



## Valorization of Agro-Food by-Product for Sustainable Gluten-Free Biscuit: Effect of Acha-Okara-Coconut Residue Flour Blends on Products' Nutritive value and Consumer Acceptability

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### Abstract

Large disposal of agro-food by-products is a global concern due to their negative impacts on the environment and economy. The use of *okara* and coconut residue for sustainable biscuit production could be a promising approach to reduce the challenge of food waste and promote environmental sustainability. The study evaluated the effect of *okara* and coconut residue addition into acha flour on biscuits' nutritional value (proximate composition and mineral contents) and consumer acceptability. Acha flour (100%) was used as the control and was compared with the other three formulations (100:0:0, 90:5:5, 80:15:5, and 70:25:5) containing *okara* (5-25%) and coconut residue flours (5%). Addition of *okara* and coconut residue into acha flours significantly improves the nutritional value, sensory quality, and consumer acceptance. When compared with the control (acha flour), biscuits containing *okara* and coconut residue blends had higher protein and fibre contents. Moisture, total ash, fibre, protein, iron, magnesium, and zinc increased while carbohydrate contents decreased with increasing addition of *okara* and coconut residue into acha flour. Sensory attributes (colour, taste, and crunchiness) of biscuits increased significantly. *Okara*-coconut residue biscuits showed a similar relationship and differed completely from the control sample. Biscuit with 40% *okara* and 5% coconut residue had the highest overall acceptability score (8.1) on a 9-point hedonic scale. This innovative solution can be used to address the challenges of food security and agro-food by-product management. Hence, by utilising *okara* and coconut residue for biscuit production, stakeholders in the food chain can promote sustainable food systems, economic empowerment, improve public health, and consumer acceptance.

**Keywords:** sensory attributes, biscuit, composite flour, coconut residue, *okara*,

### Introduction

Consumers of biscuits are now interested in products that are produced from gluten-free ingredients due to the trending celiac disease, which are nutritious and could promote their health (Bodobodak *et al.*, 2024; Nejatian *et al.*, 2022). Biscuits are confectionery products prepared mainly from wheat flour. They are ready-to-eat food products, which are consumed as in-between meals and in food-feeding programmes. Due to their affordability, shelf stability, convenience and nutritive value, biscuits remain the most popular and largest category of snacks among bakery products. In Nigeria, for instance as an importing economy, over-dependence on wheat flour for biscuit in the last decades had negative impacts on the use of other indigenous cereals that are endowed in the country, as substitutes for wheat. Researchers are further challenged to source for possible substitute for wheat, using ancient or indigenous grains to subdue the high cost of wheat and the impact of climate change. For instance, Acha (*Digitaria exilis*) is a staple food crop in West Africa (Nigeria, Ghana, Mali, and Burkina Faso) to make indigenous dishes such as porridge, non-leavened bread, and couscous (Zhu, 2020; Sobowale *et al.*, 2023). Acha is an important cereal crop because it is gluten-free, rich in methionine and cysteine

(which are lacking in other cereal crops), and also possesses a low glycemic index, which could be an advantage in type II diabetic conditions (Jideani & Jideani, 2011; Sobowale *et al.*, 2023). The global rising food requirements for the growing population demands that potentials of agro-food by-products, such as *okara* and coconut residue that are rich in proteins, dietary fibre, minerals and vitamins, be exploited. Therefore, could fortifying acha using *okara* and coconut residue flour blends enhanced nutritional value and consumer acceptance of biscuits made from the composited flours? Acha (*Digitaria exilis*) a very nutritious cereal crop of West African origin that belongs to the *Graminaea* family, is also referred to as fonio, findi, funde, pom, and kabug (Jideani & Jideani, 2011). Small-seeded cereals called acha grains are indigenous to Western Africa and are crucial cereal crops for ensuring food security. Other regions of the world have taken notice of acha as a novel food because of its appealing nutritional qualities (such as being gluten-free and whole grain) and possible culinary uses (Zhu, 2020). Vitamins, minerals, fibre, carbohydrates, protein, and amino acids are all abundant in this little-known grain (Zhu, 2020; Sobowale *et al.*, 2023).



