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Modelling the characteristics of flour from wheat and orange fleshed sweet potato using simplex lattice design for chin-chin production

O. F. Grace[1], O. James[3]*, A. B. Aishat[2] and Ade-Omowaye B. I. Olayemi[2]

[1]*Faculty of Food and Consumer Sciences, Food Science Department, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria*

[2]*LAUTECH SDG 2 (Zero Hunger) Research Group, LAUTECH, Ogbomoso, Nigeria*

[3]*LAUTECH SDG 17 (Partnerships to achieve the Goals) Research Group, LAUTECH, Ogbomoso, Nigeria*

[4]*Department of Food Science and Technology, Osun State University, P.M.B. 4494, Osogbo, Nigeria*

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Abstract

Optimized composite flour from wheat flour (WF) and orange fleshed sweet potato (OFSP) meal was used for the production of chin-chin. The roots of OFSP were washed, air-dried, peeled, sliced to 1 cm thick, dried at 50°C for 18 h and then milled to pass 200 µm sieve aperture to obtain OFSP flour. Composite flours (CF) were formulated from OFSP and WF using Simplex Lattice Design (SLD) and its characteristics were analyzed and modelled. The indices for validating the models showed adequacy of the models. The CF had improved water absorption capacity, oil absorption capacity and beta-carotene. Meanwhile, optimization of relevant properties resulted in an optimized CF which comprised 12.5% OFSP flour and 87.5% WF. The sensorial scores of chin-chin from the optimized CF indicated acceptability by the taste panelists. Chin-chin from the optimized CF would contribute to beta-carotene intake of consumers while reducing wheat importation.

Keywords: Modelling; Characteristics; Composite flour; Chin-chin

Introduction

Sweet potato (*Ipomoea batatas*) is usually cultivated in many developing countries around the world for household consumption and processing into value added food products. It is noted that Asia and Africa continents produce above 95% of the world production. In these regions sweet potato is utilized for its starch (El Sheikha and Ray, 2017). The yields of sweet potato are acceptable to farmers even when grown, on a less fertile soil and under harsh climatic conditions. Sweet potato can do well with little or no application of external agro-inputs and minimal crop supervision. There are several varieties of sweet potato available for consumption and processing. The different varieties of sweet potato may be white, yellow, orange, red, cream, pink or purpled fleshed (Bodjrenou *et al.* 2023).

The roots of orange fleshed sweet potato (OFSP) contain considerable amount of vitamin A and most disseminated in sub-Saharan Africa regions such as Malawi, Tanzania, Rwanda, Burundi and Nigeria. It has an advantage over other varieties of sweet potato due to its relatively high beta-carotene and fiber. Asides this, it is of low glycemic index because of its low starch digestibility thereby making it suitable for consumption by people living with diabetics or people high body mass index. The roots of OFSP also contain sizeable quantities of some key vitamins such as B, C, E and K (Low, 2020; Akinwande *et al.* 2023).

Although, OFSP root is rich in beta-carotene, which could be harnessed in reducing incidence of vitamin A deficiency, especially among children, it is not shelf stable because of its

*Corresponding author's e-mail: james.oyedokun@uniosun.edu.ng

high moisture and being metabolically active (Sanchez *et al.* 2021). Therefore, OFSP root must be processed into shelf stable intermediate products like flour as raw material for making snacks (Kolawole *et al.* 2018; Kolawole *et al.* 2020; Kolawole *et al.* 2021; Olatunde *et al.* 2023). Snacks are widely consumed food products because of their convenience, easy preparation and distinctive taste (Akinwande *et al.* 2022). Such snacks include chin-chin, which is a fried food product that is acceptable for consumption among children and adult in the developing countries such as Nigeria. However, at present, WF is the major ingredient in chin-chin industry (Bongjo *et al.* 2023). Consequently, many non-wheat producing developing countries spend whopping amount of money on importation of WF from the growing countries. Sourcing for an alternative to WF locally or an indigenous foodstuff that can partly or wholly replace WF for chin-chin would be desirable with a view of saving the much needed foreign currencies. Therefore, this study considered modelling and optimizing wheat-OFSP composite flour (CF) using simplex lattice design (SLD) with a view of utilizing it for the production of chin-chin.

