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Original research paper

PHYSICOCHEMICAL PROPERTIES OF ACHA-PEANUT COMPOSITE FLOUR SEPARATELY ENRICHED WITH CARROT AND ORANGE-FLESHED SWEET POTATO FLOURS

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Abstract: Physicochemical characteristics of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato(OFSP) flours, yielding four samples based on a 19 g protein target were assessed: A (100% acha), AP (81.08% acha + 18.92% peanut), APC (64.21% acha + 20.64% peanut + 15.15% carrot), and APO (64.55% acha + 20.74% peanut + 14.71% OFSP). Sample APO had significantly ($p<0.05$) higher protein content (19.72%), while AP had higher fat (3.54%). APC had higher ash (3.14%) and fibre (5.08%), whereas sample A had higher carbohydrate (79.95%) and energy (387.77 kcal) values. Sample APC had significant ($p<0.05$) higher differences observed in bulk density (0.82 g/ml), water absorption (1.56 g/g), oil absorption (1.47 g/g), and swelling index (3.01). APC also had the lowest peak (366.10 RVU), trough (167.50 RVU), breakdown (199.80 RVU), final (393.20 RVU), and setback (244.30 RVU) viscosities, while sample A had the lowest peak temperature (59.12°C) and peak time (5.36 min). APC contained higher calcium (21.12 mg/100g), magnesium (72.64 mg/100g), iron (9.07 mg/100g), zinc (3.96 mg/100g), and beta-carotene (6.75 mg/100g), whereas sample A had higher thiamine (0.41 mg/100g), and APO had higher vitamin C (3.11 mg/100g). Antinutrient contents ranged from 0.12-1.02 mg/100g, 0.13-0.90 mg/100g, 0.14-0.32 mg/100g and 0.22-0.61 mg/100g for tannins, phytates, oxalates and trypsin inhibitors, respectively. APC had the lowest tannin and phytate values, while lower oxalates and trypsin inhibitors were found in samples A and APO, respectively. These findings underscore the potential of these composite flours in improving dietary quality and addressing nutrient deficiencies, particularly for children.

Key words: *Fonio, viscosity, minerals, vitamins, nutrient enrichment, antinutrients*

INTRODUCTION

Composite flours are produced by combining two or more flours to achieve specific qualities in the final product. They provide opportunities to develop diverse and healthier food products by taking advantage of each component's unique properties and creating a better end product (Hassona, Hussein, Morsy & Abd El-Aal, 2023). Composite flours find versatile applications in various food categories such as baked goods, pasta, snacks, and gluten-free alternatives, catering to diverse dietary needs and consumer preferences (Banua, Kaura, Bhada-riya, Singh & Sharma, 2021). Cereals are pivotal in formulating composite flours, serving

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as the foundation of many staple foods worldwide. Their widespread use in composite flour production stems from their ready availability, adaptability, and nutrient density, notably in carbohydrates and fibre. However, the lack of essential amino acids and vitamins highlights the need for alternative methods towards enriching cereal-based diets.

Acha (otherwise called Fonio) is a small-seeded *Digitaria* grass that holds significant historical and agricultural importance in West Africa. Though underutilized, it stands out as a nutrient-dense grain packed with starch, fibre, minerals, vitamins, and valuable phytochemicals renowned for their antioxidative properties (Taylor, Belton, Beta & Duodu, 2014). Particularly rich in amino acids cysteine and methionine, crucial for skin and liver health, acha surpasses other cereals in nutritional value. Its low gluten content and glycaemic index further position it as a promising ingredient in the formulation of functional foods (Bassey et al., 2023).

Peanut (*Arachis hypogaea* L.), is an important legume crop noted for its distinct flavour when roasted or boiled. Legumes like peanuts, soybeans, and cowpeas have emerged as substitutes for animal proteins in developing nations due to their affordability. Peanuts are rich reservoirs of protein, energy, oil, phosphorus, magnesium, calcium, B vitamins, vitamin E, resveratrol, and essential amino acids, contributing significantly to health maintenance and disease prevention (Singh, Raina, Sharma, Chaudhary & Rajpal, 2021; Chen et al., 2022). Incorporating peanut flour and similar legume flours into cereal flour augments nutritional content and enhances the functionality of resulting products, thereby enhancing their nutritional profile and health benefits (Khvostenko et al., 2023). Carrots (*Daucus carota* L.) are renowned for their abundant carotenoid content, which gives them their characteristic orange colour (Klein & Rodriguez-Concepcion, 2015). In addition to carotenoids, carrots are also excellent sources of vitamins, anthocyanins, and numerous phenolic compounds that act as potent antioxidants (Ahmad et al., 2019; Nagraj, Jaiswal, Harper & Jaiswal, 2020). Beta carotene, a type of carotenoid found in carrots, plays a crucial role as a precursor to vitamin A in the human body. The inclusion of carrots in diets may contribute to alleviating the challenges associated with vitamin A deficiency, a prevalent issue in Nigeria (Aghaji, Duke & Aghaji, 2019).

Orange Fleshed Sweet Potato (OFSP) like regular sweet potato (*Ipomoea batatas*), is a rich source of beta carotene, anthocyanins, poly-phenols, starch, soluble fibre, and minerals, offering antioxidant and anticarcinogenic benefits (Mbogo, Muzhingi & Janaswamy, 2021). OFSP is part of various food initiatives across Sub-Saharan Africa due to its bio-fortification with additional beta carotene, which gives it its distinctive orange colour (Oloniyo, Omoba, Awolu & Olagunju, 2021).

