	Trypsin inhibitor	Oxalate	HCN
	(%)	(mg GAE/g)	(mg/g)	(mg/g)	(mg/g)	(mg/kg)
FloursYFCF	15.11 ± 1.22^{f}	0.15 ± 0.02^{h}	0.66 ± 0.02^{a}	1.10 ± 0.03^{f}	1.14 ± 0.10^{b}	4.27 ± 0.51^{a}
R94^{A} NGB	37.83 ± 1.01^{b}	10.86 ± 1.20^{b}	0.50 ± 0.01^{b}	4.52 ± 0.13^{b}	3.30 ± 0.05^{a}	0.19 ± 0.00^{e}
R92^{A} NGB	24.27 ± 0.77^{d}	9.07 ± 0.56^{c}	0.63 ± 0.02^{a}	4.70 ± 0.15^{a}	2.86 ± 0.04^{a}	0.21 ± 0.03^{e}
F94^{A} NGB	43.24 ± 0.42^{a}	12.57 ± 1.26^{a}	0.21 ± 0.00^{e}	2.96 ± 0.20^{d}	1.29 ± 0.02^{b}	0.14 ± 0.00^{e}
F92^{A} NGB	28.96 ± 0.21^{c}	10.96 ± 0.43^{b}	0.37 ± 0.01^{cd}	3.13 ± 0.16^{c}	1.18 ± 0.00^{b}	0.15 ± 0.02^{e}
Snacks						
C15F94^{A}	12.36 ± 0.39^{g}	0.45 ± 0.01^{g}	0.35 ± 0.02^{cd}	0.96 ± 0.00^{g}	1.10 ± 0.02^{b}	2.89 ± 0.05^{b}
C30F94^{A}	15.52 ± 0.55^{f}	0.73 ± 0.02^{f}	0.33 ± 0.00^{cd}	1.16 ± 0.00^{e}	1.17 ± 0.02^{b}	2.75 ± 0.10^{b}
C45F94^{A}	17.46 ± 0.33^{e}	1.68 ± 0.02^{d}	0.32 ± 0.01^{d}	1.39 ± 0.04^{e}	1.20 ± 0.02^{b}	2.13 ± 0.00^{d}
C15F92^{A}	10.97 ± 0.10^{h}	0.34 ± 0.00^{g}	0.39 ± 0.03^{cd}	1.10 ± 0.02^{f}	1.05 ± 0.05^{b}	2.61 ± 0.31^{b}
C30F92^{A}	12.1 ± 1.15^{g}	0.67 ± 0.03^{f}	0.38 ± 0.02^{cd}	1.27 ± 0.01^{e}	1.12 ± 0.04^{b}	2.35 ± 0.06^{c}
C45F92^{A}	15.88 ± 0.23^{f}	1.45 ± 0.01^{e}	0.38 ± 0.00^{cd}	1.58 ± 0.02^{d}	1.16 ± 0.03^{b}	2.03 ± 0.04^{d}
YFCF100	9.51 ± 0.45^{h}	0.03 ± 0.00^{i}	0.40 ± 0.02^{c}	0.88 ± 0.03^{g}	0.97 ± 0.00^{b}	2.97 ± 0.00^{b}

Values (mean ± standard deviation) with different superscripts in the same column differ significantly ($p \leq 0.05$). YFCF and YFCF100: yellow-fleshed cassava flour and snacks; R94^{A} NGB and F94^{A} NGB: R92^{A} NGB and F94^{A} NGB: raw and fermented cultivars of pigeon pea; C15F94^{A}, C30F94^{A} C4594^{A}, C15F92^{A} C3092^{A} C45F92^{A}: flour and snacks containing cassava and fermented pigeon pea cultivars (85: 15, 70:30, 55:45).

Table 4
Color characteristics of snacks.

