SEET ENGINEERING AND TECHNOLOGY JOURNAL

SEET Engineering and Technology Journal, 1 (issue), month (2025), page range
Journal homepage: https://www.seetfutoetj.ng/index.php/setj
PRINT ISSN: xxxx-xxxx || ONLINE ISSN: xxxx-xxxx

Modelling and optimization of physicochemical properties of wheat flour and chemically modified African yam bean – cassava starch blends

Elemuo, G. K.[1,*], Obasi, N. E.[2], Uzochukwu, A. O.[2], Odimegwu, E. N.[1], Uzomah, A.[1]

[1] Department of Food Science and Technology, Federal University of Technology Owerri, Imo State, Nigeria

[2] Department of Food Science and Technology, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria

[*]Corresponding Author's E-mail: godswill.elemuo@futo.edu.ng

Abstract

African yam bean and cassava starches had undergone chemical modification (sodium acetylation) and blended with wheat flour to create a composite flour-starch combination. D-optimal mixture design yielded three mixture components. Using cubic models to create regression equations from the experimental values, the physicochemical characteristics of the flour-starch mixture were ascertained. 3D response surface plots were used to create and visually portray the dependent responses' linear, binary, and ternary impacts as well as their interactions. In order to verify sufficient model signals, generated models were evaluated for adequacy and verified using criteria at $p<0.05$, non-significant ($p>0.05$) lack-of-fit (LoF), >0.7 adjusted R2, and >4 appropriate precision. The optimal value was represented by the desirability value of 0.72 in the numerical optimization results generating the optimum blends of wheat flour (84.38 g), African yam bean (10.62 g) and cassava (5.00 g) starches selected. By conducting confirmatory runs and determining the mix's 95% confidence levels, the D-optimal mixture design generated three experimental components were sufficient for modelling and optimizing the dependent responses tested, including but not limited to the ranges for pH (5.66 – 7.44), least gelation concentration (5.98 – 8.84 % m/v), gelation temperature (63.50 – 72 ^{0}C), moisture (3.95 – 4.84 %), bulk density (0.43 – 0.52 g/cm^3), water absorption capacity (60.56 – 74.42 mL/g), oil absorption capacity (62.11 – 74.23 mL/g), swelling power (1.15 – 8.10 %), specific volume (2.00 – 5.75 %), solubility (28.51 – 62.50 %), and viscosity (15.55 – 26.25 Cp).

Keywords: Physicochemical properties; Modelling; Enhanced flour-mix; D-optimal mixture-design

1.0 Introduction

The solution to inadequate energy intake in many vulnerable countries would be placed majorly to adequate usage of cereals mix, legumes and tubers locally available to them (Nnam, 2003). Flour mix and different food products that will boost post – injection satiety with adequate impact on the energy intake of the general population has been produced with these food materials (Olaoye *et al.,* 2006). African yam bean also is laced with amino acid profile comparing with those of soy beans, pigeon peas and cowpeas with improved functional properties when compared to cowpeas (Achinewhu & Akah, 2003). Cassava on the other hand, is one of the important root crops with high starch yield in the tropics and compared with sweet potato in this category (Grace, 1977). Bertolini et al. (2001) reported that wheat flour has been partially replaced up to 10% with cassava flour as mix for bread and other confectioneries. Starches are the mostly used biodegradable polymer which occurs naturally in grains, fruits, tubers and roots of most plants which also act as its major storage. Starches have three chemical reaction points which takes place on the 2, 3 and 6 carbon positions of the linear chain amylose, in which the α-*D*-glucopyranose units are joined with α–1,4–glycosidic bonding, and on the jointed site of the amylopectin chain whose α–1, 6–glycosidic bonding is contained in the carbon chain (Kaur et al., 2012). Starches produce pastes that are fairly stable which thereby decreases their storage stability (stability during shelf keeping) which causes loss of water from the matrices and subsequent shrinkages (Tester et al., 2004). Hence, to overcome these limitations, and to add value by improving its paramount physicochemical properties, starches are modified. This study modelled and optimized the physicochemical properties of wheat flour and chemically modified African yam bean – cassava starch blends and established its quality functionalities.

2.0 Materials and Methods

2.1. Materials.

Healthy seeds of African yam bean and wheat were obtained from local market at *Orie – Ugba*, Umuahia Abia State while the fresh cassava roots were sourced from the extension department National Root Crop and Research Institute (NRCRI), Umudike, Abia State.

2.2. Methods.

2.2.1. Experimental design

A total of 14 runs were obtained from D – optimal mixture design which was used to achieve the goals of optimization for the modified starch – wheat flour mix. The method was implored to generate predictive experimental models used in generating the linear, binary and ternary effects of the mixture independent variables and their interactions on the physicochemical properties of the enhanced flour. In the experiment, two runs were duplicated to be able to measure the internal error between design points. Model adequacy and fitness on the physicochemical properties of the flour – starch mix was evaluated using analysis of variance (ANOVA). A probability level ($p<0.05$) was used to judge model adequacy, non significant ($p>0.05$) lack-of-fit was considered for model adequacy as described by Cornell, (1986) and reported by Elemuo and Obasi (2022). Other fitness statistics used were >0.7 adjusted R^2 and >4 adequate precision of the model. Plots generated for the adequate models, ANOVA and other fit statistics were used for evaluating model adequacy. All the analysis was performed using Design – Expert (Version 12.0.10, Stat – Ease Inc., Minneapolis, 2021) software. Cubic model was adopted using the equation "(1)" below:

$$Y = \sum_{c=1}^{a} \beta_c x_c + \sum_{c \neq d}^{a} \beta_{cd} x_c x_d + \sum_{c \neq d \neq e}^{a} \beta_{cde} x_c x_d x_e + \varepsilon_{cde} \quad (1)$$

Where, β_c shows the main effects, β_{cd} shows the binary effects between the $c^{th}$and d^{th} components, β_{cde} also shows the ternary effects in between the c^{th}, d^{th} and e^{th} components. The predicted dependent response is taken as the Y, a is the product components (a = three product components), ε_{cde} shows the experimental error used in measuring the mixture components from the experimental data. The cubic model (actual components) selected for the dependent variables (Y) is largely expressed with the equation below:

$$Y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{123} x_1 x_2 x$$

Where, Y represents the dependent variables predicted, $\beta' s$ represents the model terms across the linear, binary and ternary effects of the model, thus, x_1 represents wheat flour, x_2 represents African yam bean starch and x_3 represents cassava starch. The method used for the optimization of the dependent variables and the numerical optimization were used as described by (Myers et al., 2009). The model was validated by generating the plot of predicted values against the actual values

2.2.2. Production of starch from cassava

Starch was produced from cassava using methods described by (Moorthy et al., 1996). Roots of cassava were harvested, cleaned of dirt, peeled, washed and grated. The cassava mash produced was ground again and water mixed using the ratio of 1: 5 w/v %. Resulting mash was then passed in double layered nylon cloth to filter it and to obtain the resulting solution of starch. The resultant starch was separated using sedimentation method and the effluent was subsequently decanted. The produced starch was then put in the oven for drying at a temperature of 60 ^{0}C for 24 h.

2.2.3. Production of African yam bean starch

The method described by (Sathe & Salunkhe, 1981), was modified and used. African yam bean seeds were sorted and soaked in water for about 45 min. to soften the seed coat. Then the seeds were rasped between the palms and the softened testa was removed by decanting when floated. The dehulled seeds will then be oven dried (60 ^{0}C, 24 h) and milled into flour and pulverized using a mesh size of 0.4 mm, then a pack of 3 kg of bean flour will be extracted by the use of different solvents to produce starch.

