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Quality attributes of cassava-fish crackers enriched with different flours: An optimization study by a simplex centroid mixture design

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Abstract

A simplex centroid mixture design (SCMD) was used to optimize ingredient combination comprising cassava starch (CS), high quality cassava flour (HQCF) and fish flour (FF) in the production of cassava-fish crackers. The standard slurry method was used and the effect of ingredient combination on some quality attributes of the crackers fried at 180 °C ± 5 °C for 15 s was investigated. Ingredient combination has a significant positive effect on oil and moisture contents, texture but expanded less. Increase in CS and FF resulted in decrease oil uptake while it increases with HQCF. Lightness decreased with increase in FF while redness and yellowness increases. Regression analyses indicated that the quadratic, cubic as well as special cubic nonlinear terms were significant ($p < 0.05$) in many of the models derived. Optimum ingredient mixture resulting in lower oil content and breaking force with maximum expansion and desirable physico-chemical properties was 85% CS, 10%HQCF and 5% FF.

Practical applications

This work provides valuable information on deep fat frying of cassava-fish crackers using different levels of CS, HQCF and FF which are appreciated in many countries due to its pleasant sensory characteristics. The technique used is cost effective and produces fried cassava-fish crackers of relatively good quality. This study could be used by small and medium scale food processors that are interested in producing cassava-fish crackers of good quality due to availability of relatively cheap ingredients. The understanding of the influence of ingredient combinations on quality parameters is useful for deciding the appropriate level of each for an acceptable product. Predictive models generated can also be a viable tool for predicting product attributes as a function of the independent variables as well as designing of the frying process.

KEYWORDS

Cassava-fish crackers, expansion, oil content, optimization, quality, texture

1 | INTRODUCTION

Snack foods and especially fried snacks, are a popular form of refreshment among consumers (Hein et al., 1998), and they provide convenience and manageable portion while also fulfilling short term hunger (Tettweiler, 1991). There is a huge sale of snack foods approximating to $30–50 billion annually in the world as it is considered to be part of a human diet and their consumption has been continuously increasing in many countries (Kayacier et al., 2014). Generally, street foods whether of plant or animal origin are very popular in Nigeria as in many developing countries (Sobukola et al., 2008). This is as a result of their significant role in the enhancement of the nutritional status of the people, where the average nutrient intake is less than desired (Ihekoronye and Ngoddy, 1985). While street foods are appreciated for their unique flavor as well as their convenience, they are also often essential for maintaining the nutritional status of the population. Vending of these street foods assures food security for low-income urban populations and provides a livelihood for a large number of workers who would otherwise be unable to establish a business for want of capital. It also offers business opportunities for developing countries entrepreneurs (WHO, 1996).

Development of an entirely new snacks or replacement of some common ingredients with new substitutes in others is important for the snack industry in order to ensure consumers satisfaction. Cassava cracker, an important snack that originates from Asia, is gaining popularity across the world especially in developing countries like Nigeria as a snack that is highly desirable due to its unique characteristics such as texture, flavour and the melting feel in the mouth.

The major component of cassava cracker is cassava starch which has many remarkable characteristics such as high paste viscosity, high paste clarity, a neutral bland taste and desirable textural characteristics. These surpasses properties offered by other starches (corn, wheat, sweet potato, and rice) thus making it useful for such an expanded product. However, in some cases another starch or other ingredients can be substituted in order to complement each other (Tongdang et al., 2008). High Quality Cassava Flour (HQCF), is an unfermented food grade flour that can be used as a substitute for many flours in the bakery and confectionary world as well as in the production of snacks (Falade and Akingbala, 2010). Because of its varied functionality, its use in food, feed and chemical industries will be on the increase (Balagopalan et al., 1988) coupled with its ease of production from readily available, high yielding, nontoxic, and nutritionally superior cassava varieties.

Hunger and malnutrition remains a serious problem in many parts of the world, however many countries have made great strides to improve their food and nutrition situation (FAO, 2007). To improve dietary quality in the face of the current worldwide epidemics of obesity and chronic noncommunicable diseases, there is need to increase the consumption of fish in different forms. Fish is an important source of high quality and highly digestible protein and a respectable source of essential minerals (Nettleton, 1992). *Ethmalosa Frimbriata* (Bonga fish) is high in protein (53.84%) and essential minerals such as phosphorus (0.48–1.83%), calcium (0.26–3.02%), magnesium (0.09–0.18%), and iron (194.86–246.82 mg kg^{-1}) (Dègnon et al., 2013). Bonga fish is also highly desirable because of its flavor which imparts positively in food products. Incorporating this type of fish in a commonly consumed snack such as crackers can be a vehicle of combating some notable diseases.

Many snack products are usually fried in oil which imparts flavour and at the same time higher oil content which is not desirable by well-informed consumers. Hence, consumer's preference for healthy snacks and their desire for more acceptable products have increased their consciousness and concern about their health. These increased demands for healthy and nutritious snacks require changes in processing parameters, composition as well as nature of food materials to be used. Sobukola et al. (2013) reported that these changes can modify the oil content, textural, and colour parameters as well as other properties of the fried product. The final quality of an expanded snack such as crackers depends on many factors such as quality of raw materials, formulations, process conditions, ratio and type of flour mixtures. There have been a few numbers of publications reporting on the properties of cassava starch mixtures with other flours but very scarce report on cassava-fish crackers from cassava starch, HQCF and fish flour. Therefore, the objective of this study was to evaluate the quality attributes of cassava-fish crackers enriched with different flours based on a simplex centroid mixture design.

TABLE 1 Composition of different formulations based on experimental design

Experimental run	Sample code	X_1	X_2	X_3
1	$C_{85}H_5F_{10}$	0.85	0.05	0.10
2	$C_{85}H_{10}F_5$	0.85	0.10	0.05
3	$C_{85}H_{15}F_0$	0.85	0.15	0.00
4	$C_{85}H_0F_{15}$	0.85	0.00	0.15
5	$C_{90}H_5F_5$	0.90	0.05	0.05
6	$C_{90}H_{10}F_0$	0.90	0.10	0.00
7	$C_{90}H_0F_{10}$	0.90	0.00	0.10
8	$C_{95}H_5F_0$	0.95	0.05	0.00
9	$C_{95}H_0F_5$	0.95	0.00	0.05
10	$C_{100}H_0F_0$	1.00	0.00	0.00
11	$C_{85}H_{10}F_5$	0.85	0.10	0.05
12	$C_{85}H_5F_{10}$	0.85	0.05	0.10
13	$C_{85}H_0F_{15}$	0.85	0.00	0.15
14	$C_{90}H_{10}F_0$	0.90	0.10	0.00

where $X_1 + X_2 + X_3 = 1$ or 100%, $X_1 =$ cassava starch (C), $X_2 =$ high quality cassava flour (H), $X_3 =$ fish flour (F).