Materials and Methods

The source of the roots of OFSP was obtained from Ladoke Akintola University of Technology Teaching and Research Farm, Ogbomoso, Nigeria. Other optimal and optional ingredients used materials were sourced from a local store in Ogbomoso, Nigeria. While the reagents used were of analytical grade.

OFSP flour

OFSP flour was prepared by following the production steps shown (Figure 1). Fresh roots of OFSP wet cleaned, air dried

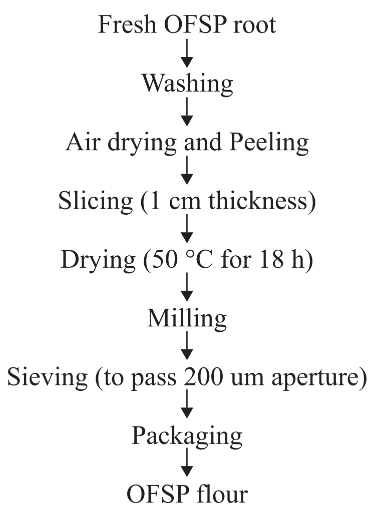

Fig. 1. Flow chart for the production of OFSP flour

and peeled. The peeled tubers were sliced into 1 cm thick and then subjected to drying at 50°C using a tunnel drier for 18 h to obtain dried chips. The chips were ground followed by sieving to give OFSP flour with particle size of about 200 µm. The flour was packaged in an air tight plastic pouches until it was needed for analyses.

Formulation of wheat-orange fleshed sweetpotato composite flour

The experimental design (Table I) and runs for components in CF (Table II) were generated using simplex lattice design (SLD) of Design Expert (Stat-Ease, Inc. USA).

Table I. Components and their levels in composite flour

Component	Low level (%)	High level (%)
Wheat flour	70	100
OFSP flour	0	30

Table II. Experimental runs for the components in composite flour

Run	Wheat flour (X_1)	OFSP flour (X_2)
1	92.50	7.50
2	70.00	30.00
3	100.00	0.00
4	85.00	15.00
5	77.50	22.50

Determination of bulk density of composite flour

The bulk density (BD) of all the samples was determined as described by AOAC (2023). Flour of 20 g was poured into measuring cylinder of 100 ml capacity. The bottom of the cylinder was gently tapped for severally to a constant volume. The flour volume was noted and BD calculated as shown in Equation (1)

$$\text{Bulk density (g/ml)} = \frac{\text{Weight of sample}}{\text{Volume of sample after tapping}} \qquad (1)$$

Determination of water absorption capacity of composite flour

Water absorption capacity (WAC) of the samples was done following method of Adeleke and Odedeji (2010). 15 ml potable water was mixed with 1 g of flour in a centrifuge tube of 25 ml in capacity. The tube with its content was vortexed for about 2 min. and subjected to centrifugation at about 4000 rpm for about 20 min. The supernatant was decanted off and the adhering water on the sediment was removed and then reweighed. The WAC was expressed as the weight (g) of water bound by 100 g dried flour.

Oil absorption capacity of composite flour

The oil absorption capacity (OAC) of the samples was determined as described by Adeleke and Odedeji (2010). 10 ml vegetable oil was mixed with 1 g of the flour in a centrifuge tube of 25 ml capacity. The tube was vortexed for 2 min and subjected to centrifugation at 4000 rpm for 20 min. The un-absorbed oil was decanted off and noted. OAC was expressed as volume (ml) of vegetable oil bound by 100 g dried flour.

Swelling capacity of composite flour

The swelling capacity (SC) of the flour samples was determined by weighing 10 g of flour into a clean and dry measuring cylinder. About 60 ml water was mixed with it and then quickly stirred to avoid air bubbles. This was followed by settling and initial volume noted. The mixture was made to continue to settle for 4 h and the final volume on the measuring cylinder was recorded. SC was determined as follows (Equation (2):

$$SC = \frac{\text{Final volume}}{\text{Initial volume}} \quad (2)$$

Determination of proximate composition of composite flour

The proximate composition was determined as described by AOAC (2023).