Snacks	L*	a*	b*	BI
C15F94^{A}	36.63 ± 1.06^{b}	-1.56 ± 0.06^{g}	13.53 ± 0.97^{b}	63.37 ± 1.30^{c}
C30F94^{A}	35.68 ± 1.04^{b}	-0.52 ± 0.00^{c}	13.61 ± 1.15^{ab}	64.32 ± 0.56^{c}
C45F94^{A}	33.89 ± 1.02^{c}	-0.43 ± 0.02^{b}	12.23 ± 1.23^{bc}	66.11 ± 0.68^{b}
C15F92^{A}	35.09 ± 0.89^{b}	-0.81 ± 0.04^{f}	13.71 ± 1.21^{ab}	64.91 ± 0.73^{c}
C30F92^{A}	33.54 ± 1.23^{c}	-0.75 ± 0.03^{e}	13.10 ± 1.08^{b}	66.46 ± 0.79^{b}
C45F92^{A}	30.33 ± 0.92^{d}	-0.63 ± 0.02^{d}	10.62 ± 1.11^{c}	69.67 ± 1.49^{a}
YFCF100	39.78 ± 0.780^{a}	-0.23 ± 0.02^{a}	15.41 ± 1.42^{a}	60.22 ± 1.63^{d}

Values (mean ± standard deviation) with different superscripts in the same column differ significantly ($p \leq 0.05$). YFCF and YFCF100: yellow-fleshed cassava flour and snacks; C15F94^{A}, C30F94^{A} C4594^{A}, C15F92^{A} C3092^{A} C45F92^{A}: flour and snacks containing cassava and fermented pigeon pea cultivars (85: 15, 70:30, 55:45); BI: brown index

darker and more reddish. Other authors attributed the darker color to the greater amount of oxidized phenol compounds formed in the composite snacks (Krystyjan et al., 2015).

3.6. Sensory

The sensory scores for composite snacks varied significantly with the incorporation of FPP (Table 5). Sensory attributes, namely, color and crispiness, decreased with the relative incorporation of pigeon pea in maize-based snacks and were significantly ($p < 0.05$) lower than those in cassava flour (control) snacks. A suggested reason for the reduction in appearance could be non-enzymatic browning, which is reflected in browning (Kaur et al., 2019). This finding is in agreement with previous results for fried cassava and fish crackers (Wang et al., 2012) and bee pollen biscuits (Krystyjan et al., 2015). Flavor, taste, and acceptability ratings of incorporated snacks at 15% and 30% incorporation levels of 94^{A} NGB and 92^{A} NGB were higher than those of the control snacks. Overall, the protein-starch interaction of the snacks can account for the enhanced flavor, taste, and acceptability of the snacks (Adegunwa et al., 2015).

Table 5
Sensory properties of snacks.

Snacks	Color	Flavor	Crispiness	Taste	Acceptance
C15F94^{A}	6.23 ± 1.21^{b}	6.80 ± 1.20^{a}	6.30 ± 0.39^{b}	6.97 ± 0.38^{a}	7.23 ± 0.47^{a}
C30F94^{A}	5.63 ± 0.71^{bc}	6.57 ± 0.79^{ab}	5.93 ± 0.74^{bc}	7.12 ± 0.82^{a}	6.87 ± 0.54^{a}
C45F94^{A}	5.20 ± 0.85^{c}	6.13 ± 0.41^{bc}	5.45 ± 1.21^{cd}	5.75 ± 0.73^{bc}	6.13 ± 1.06^{b}
C15F92^{A}	5.70 ± 1.20^{b}	5.70 ± 0.55^{c}	5.37 ± 0.91^{d}	5.18 ± 1.26^{c}	5.87 ± 0.79^{bc}
C30F92^{A}	5.14 ± 0.77^{c}	7.03 ± 1.03^{a}	5.18 ± 1.54^{d}	6.80 ± 0.29^{a}	7.10 ± 1.03^{a}
C45F92^{A}	5.10 ± 0.69^{c}	5.63 ± 0.63^{cd}	5.00 ± 0.39^{d}	5.77 ± 0.45^{b}	5.23 ± 1.12^{bc}
YFCF100	7.24 ± 0.89^{a}	5.03 ± 0.43^{d}	7.30 ± 1.72^{a}	5.41 ± 1.06^{bc}	7.18 ± 0.90^{a}

Values (mean ± standard deviation) with different superscripts in the same column differ significantly ($p \leq 0.05$). YFCF and YFCF100: yellow-fleshed cassava flour and snacks; C15F94^{A}, C30F94^{A} C4594^{A}, C15F92^{A} C3092^{A} C45F92^{A}: flour and snacks containing cassava and fermented pigeon pea cultivars (85: 15, 70:30, 55:45).