2 | MATERIALS AND METHODS

2.1 | Materials

Native Cassava Starch (CS) from Matna Foods, Nigeria Ltd and High Quality Cassava Flour (HQCF) from Thai farms, Nigeria were procured from the manufacturers while dried Fish (*Ethmalosa frimbriata*) were procured from local market in Abeokuta, Ogun state, Nigeria. Materials were stored in plastic containers prior to analysis and use in the laboratory. Proximate composition of the materials was determined using standard analytical techniques. Distilled water were used in preparing the semi half-finished crackers while refined bleached deodorized vegetable oil was used as the frying medium.

2.2 | Sample preparation

The modified method of Lakleang (1991) as shown in Figure 1 was used. Known amount of water was added to the dry ingredient combination (Table 1) based on the water content of the ingredients and was adjusted in order to ensure that all samples contains the same moisture content (90.99%). Accurately weighed dry ingredients were first mixed for about 2 min using a mixer (SAISHO hand mixer S-1496 HM, Hong Kong) at medium speed. Warm water was then added and mixed for additional 5 min to obtain the slurry. The slurry in a stainless steel bowl was placed in a water bath and stirred continuously for 2-3 min at 80 °C ± 2 °C. The partially gelatinized slurry was taken out of the water bath and dropped with a teaspoon on a tray at room temperature (30 °C ± 2 °C) before drying in a cabinet dryer (Genlab drying cabinet, DC500, Widens Cheshire, UK) at 50–55 °C for ~12 h and packaged in polyethylene bags for further processing. Semi-finished cassava-fish crackers were then deep fried in oil at 180 °C ± 5 °C for 15 s prior to analyses.

2.3 | Sample analyses

2.3.1 | Moisture and oil contents

Standard analytical procedures based on AOAC (2000) was used to determine moisture and oil content of the fried crackers and means values were reported on dry basis.

2.3.2 | Texture (breaking force determination)

The texture of the fried crackers was analyzed using the procedure described by Da Silva and Moreira (2008), which consists of a three-point bending test. The sample was placed on a rig in order to apply the load centrally. The system was mounted on a universal texture analyzer (Perten Instrument TVT-300XPH, Sweden) using a support span of 16 mm. A probe of 2.5-mm-thick steel blade with round edge was used to fracture the sample. The force (*N*) at the fracture point highest value in the plot was recorded as the breaking force. The samples were equilibrated to 28 °C ± 2 °C for texture studies.

2.3.3 | Linear expansion

Linear expansion was obtained by measuring the length of four lines drawn on 10 unpuffed samples using fine permanent marker with a thermally stable ink. The percentage linear expansion was calculated according to *Equation* 1 (Yu, 1991):

TABLE 2 Proximate composition of raw materials for the production cassava-fish crackers

Composition	Cassava starch	HQCF	Fish flour
Moisture (%)	10.50 ± 0.11	8.01 ± 0.01	3.69 ± 0.01[a]
Protein (%)	0.22 ± 0.01	0.23 ± 0.01	85.22 ± 0.01
Fat (%)	0.63 ± 0.01	0.30 ± 0.01	4.19 ± 0.01
Ash (%)	0.05 ± 0.01	0.72 ± 0.01	6.78 ± 0.01
Crude fiber (%)	0.46 ± 0.01	1.80 ± 0.01	0.00 ± 0.00
Carbohydrate (%)	88.14 ± 0.00	88.94 ± 0.01	0.12 ± 0.01

[a]Values are mean of triplicates ± standard deviation. Where HQCF is high quality cassava flour.

$$\text{Percentage linear expansion} = \text{Final length after frying} - \text{initial length before frying} \times 100 \quad (1)$$

(Initial length before frying)

2.4 | Determination of color parameters

2.4.1 | Image capture

The method of Mariscal and Bouchon (2008) was adopted using a colored digital camera (model Nikon COOLPIX L21, Japan). The digital camera was placed on a stand inside a box resistant to light with internal black surfaces. Four fluorescent lamps to illuminate the interior area of the box were placed inside the box above the sample at 45 ° to increase diffuse reflection responsible for color. The camera was placed at angle of 90 ° to reduce gloss. While a white standard photographic surface was used standardize the illumination level before capturing the sample images. The resolution used was 1600 × 1200 pixels stored in JPEG (Joint Photographic Experts Group) format.

TABLE 3 Mean values of some quality attributes of fried cassava-fish crackers

Sample code	Oil content (%)	Expansion (%)	Breaking force (N)	Moisture content (%)	*L**	*a** (−)	*b**	Δ*E*
$C_{85}H_5F_{10}$	17.36	8.96	12.54	5.76	65.17	1.35	0.99	26.45
$C_{85}H_{10}F_5$	30.82	42.87	36.16	6.00	66.89	1.77	−8.18	28.45
$C_{85}H_{15}F_0$	18.57	19.67	72.84	7.42	62.17	6.61	13.24	18.34
$C_{85}H_0F_{15}$	19.73	−4.53	33.41	7.17	65.74	1.80	3.63	31.25
$C_{90}H_5F_5$	20.44	16.67	25.70	6.82	55.51	1.83	−0.91	29.31
$C_{90}H_{10}F_0$	22.35	37.17	28.65	7.14	71.77	4.84	10.32	25.56
$C_{90}H_0F_{10}$	16.50	18.17	26.53	5.89	59.58	1.80	3.16	19.76
$C_{95}H_5F_0$	19.96	24.90	23.67	6.98	57.40	1.65	−5.93	27.39
$C_{95}H_0F_5$	19.88	45.93	17.94	5.65	70.01	5.47	12.12	18.66
$C_{100}H_0F_0$	13.37	14.87	22.00	7.46	63.24	7.63	16.26	17.17
$C_{85}H_{10}F_5$	23.08	42.87	36.16	4.64	69.20	1.42	−6.68	27.23
$C_{85}H_5F_{10}$	20.80	8.96	12.54	5.76	67.54	1.22	0.35	27.26
$C_{85}H_0F_{15}$	14.52	−4.53	33.41	8.96	56.34	1.53	2.53	22.51
$C_{90}H_{10}F_0$	24.73	37.17	28.65	6.32	65.46	5.86	10.24	25.55

Values are means of triplicate determination ± standard deviation. All values of *a** are negatives. *C* = Cassava starch, *H* = high quality cassava flour, *F* = fish flour. *L** = lightness, *a** = redness, *b** = yellowness, Δ*E* = colour change.