2.2.4. Production of modified starches

A mono-type of cross-linked African yam bean and cassava starches was produced using the reagents: sodium acetate, a method described by (Akpa & Dagde, 2012). About 200 g of native starches was weighed into a container made of plastic, 0.2 g silicon oxide was added as a 0.2 g silicon oxide was added as a fluxing agent to the starch, then mixed for about 5 minutes then preceded with the addition of 20g of sodium hydroxide as an alkaline catalyst, then mixed for about 20 minutes, 29g of sodium acetate was also added to the mixture as a cross-linking agent, then mixed for another 15 minutes. The mixture is then heated using water bath running at temperature of 75°C and stirred steadily for about 1 hour, then the mixture is poured out to cool.

2.2.5. Flour – starch mix preparations

The flour – starch mix made up of wheat flour and chemically modified starches from African yam bean and cassava (independent variables) were prepared using the combination adopted from the experimental design generated from the design experts.

2.3. Determination physical properties of enhanced flour – starch mix.

2.3.1. Least gelation concentration

Least gelation concentration of the flour composite was evaluated with methods reported by (Sathe et al., 1982). Composite flour was added as suspensions with distilled water in test tubes in the variants of 2 %, 4 %, 6 %, 8 %, 10 %, 12 %, 14 %, 16 %, 18% and 20% (m/v) and were heated for about 1 hour in in water bath set at a near boiling temperature, then the mixture is cooled rapidly under streamlined lined cold water. The tubes used were cooled at a temperature of 40^{0}C for about 2 hours. Least gelation concentration was evaluated as time in which the mix contained in the inverted tube remained same and didn't turn over.

2.3.2. Gelatinization temperature

The gelatinization temperature was evaluated with methods reported Association of Official Analytical Chemists (AOAC, 2005). Each 1.5 g portion of the composite flour samples were mixed in beaker containing 10ml distilled water and stirred continuously in a water bath until there was a thickened milky colour change. Then a thermometer was inserted. This point of colour change was the point which it gels and that temperature will be expressed as the temperature of gelatinization.

2.3.3. Moisture content

Moisture composition of the composite flour samples was evaluated with methods reported by the Association of Official Analytical Chemists (AOAC, 2005). Five (5) moisture cans were placed in the oven to be dried at 105°C for 15 minutes. It is then placed to cool in a desiccator for about 10 minutes and weighted. A 2 g portion of each of the composite flour samples were weighed in the moisture cans and labelled. The moisture cans were then placed in the oven pre – set at the temperature of 105°C for about 4 h. The moisture cans were then removed and stored in the desiccator to cool for about 15 mins. Then the moisture cans were brought out and weighted. The moisture content of the composite flour samples was determined using "Eq. (3)"

$$\% \, Moisture = \frac{Weight \; of \; sample \; with \; moisture}{Weight \; of \; sample \; before \; drying} \; X \; \frac{100}{1} \quad (3)$$

2.3.4. Bulk density

Bulk density of the composite flour – starch samples was evaluated using the method reported by (Maninder et al., 2007). The composite mix were put in a graduated 10 ml cylinder. Then the base of each of the cylinders were tapped continuously until decreasing level of the composite sample ceased filling the 10 ml mark. The BD of the samples was determined as the weight-per-volume (wpv) of composite flour mix (g/cm^{3}) as shown in the "Eq. (4)"

$$Bulk \; density = \frac{Weight \; of \; sample}{Volume \; of \; sample} \quad (4)$$

2.3.5. Water absorption capacity

Water absorption capacity of the composite flour – starch samples were calculated using the methods described by (Sathe et al., 1982). A 1 g of composite flour mix was mixed with 10 ml distilled water for 5 minutes using a magnetic stirring machine. The mix was then centrifugated at 3,500 rpm for about 30 minutes and the supernatant volume was recorded. Water absorption capacity was determined using the "Eq. (5)"

$$WAC = \frac{Volume\ of\ distilled\ water}{Weight\ of\ sample\ used} X \frac{100}{1} (5)$$

2.3.6. Oil absorption capacity

The Oil absorption capacity of the flour – starch composite was evaluated with the method described by (Sathe et al., 1981). A 1 g of the composite flour sample was weighed and 10 ml vegetable oil having a known density of 0.99 mg/ml was mixed with the sample mix. The mix was then stirred with a magnetic stirring machine at 1,000 rpm for about 5 mins. The composite flour mix was then centrifugated at 3,500 rpm for about 30 minutes and the supernatant volume was recorded with a graduated 10 ml measuring cylinder. The OAC was calculated using "Eq. (6)"

$$OAC = \frac{Volume\ of\ oil\ absorbed\ X\ Density}{Weight\ of\ sample\ used} X \frac{100}{1} (6)$$

2.3.7. Solubility, swelling power and volume

The solubility, swelling power and volume of the flour – starch mix were evaluated with the methods reported by (Hirch & Kokini, 2002). The samples were filled in labelled graduated tubes and centrifugated. The resultant solution was then stirred, heated to 95°C in a water bath while the composite flour sample is shaken gently to make sure that the granules of the starch remain suspended until it gelatinizes. Then the gelatinized composite flour – starch samples were maintained at a temperature of 95°C in water bath for about 1 hr. The composite flour – starch samples were then cooled by passing through running tap between a temperature of 25 to 28^0C and then centrifugated for about 30 minutes at a speed of 1000 rpm. After centrifugation was done, the swelling volume of the composite flour was determined by recording the volume of the swell sediments left in the tube. Then the supernatants were separated from the swell sediment, and then put in a metal plate and weighted, again it was dried at the temperature of 105°C for 1 hour, reweighed and dried all over. The composite flour solubility, swelling power and volume were calculated with the "Eq. (7)" and "(8)" respectively.

$$Swelling\ power \wedge volume = \frac{Weight\ of\ swollen\ sediments}{Weight\ of\ dried\ starch} (7)$$

$$Solubility = \frac{Weight\ of\ dry\ supernatant}{Weight\ of\ composite\ flour\ sample} X \frac{100}{1} (8)$$

2.3.8. Viscosity

The Viscosity of the composite flour was determined using a viscometer of the model LvDv I+, Brookfield, USA., with the method described by (AOAC, 2005). The temperature of the gelatinized composite flour sample was raised and then positioned in the viscometer in which the spindle was dipped in a beaker base. The spindle was pre – set to run at the speed rate of 10, 20, 50 and 100 rpm and the readings were recorded as it speeds. This method was replicated for the composite flour - starch samples at the temperature of 10, 20, 30, 60 and 80°C respectively.

3. Result and Discussion

3.1. Physicochemical properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava

The result obtained for the physicochemical properties of the flour – starch mix were presented in Table 1.

3.1.1. pH

The pH value of the samples ranges from 5.66 – 7.44 (Table 1). Run 80:10:10 (80 g wheat flour; 10 g African yam bean starch; 10 g cassava starch blends) had the lowest mean score for pH while run 85.5:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch blends) had the highest mean score. The analysis of variance of the model is presented in Table 2. The linear effect of wheat flour ($7.46\,x_1$), African yam bean starch ($6.38\,x_2$) and cassava starch ($5.81\,x_3$) significantly ($p<0.05$) increased the pH of the mix. The model is significant ($p <0.0001$) with non-significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.9314 with the adjusted R^2 >0.7 with the adequate precision ratio >4 indicating adequate model signal. The 3D response plot showing the effect of pH on the linear mixture components is represented in Fig. 1. The final significant ($p<0.05$) model equation (actual components) is given in "Eq. (9)".

$$pH = 7.46\,x_1 + 6.38\,x_2 + 5.81\,x_3$$
(9)

The pH of substances is defined the extent of alkalinity or acidity of that material. Composite flour - starch pastes from chemical modification by cross-linking have been found to have improved resistance to breaking with higher cooking period with increased acidity or shear rates (Langan, 1986). There was increase in the pH of the flour – starch mix for the modification with sodium acetate respectively which is in line with the reported work by (Akpa & Dagde, 2012). The pH of flour – starch mix obtained tend to increase towards neutrality which indicates that the flour mix is suitable for use in the industries where usually the pH change in products is not desired.