3.7. βeta carotene, hardness and moisture contents of the snacks during storage

Generally, the β-carotene content of the snacks decreased (0.79–0.22 μ/g) with increasing storage time (Table 6). Among the stored snacks, C15F92^{A} had the lowest percentage of β-carotene (31.88%), while YFCF100 (73.4%) had the highest. Eyinla et al. (2019) observed the same results for Garri and eba made from β-carotene cassava flour. In another study, emulsions encapsulating β-carotene constructed with whey protein isolate-cinnamaldehyde conjugates showed decreases in the retention rate of β-carotene with increased storage temperature and time (Zhao et al., 2022). This reduction could be attributed to the instability of β-carotene during storage. Literature studies indicated that the degradation of β-carotene on storage is complex in nature, and the polyene chain has been noted as the principal cause of instability (including susceptibility to oxidation and geometric isomerization), which is aided by pro-oxidants such as oxygen, moisture, heat, light, and enzymes similar to the oxidation process in lipids (Honi et al., 2017, pp. 13415). The hardness of the snacks are presented in Table 6. The hardness values reported from the breaking force tests showed a decreasing trend with increasing FPP incorporation in the cassava flours, regardless of the cultivar. These values ranged from 86.51 to 90.20 N and 80.91 to 84.46 N for snacks prepared with the 94^{A} NGB and 92^{A} NGB substitution levels, respectively. The replacement of native flour with flour from other botanical sources may increase or decrease the hardness of the snack, depending on the components such as fibers, proteins, and the functionality of the flours (Oyeyinka et al., 2017). Kaur et al. (2019) replaced wheat flour with roasted flaxseed (10–30%), and the results showed increased hardness, similar to the trend in this study. However, a general decrease in hardness was observed, but this change was not significant ($p \geq 0.05$) for up to 20 days for various composite snacks and for 30 days for 100% of the cassava snacks. This decrease in hardness could be attributed to the absorption of moisture (8.21–13.85%) by the snacks during storage

Table 6
Storage characteristics of snacks after the samples were stored at ambient temperature.