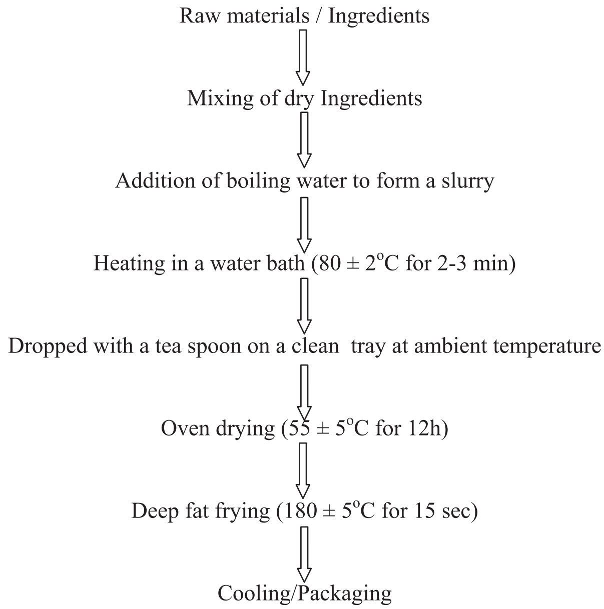

FIGURE 1 Production process for cassava crackers (modified Iakleang, 1991)

2.4.2 | Color measurement

L, *a*, *b* coordinates were obtained by the use of Adobe photoshop CS6 software (Adobe Systems, CA) which were then used to generate L^* (Lightness), a^* (Redness), and b^* (Yellowness) according to Yam and Papadakis (2004) as shown below:

$$L^* = \frac{L}{255} \times 100 \tag{2}$$

$$a^* = a \times \frac{240}{255} - 120 \tag{3}$$

$$b^* = b \times \frac{240}{255} - 120 \tag{4}$$

Change in color between the raw (L_o*, a_o*, and b_o*) and fried crackers (L^*, a^*, and b^*) were determined by taking Euclidean distance between the products using the equation:

$$\Delta E^* = \sqrt{[(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2]^2} \tag{5}$$

2.5 | Scanning electron micrograph (SEM)

The fried samples (optimized Cassava-fish crackers and a commercial sample) were appropriately defatted by submerging them in petroleum ether for 4 h after frying. Thereafter, the samples were coated with a thin gold layer (20 nm) using a Varian Vacuum Evaporator PS 10E (Evey Engineering's Warehouse, Hoboken, NJ) and analyzed using a variable pressure scanning electron microscope LEO 1420VP (LEO Electron Microscopy, Cambridge, UK) at an acceleration potential of 25 kV. An Oxford 7424 solid-state detector (Oxford Instruments, Oxford, UK) was used to obtain the electron microphotographs at 500× magnifications (Sobukola et al., 2013).

2.6 | Comparison of optimized cassava-fish crackers and commercial fried crackers

Optimized and reference (commercial type) fried crackers were compared in terms of quality attributes using instrumental analysis.

2.7 | Sensory evaluation

A simple paired comparison preference test was also conducted using 30 panelist to rate the optimized and commercial fried crackers in terms of taste, aroma, oiliness, color, texture, and overall appearance.

2.8 | Experimental design and ingredient optimization

Simplex-centroid mixture design (SCMD) for three-component mixtures expanded with internal points with constraints of Design Expert version 6.0.8 (Stat Ease, Minneapolis, MN) was used to investigate the effect of CS substitution with HQCF and FP on some quality attributes of fried crackers from its mixtures. Fourteen experimental runs (Table 1)

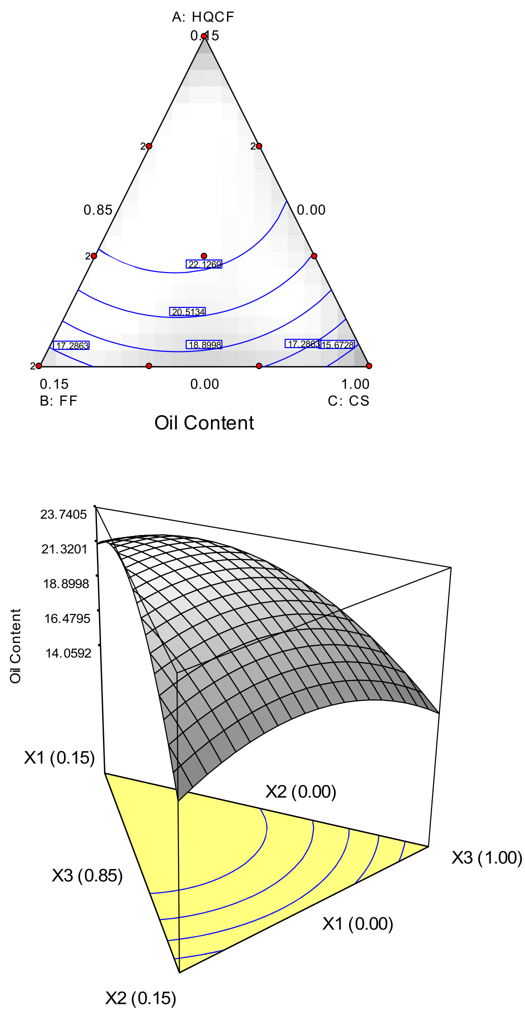

FIGURE 2 Surface (3D) and contour plots of oil content (DB) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

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TABLE 4 Regression models for quality properties of cassava-fish crackers

Responses		OC[a] (%)	EX[b] (%)	BF[c] (N)	MC[b] (%)	(L*)[c]	(a*)[c]	(b*)[c]	(ΔE)[c]
Independent variables	HQCF (X_1)	18.57	28.54	71.93	7.24	62.17	−6.61	13.24	17.43
	FF (X_2)	17.13	−9.66	31.45	7.27	61.04	−1.66	3.08	14.86
	CS (X_3)	13.37	16.25	22.40	7.45	63.24	−7.63	16.26	16.36
Nonlinear blending terms	H/F(X_1/X_2)	23.25	74.13	−118*	−7.70*	25.18	12.14*	−51.94*	−11.40
	X_1/X_3	26.01	44.99	−96.*	−2.33	1.37	16.29*	−56.59*	5.14
	X_1/X_3	13.24	129.4	−11.1	−7.15	11.95	4.56	−9.15*	−3.67
	$X_1X_2X_3$	−77.2	−612		38.11*	−295	−5.22	84.33*	−21.12
	X_1-X_2	49.87				8.86	9.03	−77.52*	−21.93
	X_1-X_3	12.46				78.14	−27.27	116.21*	92.91*
	X_2-X_3	−31.3				−65.5	11.35	−30.84*	−45.80
R^2		0.79	0.78	0.88	0.83	0.80	0.99	0.99	0.86

*Significance at a $p < 0.05$.
[a]Fitted by quadratic model.
[b]Fitted by special cubic model.
[c]Fitted by cubic model.
Where OC, EX, BF, MC, L*, a*, b*, and ΔE are oil content, expansion, breaking force, moisture content, lightness, redness, yellowness, and change in colour, respectively.

showing different levels of ingredient combinations were generated with X_1, X_2, and X_3 ranging from 85–100, 0–15, to 0–15%, respectively based on series of preliminary experiments. The responses were oil content, moisture content, texture, expansion, lightness, redness, yellowness, and change in color). Models were fitted to the data as necessary to obtain the regression equations. The statistical significance of the terms in the regression equations was examined by analysis of variance (ANOVA) for each response. The fried crackers quality parameters were optimized using numerical method of SCMD based on desirability concept to obtain fried crackers of acceptable qualities. The independent variables were kept within the experimental range while the responses were either minimized (oil, moisture, texture, redness, yellowness, and change in color) or maximized (expansion and lightness). The predictive models obtained were then used to generate the response surface and contour plots.