Researchers have reported extensively on numerous food applications of acha flour, notably are on bread (Chinma *et al.*, 2016), biscuits (Ayo, Zakariya, & Okoh, 2021), masa (Malomo & Abiose), porridges and couscous. *Okara* is a creamy-grey or sometimes white-yellowish mash or residue remaining after filtration of wet-milled dehulled soybean seeds after soymilk and tofu production. *Okara* is rich in proteins and dietary fibre, and *in vitro* experiments have shown that it is a potential source of antioxidant components (Adeyanju, Emmanuel, Adetunji, & Adebo, 2024; da Silveira *et al.*, 2025).

Coconut (*Cocos nucifera*) is a tropical cash crop of the palm species, considered a crop of great economic value. Coconut flour is a fine-textured, gluten-free powder obtained as a residue from coconut milk or oil extraction (Hopkin *et al.*, 2022). The flour is gluten-free, protein-rich (14-18 g/100 g flour), high-fat (11-14 g/100 g flour), and fibre, with nearly 75% of total carbohydrates being from fiber (Hopkin *et al.*, 2022). However, coconut flour is trans-fatty acid free and contains reduced carbohydrates proportion, and as such serve as a functional food for individuals placed on carbohydrate and gluten-free diet. Utilising the potential of this agro-food by-product as a source of dietary fibre and low-carbohydrate or gluten-free, could promote the health benefits of consumers of products containing coconut flour and impart greatly on the economic status of the coconut industry (Adebowale & Ajibode, 2021; Hopkin *et al.*, 2022).

Attempts have been directed towards composite flour technologies for the development of improved and functional food products from indigenous or ancient cereal crops and legumes, and/or their by-products. Notably among the food products are porridges (Adeyanju *et al.*, 2024), bread (Adebowale & Ajibode, 2024), cracker biscuits (Ilelaboye & Jesusina, 2020a), and chin-chin (Ilelaboye & Jesusina, 2020b). Ayo *et al.* (2018) investigated the sensory quality of biscuits made from composited flours of acha and *okara*. The researchers found that the general acceptance level of biscuits was up to 15%, however, the most preferred biscuit was at 5% *okara* flour addition. Ilelaboye and Jesusina (2020a) evaluated cracker biscuit produced from *okara* fortified plantain-sorghum flour blend and found that the biscuit with 5% *okara* addition is the most preferred among other samples been tested. The researchers made an assertion that composite flours containing plantain and sorghum flours fortified with *okara* has the potential to replace wheat flour for the production of nutritious and organoleptically acceptable biscuit. Despite the extensive studies of food utilisation of acha by different researchers, information is sparse on the composited flours of acha, *okara*, and coconut residue blends for biscuit production. In order to improve the nutritional value, organoleptic qualities, and consumer acceptability, this study assesses

the feasibility of using acha, okara, and coconut residue flour blends for the production of health and nutrient-dense food ingredients, specifically in biscuits. By incorporating okara and coconut residue into acha flour, the study aims to create a more sustainable and palatable food option for consumers, particularly those with dietary challenges like gluten intolerance. The study also reveals the potential for producing nutrient-dense foods that will satisfy the constantly changing demand for healthier food alternatives and further application in the food industry.

## Materials and methods

Acha grains, soybean grains, and coconut kernels with other ingredients (like eggs, baking powder, evaporated milk, baking fat, granulated sugar, and edible salt) for the study were purchased from Iddo-Market and supermarkets in Lagos Mainland, Lagos State (6.4709 °N Longitude, 3.3831 °E Latitude).

## Preparation of acha flour

Acha grains (Cream-coloured variety) were washed with tap water to separate stone and sand, and then dried in the cabinet drier at 50 °C for 6 h. The dried Acha grains were milled into flour using the hammer mill with a 500 µm sieve size, allowed to cool, and packaged in ziplock bags and kept under 25±2 °C.

## Processing of soybeans to Okara flour

Okara flour was processed from matured soybeans using the procedure described by Soybean was soaked in water for 8 to 10 hours at ambient temperature. It was then wet-milled to obtain the slurry through the grinding process. The slurry was then wet-sieved using the muslin cloth. Soymilk was collected as creamy-liquid/filtrate and the residue represent the wet Okara. The wet Okara was dried in a cabinet dryer (50 °C, 6 h) and the dried product was milled using a laboratory mill fitted with a 500 µm sieve size. *Okara* powder was packaged in a zip lock bag and kept at -20 °C till needed for flour blends formulations.