Parameters	Snacks/Storage	0	10	Time (days) 20	30	40
β-carotene (μg/g)	C15F94^{A}	0.74 ± 0.02^{a}	0.74 ± 0.01^{a}	0.72 ± 0.02^{a}	0.50 ± 0.02^{b}	0.35 ± 0.00^{c}
	C30F94^{A}	0.69 ± 0.00^{a}	0.68 ± 0.00^{a}	0.67 ± 0.02^{a}	0.56 ± 0.00^{b}	0.42 ± 0.02^{c}
	C45F94^{A}	0.56 ± 0.01^{a}	0.54 ± 0.01^{ab}	0.52 ± 0.03^{b}	0.44 ± 0.00^{c}	0.31 ± 0.00^{d}
	C15F92^{A}	0.69 ± 0.01^{a}	0.66 ± 0.02^{ab}	0.64 ± 0.00^{b}	0.50 ± 0.02^{c}	0.22 ± 0.02^{d}
	C30F92^{A}	0.62 ± 0.00^{a}	0.62 ± 0.01^{a}	0.59 ± 0.01^{a}	0.40 ± 0.01^{b}	0.30 ± 0.00^{c}
	C45F92^{A}	0.50 ± 0.02^{a}	0.50 ± 0.00^{a}	0.48 ± 0.01^{a}	0.36 ± 0.02^{b}	0.35 ± 0.00^{c}
	YFCF100	0.79 ± 0.01^{a}	0.78 ± 0.01^{a}	0.74 ± 0.00^{b}	0.65 ± 0.00^{c}	0.58 ± 0.01^{d}
Hardness (N)	C15F94^{A}	90.20 ± 1.31^{a}	87.67 ± 1.41^{ab}	85.30 ± 0.95^{b}	78.12 ± 1.11^{c}	74.05 ± 0.92^{d}
	C30F94^{A}	87.17 ± 0.86^{a}	84.85 ± 1.77^{ab}	82.04 ± 0.25^{b}	76.07 ± 1.23^{c}	69.12 ± 0.16^{d}
	C45F94^{A}	86.51 ± 1.29^{a}	84.19 ± 0.07^{b}	79.19 ± 0.17^{c}	72.77 ± 0.36^{d}	67.44 ± 1.43^{e}
	C15F92^{A}	84.46 ± 1.80^{a}	83.04 ± 1.33^{a}	78.43 ± 0.22^{b}	71.42 ± 0.28^{c}	69.90 ± 1.61^{d}
	C30F92^{A}	82.37 ± 0.78^{a}	79.30 ± 1.40^{ab}	77.37 ± 0.34^{b}	71.29 ± 1.26^{c}	67.03 ± 1.22^{d}
	C45F92^{A}	80.91 ± 1.23^{a}	77.19 ± 0.74^{a}	73.09 ± 0.28^{b}	68.35 ± 0.58^{c}	61.44 ± 0.01^{d}
	YFCF100	81.10 ± 1.57^{a}	76.26 ± 0.90^{ab}	70.38 ± 0.19^{bc}	68.65 ± 1.28^{c}	63.31 ± 0.01^{d}
% Moisture	C15F94^{A}	9.37 ± 0.29^{d}	10.45 ± 0.43^{cd}	11.67 ± 053^{bc}	12.33 ± 0.41^{ab}	12.99 ± 0.30^{a}
	C30F94^{A}	9.21 ± 1.37^{c}	10.61 ± 0.30^{c}	11.86 ± 0.12^{bc}	12.78 ± 0.07^{ab}	13.40 ± 0.13^{a}
	C45F94^{A}	8.01 ± 0.71^{d}	10.27 ± 0.26^{c}	11.82 ± 0.33^{bc}	12.44 ± 0.17^{ab}	13.31 ± 0.25^{a}
	C15F92^{A}	9.43 ± 0.09^{d}	10.64 ± 0.13^{c}	11.15 ± 0.05^{bc}	12.28 ± 0.26^{ab}	12.88 ± 0.31^{a}
	C30F92^{A}	9.32 ± 0.47^{c}	10.60 ± 0.19^{c}	11.83 ± 0.37^{b}	12.50 ± 0.11^{b}	13.40 ± 0.00^{a}
	C45F92^{A}	8.21 ± 0.29^{e}	10.10 ± 0.40^{d}	11.98 ± 0.16^{c}	12.76 ± 0.23^{b}	13.85 ± 0.09^{a}
	YFCF100	8.86 ± 0.49^{e}	9.87 ± 0.01^{c}	10.04 ± 0.00^{c}	11.87 ± 0.00^{b}	12.41 ± 0.01^{a}

Values (mean ± standard deviation) with different superscripts on the same row differ significantly
Values (mean ± standard deviation) with different superscripts in the same row differ significantly ($p \leq 0.05$). YFCF and YFCF100: yellow-fleshed cassava flour and snacks; C15F94^{A}, C30F94^{A} C4594^{A}, C15F92^{A} C3092^{A} C45F92^{A}: flour and snacks containing cassava and fermented pigeon pea cultivars (85: 15, 70:30, 55:45)

(Table 6). Oyeyinka et al. (2017) made a similar observation and observed marked differences after four weeks of storing snacks made from bambara and compea flour and paste.