Determination of moisture content of composite flour

The hot air oven drying method was used. Petri dishes were washed, dried and allowed to cool in a desiccator. The weight of petri dish (W_1) was noted and 2 g sample of flour was weighed into the dish (W_2). The petri dish with its content was put in the oven at a temperature of about 105 ^{o}C for 1 h until a constant weight was obtained, and then cooled in a desiccator for 30 min. The dish with its content was weighed again (W_3). The moisture content was determined by using Equation (3).

$$\%\ \text{Moisture} = \frac{w_2 - w_3}{w_2 - w_1} \times 100 \quad (3)$$

Determination of ash content of composite flour

Cleaned and dried crucibles were weighed (W_1) and about 2 g of flour sample was weighed into it (W_2). This is followed by incineration in a muffle furnace at 550^{o}C for 6 h. The ashed samples were made to cool in a desiccator and weighed (W_3). The ash content was determined by using Equation (4).

$$\%\ \text{Ash} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad (4)$$

Determination of protein content of composite flour

The Kjeldahl method was used for determining the protein content. About 1.0 g CF was weighed into the digestion flask and concentrated H_2SO_4 (15 ml) and digestion mixture (8 g) were added. This is followed by thorough mixing and digestion to obtain a clear solution. The digest was allowed to cool and put in a volumetric flask of 100 ml in capacity. The volume was made up to the mark of the flask with distilled water. The digest was then subjected to distillation. The digest (10 ml) was put in a distillation tube and 0.5 N NaoH (10 ml) was added stepwise for 10 min. The NH_3 produced in form of NH_4OH was collected in a conical flask with 4% boric acid solution (20 ml) and some drops of modified methyl red to serve as indicator. This was followed by titration of the distillate against 0.1 N HCl solutions until a pink colour appeared. The same procedure was followed for the blank. The percentage nitrogen was determined by using Equation (5) and then multiplied by 6.25 which is conversion factor.

$$\%\ N = \frac{(S-B) \times N \times 0.014 \times D \times 100}{\text{Weight of the sample} \times V} \quad (5)$$

Where S is sample titration reading; B is the blank reading; N is normality of HCL; D is dilution of sample on digestion; V is the volume for distillation.

Determination of fat content of composite flour

For crude fat determination, 1.0 g flour sample was subjected to oil extraction for 6 h and the weight of the extracted oil was determined. The crude fat content was calculated as shown in Equation (6)

$$\%\ \text{Fat} = \frac{\text{Eether extract weight}}{\text{Sample weight}} \times 100 \quad (6)$$

Determination of crude fiber content of composite flour

Flour sample (1.5 g), W_0, was treated with pre-heated H_2SO_4 solution (150 ml) with the addition of foam-suppresser. This was followed by opening of cooling circuit and turning on of heating elements. Thereafter, the sample was subjected to drying at 150 ^{o}C for 1 h and then cooled in desiccator and weighed (W_1). The sample in crucibles were retained in furnace at 55 ^{o}C for 4 h, cooled in desiccator and weighed (W_2). Percentage crude fiber was determined as shown in Equation (7).

$$\%\ \text{Fiber} = \frac{W_1 - W_2}{W_0} \times 100 \quad (7)$$

Determination of beta-carotene content of composite flour

The beta-carotene of the CF was determined following the methods of Rodriguez-Amaya and Kimura (2004) and Ukpabi and Ekeledo (2009). The extraction was done by using petroleum ether while the absorbance was read with a spectrophotometer. Beta-carotene was determined by using Equation (8).

$$\text{Beta-carotene content (mg/100g)} = \frac{\text{Absorbance} \times \text{total volume of extract (ml)} \times 10^3}{\text{absorption coefficient of beta-carotene in petroleum ether} \times \text{weight of the sample}} \quad (8)$$

Determination of oxalate content of composite flour

The oxalate content of the CF was determined by weighing 1 g flour sample into conical flask which contained 3 N H_2SO_4 (75 ml). The solution was mixed at regular interval for 1 h. This was followed by filtering and the filtrate (25 ml) with temperature of about 85 °C was titrated against 0.1 N $KMnO_4$ solutions to obtain a light pink colour. The oxalate content was determined using Equation (9).

$$\text{Oxalate content} = \frac{\text{T} \times (\text{Vme})(\text{Df}) \times 10^5}{\text{ME} \times \text{Mf}} \text{mg/100} \quad (9)$$

Where T is titre of $KMnO_4$ (ml); Vme is volume- mass equivalent; Df is the dilution factor (V_T/A x 2.4, where V_T is total volume of the titrate and A is the aliquot used); ME is molar equivalent of $KMnO_4$ in oxalate and Mf is mass of the CF.