In developing countries like Nigeria, protein energy malnutrition (PEM) remains a prevailing concern, particularly among vulnerable populations such as infants, toddlers, adolescents, and pregnant women (de Vries-Ten Have, Owolabi, Steijns, Kudla & Melse-Boonstra, 2020). The deficiency in protein and essential amino acids, compounded by micronutrient deficiencies resulting from carbohydrate-based diets, leads to chronic malnutrition, stunting, and increased susceptibility to infections and other health complications (Abubakar et al., 2017). The aim of this study therefore was to produce protein and beta-carotene-enriched acha-based flours, and to assess their suitability as raw materials for processing ready-to-eat foods.

MATERIALS AND METHODS

Raw material procurement

Acha grains and carrot roots were purchased from a local market in Jos, Plateau State. Peanuts were obtained from North Bank Market and pressed at a local mill, both in Makurdi, Benue State, while Orange-fleshed sweet potatoes were obtained from Benue State Agricultural and Rural Development Authority (BNARDA).

Preparation of acha, peanut, carrot and orange-fleshed sweet potato flours

Acha flour was prepared following the procedure outlined by Istifanus, Umar, Ayika, Danladi, and Agbo (2019), involving destoning, washing, and drying the grains at 60^{o}C for 8 h in an oven (GENLAB B6S, England, UK). The dried grains were milled using a hammer mill (BS 5000-99 Brook Crompton, Huddersfield, England,) and sieved (500 μm) to obtain flour (Fig. 1).

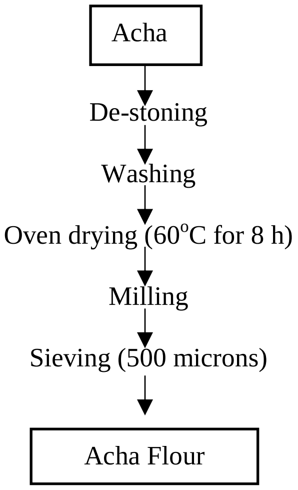

Figure 1. Flow chart for preparation of acha flour (Istifanus et al., 2019)

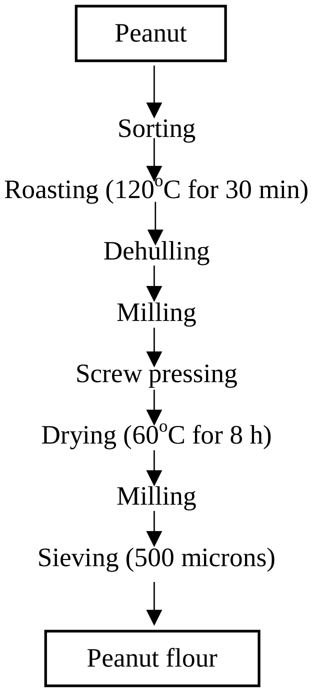

Figure 2. Flow chart for preparation of peanut flour (Bansal and Kochhar, 2014)

The method described by Bansal and Kochhar (2014) was employed for peanut flour production (Fig. 2). The nuts were sorted, roasted at 120°C for 30 min, and then dehulled. They were then ground and pressed to remove oil. The resulting meal was dried at 60^{o}C for 8 h in an oven (GENLAB B6S, England, UK). The dried meal was milled (BS 5000-99 Brook Crompton, Huddersfield, England, UK) and sieved through a 500-micron sieve to obtain flour.

Carrot powder was prepared as described by Sule, Oneh, and Agba (2017). Fresh carrot roots were washed, sliced (approximately 0.3 cm), and soaked in water containing 0.2% potassium metabisulphite for 3 minutes to prevent carotenoid oxidation. Subsequently, they were drained, spread on trays, and dried in an oven (GENLAB B6S, England, UK) at 55°C for 8 h. The dried carrot slices were then milled using a hammer mill (BS 5000-99 Brook Crompton, Huddersfield, England, UK) and sieved through a 500-micron sieve to obtain fine powder (Fig. 3).

Orange-fleshed sweet potato (OFSP) flour was prepared following the method outlined by Avula (2005). OFSP tubers were washed, peeled, sliced into approximately 0.3 cm thick pieces, and treated with 0.2% potassium metabisulphite as done for carrots. After draining and drying in the oven (GENLAB B6S, England, UK) at 55 °C for 8 h, the dried OFSP slices were milled (Brook Crompton, Huddersfield England, BS 5000-99) and sieved to obtain fine flour (Fig. 4). All sample flours were individually packed in low-density polyethylene bags and stored under ambient conditions until further analysis.

Blend formulation

Four blends were prepared according to the specifications outlined in Table 1. Sample A consisted of 100% acha and was designated as the control. Samples AP (81.08% acha + 18.92% peanut), APC (64.21% acha + 20.64% peanut + 15.15% carrot), and APO (64.55% acha + 20.74% peanut + 14.71% OFSP) were formulated to fulfil the recommended dietary allowance (RDA) of 19 g protein/day for children between 4 to 8 years (Institute of Medicine, 2005).

The proportions of the raw materials necessary to meet the protein target of the flour blends were determined through material balancing based on their respective protein contents, employing the methodology outlined by Chiba (2009).