3.8. Free fatty acid (FFA) and peroxide values (PV) of the snacks during storage

The Free fatty acid (FFA) and peroxide values (PV) of the prepared snacks that were stored for 40 days ranged from 0.45 to 1.82% and 0.66

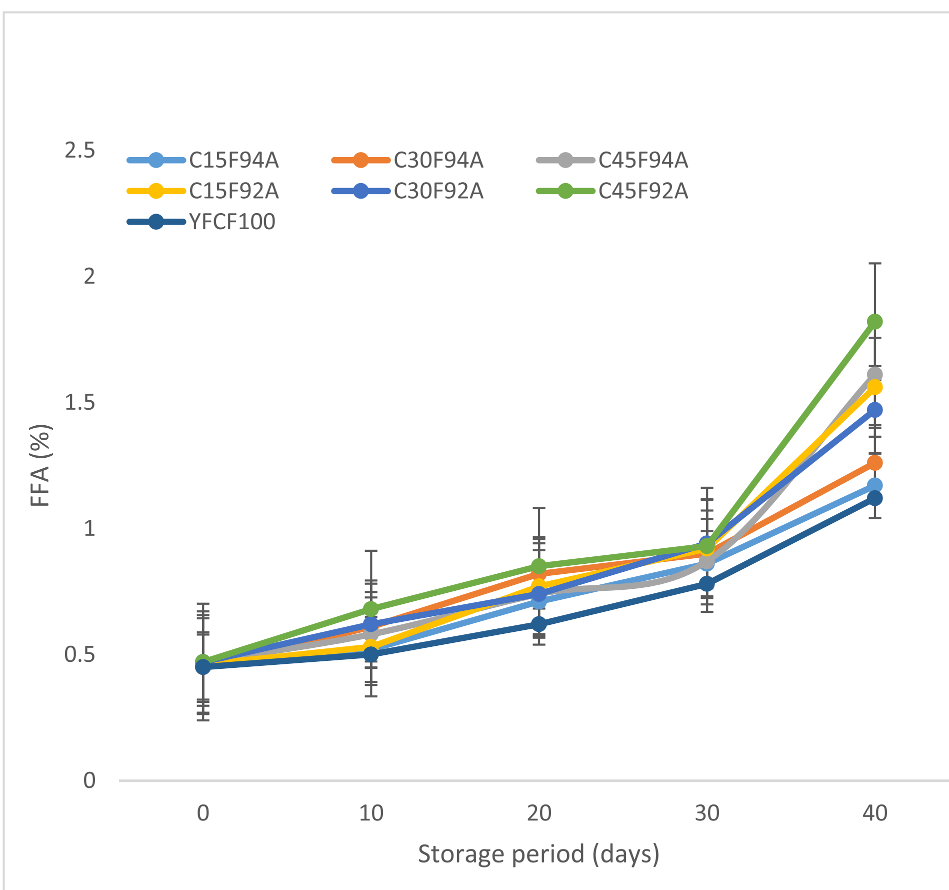

Fig. 2. Changes in free fatty acid (FFA) of the snacks during storage.

to 5.15 meqO2/kg oil, respectively (Figs. 2–3). Also, FFA and PV of various snacks were significantly ($p \leq 0.05$) enhanced as storage period progressed (> 2-fold increase in FFA, and 7-fold increase in PV). Reports on snack curls' preservation yielded similar outcomes (Raja et al., 2014). The formulated snacks remained in good quality for the full 30-day storage period, after which an unacceptably rancid smell developed. This was because the values of FFA (<1) and PV (≤5 meqO2/kg oil) at 30 days storage were, respectively, indicators of acceptable levels of rancidity and lipid oxidation for shelf stable ready to eat snacks (FSSAI, 2022).

3.9. Changes in microbial quality of the snacks during storage

The total plate count (TPC) is the colony count of the mesophilic bacteria in the food growing under aerobic conditions, and a high TPC, which is undesirable, can be a pointer to the existence of a public health hazard during food processing. Although TPC values (0.00–5.35 log cfu/g) were within the permissible level published by the FDA for microbial limits in food, the results followed a significantly ($p \leq 0.05$) increasing trend as the storage period increased (Fig. 4). This might be due to the enrichment of protein in the fortified snack products, which favors microbial growth. This is corroborated by the findings of Raja et al. (2014), who reported similar findings for snack curls. As shown in Fig. 5, the counts of yeast and mold ranged from 0.00 to 2.94. After 30 days of storage, signs of mold and yeast growth were found, indicating the appropriate time to terminate the snacks' storage test for this study. Thus, the development of yeast and mold is increasingly being employed as a food shelf-life tactic to enhance the safety of snacks and avoid health risks to the general public. Oyeyinka et al. (2017) earlier study demonstrated that during the final stage of snack preservation, yeast and mold growth emerged. The safety and storage qualities of processed food products are greatly dependent on their microbial characteristics. Some microbiological characteristics can vary greatly based on the conditions of processing, handling, storage, and cleanliness (lawal et al., 2016).