Determination of phytate content of composite flour

The procedure of was used to determine the phytate content of the CF. Exactly 2 g sample was mixed with 0.2 N HCl (20 ml) and then filtered. The filtrate (0.5 ml) was stirred with ferric ammonium sulphate (1 ml) and then boiled for 30 min. This was followed by cooling with ice for 15 min. It was then subjected to centrifugation at 3000 rpm for 15 min. The supernatant (1 ml) was mixed with 2, 2-pyridine solution (1.5 ml) and the absorbance was read in a spectrophotometer. The amount of phytic acid in the sample was determined through extrapolation from a standard curve constructed using phytic acid solution.

Statistical analysis

Regression models were generated for the responses (Design Expert software, USA). The models were represented by Equation (10)

$$\hat{Y} = \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 \quad (10)$$

where $\hat{Y}$ is a response; β_1, β_2 and β_{12} are regression coefficients; X_1 and X_2 are linear factors and X_1X_2 is an interaction factor.

Model validation

The models were assessed for prediction adequacy by using coefficient of determination (R^2), average absolute deviation (AAD), bias factor (Bf) and accuracy factor (Af) in form of Equation (11-13), respectively (Akinwande *et al.* 2024).

$$\text{AAD} = \frac{\left[\sum_{i=1}^{N}\left(\frac{|Yi,exp - Yi,cal|}{Yi,exp}\right)\right]}{\text{N}} \quad (11)$$

$$\text{Bf} = 10^{\frac{1}{N}\sum_{i=1}^{N}(\log(\frac{Yi,cal}{Yi,\text{exp}})} \quad (12)$$

$$\text{Af} = 10^{\frac{1}{N}\sum_{i=1}^{N}|(\log(\frac{Yi,cal}{Yi,\text{exp}})|} \quad (13)$$

average absolute deviation = AAD, bias factor = Bf and Af = and accuracy factor

Optimization

Optimization was performed to maximize WAC, fiber; and minimize OAC; of the CF for an acceptable chin-chin.

Chin-chin production from wheat and optimized composite flour

Wheat flour and the optimized CF were used to produce

Flour
↓
Mixing with other ingredients
(sugar, salt, baking powder, butter, eggs, water)
↓
Kneading
↓
Rolling
↓
Cutting (2cm by 2cm)
↓
Frying (160°C for 20 min)
↓
Cooling
↓
Packaging
↓
Chin-chin

Fig. 2. Flow chart for the production of chin-chin
Source: Akubor (2004)

chin-chin as shown in Figure 2. The two flours contain the same quantity of all other ingredients.

Sensory evaluation

Preference test was used to assess the sensory properties of chin-chin. The test was conducted by 50 panelists as described by Akinwande *et al.* (2024). The attributes evaluated on chin-chin were colour, mouth feel, odour, sweetness and overall acceptability. The chin-chin samples were evaluated on a nine-point hedonic scale ranging from 9 to 1 representing like extremely and dislike extremely, respectively. Chin-chin was served and presented in a white plastic plate coded with a random set of 3 digit numbers. Potable water was provided to the panelists for rinsing their mouths before testing each sample.

Statistical analysis

Data obtained from the CF was analyzed using Design Expert software, USA. The sensory properties of chin-chin samples were subjected to t-test using Minitab Statistical Software, UK.

$$Y_1 = 0.0081\ X_1 + 0.0058\ X_2 + 0.0000070\ X_1X_2 \quad (2)$$

$$Y_2 = 0.018\ X_1 + 0.032\ X_2 + 0.000063\ X_1X_2 \quad (3)$$

$$Y_3 = 0.019\ X_1 + 0.048\ X_2 - 0.00038\ X_1X_2 \quad (4)$$

Results and discussion

The functional properties of wheat-orange fleshed sweet potato composite flour

The bulk density (BD), water absorption capacity (WAC) and oil absorption capacity (OAC) and their models (Equation (2) to (4)) represented by Y_1, Y_2 and Y_3, respectively. The R^2 values ranged from 0.94 to 0.97, AAD values approached 0 while Bf and Af values were approached unity (Table III). These statistical indices indicated similarity between the experimental and calculated (predicted) values of the functional properties (Table IV). Both factors WF (X_1) and OFSP flour (X_2) impacted significant ($p \leq 0.05$) positive effects on the functional properties of the CF. Meanwhile, factor , X_1X_2 impacted no significant ($p \geq 0.05$) effect on BD and WAC but impacted significant ($p \leq 0.05$) negative effect on OAC.