## Preparation of coconut residue flour

Matured coconut kernels were cracked manually, and the white endocarps (meals) were scraped from the pericarp using a sharp kitchen knife. The dark-brown skin covering the meat was scraped manually, and meals were then pulverised into a smooth paste using a table top blender. With the addition of hot water (80±5 °C), the paste was mixed thoroughly and centrifuged to remove the supernatant. The supernatant, which is an oil-in-water emulsion, was scooped to reduce the crude fat content. The process was repeated thrice, and the sediment was dried in a cabinet dryer (60 ± 5 °C) for 3 h.



The dried mass was cooled to room temperature and pulverised to remove lumps. The residue was packaged in a zip lock bag and kept in the fridge (-20 °C) till needed for formulation (Adebowale & Ajibode, 2021).

### Formulation composite flours

Samples were formulated by substituting Acha flour (the base material) with *Okara* and coconut residue flours at different proportions. The 90:5:5, 80:15:5, and 70:25:5 ratios were selected for the study because these ratios received high ratings in the preliminary consumer tests for acceptance. Biscuits with larger ratios of *Okara* and more than 5% defatted-coconut residue were rated lower, owing to the strong beany and coconut flavours of *Okara* and coconut, respectively. The amount of Acha was substituted with *okara* flour from 5% to 25%, while keeping that of coconut residue at 5% for the composited samples. The 100% Acha flour was used as the control sample. The samples were homogenized thoroughly and uniformly using a Kenwood mixer at a speed of 5 for 3 min.

### Production of Biscuit Samples

A base of 100 g of flour or their blends was used to make the biscuits. According to the AACC (2000) criteria, 100 g of flour per sample was combined with 35 g of sugar, 28 g of baking oil, 30 g of egg, 0.93 g of edible salt, 1.11 g of sodium bicarbonate, and 1 g of vanilla flavour. Water was then added. The biscuits were baked at 200 °C for 15 minutes.

### Determination of Proximate Composition and Mineral Contents

The proximate contents of the biscuit samples were determined following the AACC (2000) standard. By deducting the totals of moisture, fat, ash, fibre, and protein from 100, the difference method was used to calculate the composition of carbohydrates. The previously outlined method was used to measure the mineral content (Mg, Fe, and Zn) (Hussein et al., 2023).

### Sensory Evaluation

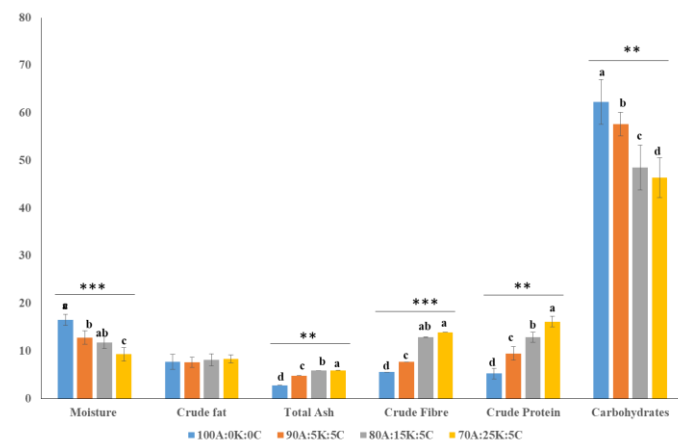
Consumer-based sensory evaluation was conducted using untrained participants who were recruited through a short advertisement on social media (Facebook and WhatsApp). The participants (judges) were staff and students within the Institution community (aged 18 and 34 years; 30 males and 27 females) and were screened for acuity and allergies. After the screening, 45 participants were used for the actual evaluation of

samples. The samples were randomized and assigned 3 random digits as a code. They were asked to evaluate the samples for colour, taste, texture, crunchiness, aroma, overall acceptability, and willingness to buy. Filtered water was provided to judges to clean their palate in-between evaluations. The evaluation was conducted in the sensory evaluation unit with individual judges in their booths to avoid communication during the exercise. Samples were rated on a 9-point hedonic scale with minimum and maximum values of 1 and 9 designated as dislike extremely and like extremely, respectively (Adebowale, Taylor, & de Kock, 2022).