3 | RESULTS AND DISCUSSION

3.1 | Proximate composition of raw materials and model description

Table 2 shows the proximate composition of the materials used in producing the cassava-fish crackers. From the table, moisture, protein, fat and ash contents varied between 3.69–10.5%, 0.22–85.22%, 0.3–4.19%, and 0.05–6.78%, respectively. The carbohydrate and crude fiber contents however ranged between 0.12–88.94% and 0.46–1.80%, respectively. From the result, fish four had the highest level of protein while HQCF had the highest carbohydrate content.

Table 3 shows the mean values of the quality attributes of fried Cassava-fish crackers while table 3 presents the estimated regression models and ANOVA of the terms describing the effect of CS substitution with HQCF and FF. The coefficients of determinations (R^2) of

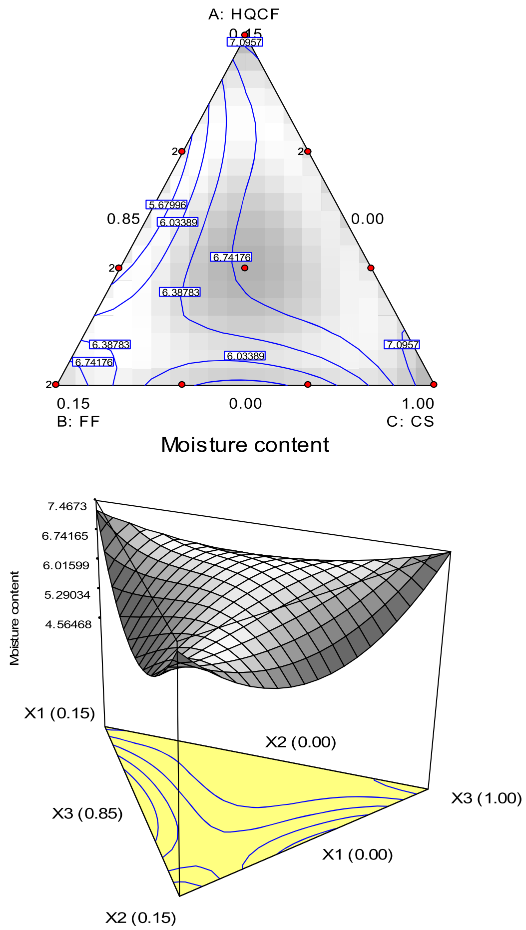

FIGURE 3 surface (3D) and contour plots of moisture content (DB) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively.

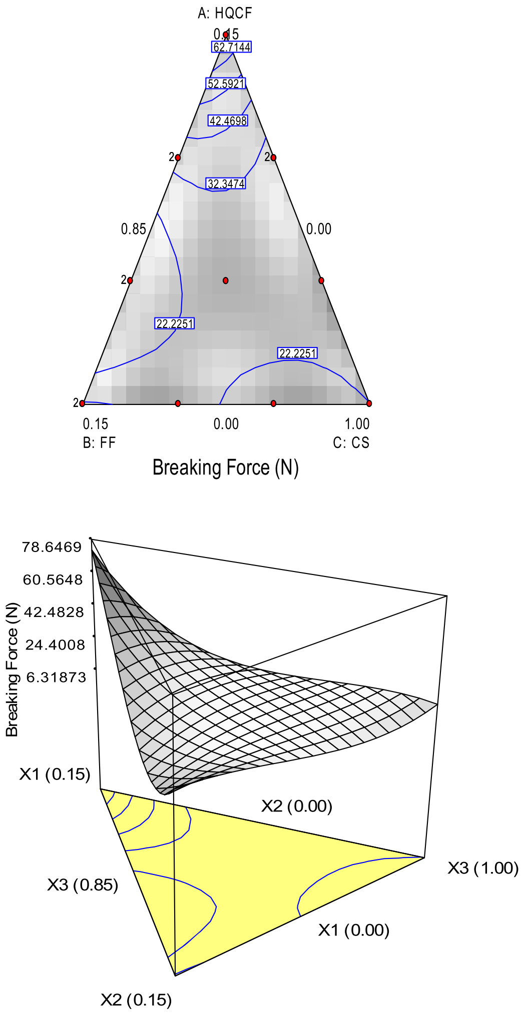

FIGURE 4 Surface (3D) and contour plots of breaking force (N) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

regression models varied between 0.78 and 0.99. Some of the developed models are capable of being used to navigate the design space and can be used as predictive models. Howbeit, the models presented a nonsignificant lack of fit and hence are good indicator of the responses and can be used for prediction (Myers et al., 2009). Significant differences were observed between the breaking force and moisture content of non linear blending terms of HQCF and FF, HQCF, and CS, and HQCF and FF; as well as FF and CS and HQCF, FF, and CS, respectively. The regression analyses indicated that the quadratic, cubic as well as special cubic nonlinear terms were significant ($p < 0.05$) in many of the regression models derived. In these models, positive values of partial regression coefficients for the non-linear terms indicate a constituent synergistic effect in the binary or ternary blends, while negative values suggest antagonistic effects (Fustier et al., 2008).

3.2 | Oil content

Oil content during frying is one of the most important quality attributes of fried foods. Numerous studies have reported that excessive consumption of fat is a key dietary contributor to coronary heart disease, and other related ailments (Browner et al., 1991). Moriera *et al.* (1997) reported that during frying, tortilla chips absorbed only 20% of the oil and 80% stayed on the chip's surface. They also observed that during cooling the chips absorbed 64% of the total oil content, and the rest of it remained on the chip's surface. As food product fries, the internal cells become dehydrated and the evaporated water is partially replaced by frying oil (Bouchon et al., 2003). Oil content of fried crackers varied between 13.37% and 30.82% (db) (standard deviation (SD) was between 0.02 and 0.85), not shown as presented in Table 3. The effect of the ingredient combination on oil content of the fried crackers is shown in Figure 2. From the figure, an increase in HQCF level resulted in increased oil content while it decreased as cassava starch and fish flour increased. This increase in oil content as HQCF increased is due to disruption in the formation of a continuous network of structure that can serves as a barrier to oil uptake. Reduction in oil content as