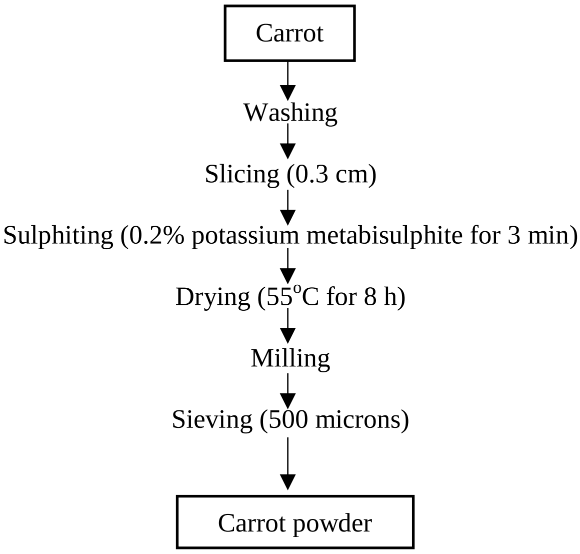

Figure 3. Flow chart for preparation of carrot powder (Sule et al., 2017)

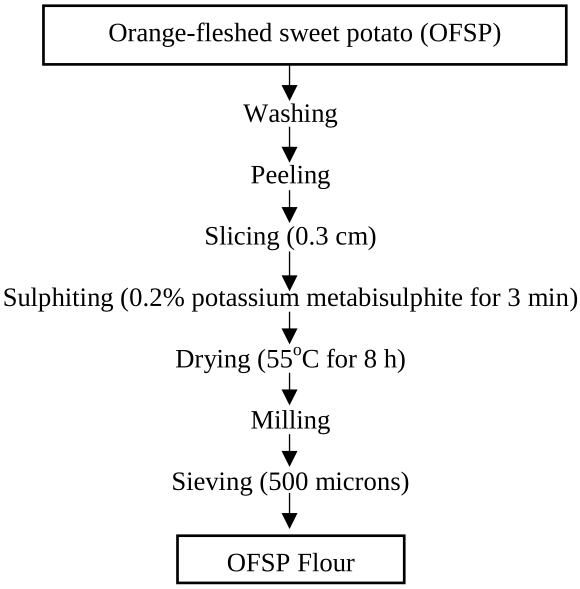

Figure 4. Flow chart for preparation of Orange-fleshed sweet potato (OFSP) flour (Avula, 2005)

Table 1.
Blend formulation based on target protein content (approximately 19 g)

Blend	Acha	Peanut	Carrot	OFSP	Total (%)
A	100	-	-	-	100
AP	81.08	18.92	-	-	100
APC	64.21	20.64	15.15	-	100
APO	64.55	20.74	-	14.71	100

Physicochemical Analysis

Determination of proximate composition

The procedures described by AOAC (2012) were used to determine the proximate composition, except carbohydrate. Crude protein content was determined using the Kjeldahl method, and the percentage nitrogen (%N) obtained was used to calculate the percentage crude protein (% CP) using the relationship: % CP = % N × 6.25. Ash content was determined by incinerating the samples in a Muffle furnace at 550 °C for 4 hours. The ash was cooled in a desiccator and weighed. Crude fat was determined using a Soxhlet apparatus. Crude fibre was determined by dilute acid and alkali hydrolysis method while moisture content was determined using the oven drying method. Carbohydrate content was calculated by difference (Ihekoronye & Ngoddy, 1985). The energy value of each sample was calculated using the Atwater factor described by FAO (2003) as follows: Calorific value (Kcal/100g) = % Protein x 4.0 + % Fat x 9.0 + % Carbohydrate x 4.0.

Determination of functional properties

Bulk density, water absorption capacity, oil absorption capacity, and swelling index were determined following the procedure of Onwuka (2005). Dry 10 ml graduated cylinders were weighed and filled with flour up to the 10 ml mark, tapped gently, and reweighed to calculate bulk density [(weight of the sample (g)]/ [volume of sample (ml)]. For water and oil absorption capacities, 1 g of sample was mixed with 10 ml of water and olive oil, respectively, centrifuged after 30 min, and the volume difference was measured. Water density was taken as 1 g/ml, while oil density was 0.98 g/ml. The swelling index was calculated from the initial and final volumes after 1 g of the sample was mixed with water and left for 45 min.

Determination of pasting properties

Pasting properties were evaluated using a Rapid Visco Analyzer RVU 232015 (Newpoint Scientific Dingling USA) as described by Newport Scientific (1998). Three grams (3 g) of sample were weighed into a canister with 25 ml of distilled water. The mixture was heated from 50 to 95 °C for 2 minutes, and then cooled to 50°C for 2 minutes. Parameters such as peak viscosity, trough, breakdown, final viscosity, set back, peak time, and pasting temperature were recorded using thermocline for Windows software. Viscosity was expressed in Rapid Visco Units (RVU).

Determination of micronutrients

The mineral contents (calcium, magnesium, iron, and zinc) of the flour samples were assessed post-ashing. The resulting ash was dissolved in 100 ml of 10% hydrochloric acid, filtered, and quantitatively estimated using an atomic absorption spectrophotometer (Scientific Model VGP 210, Buck Scientific, USA) equipped with filters corresponding to the specific minerals, following the AOAC (2012) guidelines. Vitamins B1 and C were analyzed using High-Performance Liquid Chromatography (Model BLC-10/11 HPLC system, Buck Scientific, USA) techniques as described by AOAC (2012). Beta carotene content was determined using a spectrophotometer (Model 22UV/VIS, Angstrom Advanced, USA) following the procedures specified in AOAC (2012).

Determination of antinutrients

The method described by Singleton, Orthofer and Lamuela-Raventos (1999) was used for the determination of tannins. Phytate content was determined using the anion exchange method described by Ma et al. (2005). Oxalates were determined as described by the AOAC (2012) method, while the determination of trypsin inhibitors was by the method of Smith, Megen, Twaalfhaven and Hitchcock (1980).

Statistical analysis

Experiments were conducted in triplicates. Data was subjected to analysis of variance

(ANOVA). Means were separated using Duncan's Multiple Range Test, with a significance level set at 5% ($p < 0.05$). Statistical analysis was performed using the GenStat statistical package (17th ed.) (VSN International Ltd., Hertfordshire, UK).