3.1.2. Least gelation concentration

The least gelation concentration of the mix ranged from 6 to 8.84 % (m/v). Run 80:15:5 (80 g wheat flour; 15 g African yam bean starch; 5 g cassava starch blends) had the lowest mean score for least gelation concentration parameter while run 85:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch) had the highest mean score (Table 1). The analysis of variance of the model is presented in Table 2. The linear effect of wheat flour ($8.90\,x_1$), African yam bean starch ($6.01\,x_2$) and cassava starch ($6.81\,x_3$) significantly ($p<0.05$) increased the gelation of the mix. The binary effect of wheat flour and African yam bean ($-1.59\,x_1 x_2$), wheat flour and cassava starch ($-2.40\,x_1 x_3$), African yam bean starch and cassava starch ($-1.39\,x_2 x_3$) significantly ($p<0.05$) decreased the least gelation concentration.

Table 1: Three components D – optimal mixture design generated for the modelling and optimization of the physicochemical properties of wheat

	Independent variables			Dependent variables										
Design points	x_1 (g)	x_2 (g)	x_3 (g)	pH	LGC (% m/v)	Gelation temp (^{0}C)	Moisture (%)	Bulk density (g/cm^3)	WAC (mL/g)	OAC (mL/g)	Swelling power (%)	Specific volume (%)	Solubility (%)	Viscosity (cp)
1	80.00	10.00	10.00	5.66±0.89	6.80±1.48	70.00±0.05	4.79±2.04	0.46±1.02	62.11±0.91	68.44±1.62	4.75±0.59	3.00±2.17	36.70±0.70	16.85±0.12
2	80.83	10.83	8.34	6.10±0.74	6.70±1.56	69.00±0.01	4.82±1.07	0.47±0.04	61.80±1.42	66.60±0.74	4.85±0.93	3.35±1.14	40.38±0.62	16.50±0.22
3	85.00	10.00	5.00	7.44±0.93	8.84±1.48	60.00±0.00	3.90±1.24	0.52±2.06	74.42±1.20	77.50±0.58	4.95±0.31	4.00±1.24	42.10±1.37	26.25±0.54
4	82.50	10.00	7.50	6.81±1.05	7.20±1.81	64.50±0.06	4.81±1.48	0.47±0.05	68.32±1.03	70.92±0.26	3.00±0.22	2.85±0.78	55.22±0.02	20.80±0.07
5	82.50	12.50	5.00	6.94±0.41	7.10±1.04	64.50±0.03	4.81±1.52	0.49±1.01	68.70±1.07	70.40±0.14	3.35±0.08	3.85±0.09	48.37±2.07	20.90±0.24
6	80.00	13.50	6.50	6.23±1.02	6.41±1.22	72.00±0.17	4.05±1.67	0.47±0.86	62.87±1.51	68.11±0.93	1.15±0.01	2.00±0.04	62.50±0.08	20.45±0.33
7	80.83	13.33	5.84	6.37±0.32	6.30±1.37	68.00±0.04	3.95±1.82	0.46±1.78	61.00±1.04	66.00±0.17	8.05±0.19	5.35±2.09	45.59±0.10	16.25±0.46
8	82.50	12.50	5.00	6.70±0.61	7.03±1.93	66.00±0.05	3.98±2.18	0.45±0.07	68.90±0.71	71.33±0.45	7.15±0.04	5.15±1.30	49.40±1.71	15.85±0.57
9	81.67	11.67	6.66	6.50±0.49	6.90±1.52	64.50±0.10	3.97±1.02	0.44±0.03	60.56±0.08	62.11±0.88	5.45±0.82	4.15±1.45	39.20±1.86	18.80±1.23
10	80.00	12.50	7.50	6.34±0.85	5.98±1.08	69.50±0.07	3.86±0.86	0.43±2.10	62.65±0.47	69.90±1.28	4.25±0.09	3.50±0.28	35.19±1.19	16.40±1.42
11	81.00	13.50	5.50	6.44±0.94	6.19±0.78	68.00±0.00	4.20±1.74	0.43±1.23	63.90±1.83	68.90±0.37	4.20±0.15	3.30±0.36	28.51±0.87	18.20±0.16
12	83.33	10.83	5.84	7.10±1.24	7.92±1.84	63.50±0.09	4.83±0.92	0.48±1.30	71.48±0.09	73.29±1.78	3.15±0.03	2.85±2.03	56.90±0.47	22.75±0.39
13	80.00	15.00	5.00	6.49±0.57	6.00±0.55	70.50±0.05	4.30±1.03	0.45±0.09	61.96±0.21	67.90±0.64	8.10±0.95	5.75±1.72	38.30±1.05	15.55±1.04

14	84.50	10.00	5.50	7.34±0.78	8.39±1.67	62.00±0.01	4.84±1.29	0.50±1.06	72.31±2.07	74.25±2.18	6.35±0.05	4.75±1.26	48.20±0.60	24.75±0.58

Table 1: Three components D – optimal mixture design generated for the modelling and optimization of the physicochemical properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava mix

x_1- Wheat flour (%); x_2- *African yam bean* starch (%); x_3- cassava starch (%); LGC- least gelation concentration (% m/v); Gelation temp- gelation temperature (^{0}C) WAC- water absorption capacity (mL/g); OAC- oil absorption capacity (mL/g).

The ternary effect of wheat flour and African yam bean starch $(5.82 x_1 x_2 (x_1 - x_2)$, African yam bean and cassava starches $(4.46 x_2 x_3 (x_2 - x_3)$ increased the least gelation concentration significantly (p<0.05). The model is significant (p = 0.0002) with non-significant (p>0.05) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.9957 with the adjusted R^2 >0.7 with the adequate precision ratio >4 indicating adequate model signal. The 3D response plot showing the effect of LGC on the linear mixture components is represented in Fig. 1. The final significant (p<0.05) model equation (actual components) is shown in "Eq. (10)".

$$LGC = 8.90 x_1 + 6.01 x_2 + 6.81 x_3 - 1.59 x_1 x_2 - 2.40 x_1 x_3 - 1.3$$

The study reported by Sathe et al. (1982) found the relationships in the variations of the gelling capacity of different type of flour mix to different proportions of carbohydrate, protein and ethyl extract that forms the flour – starch building blocks. Interaction in between these variables had a major role in the functional properties affecting gelation of the composite flour - starch. When high values of the least gelation capacity were gotten, then the variables were neither high nor low (Awolu et al., 2017).