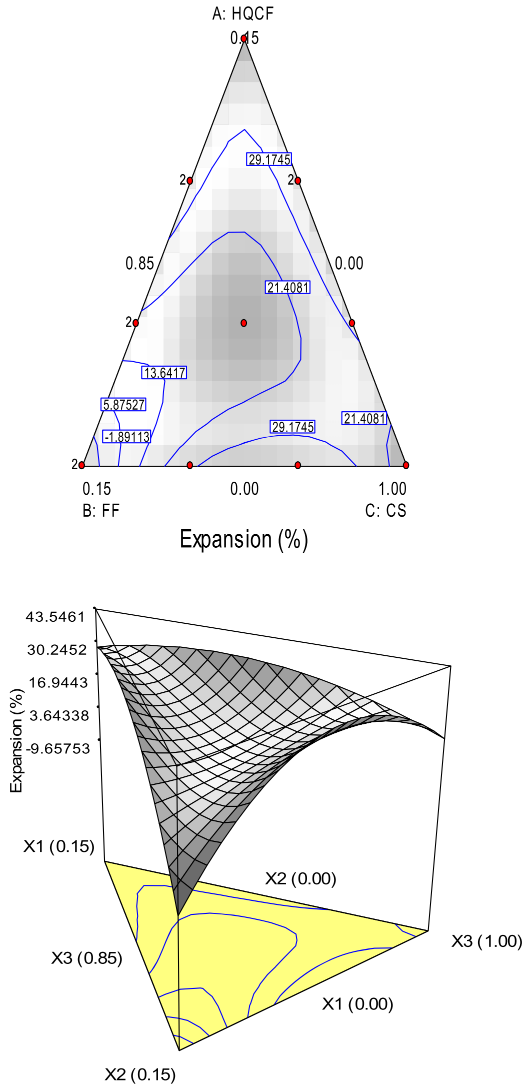

FIGURE 5 Surface (3D) and contour plots of expansion (%) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), AND CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

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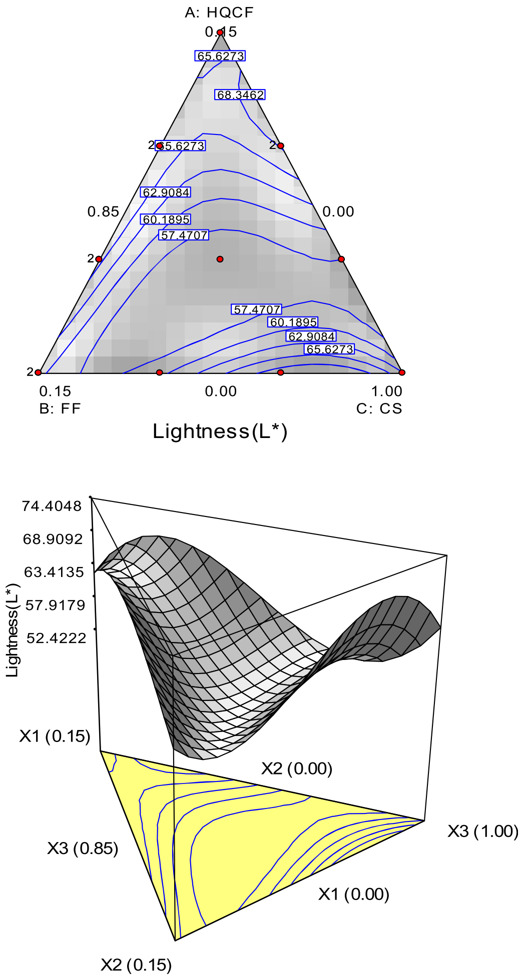


FIGURE 6 Surface (3D) and contour plots of lightness (L^*) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

fish powder increases might be due to structural changes that occurred in the product during frying. Similar result has earlier being reported by Maneerote et al. (2009). They reported that oil content of deep fat fried rice crackers reduced with increase in fish powder content. It was further reported that deep fried rice crackers mixed with fish powder of 5, 10, and 15 g/100 g reduced the oil content by ~10, 14, and 22 g/100 g (db), respectively, in comparison to crackers without fish powder. The decrease in oil content as cassava starch content increased can be attributed to the gelatinization of surface starch molecules during frying which forms a complex network that serves as barrier to oil uptake during frying and subsequent cooling. Sobukola et al. (2013) reported that during frying process, any change in the nature, process parameters of the product such as product composition and frying parameters will modify the oil content, texture and other quality properties of such product.

3.3 | Moisture content

Moisture content of fried samples is very important because it can determine the textural properties and microbial stability of the product to a larger extent (Sobukola and Bouchon, 2014). It is dependent on the initial moisture content, frying temperature, cracker composition amongst others. Table 3 also shows that the moisture content of the fried crackers varied between 4.64 and 8.96% (db) (SD was between 0.04 and 0.15) within the experimental mixtures while the coefficient of regression (R^2) is 0.83 (Table 4) and fitted by special cubic model. The 3D surface plot for moisture content using different combinations of the ingredient is presented in Figure 3. The highest moisture content was obtained for sample $C_{85}H_0F_{15}$ while the lowest was observed in sample $C_{85}H_{10}F_5$. It was observed that as fish flour reduced, moisture content decreased while it increased as HQCF and cassava starch increased. Nair et al. (1996) observed that maximum linear expansion was obtained from dried crackers which had 15% moisture content. On the other hand, for expansion due to vapour formation and for softness and deformity of solid phase, it is necessary to have some minimum level of moisture in the intermediate product. During frying, food materials are heated through the oil which serves as the heating medium, and the free water evaporates on getting to its boiling point. It has been reported that the boiling point of free water in food

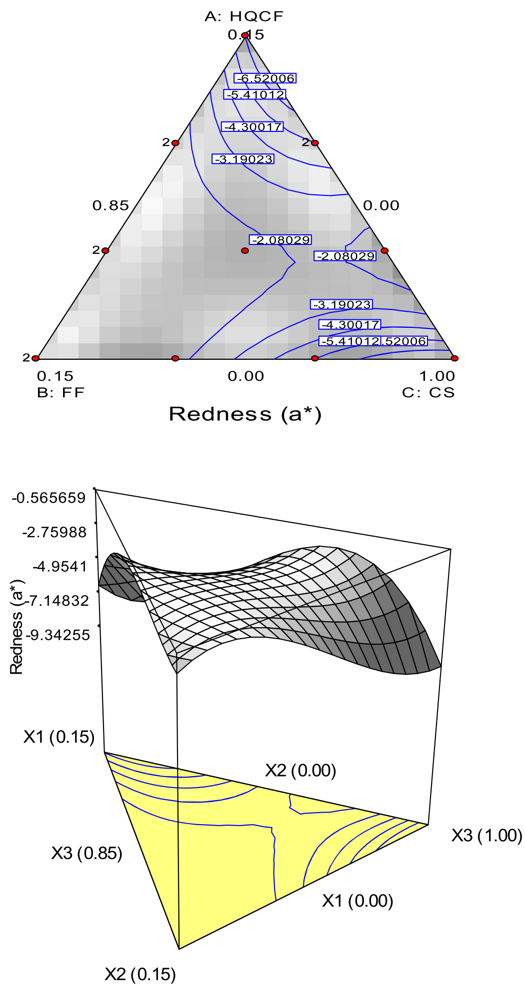


FIGURE 7 Surface (3D) and contour plots of redness (A^*) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