RESULTS AND DISCUSSION

Proximate composition of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

The proximate composition (dry weight basis) of the flour blends is presented in Table 2. Composite flours exhibited significantly ($p<0.05$) higher protein content (19.63-19.72%) compared to the control (12.38%), aligning with the formulation protein target of 19 g. Proteins are essential nutrients for structural and functional biomolecules, providing necessary amino acids for metabolism (Neela & Fanta, 2019). Peanut meal flour serves as a vital protein source for both human and animal feed supplementation (Asibuo, Akromah, Dapaah & Safo-Kantanka, 2008; Purohit & Rajyalakshmi, 2011). Legume meals and flours have higher protein content than their seeds due to oil removal (Mgbemere, Akpapunam & Igene, 2011; Purohit & Rajyalakshmi, 2011).

Acha-peanut composite flour (AP) displayed significantly ($p<0.05$) higher fat content (3.54%) compared to other flours. The control (100% acha) flour exhibited the lowest fat content (2.05%), consistent with a low fat content of cereals. Lipids are crucial for cell structure and function, contributing to food's energy value (Eleazu & Ironua, 2013). Additionally, fats serve as carriers for fat-soluble vitamins (A, D, E, K) and enhance the sensory qualities of baked goods while retaining flavour (Ikuomola, Otutu & Oluniran, 2017). However, high-fat diets have been linked to obesity and heart disease (Okpala & Chinyelu, 2011). A similar fat content of 2.50-3.40% was reported by Majekodunmi and Olapade (2018) in acha-cowpea composite flours.

Ash content is often linked to food mineral content (Iwe, Onyeukwu & Agiriga, 2016; Sule et al., 2017). Ash content of the flour samples ranged from 1.51% in the control flour to 3.14% in acha-peanut-carrot composite flour, indicating a likelihood of higher mineral content (Liang & Liang, 2019). The ash content observed in this study aligns with findings reported by Adeyanju et al. (2022) for wheat, acha, and African yam bean composite flours (1.16-2.14%), but lower than values reported by Woripre, Mbaeyi-Nwaoha & Ofoegbu (2022) for acha-mungbean-cashew nut flour blends (3.71-4.80%).

The incorporation of peanut, carrot, and orange-fleshed sweet potato flours augmented the crude fibre content (from 4.11-5.08%) of acha flour, highlighting these raw materials as robust sources of dietary fibre. Dietary fibre plays a crucial role in maintaining gastrointestinal and cardiovascular health. It helps reduce intracolonic pressure, thereby lowering the risk of colon cancer and related health concerns (Awuchi, Victory & Echeta, 2019). Additionally, dietary fibre may have a positive impact on blood glucose levels, as indicated by research by Fakolujo and Adelugba (2021). However, an excessively high-fibre diet can impact mineral elements negatively (Ikpeme, Ekpeyoung & Igile, 2012). Conversely, Woripre et al. (2022) noted higher fibre levels in acha-mungbean-cashew nut flour blends.

All flour blends significantly ($p<0.05$) varied in carbohydrate content, spanning from 68.62-79.95%, with the control flour (100% acha) exhibiting the highest content. The reduced carbohydrate content in composite flours results from a dilution effect due to acha substitution, known for its substantial carbohydrate content (Inyang, Ufot, Daniel & Bello, 2018; Ayo et al., 2024). The relatively high carbohydrate levels in composite flours indicate their potential contribution to energy requirements (384.37-387.77 kcal).

Functional properties of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Functional properties of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours are presented in Table 3. Samples differed significantly ($p<0.05$) in bulk density, water absorption capacity, oil absorption capacity and swelling index. Acha-peanut-carrot (APC) and acha-peanut-orange-fleshed sweet potato (APO) composite flours both displayed the highest bulk density (0.82 g/ml), followed by sample AP (0.81 g/ml), while the control flour (100% acha) exhibited the lowest bulk density (0.77 g/ml). The increase in bulk density as the proportion of acha in the blends decreases can be attributed to the higher fibre content of non-starch polysaccharides (Yagci & Gogus, 2008; Frohlich, Boux & Malcolmson, 2014).

Table 2.
Proximate composition (dry weight basis %) and energy value of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Blend	Crude protein (%)	Crude fat (%)	Ash (%)	Crude fibre (%)	Carbohydrate (%)	Energy (kcal)
A	$12.38^c \pm 0.02$	$2.05^d \pm 0.01$	$1.51^d \pm 0.01$	$4.11^d \pm 0.01$	$79.95^a \pm 0.03$	$387.77^a \pm 0.45$
AP	$19.63^a \pm 0.01$	$3.54^a \pm 0.01$	$2.91^b \pm 0.14$	$4.63^c \pm 0.02$	$69.29^c \pm 0.41$	$387.54^a \pm 1.01$
APC	$19.71^b \pm 0.07$	$3.45^b \pm 0.10$	$3.14^a \pm 0.01$	$5.08^a \pm 0.15$	$68.62^d \pm 0.02$	$384.37^c \pm 0.77$
APO	$19.72^b \pm 0.02$	$2.73^c \pm 0.22$	$2.21^c \pm 0.02$	$4.88^b \pm 0.07$	$70.46^b \pm 0.15$	$385.29^b \pm 0.03$

Values are means ± standard deviations of triplicate determinations. Means in the same column with same superscripts are not significantly (p>0.05) different
Key: A= acha flour, AP = acha-peanut flour, APC = acha-peanut-carrot flour, APO = acha-peanut-orange-fleshed sweet potato flour

This study demonstrates that the addition of composite materials to acha flour enhances fibre content and consequently, increases bulk. Composite flours with higher bulk density are well-suited for food preparation and packaging, offering advantages in storage and handling. Conversely, lower bulk density is beneficial for formulating complementary foods (Chandra, Samsher & Kumari, 2015).