Table III. Coefficient of regression for functional properties of flour

Coefficient	Bulk density	Water absorption capacity	Oil absorption capacity
β_1	0.0081*	0.018*	0.019*
β_2	0.0058*	0.032*	0.048*
β_{12}	0.000007	0.000063	- 0.00038*
R^2	0.9423	0.9669	0.9441
AAD	0.006	0.10	0.02
Bf	1.00	1.1	1.02
Af	1.01	1.1	1.02

*Significant at $p \leq 0.05$.
β_1 = linear effects of wheat flour, β_2 = linear effects of OFSP flour, β_{12} = interaction effects of wheat flour and OFSP flour, R^2 = coefficient of determination, AAD = average absolute deviation, Bf = bias factor, Af = accuracy factor.

Table IV. The experimental and predicted values for the functional properties of the flours

Wheat flour (X_1)	OFSP flour (X_2)	Bulk density		Water absorption capacity		Oil absorption capacity	
		Exp.	Pre.	Exp.	Pre.	Exp.	Pre.
92.50	7.50	0.80	0.80	1.88	1.95	1.82	1.85
70.00	30.00	0.76	0.76	2.05	2.35	1.94	1.97
100.00	0.00	0.81	0.81	1.74	1.80	1.87	1.90
85.00	15.00	0.79	0.78	1.89	2.09	1.81	1.85
77.50	22.50	0.76	0.77	2.00	2.22	1.89	1.89

Although, an increase in both X_1 and X_2 in the formulation had an increasing effect on BD of the CF, WF had greater effect than OFSP flour on the functional property. This is suggesting that WF is bulkier than OFSP flour (Ndife *et al.* 2020; Chikpah *et al.* 2020). The higher BD recorded for WF than flour from OFSP could result from varied nature of starch in the two food materials. The CF from wheat and OFSP flours may be suitable for manufacturing chin-chin owing to its relatively lower BD than that of WF. However, greater increase in WAC was noted with an increase in the level of OFSP than when the level of WF was increased in the CF. This could be due to greater amount of hydrophilic components in OFSP than the ones in WF. This corroborates some previous reports. For instance, Edun *et al.* (2019) noted upward trend in WAC (1.45 to 2.08 ml/g) as the level of OFSP increased from 0 to 30% in a wheat based CF. The CF from this study may be suitable for the production of fried or baked food products softer and denser in weight than WF. An increase in OFSP flour in the formulation had greater increasing effect on OAC than wheat flour. This may be due to lipophilic effects of OFSP flour components. This agrees with the report given by Edun *et al.* (2019) in which an increase from 1.45 to 1.67 ml/g in OAC as the level of OFSP increased from 0 to 30% in a wheat based CF was reported. However, it is contrary to the report given by Kindeya *et al.* (2021) in which lower value (17.85%) of OAC for OFSP flour than the value (21.3%) for WF was reported. Increased OAC with inclusion of OFSP flour in wheat based CF may enable production of fried food products such as chin-chin with enhanced palatability (Kindeya *et al.* 2021). However, the interaction factor of wheat and OFSP flours had reducing effect on OAC of the CF, though the magnitude of the effect was low.

The proximate composition of wheat-OFSP composite flour

Linear effects of WF (X_1), OFSP flour (X_2) and their interaction effect (X_1X_2) on moisture (Y_4), ash (Y_5), protein (Y_6), fat (Y_7) and fibre (Y_8) are presented by Equation (5) – (9). The R^2 values ranged from 0.90 to 0.99, AAD values approached zero while Bf and Af values approached unity (Table V). The statistical indices implied similarity between the experimental and calculated (predicted) values of the proximate composition of the CFs (Table VI). Linear factor X_1, significantly (*p*

Table V. Coefficient of regression for the proximate composition of the flour blends

Coefficient	Moisture	Ash	Protein	Fat	Fiber
β_1	0.095*	0.0044*	0.16*	0.06*	0.0038*
β_2	-0.068*	0.048*	-0.20*	-0.20*	0.028*
β_{12}	0.0017*	-0.0003	0.0028*	0.0028	-0.0002*
R^2	0.97	0.99	0.95	0.90	0.97
AAD	0.01	0.04	0.05	0.05	0.04
Bf	1	1.01	1.01	1.02	1.00
Af	1.01	1.04	1.05	1.04	1.04

*Significant at $p \leq 0.05$.
β_1 = linear effects of wheat flour, β_2 = linear effects of OFSP flour, β_{12} = interaction effects of wheat flour and OFSP flour, R^2 = coefficient of determination, AAD = average absolute deviation, Bf = bias factor, Af = accuracy factor.