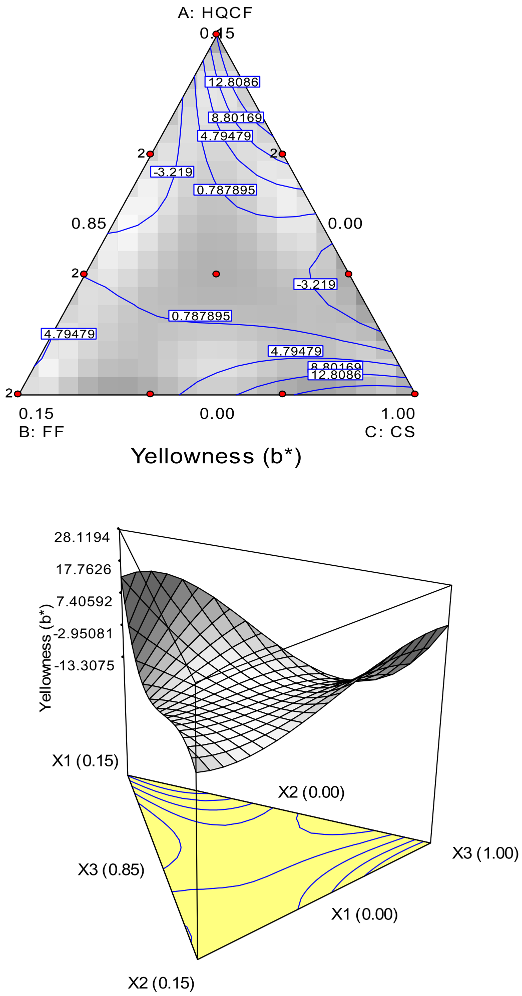


FIGURE 8 Surface (3D) and contour plots of yellowness (B*) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

material is higher than that of pure water because of dissolve solute in the food materials (Shyu et al., 2005). High moisture content of fried food reduces it textural properties, which leads to poor acceptability of a snack food like crackers. However, a little amount of moisture content is necessary in some fried food product such as French fries, this increases it juiciness and makes it more palatable and acceptable. Fried foods with higher moisture content tend to have higher rate of rancidity during storage, which is an oxidation reaction of oil. The moisture serves as a source of oxygen which is needed for the reaction to take place. Therefore an appreciable amount of moisture is needed in a snack like cracker to aid expansion.

3.4 | Texture

Texture of food is related directly to physical and chemical properties, perceived by eye prior to the consumption. Crispness and crunchiness are sensory attributes used to describe the texture perception of many types of foods. For fried food products, crispy and crunchy nature are texture character which is an important sensory characteristic on which consumer base their appreciation (Luyten et al., 2004). Breaking force which is the minimum force required to crush a product is normally used to describe the hardness of a product.

In this study, the breaking force is presented in Table 3 and it varied between 12.54 and 72.84 N (SD was between 0.05 and 8.34) within the experimental runs. From Table 4, the main effect of ingredient substitution (HQCF and FF, HQCF, and CS) have significant ($p < 0.05$) effect on texture while the coefficients of determination ($R^2 - 0.88$) fitted with cubic model. The 3D surface plot for texture at different flour blends are presented in Figure 4 and reduced with increase in fish flour which has a higher protein content (88.94%) as shown in Table 2. This can be due to protein denaturation which results in loss of water-holding capacity or coagulation, hydrolysis and solubilization of proteins. Breaking force increase as HQCF level increases due to gelatinization of the starch which affected the hardness of the crackers. During frying, starch gelatinizes and water

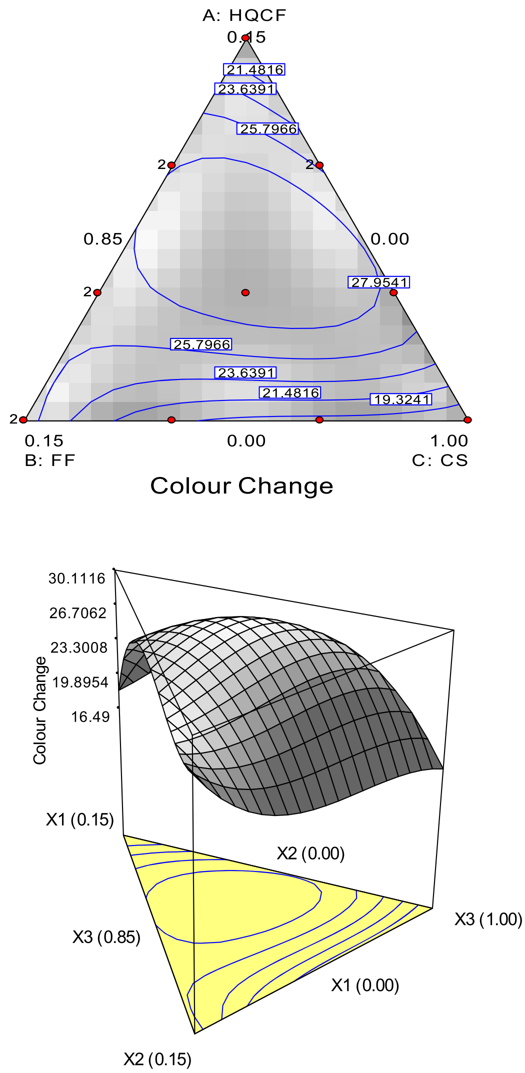


FIGURE 9 Surface (3D) and contour plots of colour change (ΔE) of fried cassava-fish crackers from the flour blends of HQCF (X_1), FF (X_2), and CS (X_3). Where HQCF, FF, and CS are high quality cassava flour, fish flour, and cassava starch, respectively

TABLE 5 Mean and standard deviation of instrumental analysis of optimized and control samples

Quality attributes	Optimized sample	Control sample
Oil content (%)	30.72 ± 0.10[a]	36.32 ± 0.16[b]
Expansion (%)	61.35 ± 6.09[a]	77.46 ± 3.10[b]
Moisture content (%)	1.87 ± 0.01[a]	2.26 ± 0.06[b]
Breaking force (*N*)	57.50 ± 0.25[a]	93.00 ± 0.20[b]
Lightness (L^*)	89.85 ± 1.57[a]	99.38 ± 3.83[b]
Redness (a^*)	3.98 ± 1.57[b]	1.24 ± 1.41[a]
Yellowness (b^*)	15.41 ± 0.18[a]	10.02 ± 4.73[a]

Values are means of duplicate ± standard deviation.