The water absorption capacity of the flours varied significantly ($p<0.05$) from 1.02-1.56 g/g. Blend composed of acha, peanut and carrot (APC) exhibited the highest water absorption capacity. This increase is linked to amylose leaching, solubility enhancement, and starch crystalline structure loss (Chandra et al., 2015). The higher fibre (5.08%) in APC as a result of peanut and carrot incorporation may have contributed to increased water absorption capacity. Sule et al. (2017) also linked increased water absorption to the strong water affinity of fibres in high-fibre food products, enhancing dough-making potential. Values in the present study surpassed those reported by Orisa and Udofia (2017) for wheat, acha, cowpea, and *Moringa oleifera* powder blends (0.87-1.11 g/g).

Oil absorption capacity, attributed to physical oil entrapment, ranged from 0.86-1.47 g/g in this study. All samples displayed higher oil absorption than the control flour. The blend containing acha, peanut, and carrot (APC) had the highest oil absorption capacity (1.47 g/g), possibly due to the lipid-binding capacity of hydrophobic proteins in the composite flour.

These values were lower than those reported by Orisa and Udofia (2017) for similar blends (1.61-1.79 g/g) and align with results for wheat and sesame peel flour blends (Zouari, Besbes, Ellouze-Chaabouni & Ghribi-Aydi, 2016).

The swelling index of the flour blends significantly increased with the addition of composite materials into acha. There was a direct correlation between the swelling index and water absorption capacity. Values in the composite flours (2.52-3.01) were higher than the control (1.61), with sample APC displaying the highest swelling index. This increase could be attributed to the higher fibrous content in the composite flours, which allows them to absorb water through hydrogen bonding. These values were higher than those documented by Onuegbu, Ngobidi, Ihediohanma and Bede (2021) for wheat-acha blends (ranging from 1.15-1.24) but lower compared to acha-tiger nut blends (ranging from 3.00-9.33) reported by Ayo, Ojo, Popoola, Ayo and Okpasu (2018).

Pasting properties of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Samples showed significant ($p<0.05$) differences in their pasting properties (Table 4). Peak viscosity values ranged from 323.60-379.40 RVU. The highest peak viscosity was observed in the control sample (100% acha flour), while composite flour composed of acha, peanut, and carrot (APC) exhibited the lowest peak viscosity (323.60 RVU), due to starch dilution effect, as a result of increasing protein (19.71%) and fibre (5.08%) contents. Similar reductions in peak viscosity have been documented in composite flours by Wireko-Manu, Laryea and Oduro (2018) and Obinna-Echem, Eke-Ejiofor, Vito and Wordu (2021). Peak viscosity refers to the maximum viscosity reached during the heating process, just before the starch granules form a paste and undergo physical breakdown (Ojo et al., 2017). It is often associated with the final product quality and provides insight into the viscous load expected during mixing (Sule et al., 2017).

Trough viscosity (TV) ranged from 150.60-170.20 RVU. Sample A (100% acha) exhibited the highest trough viscosity, while sample APC had the lowest. The trough phase, or hold period, occurs when the sample is exposed to constant temperature and mechanical shear stress. It represents the minimum viscosity value in the constant temperature phase of the RVA profile and assesses the paste's ability to resist break-down during cooling (Balet, Guelpa, Fox, & Manley, 2019).

High trough viscosity indicates the stability of the flour blend during heating and cooling. The reduction in trough viscosity could be attributed to a decrease in starch content due to the incorporation of other materials. Odedeji and Adeleke (2010) reported lower trough values (86.42-161.08 RVU) in wheat-potato composite flours, while Majeko-dunmi and Olapade (2018) also noted low values (88.92-104.50 RVU) in acha-cowpea blends. Breakdown viscosity (BDV) denotes the difference between peak and trough viscosities, assessing flour's capacity to endure heating and shear stresses in cooking (Sule et al., 2017). Sample APC exhibited the lowest BDV (173.00 RVU), while the control (100% acha) displayed the highest value (207.90 RVU).

Reduced BDV may stem from higher fibre content, potentially compromising stability at elevated processing temperatures, while higher BDV correlates with better resistance to prolonged high temperatures and cooking stresses (Akanbi, Saari & Adebwale, 2009; Obinna-Echem et al., 2021). BDV values in this study however exceeded those reported by Inyang and Nwabueze (2020) for acha-green banana composite flour (11.00-88.00 RVU).

Final viscosity, also known as cold paste viscosity, measures viscosity changes after holding cooked starch at 50 °C (Ikegwu, Okechukwu & Ekumankana, 2010). It is a key parameter indicating starch quality, gauging its ability to form a viscous paste or gel post-cooking and resist shear forces during stirring (Adeyemi & Idowu, 1990).

Table 3.
Functional properties of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Blend	Bulk density g/ml	Water absorption capacity g/g	Oil absorption capacity g/g	Swelling index
A	$0.77^{b}\pm0.03$	$1.02^{c}\pm0.01$	$0.86^{d}\pm0.01$	$1.61^{c}\pm0.15$
AP	$0.81^{ab}\pm0.01$	$1.53^{ab}\pm0.01$	$1.01^{c}\pm0.01$	$2.52^{b}\pm0.03$
APC	$0.82^{ab}\pm0.01$	$1.56^{a}\pm0.02$	$1.47^{a}\pm0.02$	$3.01^{a}\pm0.01$
APO	$0.82^{a}\pm0.01$	$1.51^{b}\pm0.01$	$1.11^{b}\pm0.01$	$2.81^{a}\pm0.01$

Values are means ± standard deviations of triplicate determinations. Means in the same column with same superscripts are not significantly (p>0.05) different.