Table VI. The experimental and predicted values for the proximate composition of the flour blend

		Moisture		Ash		Protein		Fat		Fibre	
Wheat flour (X1)	OFSP flour (X2)	Exp.	Pre.	Exp.	Pre.	Exp.	Pre.	Exp.	Pre.	Exp.	Pre.
92.50	7.50	9.42	9.37	0.51	0.57	15.23	14.79	6.25	6.28	0.44	0.41
70.00	30.00	8.08	8.03	1.16	1.17	10.3	10.71	4.4	4.3	0.66	0.65
100.00	0.00	9.42	9.44	0.45	0.42	15.42	15.51	6.28	6.32	0.37	0.38
85.00	15.00	9.18	9.11	0.75	0.74	14.57	13.75	6.19	5.93	0.47	0.47
77.50	22.50	8.42	8.66	0.98	0.94	11.21	12.39	4.6	5.26	0.51	0.55

≤ 0.05) impacted positively on the parameters of the CF. Meanwhile, linear factor, X_2, had significant ($p \leq 0.05$) positive effect on ash and fibre but negative effect on moisture, protein and fat. The interaction factor, X_1X_2, conferred significant ($p \leq 0.05$) positive effect on both moisture and protein but negative effect on fibre content. Moisture content of flours is very critical to their shelf lives. Consequent upon this, CF made

$$Y_4 = 0.095X_1 - 0.068X_2 + 0.0017X_1X_2 \quad (5)$$

$$Y_5 = 0.0044X_1 + 0.048X_2 - 0.0003X_1X_2 \quad (6)$$

$$Y_6 = 0.16X_1 - 0.20X_2 + 0.0028X_1X_2 \quad (7)$$

$$Y_7 = 0.06X_1 - 0.20X_2 + 0.0028X_1X_2 \quad (8)$$

$$Y_8 = 0.0038X_1 + 0.028X_2 - 0.0002X_1X_2 \quad (9)$$

of wheat-OFSP flour may have better keeping quality than WF. Kindeya *et al.* (2021) reported higher moisture content in WF (10.16%) than flour from OFSP (4.49%) and flour from haricot bean (8.49%). The reduction in the protein content when flour from OFSP increased may be due to low level protein in OFSP roots (Edun *et al.* 2019; Kindeya *et al.* 2021). Since OFSP flour contributed more than WF to ash and fibre contents of the CF, it follows that OFSP roots used in this study may be rich in the nutrients. Ewunetu *et al.* (2023) reported higher values of ash and fiber for OFSP flour than for flour from WF. While, the authors reported 0.80% ash and 2.41% fiber for WF, they reported 4.02% ash and 10.67% fiber for OFSP powder. The relatively lower fat content of CF than that of WF, may be attributed to little or no fat in OFSP roots as Rakotosamimanana (2024) reported higher fat content for the biscuit produced from WF than the one from OFSP flour. The low level of fat in the CF implies less susceptibility of the flour to rancidity during storage thereby enhancing its keeping quality.

Beta-carotene and anti-nutritional factors of wheat-OFSP composite flour

The linear effects of WF (X_1), OFSP flour (X_2) and their interaction effect (X_1X_2) on the beta-carotene and anti-nutritional properties were studied. The models representing beta-carotene (Y_9), oxalate (Y_{10}) and phytate (Y_{11}) are presented by Equation (10) – (12). The R^2 values ranged from 0.95 to 1.00, AAD values approached 0, while Bf and Af tended towards 1 (Table VII). These values indicated similarity between experimental and calculated (predicted) values of beta-carotene, oxalate and phytate of the CF (Table VIII). The linear factors X_1 and X_2, had significant ($p \leq 0.05$) increasing effects on beta-carotene, oxalate and phytate of

Table VII. Coefficient of regression of beta-carotene and anti-nutritional properties of flour

Coefficient	Beta-carotene	Oxalate	Phytate
β1	0.0022*	0.00866*	0.4599*
β2	0.0114*	0.0652*	0.62584*
β12	-0.0000261	-0.000462	0.000791285*
R^2	0.995	0.95	0.996
AAD	0.02	0.02	0.00
Bf	1.01	1.00	1.00
Af	1.02	1.02	1.00