### Statistical analysis

The data were analysed in triplicate using the XLSTAT program for Windows with a one-way analysis of variance (ANOVA) at a significance level of  $p < 0.05$ . To identify differences between distinct means, Tukey's HSD test was utilised. The Microsoft Excel program was used to plot bar charts. To demonstrate the connections between the various biscuit samples and the sensory characteristics, principal component analysis, or PCA, was used.

### Results



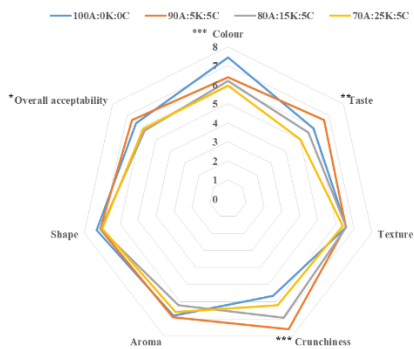
**Figure 1** Proximate composition of biscuit samples made from different formulation ratios of Acha: *okara*: coconut residue flour blends. Values for different vertical colour bars with different letters, differ significantly. \*\*\* = highly significant at  $p < 0.0001$ ; \*\* = very significant at  $p < 0.001$

**Table 1** Mineral concentration of biscuits from Acha fortified with *okara* and coconut residue

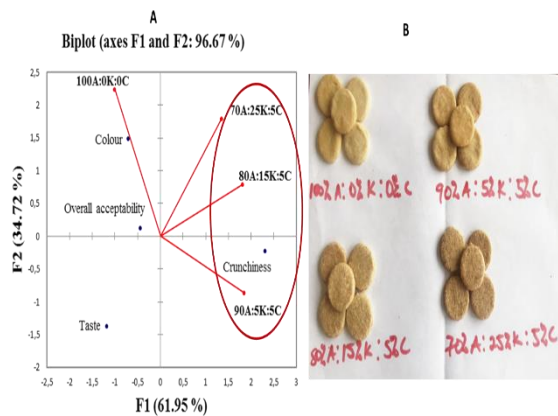
Sample	Mineral concentration (mg/kg)		
	Fe	Mg	Zn
100A:0K:0C	7.93 <sup>d</sup> ±0.02	34.22 <sup>d</sup> ±0.02	0.91 <sup>d</sup> ±0.03

90A:5K:5C	8.71 <sup>a</sup> ±0.02	36.91 <sup>b</sup> ±0.01	0.95 <sup>c</sup> ±0.02
80A:15K:5C	8.12 <sup>c</sup> ±0.03	36.11 <sup>c</sup> ±0.03	0.98 <sup>b</sup> ±0.04
70A:25K:5C	8.46 <sup>b</sup> ±0.01	38.10 <sup>a</sup> ±0.03	1.01 <sup>a</sup> ±0.04
LSD <sub>p0.05</sub>	< 0.0001	< 0.0001	< 0.0001

Values are mean ± SD of triplicate determinations. Mean values within the same column with different superscript(s) differed significantly ( $p < 0.0001$ ).



**Figure 2** Radar plot showing sensory attributes score and overall acceptability of the different biscuit samples made from different formulation ratios of Acha, *okara*, and coconut residue flour blends. \* $p < 0.05$ ; \*\* $p < 0.001$ ; \*\*\* $p < 0.0001$  (1 = dislike extremely; 9 = like extremely)



**Figure 3** A-Principal Component Analysis (PCA): The loading/correlation plot of sensory attributes of biscuits showing the significant differences. B- Image of a laboratory-scale processed composite biscuits from different ratio of Acha: *okara*: coconut residue flour formulations