Key: A= acha flour, AP = acha-peanut flour, APC = acha-peanut-carrot flour, APO = acha-peanut-orange-fleshed sweet potato flour

Table 4.
Pasting properties of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Blend	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Pasting temp (^{o}C)	Peak time (min)
A	$379.40^{a}\pm0.01$	$170.20^{a}\pm1.25$	$207.90^{a}\pm1.43$	$417.20^{a}\pm1.45$	$246.70^{a}\pm0.16$	$59.12^{d}\pm1.10$	$5.36^{c}\pm0.05$
AP	$366.10^{b}\pm0.01$	$167.50^{a}\pm0.98$	$199.80^{b}\pm1.16$	$393.20^{ab}\pm2.59$	$244.30^{b}\pm0.31$	$62.52^{c}\pm0.02$	$5.68^{b}\pm0.02$
APC	$323.60^{d}\pm0.64$	$150.60^{c}\pm0.79$	$173.00^{d}\pm1.42$	$354.80^{c}\pm4.94$	$208.20^{d}\pm0.23$	$66.54^{a}\pm0.63$	$5.91^{a}\pm0.00$
APO	$351.10^{c}\pm0.00$	$160.20^{b}\pm1.41$	$191.10^{c}\pm1.09$	$370.30^{c}\pm2.26$	$196.00^{c}\pm0.16$	$64.47^{b}\pm0.20$	$5.83^{a}\pm0.08$

Values are means ± standard deviations of triplicate determinations. Means in the same column with same superscripts are not significantly (p>0.05) different

Key: A= acha flour, AP = acha-peanut flour, APC = acha-peanut-carrot flour, APO = acha-peanut-orange fleshed sweet potato flour

The present study shows a direct correlation between final and peak viscosities, with increased final viscosity linked to amylose molecule re-association (Tsakama, Mwangwela, Manani & Mahungu, 2010). Final viscosity decreased from 417.20 RVU in acha to 354.80 RVU in acha-peanut-carrot blend (APC) possibly due to dilution resulting from increased protein and fibre, thus affecting starch quality. Inyang and Nwabueze (2020) reported lower values (375.00-1300.00 RVU) for acha-green banana blends. Similar reductions in final viscosity in composite flours are documented by other researchers (Tharise, Julianti & Nurminah, 2014; Ouazib, Dura, Zaidi & Rosell, 2016).

Setback viscosity (SBV) values serve as indicators for starch retrogradation and syneresis during storage or thawing, directly influencing the texture of starch-based food products (Ohizua et al., 2017). In this re-ordering of the starch molecule stage, high amylose content starches exhibit higher setback viscosity (Ashogbon & Akintayo, 2012). Samples showed a significant ($p<0.05$) decrease in SBV from 246.70 in Sample A (100% acha) to 196.00 in Sample APO. The reduction in SBV is attributable to low amylose content, increased molecular weight, and higher fibre content. These characteristics are believed to improve digestibility and reduce the tendency for starch retrogradation in composite flours and their products, as noted by various researchers (Shittu, Lasekan, Sanni & Oladosu, 2001; Peroni, Rocha & Franco, 2006; Sandhu and Singh, 2007). A similar reduction in SBV due to legume flour incorporation has been reported (Ouazib et al., 2016).

Pasting temperature reflects a starch resistance to swelling, indicating the minimum temperature needed for cooking (Sandhu, Singh, & Malhi, 2005). It can affect the stability of other components in composite flour and also reflects energy costs (Sule et al., 2017). The composite flours showed pasting temperatures ranging from 59.12-66.54 °C, lowest in 100% acha and highest in the acha-peanut-carrot (APC) blend. Higher pasting temperatures suggest increased fibre and water absorption due to starch granule associative forces (Otunola & Afolayan, 2018). The pasting temperatures in the present study, comparable with the report of Majekodunmi and Olapade (2018), were however lower than the boiling temperature of the water, hence would save energy during processing (Adebowale, Sanni & Onitilo, 2008).

Peak time signifies the time to achieve peak viscosity and serves as an indicator of flour cooking duration (Adebowale, Sanni & Awonorin, 2005). In this study, peak times varied from 5.36-5.91 min, with the control flour exhibiting the lowest value. Though samples APC and APO were not significantly ($p>0.05$) different in peak time, the former exhibited a higher value (5.91 min). Similar increments in peak time in acha-based blends have been reported by other researchers, attributed to higher protein content (Majekodunmi and Olapade, 2018; Inyang and Nwabueze, 2020). Peak time was directly correlated with pasting temperature, indicating that flours with lower pasting temperatures, like the control, require less cooking time.

Selected micronutrient content of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Micronutrients are essential for fundamental body functions, and their inadequate intake is associated with nutritional deficiencies, compromised immunity, impaired growth, increased susceptibility to infections, chronic diseases, and diminished well-being (Inyang & Nwabueze, 2020). As presented in Table 5, there was no significant ($p>0.05$) difference between samples APC and APO in terms of calcium (20.20-21.12 mg/100g), magnesium (71.23-72.64 mg/100g), and iron (9.01-9.07 mg/100g) contents. Similarly, no significant ($p>0.05$) difference was observed in zinc content (3.88-3.96 mg/100g) between samples A and AP. The notably high levels of calcium, magnesium, iron and zinc in sample APC corroborate the findings of Singh and Kulshrestha (2008), emphasizing carrots as valuable mineral sources. Calcium and magnesium are crucial for bone health, growth, dental integrity, and muscular and nervous system functionality (Lilly, Immaculate & Jamila, 2017). Conversely, iron and zinc are essential for oxygen transport, energy production, anaemia prevention, immune res-ponse, growth, development, and metabolic fun-ctions (Sule et al., 2017). The mineral values closely align with those reported in acha, green banana, and cowpea flour blends (Inyang & Nwabueze, 2020), wheat, acha, and germinated African yam bean flour blends by Adeyanju et al.