4. Conclusions

The properties of gluten-free composite flour from beta-carotene cassava and pigeon pea prepared from four different blends were investigated, and flour blends were evaluated as ingredients in the preparation of snacks. The formulated snacks showed a drastic decline in beta-carotene content with the incorporation of fermented pigeon pea flours. Snack products with enhanced nutritional composition, phytonutrient constituents, and metabolized energy were produced from composite flour blends compared to 100% YFCF snacks. The physical qualities of the snacks were found to be promising with respect to their color parameters and hardness. The C15F94[A] sample was found to be highly acceptable. Although beta-carotene retention declined on storage, both 100% YFCF and FPP-incorporated cassava snacks were shelf stable in polyethylene pouches for a period of 30 days at ambient conditions (30 ± 2 °C) without any marked loss of physicochemical, rancidity, and microbial qualities. Moreover, future studies are needed to determine the application of food delivery systems for the optimal retention of vitamin A in snacks.

CRediT authorship contribution statement

A.I. Lawala: Ideas formulation, involved in the analysis, drafted and revised the manuscript. **K.K.Olatoye:** Contributed to physical and statistical analysis of the data. **K.A. Babalolac:** Conducted the research, data collection and investigation process.

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Declaration of Competing Interest

The author wishes to declare that there's no financial/personal

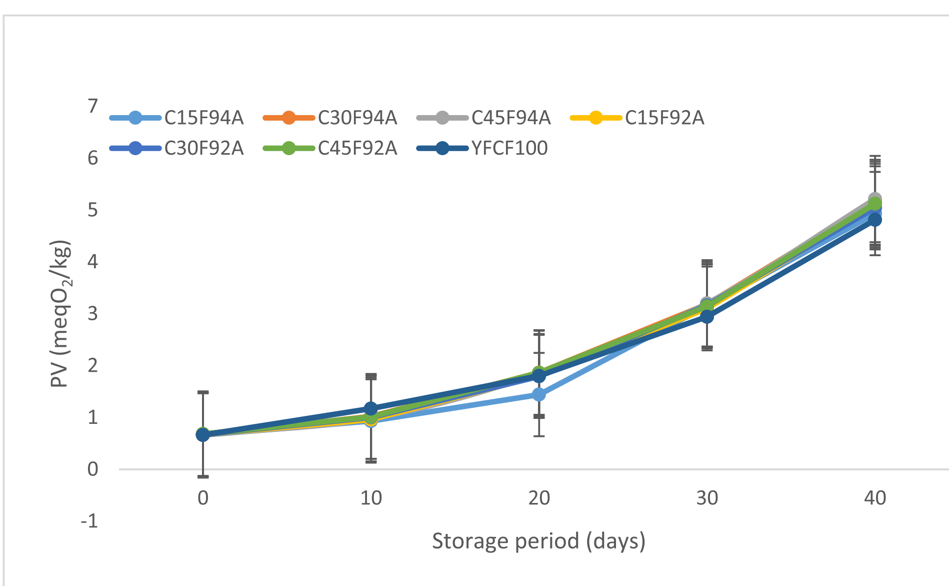

Fig. 3. Changes in peroxide value (PV) of the snacks during storage.