Table VIII. The experimental and predicted values for beta-carotene and anti-nutritional factors of flour

Wheat flour (X_1) (%)	OFSP (X_2) (%)	Beta-carotene (mg/100g)		Oxalate (mg/g)		Phytate (mg/g)	
		Exp.	Pre	Exp.	Pre	Exp.	Pre
92.50	7.50	0.26	0.27	0.97	0.97	48.30	47.78
70.00	30.00	0.44	0.44	1.58	1.59	52.67	52.63
100.00	0.00	0.22	0.22	0.87	0.87	45.89	45.99
85.00	15.00	0.33	0.32	1.10	1.13	49.31	49.49
77.50	22.50	0.37	0.38	1.40	1.33	51.06	51.10

the CFs. Whereas, interaction factor (X_1X_2) had significant ($p \leq 0.05$) increasing effect on phytate only. The flour from OFSP contributed more to beta-carotene content than WF in the CF as the roots of OFSP are richer in terms of beta-carotene than WF (Malavi *et al.* 2022; Ndife *et al.* 2020). However, flour from OFSP contributed more to the oxalate and phytate contents of the CF than WF. This could be partly stemmed from refining with attended reduction in anti-nutrients associated with such operations as milling and sieving during flour production (Oloniyo *et al.* 2021). However, when OFSP flour or its CF is subjected to such processing methods as boiling, frying and baking, anti-nutritional factors may decrease considerably (Abong *et al.* 2021).

$$Y_9 = 0.0022X_1 + 0.0114X_2 - 0.0000261X_1X_2 \quad (10)$$

$$Y_{10} = 0.00866X_1 + 0.0652X_2 - 0.000462X_1X_2 \quad (11)$$

$$Y_{11} = 0.4599X_1 + 0.62584X_2 + 0.000791285X_1X_2 \quad (12)$$

The numerical optimum values of flours from wheat and OFSP in CF obtained by maximizing WAC and fiber, and minimizing OAC, with their predicted values are shown in Table IX and the results of sensory analyses of chin-chin from optimized CF from flours of wheat and OFSP shown in Table X. The sensorial attributes of chin-chin from the optimized CF indicated acceptability by the panelists, although, they different from chin-chin from WF (control). The optimized CF has the potential of being utilized for chin-chin production as Thiele *et al.* (2022) reported the utilization of OFSP puree for bread production. The utilization of optimized CF for chin-chin would further reduce wheat imports by countries with a competitive advantage in OFSP production, resulting in much-needed foreign currency savings.

Conclusion

The characteristics of CF from WF and OFSP flour were modelled and optimized for chin-chin production. The statistical indices for validating the generated mathematical models showed adequacy of the models. The R^2 values were between 0.90 and 0.99, AAD were almost zero, while Bf and Af nearly equal to one. Inclusion of flour from OFSP into WF improved beta-carotene, WAC and OAC of the CF. While, multi-response optimization of relevant properties indicated optimal CF formulated with 12.5% flour from OFSP and 87.5% flour from wheat for chin-chin production. The scores of sensorial properties of the chin-chin from optimal CF indicated acceptability, though, they were lower than the scores for WF chin-chin. Utilizing optimized CF for chin-chin production may contribute to beta-carotene intake of consumers and reduce importation of wheat by the countries with comparative advantage in the production of OFSP roots.

Table IX. Optimization of composite flour

Parameter	Goal	Lower limit	Upper limit	Solution
Wheat flour	within range	70	100	87.5
OFSP flour	within range	0	30	12.5
Water absorption capacity	maximize	1.74	2.05	1.88
Oil absorption capacity	minimize	1.81	1.94	1.82
Fiber	maximize	0.37	0.66	0.46

Table X. Sensorial properties of chin-chin produced from wheat flour and optimized wheat-OFSP composite flour

Sample	Colour	Mouthfeel	Sweetness	Aroma	Overall acceptability
A	7.95^a	7.95^a	7.90^a	7.46^a	8.30^a
B	7.15^b	7.79^b	7.71^b	6.81^b	8.00^b

A = chin-chin produced from 100% wheat flour
B = chin-chin produced from composite flour containing 87.5% wheat flour and 12.5% OFSP flour

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