(2022), and acha, mango kernel seed, and soy cake blends by Olorunfemi, Awolu and Enujiugha (2021).

Vitamin B1 (thiamine) is a vital water-soluble and heat-sensitive B vitamin essential for maintaining energy levels, supporting a healthy nervous system, promoting brain function, ensuring proper muscle function, aiding digestion, and facilitating growth and development (Yilmaz & Tuncel, 2015). Thiamine levels decreased (0.41-0.34 mg/100g) with the incorporation of composite flours into acha, the lowest value recorded in sample APC (0.34 mg/100g). These values align with findings by Okafor and Ugwu (2014) who produced extruded snacks from breadfruit, cashew nut, and coconut blends (0.13-0.42 mg/100g).

Vitamin C plays a critical role in infant physiology, promoting collagen production, supporting immune function, enhancing iron absorption, and providing antioxidant benefits (Ofoedu et al., 2021). While samples A and AP did not contain detectable levels of vitamin C, sample APO exhibited higher amounts (3.11 mg/100g), compared to sample APC (2.65 mg/100g). These values are comparable with 0.54-3.14 mg/100g reported for pasta made from wheat-carrot flour blends (Sule, Oneh & Agba, 2019).

Beta-carotene, a red-yellow pigment in plants, acts as an antioxidant protecting cells from damaging free radicals (Oloniyo et al., 2021). While undetected in samples A and AP due to a lack of natural sources in acha and peanuts, beta-carotene was observed in samples APC (6.75 mg/100g) and APO (5.38 mg/100g) as carrots and orange-fleshed sweet potatoes are rich sources of the pro-vitamin A (Neela & Fanta, 2019; Adetola, Onabanjo & Stark, 2020; Chikpah, Korese, Hensel, Sturm & Pawelzik, 2021). Beta-carotene is essential for infant growth and development and provides health benefits, including reducing the risk of cardiovascular disorders (Hendriks et al., 2011). When metabolized into vitamin A, it promotes cell growth, combats infections, reduces visual impairment, and prevents diarrhoea (UNICEF, 2019; Ofoedu et al., 2021). The beta-carotene values in this study met the Vitamin A recommended dietary allowance (400 µg/d retinol, converted to 4.8 mg/day) for children less than 8 years stipulated by the Institute of Medicine (2001). Products based on composite flours APC and APO, if processed under controlled conditions, are expected to have satisfactory beta-carotene content and could contribute to reducing the prevalence of vitamin A deficiency in Sub-Saharan Africa.

Antinutrients content of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Acha-based samples exhibited significant ($p<0.05$) variations in their antinutrient contents (Table 6), with values ranging from 0.12-1.02 mg/100g for tannins, 0.13-0.90 mg/100g for phytates, 0.14-0.32 mg/100g for oxalates, and 0.22-0.61 mg/100g for trypsin inhibitors. These relatively low values suggest a limited impact on the bioavailability of essential nutrients in the flours.

The highest tannin content was found in sample APO (1.02 mg/100g), attributed to elevated levels in orange-fleshed sweet potato compared to other raw materials. These values exceeded those reported by Adeyanju et al. (2022) for wheat, acha, and germinated African yam bean flour blends (0.40-0.54 mg/100g). Tannins, as phenolic compounds, form complexes with proteins, reducing digestibility and hindering dietary iron absorption (Gemede & Ratta, 2014; Kurz & Seifert, 2021).

Phytates, generate phytic acid, and chelate metallic ions like zinc, calcium, and iron, diminishing their bioavailability (Gibson, Raboy & King, 2018; Connorton & Balk, 2019). Although peanuts contain notable phytate levels, the highest level in the composite flours was 0.90 mg/100g (sample AP). Lower phytate amounts in composite flours with carrot and OFSP flours align with the enhancing effect of beta-carotene on iron absorption from plant foods (Adetola et al., 2020).

Oxalates hinder calcium absorption by forming insoluble calcium-oxalate complexes (Adeniyi, Orjiekwe & Ehiagbonare, 2010). Sample APO showed significantly ($p<0.05$) higher oxalate content (0.32 mg/100g), while the lowest (0.14 mg/100g) was in the control flour (100% acha), indicating higher levels in orange-fleshed sweet potato. Despite their presence in many vegetables and fruits, oxalate amounts below 10 mg/100g typically raise no nutritional concerns (Oyeleke, Dauda, Tijani, Oladejo & Musa, 2010).

Table 5.
Selected micronutrient content of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Blend	**Calcium**	**Magnesium**	**Iron**	**Zinc**	**Vitamin B1**	**Vitamin C**	**Beta-carotene**
	mg/100g						
A	20.20^{c}±0.03	71.23^{c}±1.10	9.01^{c}±0.03	3.90^{b}±0.27	0.41^{a}±0.04	ND	ND
AP	20.62^{b}±0.01	71.44^{b}±0.57	9.03^{b}±0.04	3.91^{b}±0.03	0.35^{b}±0.02	ND	ND
APC	21.12^{a}±0.20	72.64^{a}±0.04	9.07^{a}±0.16	3.96^{a}±0.10	0.34^{b}±0.06	2.65^{b}±0.39	6.75^{a}±0.84
APO	20.78^{b}±0.01	71.56^{b}±0.06	9.04^{b}±0.11	3.88^{c}±0.05	0.35^{b}±0.01	3.11^{a}±0.28	5.38^{b}±0.08

Values are means ± standard deviations of triplicate determinations. Means in the same column with same superscripts are not significantly (p>0.05) different.
Key: A= acha flour, AP = acha-peanut flour, APC = acha-peanut-carrot flour, APO = acha-peanut-orange fleshed sweet potato flour