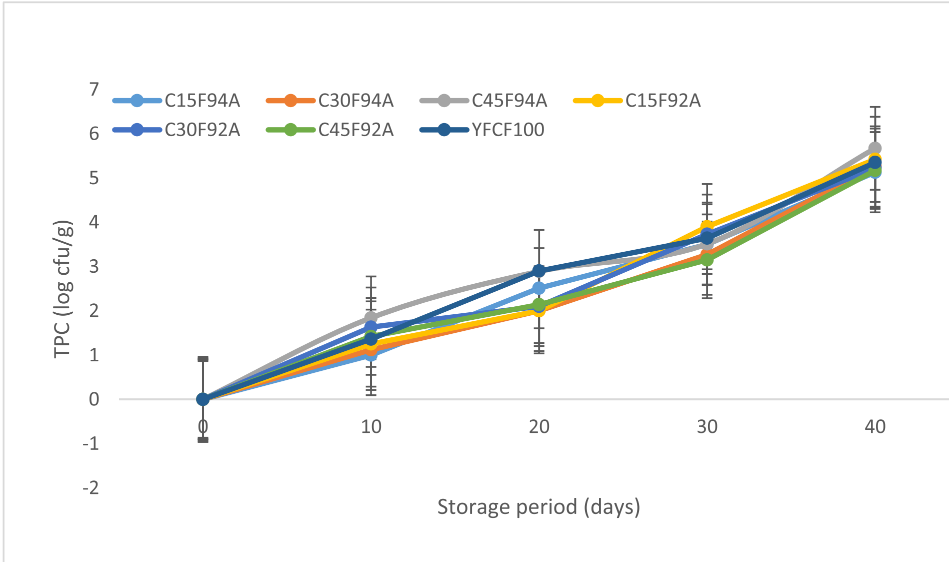

Fig. 4. Total plate count (TPC) of the snacks during storage.

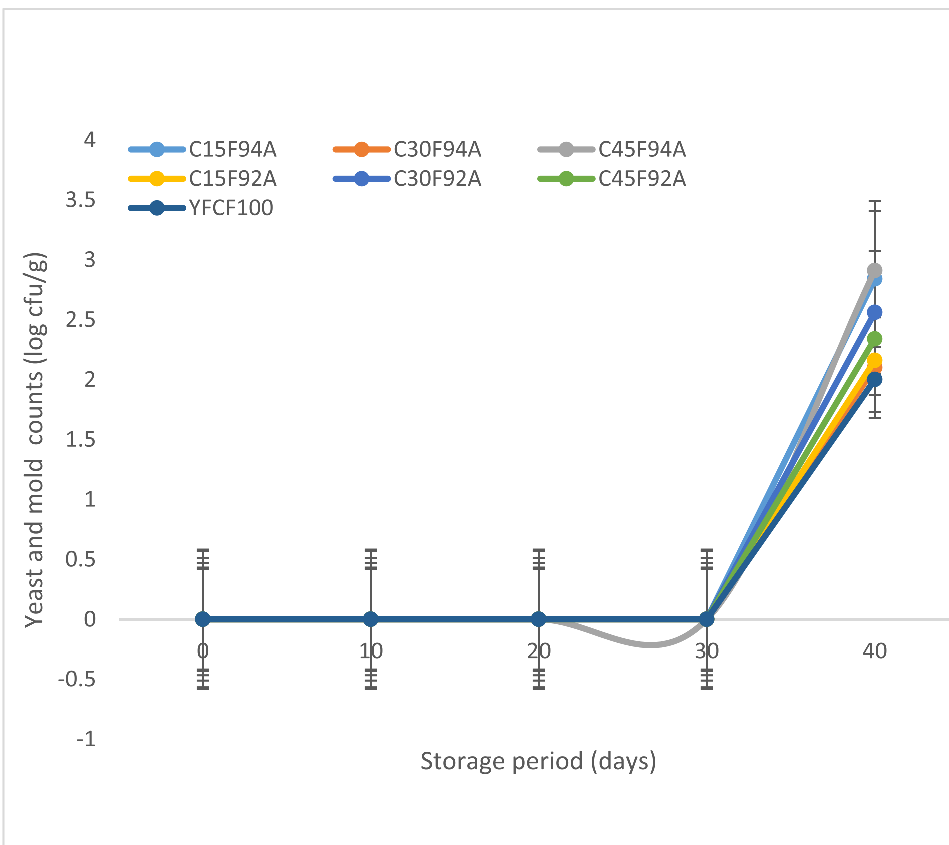

Fig. 5. Yeast and mold counts of the snacks during storage.

interest or belief that could affect their objectivity of this research.

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