### Discussions

The proximate composition of biscuit samples made from different formulation ratios of Acha: *okara*: coconut residue flour blends was presented (Figure 1). The moisture content of biscuit samples varied significantly ( $p < 0.001$ ). The moisture contents ranged

between 9.3% and 16.5%, with the control sample (100% Acha) having the highest value (16.5%), while the composited flour containing 25% *okara* and 5% coconut residue flour had the least value (9.3). The crude fat contents were not significantly different ( $p > 0.05$ ) and ranged between 7.6% and 8.1%, whereas the total ash, crude fibre, and crude protein contents of biscuits differed significantly ( $p < 0.001$ ). The values of total ash, crude fibre, and crude protein content increased with increasing substitution of Acha flour with composite *okara*-coconut residue flour. The ash content of the biscuit could be used as an index for estimating the mineral constituents of the food, which ranged between 2.7% and 5.9%. The crude fibre content of biscuits ranged between 3.1% to 5.5%, with the control (100% Acha) and the composited biscuits having the least and highest values, respectively. Recently, da Silveira *et al.* (2025) strengthened previous assertion made by Brasil (2012) that when dried *okara* is used in food formulations as functional ingredients, it could contribute to products labeled as a “source of fiber” or “high in fiber,” especially if such food product meet the recommended dietary levels of fibre respectively as 3.0 g/100 g and 6.0 g/100 g. As a result, biscuits, particularly samples made from the composites with *okara* and coconut residue flour blends, are potentially high in fibre. Foods with dietary fibre are known to promote human health because high fibre foods have the potential to regulate and control body weight increase (Hopkin *et al.*, 2022). The protein content of samples ranged from 6.1% to 5.6%. The protein content of the control was the lowest (5.2%), while the sample substituted with 25% *okara* had the highest protein content (16.1%). The carbohydrate content of samples ranged between 46.4% and 62.3%. The carbohydrate contents of samples were significantly ( $p < 0.001$ ) different, and decreased with increasing addition of *okara* and coconut residue flours. Low in carbohydrate content is obtained in the composite biscuits, especially at higher amounts of *okara* addition. This suggests that the biscuit could be an ideal food needed by individuals placed on carbohydrate- and gluten-free foods. This finding agrees with the previous report documented by Hopkin *et al.* (2022) that a low-carbohydrate or ketogenic dietary lifestyle is a better approach for individuals who were following carbohydrate- and gluten-free diets.

**Table 1** shows the mineral concentration of the biscuit made from Acha-*okara* and coconut residue. The iron, magnesium and zinc contents of biscuits ranged between 7.93 mg/kg and 8.46 mg/kg, 34.22 mg/kg and 38.10 mg/kg, and 0.91 mg/kg and 1.01 mg/kg, respectively. The mineral concentration of biscuits increased with increasing addition of *okara*-coconut residue composite flours,



suggesting that the increment may be due addition of *okara* and coconut residue flours. It can be suggested that *okara* and coconut residue flours contributed additional mineral contents to boost the residual mineral levels in acha biscuits. Iron is a major component of haemoglobin that carries oxygen to all parts of the body. This indicates that *okara* and coconut residue flours are potential sources of iron, magnesium and zinc. This findings further suggest that the addition of *okara* flour and coconut residue into Acha flour for biscuit production, could to improve the challenges of hidden hunger in the vulnerable region of sub-Saharan Africa, to promote healthy living especially the children. However, the value of iron recorded in this study is lower than the recommended daily allowance (RDA) of 10 mg/day reported elsewhere (Arinathan, Mohan, & De Britto, 2003).