Commercial cracker sample **Optimized cassava-fish cracker**

FIGURE 10 Digital picture of fried commecial cracker and optimized cassava-fish cracker

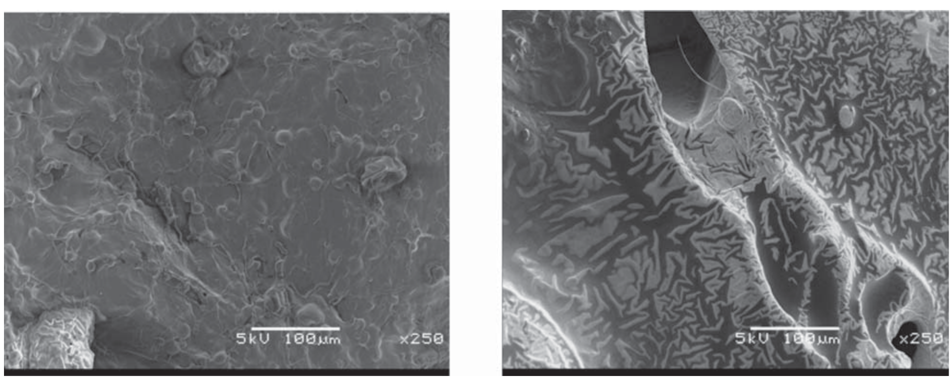
evaporates which causes' structural changes (micro and macro) in fried foods thus affecting the texture (Velez-Ruiz et al., 2002). Andersson et al. (1994) reported that in food products high in starch content, the major influence on texture is the gelatinization of starch during heating by frying. Findings have shown that frying parameters (frying time and temperature) have significant effect on the texture of fried foods. This is because the frying temperature and frying time affects the rate of moisture loss and starch gelatinization which affects the texture of the product. In this study however, constant frying parameters were used.

3.5 | Expansion

Expansion is an increase in the length and size or increase in dimensions. As shown in Table 2, it varied from −4.53 and 45.93% (SD was between 0.01 and 1.04) within the experimental runs. From Table 3, the special cubic model developed for expansion has coefficients of determination (R^2) of 0.78 with no significant factors. The 3D surface plot for expansion at different ingredient levels is presented in Figure 5. From the figures, expansion decreases as fish flour increases similar to the findings of Cheow et al. (1999) and Huda et al. (2009). At higher fraction of fish flour, the proteins form a continuous gel network around the starch thereby preventing cracker expansion (Cheow et al., 1999). Expansion of crackers increased as cassava starch increase; which is in agreement with the findings of Tongdang et al. (2008). They reported that cassava starch crackers have higher expansion than crackers from sago starch. As HQCF increases, expansion also increases though not as high as that of starch. Tongdang et al. (2008) observed that cracker expansion was reduced when other types of flour were added. This might be due to the component and structure of the flour blends used in cracker production. Also, initial moisture content as well as frying parameters are also important factors that govern the rate of expansion of a fried product (Nair et al., 1996).

3.6 | Color parameters

Color parameters which include lightness, redness, yellowness and change in colour (derived) of the fried crackers were determined as L^*, a^*, b^*, and ΔE values, respectively. Table 3, shows that L^* varied between 55.51 and 71.77 (SD was between 0.93 and 11.02), a^* varied between −1.22 and −6.61 (SD was between 0.09 and 1.53), b^* varied between −8.18 and 16.26 (SD was between 0.50 and 5.71) and ΔE varied between 17.17 and 31.25 (SD was between 0.53 and 7.49). While from Table 4, the coefficient of determination (R^2) fitted with cubic model for L^* is 0.80, a^* and b^* were 0.99 while ΔE was 0.86. Figure 6–9 shows the 3D surface and contour plots of fried crackers for L^*, a^*, b^*, and ΔE from the flour blends. From the figures, L^* value of deep fat fried crackers decreased with increase in fish flour content while a^* and b^* increases with increase in fish flour content. This is due to processing modification such as maillard reaction, a non-enzymatic browning reaction between amino acids and reducing sugars (Baik and Mittal, 2003; Moyano et al., 2002). Fish flour inclusion increases the amino acid level in the flour blends (Krokida et al., 2001) enhancing



Optimized Sample **Control (Commercial sample)**

FIGURE 11 Scanning electron micrographs of surface of optimized and reference fried cracker samples

Maillard reaction resulting in decrease in L^* value but increase of a^* and b^* values. L^* and b^* increased with increase in HQCF and cassava starch, since both flours had high L^* value (not shown). Cassava starch while frying also gelatinizes into a clear paste which affects its colour parameters (Maneerote et al., 2009).

3.7 | Numerical optimization

The optimum ingredient combination of deep fat fried cassava-fish crackers were obtained using optimization tool (numerical optimization) of Design expert version 6.0.8 based on the experimental data obtained. The target values were set in the program. The oil content, breaking force, redness, change in colour, and moisture content were minimized; expansion ratio and lightness were maximized while yellowness was in range. The results showed that the optimum ingredient combination leading to lower oil content and breaking force with maximum expansion and desirable physico-chemical properties is a combination of 85% CS, 10% HQCF, and 5% FF. Samples at this condition had oil content of 30.72%, a texture of 57.50 N, an expansion of 61.35%, a moisture content of 1.87%, a lightness parameter of 89.85, a redness parameter of 3.98, a yellowness parameter of 15.41 and a ΔE parameter of 28.45.

3.8 | Comparison of optimized and reference fried crackers sample

In comparing the optimized sample with a commercial sample (Table 5), based on instrumental analysis, the latter had higher values in terms of oil content, breaking force, % expansion, moisture content, and lightness. Higher oil content of commercial sample can be attributed to the different ingredient composition or processing steps. Figure 10 shows the digital pictures of fried cassava-fish crackers from optimized conditions and commercial samples. On close visual observation, the samples are different from each other since they contain different ingredient composition. Scanning electron microscopy (SEM) was used to observe the surface structure of the two samples with distinct differences as shown in Figure 11. Optimized sample (A) have more closed structure without visible pores that would have enhanced oil infiltration after frying while the commercial sample (B) has few but large pores which contributed to its higher oil content. Substitution of CS with HQCF and FP in optimized sample might have affected the structure of the cracker and the interaction between CS and HQCF which could have led to a stronger and continuous network serving as a barrier to oil uptake principally during cooling. Differences in breaking force may be due to level of starch content and the degree of gelatinization of the sample since starch gelatinization and swelling of starch granules affect the breaking force of crackers (Andersson et al., 1994). The lower expansion of optimized sample is due to the presence of other components such as HQCF and FF which reduces the level of CS in the sample. The nature of starch in terms of purity, amylose and amylopectin in the product and protein source which form a complex compound with starch have significant effect on expansion (Cheow et al., 1999; Tongdang et al., 2008). Commercial sample was lighter obviously due to more CS while redness and yellowness values were higher in optimized sample due to its protein source as well as degree of browning as earlier reported by Baik and Mittal (2003).

4 | CONCLUSIONS

Cassava-fish crackers were developed and its quality attributes characterized as a function of different combinations of CS, HQCF, and FF using simplex centroid mixture design. Quality attributes of cassava-fish crackers were significantly affected when CS was substituted with HQCF and FF. The optimized ingredient combination for the production of cassava-fish crackers with lower oil content and acceptable quality attributes were 85% CS, 10% HQCF and 5% FF. When compared with a commercial sample, the optimized sample had superior quality attributes in terms of lower oil and moisture contents as well as better crispiness due to lower breaking force. Hence, appropriate combination of ingredient can be used to produce healthy (low oil) cassava-fish crackers.

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REFERENCES

AOAC. (2000). *Official methods of analysis*. Washington, DC: Association of Official Analytical Chemistry.