3.1.3. Gelation temperature

The gelation temperature (GT) of the samples ranged from 60 ^{0}C – 72 ^{0}C (Table 1). Run 85:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch blends) had the lowest mean value for gelation temperature while run 80:13.5:6.5 (80 g wheat flour; 13.5 g African yam bean starch; 5.6 g cassava starch mix) had the highest mean value. The analysis of variance of the model for gelation temperature is presented in Table 2. The linear effect of wheat flour ($60.04 x_1$), African yam bean starch $(70.37 x_2)$ and cassava starch $(69.79 x_3)$ significantly (p<0.05) increased the gelation temperature of the mix. The model is significant (p<0.0001) with non-significant (p>0.05) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.9271 with the adjusted R^2 of 0.9138 with the adequate precision ratio >4 indicating adequate model signal. The 3D response plot showing the effect of GT on the linear mixture components is represented in Fig. 1. The final significant (p<0.05) model equation (actual components) is given in "Eq. (11)".

$$¿ = 60.04 x_1 + 70.37 x_2 + 69.79 x_3 (11)$$

The range of gelation temperature obtained in the study agreed with the range of 69 – 79 ^{0}C obtained by (Akpa & Dagde, 2012), who researched on the modification of cassava starches used in industries. The modification of composite flour/ starches with cross-linking method is likely to include inter and intramolecular bonding at randomized regions in the starch matrix that stabilize and strengthens the matrices (Acquarone & Rao, 2003). Therefore, modification of flour – starch mix using cross linking improved the gel temperature of modified starches.

3.1.4. Moisture content

The moisture content of the composite flour varied from 3.86 – 4.84 % (Table 1). Run 80:12.5:7.5 (80 g wheat flour; 12.5 g African yam bean starch; 7.5 g cassava starch mix) had the lowest mean score while sample 84.5:10:5.5 (84.5 g wheat flour; 10 g African yam bean starch; 5.5 g cassava starch blends) had the highest mean score. The analysis of variance of the moisture content is presented in Table 2. The linear effect of wheat flour ($4.27 x_1$), African yam bean starch ($4.28 x_2$) and cassava starch ($4.84 x_3$) significantly (p<0.05) increased the moisture content of the mix, the binary effect of the wheat flour and cassava starch ($-1.76 x_1 x_3$), African yam bean and cassava starches ($-2.71 x_2 x_3$) decreased the moisture content of the mix significantly (p<0.05). The model is significant (p = 0.0279) with non-significant (p>0.05) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.8397 with the adjusted R^2 >0.7 with the adequate precision ratio >4 indicating adequate model signal. The 3D response plot showing the effect of moisture content on the linear mixture components is represented in Fig. 1. The final significant (p<0.05) model equation (actual components) is shown in "Eq. (12)".

$$\textit{Moisture content} = 4.27 x_1 + 4.28 x_2 + 4.84 x_3 - 1.76 x_1 x_3 - 2.71 x$$

The moisture content reported in the study is much lower than the moisture content of the flour mix reported by (Okoye et al., 2017), who investigated the chemical composition and functional properties of sorghum and African yam bean flour mix and found the range of 9.68% - 14.78% indicating that the keeping quality of the flour in this study comparable to the later.

3.1.5. Bulk density

The bulk density of the composite flour – starch samples oscillated from 0.43 g/ cm^3 – 0.52 g/ cm^3 (Table 1), with runs 81:13.5:5.5 (81 g wheat flour; 13.5 g African yam bean starch; 5.5 g cassava starch mix) and 80:12.5:7.5 (80 g wheat flour; 12.5 g African yam bean starch; 7.5 g cassava starch blends) having the lowest mean scores (0.43 g/cm^3) for bulk density, while run 85:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch mix) had the highest mean score (0.52 g/cm^3). The linear effect of wheat flour ($0.50\,x_1$), African yam bean starch ($0.44\,x_2$) and cassava starch ($0.45\,x_3$) significantly ($p<0.05$) increased the bulk density of the mix (Table 2). The linear model is significant ($p = 0.0084$) with non-significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.9806 with the adjusted R^2 of 0.9043 with the adequate precision ratio of 7.5039 which indicate model adequacy. The 3D response plot showing the effect of bulk density on the linear mixture components is represented in Fig. 2. The final significant ($p<0.05$) model equation (actual components) is given in “Eq. (13)”.

$$Bulk\ density = 0.50\,x_1 + 0.44\,x_2 + 0.45\,x_3 \quad (13)$$

Bulk density was reported to be a product of the particle size because the size of the granule is inversely proportional to bulk density (Onimawo & Akubor, 2012). It was also found that bulk density is affected by starch polymer matrix and often the loose starch polymer structure may result into low bulk density (Malomo et al., 2012). High bulk density is nevertheless desired for dispersibility with easiness and diminution in paste thickness (Amandikwa, 2012), and in the other hand, low bulk density of composite flour – starch samples is a better physical attribute when evaluating its transport and storage.

Table 2: Regression equation coefficients for the modelling and optimization of the physicochemical properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava mix

Coefficients	Dependent variables										
	pH	LGC (% m/v)	Gelation temp (^{0}C)	Moisture (%)	Bulk density (g/ cm^3)	WAC (ml/ g)	OAC (ml/ g)	Swelling power (%)	Specific volume (%)	Solubility (%)	Viscosity (cp)
Linear											
x_1	7.46293*	8.89544*	60.0368*	4.267*	0.503188*	74.041*	77.2184*	4.94554*	4.11178*	45.2443*	24.8451*
(p-values)	< 0.0001	< 0.0001	< 0.0001	0.0183	0.0084	< 0.0001	0.0029	0.0317	0.0400	0.0262	0.0013
x_2	6.38087*	6.01346*	70.3704*	4.28121*	0.439764*	62.2391*	67.9835*	5.87193*	4.60089*	38.6398*	15.8193*
(p-values)	< 0.0001	< 0.0001	< 0.0001	0.0183	0.0084	< 0.0001	0.0029	0.0317	0.0400	0.0262	0.0013
x_3	5.80504*	6.81443*	69.7916*	4.8355*	0.452928*	62.3444*	68.484*	3.55491*	2.47623*	37.4638*	16.944*
(p-values)	< 0.0001	< 0.0001	< 0.0001	0.0183	0.0084	< 0.0001	0.0029	0.0317	0.0400	0.0262	0.0013
Binary											
$x_1 x_2$	-	-1.58761*	-	0.259433	-	3.68298	-4.324	-	-	24.7142	-
(p-values)		0.0166		0.8434		0.4086	0.5567			0.3793	
$x_1 x_3$	-	-2.40291*	-	-1.76168*	-	0.817679	-7.15662	-	-	66.0545	-
(p-values)		0.0089		0.0201		0.8821	0.4498			0.1047	
$x_2 x_3$	-	-1.39354*	-	-2.70735*	-	2.58332	3.4472	-	-	4.61195	-
(p-values)		0.0448		0.0145		0.6021	0.6776			0.8861	
Ternary											
$x_1 x_2 x_3$	-	8.14344	-	-	-	-269.957*	-161.084*	-	-	-231.566	-
(p-values)		0.0560				0.0316	0.0189			0.2921	
$x_1 x_2 (x_1 - x_2)$	-	5.82462*	-	-	-	-	-	-	-	260.779*	-
(p-values)		0.0114								0.0339	
$x_1 x_3 (x_1 - x_3)$	-	-2.33849	-	-	-	-	-	-	-	-99.6123	-
(p-values)		0.1787								0.3296	
$x_2 x_3 (x_2 - x_3)$	-	4.45699*	-	-	-	-	-	-	-	248.596*	-
(p-values)		0.0293								0.0415	
R^2	0.9314	0.9957	0.9271	0.8397	0.9806	0.9802	0.8739	0.9384	0.8834	0.8526	0.8010
Adj R^2	0.9189	0.9859	0.9138	0.8220	0.9043	0.9485	0.7658	0.9079	0.8153	0.7521	0.7467