Table 6.
Antinutrient content (mg/100g) of acha-peanut composite flour separately enriched with carrot and orange-fleshed sweet potato flours

Blend	**Tannins**	**Phytates**	**Oxalate**	**Trypsin inhibitors**
	mg/100g			
A	0.18^{b}±0.02	0.40^{c}±0.02	0.14^{d}±0.01	0.52^{b}±0.03
AP	0.14^{bc}±0.01	0.90^{a}±0.01	0.25^{b}±0.21	0.61^{a}±0.01
APC	0.12^{c}±0.01	0.13^{d}±0.03	0.17^{c}±0.03	0.31^{c}±0.02
APO	1.02^{a}±0.01	0.61^{b}±0.04	0.32^{a}±0.02	0.22^{d}±0.01

Values are means ± standard deviations of triplicate determinations. Means in the same column with same superscripts are not significantly (p>0.05) different
Key: A= acha flour, AP = acha-peanut flour, APC = acha-peanut-carrot flour, APO = acha-peanut-orange-fleshed sweet potato flour

Trypsin inhibitor values ranged from 0.22-0.61 mg/100g, with sample APO exhibiting the lowest and sample AP the highest. Nwatum, Ukeyima and Eke (2020) noted increased trypsin inhibitor content in wheat flour with peanut and avocado flour, suggesting legumes as primary sources. Values in the present study were lower than those reported by Adeyanju, Babarinde, Adekunle, Olajire, and Adegboye (2018) for wheat, acha, and pigeon pea flour blends (2.97-4.93 mg/100g).

CONCLUSIONS

Findings from the study showed significant variations in protein, fat, ash, fibre, carbohydrate and energy contents, with composite flours generally exhibiting higher protein content than the control reaching the targeted protein RDA. The acha-peanut-carrot sample (APC) displayed better functional properties than the other samples. Furthermore, acha-peanut-carrot (APC) demonstrated lower viscosities, while sample the 100% acha (sample A), exhibited lower pasting temperature and peak time.

Mineral and vitamin content varied significantly across the samples, with acha-peanut-carrot (APC) composite flour displaying higher levels of calcium, magnesium, iron, zinc, and beta-carotene. The 100% acha (sample A) and acha-peanut-OFSP(APO) were richer in thiamine and vitamin C, respectively. The antinutrient content of the flour samples was within acceptable limits.

Overall, these findings underscore the potential of acha-peanut composite flours enriched with carrot and orange-fleshed sweet potato in enhancing dietary quality and addressing nutrient deficiencies, particularly in children's diets. Further exploration and utilization of these composite flours could contribute significantly to improving nutritional outcomes in vulnerable populations.

AUTHOR CONTRIBUTIONS

Conceptualization, S.S.; Supervision, I.G.O.; Writing-original draft preparation, S.S.; Writing-review and editing, I.A.S, N.F.U.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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FIZIČKO-HEMIJSKA SVOJSTVA KOMPOZITNOG BRAŠNA OD FONIJA I KIKIRIKIJA OBOGAĆENOG ŠARGAREPOM ILI BATATOM NARANDŽASTE PULPE

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Sažetak: Procenjene su fizičko-hemijske karakteristike kompozitnog brašna od fonija i kikirikija obogaćenog zasebno sušenom mlevenom šargarepom i slatkim krompirom narandžaste pulpe (OFSP). Dobijena su četiri uzorka kompozitnog brašna koja su formirana da imaju ciljanu vrednost proteina oko 19 g: A (100% fonio), AP (81,08% fonio + 18,92% kikiriki), APC (64,21% fonio + 20,64% kikiriki + 15,15% šargarepa) i APO (64,55% fonio + 20,74% kikiriki + 14,71% OFSP). Uzorak APO je imao značajno ($p<0.05$) veći sadržaj proteina (19,72%), dok je AP imao veći sadržaj masti (3,54%). APC je imao viši sadržaj pepela (3,14%), vlakana (5,08%), i veću energetsku vrednost (388,37 kcal), dok je uzorak A imao više ugljenih hidrata (79,95%). Uzorak APC se značajno razlikovao ($p<0,05$) u nasipnoj gustini (0,82 g / ml), moći apsorpcije vode (1,56 g/g), moći apsorpcije ulja (1,47 g/g), i stepenu bubrenja (3,01). APC je takođe imao najniži pik (366,10 RVU), prelaz (167,50 RVU), kidanje (199,80 RVU), finalni viskozitet (393,20 RVU), i setback (244,30 RVU), dok je uzorak A imao najnižu temperaturu pika (59,12 °C) i vreme pika (5,36 min). APC je imao najveći sadržaj kalcijuma (21,12 mg/100g), magnezijuma (72,64 mg/100g), gvožđa (9,07 mg/100g), cinka (3,96 mg/100g), i beta-karotena (6,75 mg/100g), dok je uzorak A bio bogatiji u sadržaju tiamina (0,41 mg/100g), a uzorak APO je bio najveći u sadržaju C vitamina (3,11 mg/100g). Sadržaji antinutrijenata su bili u opsegu 0,12-1,02 mg/100g, 0,13-0,90 mg/100g, 0,14-0,32 mg/100g i 0,22-0,61 mg/100g za tanine, fitate, oksalate i tripsin inhibitor, respektivno. APC kompozitno brašno je imalo najniži sadržaj tanina i fitata dok su najniži sadržaji oksalata i tripsin inhibitora bili registrovani u brašnima A i APO, respektivno. Ova istraživanja naglašavaju potencijal obogaćenih kompozitnih brašna u poboljšanju kvaliteta ishrane i rešavanju nutritivnih deficijencija, naročito kod dece.

Ključne reči: *fonio, viskozitet, minerali, vitamin, nutritivno obogaćivanje, antinutrijenti*

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