**Figure 2** presents the mean scores of the sensory attributes and overall acceptability of biscuits made from different formulation ratios of Acha: *okara*: coconut residue flour blends. The sensory attributes, notably crunchiness, colour, and taste of biscuits, differ significantly at  $p < 0.0001$ ,  $p < 0.0001$ , and  $p < 0.001$ , respectively, unlike shape, texture, and aroma that were remained insignificant ( $p > 0.05$ ) among the samples. Colour, texture or crunchiness, and taste are very important as far as the acceptability of biscuits is concerned. Colour of the control was the most preferred, while that of the sample substituted with 25% *okara* and 5% coconut residue flour was the least preferred. This is because of the loss the colour of acha flour or it may be attributed to the darker colour of *okara* and coconut residue flours. However, the sample formulated with 5% *okara* and 5% coconut residue flour blended with acha flour was rated highest in terms of crunchiness, taste, aroma, and texture among the samples. The sample with 5% *okara* inclusion is thus the most preferred by the panelist with the highest overall acceptability score of 6.9 on a 9-point hedonic scale, representing nearly 77% acceptance level. The means score of crunchiness (7.2) for the composite biscuit sample (75A:25K: 5C) significantly decreased at a level above 5% with *okara* addition into acha flour with coconut residue kept at 5%. This shows that at levels of above 5%, consumer preference for the crunchiness of biscuits declined instantly. It may be inferred that the biscuits become non-crunchy when the levels of *okara* addition increase from 5% to 25%. Crunchiness is an important sensory attribute in biscuits that is often referred to as the combination of the texture and sensation of biting into a biscuit that has a satisfying snap or crunch perception. It is a very good indicator of freshness in biscuits. Biscuits that have low moisture contents are perceived to be crunchier and could provide a pleasing texture contrast to soft foods.

**Figure 3** presents the principal component analysis (PCA) and images of biscuits made from different ratios of Acha, *okara*, and coconut residue formulations. The PCA explains the variance within a sensory evaluation dataset, identifying patterns and correlations between the sensory attributes and different biscuit formulations. This is basically by identifying the structure of sensory attributes and their relationship with the samples, compressing the sensory data into a lower-dimensional representation, and making it easier to visualize and interpret. The first two principal components explained nearly 97% of the total variation (Figure 3), showing the first two principal component scores of biscuits made from acha, *okara*, and coconut residue. PC1 explained nearly 62% of the total variation and separated the biscuits based on their ingredient components, with the control (100A:0K: 0C) to the left and those biscuits containing *okara*-coconut residue to the right. PC2 accounted for nearly 35% of the total variation and separated the sample with a high amount (15% and 20%) of *okara* biscuits at the top and that with a lower (5%) amount of *okara* biscuits at the bottom. Those biscuit samples with *okara* and coconut residue flours appeared to be crunchier than the control, especially the sample made from 5% *okara* and 5% coconut residue into acha flour, which had the highest value of crunchiness. However, colour of the control appeared more significant than that of the composited *okara*-coconut residue flours. The plot showed that the control is the most preferred among biscuit samples; however, the sample made from 5% *okara* appeared to be crunchier than the control and other samples. One of the desirable attributes of biscuits that is greatly appreciated by consumers is their crispness, aside from the colour, taste, and texture. In this study, the crispness of biscuits increased with the addition smaller amount (5%) of *okara* flour in the formulation. Therefore, the sample that is crunchier, having the highest value of crunchiness, may attract better patronage than the soft or less crunchy biscuit. Loss of crunchiness in biscuits may lead to product failure or outright rejection by consumers.

### Conclusion and Future Works

Utilisation of *okara* and coconut residue to fortify acha flour for sustainable biscuit production is important and achievable with higher consumer acceptance. Incorporation of *okara* and coconut residue into acha flours in the production of biscuits significantly improved protein, crude fiber, and mineral composition of composite biscuits. The drastic reduction in carbohydrate contents of biscuits with *okara*-coconut residue flour suggests that it could be a potential functional product for individuals who



follow carbohydrate- and gluten-free foods. The colour, taste, and crunchiness of biscuits show significant improvement. *Okara*-coconut residue biscuits show a similar pattern in relationship with the sensory attributes, which are completely different from the control with subjected to considering the most important features contributing to the data variation (Figure 3). Though the composited biscuits made from *okara* and coconut residue flour blends have more nutritional value, the control (100% *acha*) has the highest overall acceptability score (8.1) followed by the 90A:5K:5C (7.9), on a 9-point hedonic scale. However, both the control and 90A:5K: 5C biscuits did not have a significant difference in terms of

consumer preference. This research offers an innovative solution to Nigeria's food security, nutrition, and agro-food by-product management challenges. By utilising *okara* and coconut residue for biscuit production, stakeholders in the food chain can promote sustainable food systems, economic empowerment, enhance consumer acceptance, and consequently improve public health. Further studies should be carried out on the effect of various pre-treatment methods on the nutrient and non-composition of *okara* and *coconut residue* for improved utilization.

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