LoF	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.11	1.48	1.56	8.34	3.92	1.63	2.64	3.03	8.95	9.47	9.63
Adeq Precision	25.7059	32.9470	21.5489	4.6682	7.5039	15.3746	9.8691	4.4251	4.5983	4.8324	9.4990
Model	<0.0001	0.0002	<0.0001	0.0279	0.0084	0.0008	0.0072	0.0317	0.0400	0.0364	0.0013

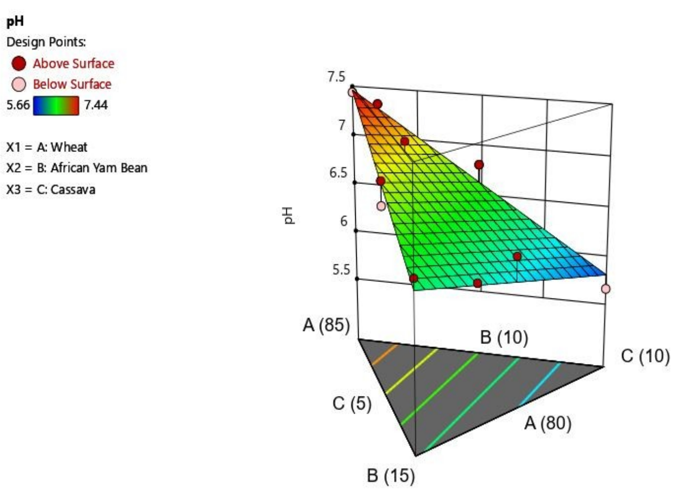
Table 2: Regression equation coefficients for the modelling and optimization of the physicochemical properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava mix

Key: LoF - Lack of fit; * Significant at the 5% confidence interval ($p < 0.05$). NS - Not significant; CV - Coefficient of variation; Adj. – Adjusted; Adeq – Adequate; x_1- Wheat flour (%); x_2- *African* yam bean starch (%); x_3- cassava starch (%); LGC- least gelation concentration (% m/v); Gelation temp- gelation temperature (^{0}C) WAC- water absorption capacity (ml/g); OAC- oil absorption capacity (ml/g)

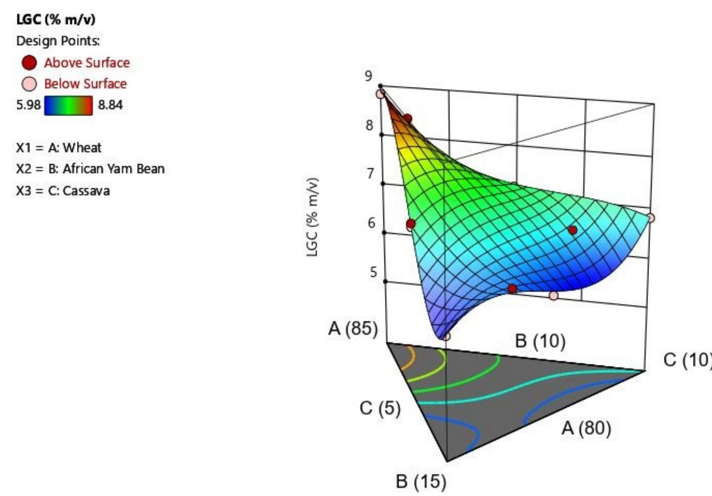
Table 3: Optimization values, predictions and desirability index of the modelling and optimization of the physicochemical properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava mix

S/N	Wheat (g)	African Yam Bean (g)	Cassava (g)	pH	LGC (% m/v)	Gelation temp (^{0}C)	Moisture (%)	Bulk density (g/cm^3)	WAC (ml/g)	OAC (ml/g)	Swelling power (%)	Specific volume (%)	Solubility (%)	Viscosity (cp)	Desirability	
1	84.377	10.623	5.000	7.328	8.840	61.325	4.297	0.495	72.971	75.595	5.061	4.173	68.482	23.720	0.722	Selected
2	84.528	10.422	5.050	7.355	8.840	61.007	4.307	0.497	73.295	75.835	5.010	4.137	62.503	24.004	0.721	

LGC- least gelation concentration (% m/v); Gelation temp- gelation temperature (^{0}C) WAC- water absorption capacity (ml/g); OAC- oil absorption capacity (ml/g)



pH



Least gelation concentration (% m/v)

Figure 1: 3D plots showing the interactive effects of pH, least gelation concentration, gelation temperature and moisture content on the linear mixture components

Bulk density result obtained from the study is low when compared to the mean scores obtained in similar study for flour mix reported by (Okoye et al., 2017) for corn – soybean starch/ flour composite blend who obtained the mean values (0.92 - 0.97 g/ml), also lower than the mean values (0.94 – 0.98g/ml) reported by (Okoye et al., 2017) for sorghum/African yam bean blends starch mix.

3.1.6. Water absorption capacity

The Water absorption capacity (WAC) of the composite flour varied from 61 ml/g – 74.42 ml/g (Table 1). Run 80.83:13.33:5.84 (80.83 g wheat flour; 13.33 g African yam bean starch; 5.84 g cassava starch mix) had the lowest mean value while run 85:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch mix. The linear effect of wheat flour ($74.04\,x_1$), African yam bean starch ($62.24\,x_2$) and cassava starch ($62.34\,x_3$) significantly ($p<0.05$) increased the water absorption capacity (Table 2). The ternary effect of wheat flour, African yam bean and cassava $(-269.96\,x_1 x_2 x_3)$ reduced the water absorption capacity significantly ($p<0.05$). The model is significant ($p = 0.0008$) with non significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.9802 with the adjusted R^2 >0.7 with the adequate precision ratio of 15.37 indicating an adequate signal. The 3D response plot showing the effect of WAC on the linear mixture components is represented in Fig. 2. The final significant ($p<0.05$) model equation (actual components) is given in "Eq. (14)".

$$WAC = 74.04\,x_1 + 62.24\,x_2 + 62.34\,x_3 - 269.96\,x_1 x_2 x_3 \quad (14)$$

Water absorption capacity shows the capacity of the starch granule to anneal with moisture in conditions where moisture is a restricting factor such as in dough and pastes productions (Awolu et al., 2017). Water absorption capacity also is important in the production of convenience foods. It was reported that a high-water absorption capacity ensures adhesiveness of the product (Houson & Ayenor, 2002). The WAC obtained in the study were relatively high and this can be attributed to the macro molecule matrix destruction which have the ability to absorb and entrap water during food processing (Chen & Lin, 2002). Increased water absorption capacity (WAC) of the composite flour blends will be useful in the production of sausages and pastries. The water absorption capacity obtained in this study is high when compared to those from native starches as the mean varied from of 13.72 – 16.42 ml/g reported by (Okoye et al., 2017), for unmodified starches were apparently low.