Andersson, A., Gekas, V., Lind, I., Oliveira, F., & Oste, R. (1994). Effect of preheating on potato texture. *Critical Reviews in Food Science and Nutrition*, *34*, 229–251.

Baik, D. O. & Mittal, S. G. (2003). Kinetics of tofu color changes during deep-fat changes during deep fat frying. *Journal of Food Engineering*, *48*, 219–225.

Balagopalan, C., Padmaja, G., Nanda, S. K., & Moorthy, S. M. (1988). *Cassava in food, feed, and industry*. Boca Raton: CRC Press.

Bouchon, P., Aguilera, J. M., & Pyle, D. L. (2003). Structure oil absorption relationships during deep-fat frying. *Journal of Food Science*, *68*, 2711–2716.

Browner, W. S., Westenhouse, J., & Tice, J. A. (1991). What if Americans ate less fat? A quantitative estimate of the effect on mortality. *Journal of American Medical Association*, *265*, 3285–3291.

Cheow, C. S., Yu, Y. S., & Howell, N. K. (1999). Effect of salt, sugar and monosodium glutamate on the viscoelastic properties of fish cracker ("Keropok") gel. *Journal of Food Processing and Preservations*, *23*, 21–37.

DA Silva, P. & Moreira, R. (2008). Vacuum frying of high-quality fruit and vegetable based snacks. *Food Science and Technology (LWT)*, *41*, 1758–1767.

Dègnon, R. G., Adjou, E. S., Ahouannou, C., Dahouenon-Ahoussi, E., Soumanou, M. M., & Sohounhloue, D. C. K. (2013). Evaluation of microbiological and nutritional quality of two types of fish flours from *Ethmalosa fimbriata* for their use as a dietary supplement. *International Journal of Biosciences*, *3*, 28–34.

Falade, K and & Akingbala, J. (2010). Utilization of cassava for food. *Food Reviews International*, *27*, 51–83.

FAO. (2007). *Marker assisted selection: Current status and future perspectives in crops, livestock forestry and fish*. Rome, Italy: FAO.

Fustier, P., Castaigne, F., Turgeon, S. L., & Biliaderis, C. G. (2008). Flour constituent interactions and their influence on dough rheology and quality of semi-sweet biscuits: A mixture design approach with reconstituted blends of gluten, water-solubles and starch fractions. *Journal of Ceramics Science*, *48*, 144–158.

Hein, M., Henning, H., & Isengard, H. D. (1998). Determination of total polar parts with new methods for the quality survey of frying fats and oils. *Talanta*, *47*, 447–454.

Huda, N., Boni, I., & Noryati, I. (2009). The effect of different ratios of Dory fish to tapioca flour on the linear expansion, oil absorption, colour and hardness of fish crackers. *International Food Research Journal*, *16*, 159–165.

Ihekoronye, A. I. & Ngoddy, P. O. (1985). *Integrated food science and technology for the tropics* (pp. 326–333). Nigeria: Macmillan Publishers.

Kayacier, A., Yuksel, F., & Karaman, S. (2014). Simplex lattice mixture design approach on physicochemical and sensory properties of wheat chips enriched with different legumes flours: An optimization study based on sensory properties. *Food Science Technology (LWT)*, *58*, 639–648.

Krokida, K. M., Oreopolou, V., Maroulis, B. Z., & Marinos-Kouris, D. (2001). Colour changes during deep fat frying. *Journal of Food Engineering*, *48*, 219–225.

Lakleang, S. (1991). *Quality and process improvements of cassava cracker*. Bangkong, Thailand: Department of Product Development, Kasetsart University.

Luyten, H., Plijter, J. J., & Vliet, T. V. (2004). Crisp/crunchy crusts of cellular foods: A literature review with discussion. *Journal of Texture Studies*, *35*, 445–492.

Mariscal, M. & Bouchon, P. (2008). Comparison between atmospheric and vacuum frying of apple slices. *Food Chemistry*, *107*, 1561–1569.

Maneerote, J., Noomhorm, A., & Takhar, P. S. (2009). Optimization processing conditions to reduce oil uptake and enhance physico-chemical properties of deep fried rice crackers. *Food Science and Technology*, *42*, 805–812.

Moriera, R. G., Sun, X., & Chen, Y. (1997). Factors affecting oil uptake in tortilla chips in deep-fat frying. *Journal of Food Engineering*, *31*, 485–498.

Moyano, C. P., Rioseco, K. V., & Gonzalez, A. P. (2002). Kinetics of crust color changes Color during deep-fat frying of impregnated French fries. *Journal of Food Engineering*, *54*, 249–255.

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. 2009. *Response surface methodology: process and product optimization using designed experiments* (3rd ed.). Hoboken, NJ: Wiley.

Nair, C. K. V., Seow, C. C., & Sulebele, G. A. (1996). Effects of frying parameters on physical changes of tapioca chips during deep-fat frying. *International Journal of Food Science Technology*, *31*, 249–256.

Nettleton, J. A. 1992. Seafood nutrition in the 1990s, issues for the consumer. In E. G. Bligh (ed.), *Seafood science and technology* (pp. 32–39). London: Fishing New Books.

Shyu, S., Hau, L., & Hwang, L. (2005). Effects of processing conditions on the quality of vacuum fried carrot chips. *Journal of the Science of Food and Agriculture*, *85*, 1903–1908.

Sobukola, O. P., Awonorin, S. O., Idowu, M. A., & Bamiro, F. O. (2008). Chemical and physical hazard profile of "robo" processing—A street vended melon snack. *International Journal of Food Science and Technology*, *43*, 237–242.

Sobukola, O.P. & Bouchon, P. (2014). Mass transfer kinetics during deep fat frying of wheat starch and gluten snacks. *Heat Mass Transfer*, *50*, 795–801.

Sobukola, O. P., Dueik, V., & Bouchon, P. (2013). Understanding the effect of vacuum level in structure development and oil absorption in vacuum-fried wheat starch and gluten-based snacks. *Food Bioprocess Technology 6*, 2010–2017.

Tettweiler, P. (1991). Snack foods worldwide. *Food Technology*, *45*, 58–60.

Tongdang, T., Meenun, M., & Chainui, J. (2008). Effect of sago starch addition and steaming time on making cassava cracker (Keropok). *Starch/Stärke*, *60*, 568–576.

Velez-Ruiz, J.F., Vergara-Balderas, F.T., Sosa-Morales, M.E., & Xique-Hernandez, J. (2002). Effect of temperature on the physical properties of chicken strips during deep-fat frying. *International Journal of Food Processes*, *5*, 127–144.

WHO. (1996). Essential safety requirements for street vended foods. WHO/FNU/FOS/96.7

Yam, K. L. & Papadakis, S. E. (2004). A simple digital imaging method for measuring and analyzing colour of food surfaces. *Journal of Food Engineering*, *61*, 137–142.

Yu, S. Y. (1991). Acceptability of fish crackers (keropok) made from different types of flour. *Asian Food Journal*, *42*, 743–745.