Figure 2: 3D plots showing the interactive effects of bulk density, water absorption capacity, oil absorption capacity and swelling power on the linear mixture components

3.1.7. Oil absorption capacity

The Oil absorption capacity (OAC) of the composite flour samples ranged from 66ml/g – 77.5ml/g, in which run 80.83:13.33:5.84 (80.83 g wheat flour; 13.33 g African yam bean starch; 5.84 g cassava starch mix) had the lowest mean value, while run 85:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch mix) had the highest mean score for oil absorption capacity (Table 1). The linear effect of wheat flour ($77.22\,x_1$), African yam bean starch ($67.98\,x_2$) and cassava starch ($68.48\,x_3$) increased the oil absorption capacity significantly ($p<0.05$) (Table 2). The ternary effect of wheat flour, African yam bean starch and cassava starch $(-161.08\,x_1 x_2 x_3)$ reduced the oil absorption capacity significantly ($p<0.05$). The model is significant ($p = 0.0072$) with non significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.8739 with the adjusted R^2 of 0.7658 with the adequate precision ratio >4 indicating an adequate signal. The 3D response plot showing the effect of OAC on the linear mixture components is represented in Fig. 2. The final significant ($p<0.05$) model equation (actual components) is given in "Eq. (15)".

$$OAC = 77.22\,x_1 + 67.98\,x_2 + 68.48\,x_3 - 161.08\,x_1 x_2 x_3 \quad (15)$$

Flours with good oil absorption capacity are useful in the production of piecrust mixes and pastries (Okoye et al., 2017). Oil absorption capacity represents mainly oils that are physically entrapped. It is also a representation of the extent to which lipid is bound with protein in food profiles (Onimawo & Akubor, 2012). The Oil absorption capacity is beneficial in food formulations such as pastries and sausages (Awolu et al., 2017). Fat acts as a shortening agent and a flavour retainer which also improves the food mouth. Fat also boasts the leavening ability of baking powders in batters and contributes to the most baked product texture characteristics (Awolu et al., 2017). The oil absorption capacity obtained in this study is higher those of the native starches at the range of 6.48 – 8.86 ml/g reported by (Okoye et al., 2017), for starches mix were apparently low.

3.1.8. Swelling power

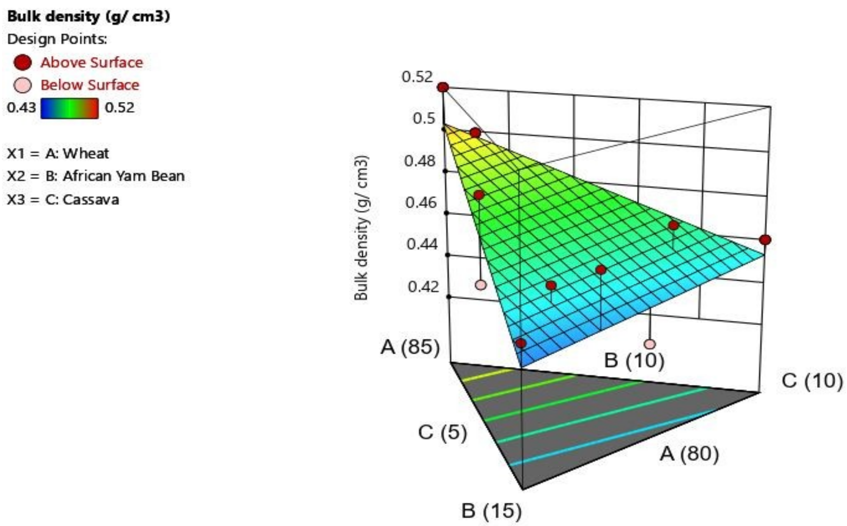
The swelling power of flour mix varied from 1.15 to 8.1 % (Table 1). Run 80:13.5:6.5 (80 g; wheat flour; 13.5 g African yam bean starch; 6.5 g cassava starch blends) had the lowest man value while run 80:15:5 (80 g wheat flour; 15 g African yam bean starch; 5 g cassava starch mix) had the highest mean scores for swelling power. The linear effect of wheat flour ($4.95\,x_1$), African yam bean starch ($5.87\,x_2$) and cassava starch ($3.56\,x_3$) significantly ($p<0.05$) increased the swelling power of the mix (Table 2). The model is significant ($p = 0.0317$) with non-significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.9384 with the adjusted R^2 >0.7 with the adequate precision ratio of 4.4251 showed adequate signal. The 3D response plot showing the effect of swelling power on the linear mixture components is represented in Fig. 2. The final significant ($p<0.05$) model equation (actual components) is given in “Eq. (16)”.

$$\textit{Swelling power} = 4.95\,x_1 + 5.87\,x_2 + 3.56\,x_3 \quad (16)$$

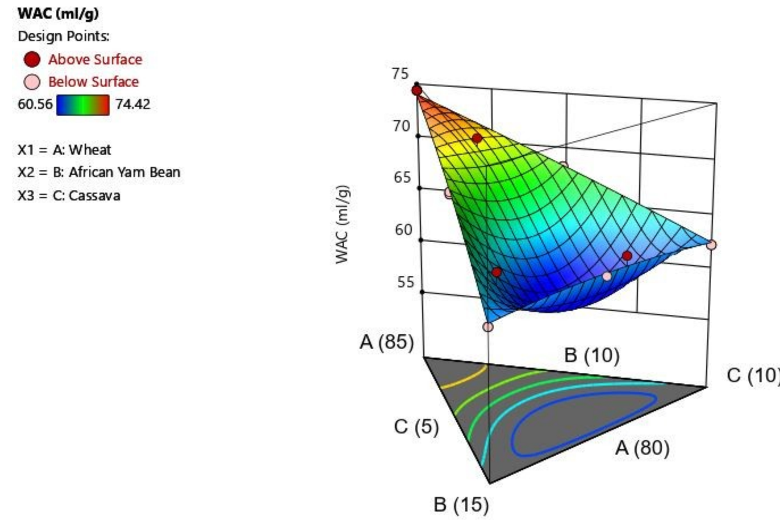
Swelling power is a function of loose particles contained in the starch which tend to rapidly absorb water. The composite flour – starch matrix gels continuously as it rapidly absorbs moisture (Gunarantne & Corke, 2007).

3.1.9. Swelling power

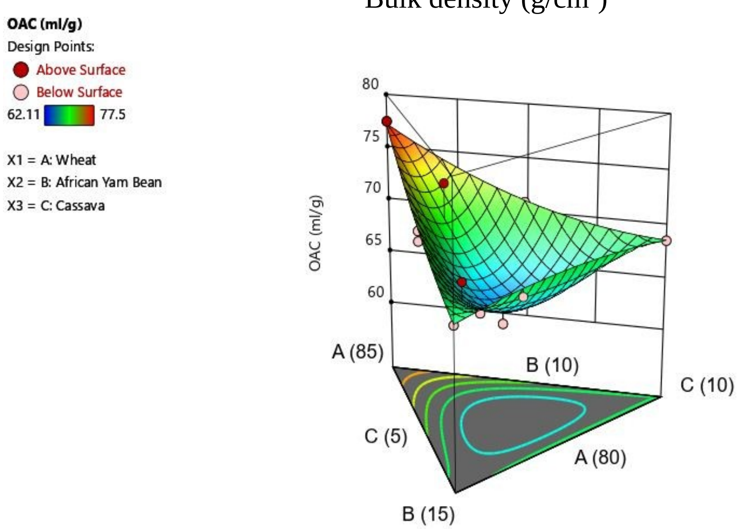
The specific volume of the mix oscillated from 2 – 5.75 % (Table 1). Run 80:13.5:6.5 (80 g wheat flour; 13.5 g African yam bean starch; 6.5 g cassava starch blends) had the lowest mean value, while run 80:15:5 (80 g wheat flour; 15 g African yam bean starch; 5 g cassava starch mix) had the highest mean scores for swelling volume (5.75 %).



Bulk density (g/cm^3)



Water absorption capacity (ml/ g)



Oil absorption capacity (mL/g)

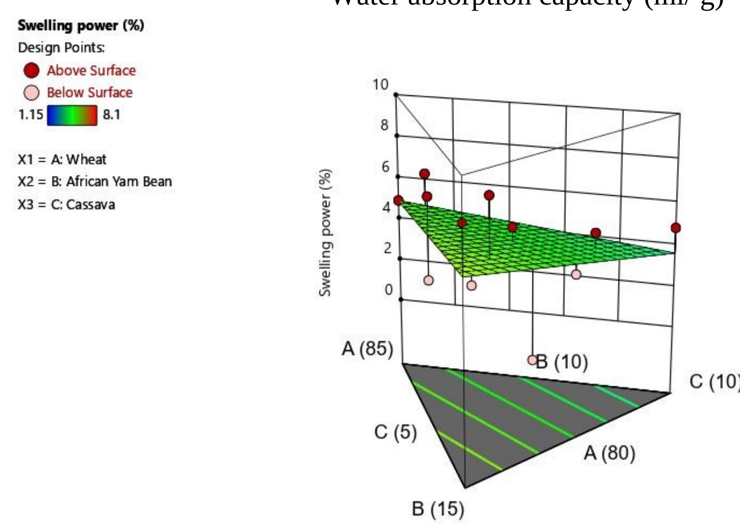


Figure 2: 3D plots showing the interactive effects of bulk density, water absorption capacity, oil absorption capacity and swelling power on the linear mixture components

The linear effect of wheat flour ($4.11\,x_1$), African yam bean starch ($4.60\,x_2$) and cassava starch ($2.48\,x_3$) significantly ($p<0.05$) increased the swelling volume of the mix (Table 2). The linear model is significant (p = 0.0400) with non-significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.8834 with the adjusted $R^2>0.7$ with the adequate precision ratio of 4.5983 which indicate model adequacy. The 3D response plot showing the effect of specific volume on the linear mixture components is represented in Fig. 3. The final significant ($p<0.05$) model equation (actual components) is given in “Eq. (17)”.

$$\textit{Specific volume}=4.11\,x_1+4.60\,x_2+2.48\,x_3 \quad (17)$$

Generally, other root crops like cocoyam samples display better swelling indices when compared to cassava (Ojinaka et al., 2009).

3.1.10. Solubility

The solubility of flour – starch mix varied from 28.51 to 62.5 % (Table 1), with runs 81:13.5:5.5 (81 g wheat flour; 13.5 g African yam bean starch; 5.5 g cassava starch mix) had the lowest mean scores (28.51 %), while run 80:13.5:6.5 (80 g wheat flour; 13.5 g African yam bean starch; 6.5 g cassava starch blends) had the highest mean score (62.5 %). The linear effect of wheat flour ($45.24\,x_1$), African yam bean starch ($38.64\,x_2$) and cassava starch ($37.46\,x_3$) significantly ($p<0.05$) increased the solubility (Table 2). The ternary effect of the wheat flour and African yam bean starch ($260.78\,x_1x_2(x_1-x_2)$), African yam bean and cassava starches ($248.60\,x_2x_3(x_2-x_3)$) also significantly ($p<0.05$) increased the solubility of the mix. The ternary model is significant (p = 0.0364) with non-significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.8526 with the adjusted R^2 of 0.7521 with the adequate precision ratio of 4.8324 which indicate model adequacy. The 3D response plot showing the effect of solubility on the linear mixture components is represented in Fig. 3. The final significant ($p<0.05$) model equation (actual components) is given in “Eq. (18)”.

$$\textit{Solubility}=45.24\,x_1+38.64\,x_2+37.46\,x_3+260.78\,x_1x_2(x_1-$$

Cross-linking also was found to decrease the solubility of flour mix from variant sources (Hoover & Sosulski, 1986). The solubility of the flour mix is the ability of the water to bind or the ability of the flour mix to bind because the matrix has not been disrupted, beaten or rasped. Increased solubility of chemically modified starches with sodium acetate was demonstrated to show increased randomness in the matrix of the flour – starch and the bursting of the starch matrix as reported by (Akpa & Dagde, 2012).

3.1.11. Viscosity

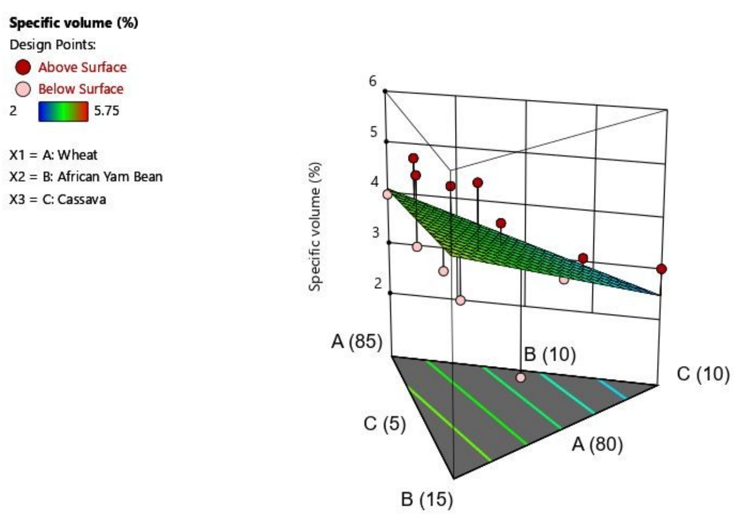
The viscosity of the samples ranged from 15.55 – 26.25cp (Table 1). Run 80:15:5 (80 g wheat flour; 15 g African yam bean starch; 5 g cassava starch mix) had the lowest mean value, while run 85:10:5 (85 g wheat flour; 10 g African yam bean starch; 5 g cassava starch mix) had the highest mean score. The linear effect of wheat flour ($24.85\,x_1$), African yam bean starch ($15.82\,x_2$) and cassava starch ($16.94\,x_3$) significantly ($p<0.05$) increased the viscosity with wheat flour contributing more to the effect followed by African yam bean starch while cassava starch had the least contribution for viscosity as represented in Table 2. The model showed significance (p = 0.0013) with non-significant ($p>0.05$) lack-of-fit relative to the pure error. The fit statistics had R^2 of 0.8010 with the adjusted $R^2>0.7$ with the adequate precision ratio >4 which indicate adequate signal. The 3D response plot showing the effect of viscosity on the linear mixture components is represented in Fig. 3. The final significant ($p<0.05$) model equation (actual components) is given in “Eq. (19)”.

$$\textit{Viscosity}=24.85\,x_1+15.82\,x_2+16.94\,x_3 \quad (19)$$

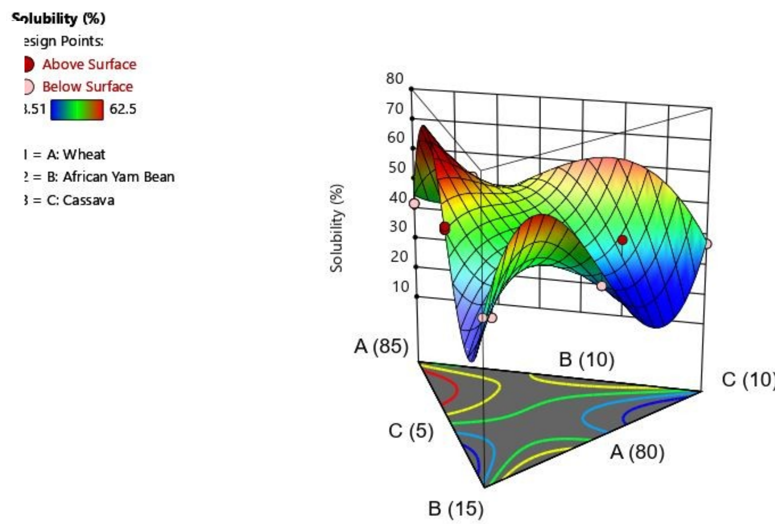
The viscosity of the substance can be defined as the increased flow restrictions which increases with decreasing the rate of temperature and also decreasing as the rate of temperature increases (Coulson & Richardson, 2004). The improved viscosity obtained from the flour – starch mix could be attributed to the breaking down of the starch and protein structural networks due to heat during processing of food (Aboubacar & Hamaker, 1999). The high viscosity of the composite flour blends will contribute as a good stabilizing and gelling agents in the production of desserts and chopping. The viscosity of starch paste can be increased or reduced using chemical modifications that are suitable (Agboola et al., 1990). The results obtained in the study depicted that cross-linking chemical modification reduced the velocity of native starches improving it.

3.2. Optimization of the physicochemical properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava

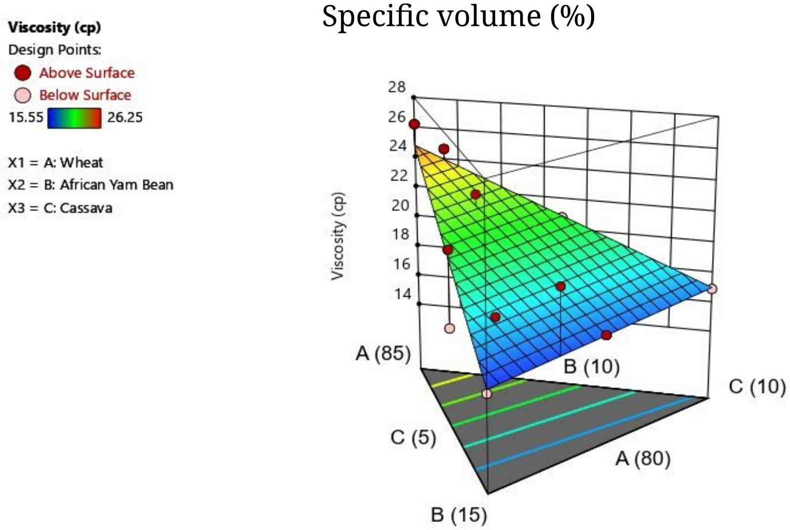
The optimization of adequate responses of the flour – starch mix was evaluated using numerical optimization generated from Design Expert software (Version 12.0.10, Stat-Ease, Inc., Minneapolis, USA). The optimization used the desirability function ranked between 0 and 1 scale which shows the closeness of a dependent response to its ideal value; if the dependent response ranks within the unacceptable intervals, the desirability value is zero (0), also if the response falls within 0.5, the desirability is in neutrality (neither accepted nor rejected) and finally, if the response falls within the ideal intervals or the response reaches the ideal value, the desirability is one (1) as reported by Elemuo and Obasi (2022). The goal of the optimization focused on maximizing the desirable responses (dependent variables) and reducing the undesirable responses where the goals, lower-limit, upper-limit, lower-weight, upper-weight and importance were pre-set for both the dependent and independent variables. The optimal values (Wheat flour: 84.38 g, African yam bean starch: 10.62 g, cassava starch: 5 g: pH: 7.33, least gelation concentration: 8.84 % m/v, gelation temperature: 61.33 ^{0}C, moisture: 4.30 %, bulk density: 0.50 g/cm^3, water absorption capacity: 72.97 ml/g, oil absorption capacity: 75.60 ml/g, swelling power: 5.06 %, specific volume: 4.17 %, solubility: 68.48 % and viscosity: 23.72 cp) was generated (Table 3) with desirability index of 0.72 (Fig. 3).



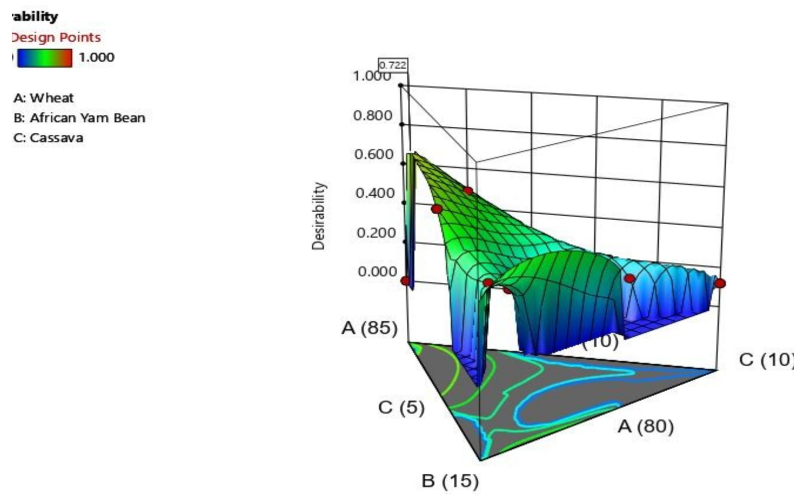
Specific volume (%)



Solubility (%)



Viscosity (Cp)



Desirability (0.72) of the enhanced flour – starch mix

Figure 3: 3D plots showing the interactive effects of specific volume, solubility and viscosity on the linear mixture components and its desirability index

4.0. Conclusion

D – optimal mixture design of response surface methodology (RSM) showed adequate signal in the modelling and optimization of the functional properties of wheat flour enhanced with chemically modified starches from African yam bean and cassava. The optimization of the dependent variables of the functional properties of the wheat flour – starch mix (pH, least gelation concentration, gelation temperature, moisture, bulk density, water absorption capacity, oil absorption capacity, swelling power, specific volume, solubility and viscosity) showed adequate models. The 3D response surface plotted the linear, binary and ternary effects of the wheat flour, African yam bean and cassava starches. Diagnostic correlations of the predicted and actual values were used to validate the adequate models. The optimized blends selected were 84.38 g of wheat flour, 10.62 g of African yam bean starch, and 5 g of cassava starch with the 3D desirability index plot of 0.72 (Fig. 3) which is the suggested optimized blend with improves responses. The beneficiaries of the developed models would be processors seeking an enhanced baking products with a legume-based starch and wheat flour portion partially replaced.

Declaration Statement

The authors agreed with total interest to submit the manuscript entitled, 'Modelling and optimization of physicochemical Properties of wheat flour and chemically modified African yam bean – cassava starch blends' for publication in your reputable Institution without conflict of interest be it design and implementation, respect towards society, resources and research output and conduct without deceptive acts.

Conflict of Interest

The authors declare no conflict of interest**.**

Author Contribution

Godswill Kodili Elemuo: Writing – original draft, Methodology.
Nneoma Elechi Obasi: Supervision, Investigation, Conceptualization. Anselm O. Uzochukwu: Writing – review & editing, Supervision, Methodology. Abimbola Uzomah: Writing – review & editing, Resources. Euphresia Nkeiru Odimegwu: Formal analysis.

Acknowledgements

We acknowledge Grifeon Projects Limited for aiding the team with their conducive laboratory space to carry out this research.

Nomenclature

LoF= Lack of fit
Adeq. = Adequate
Adj. = Adequate

References

Aboubacar A., & Hamaker, B.R. (1999). Physicochemical properties of flours that related to sorghum viscous quality. *Journal of Cereal Chemistry,* 76, 308 – 313.

Achinewhu, S.C., & Akah, G.N. (2003). Chemical, functional and sensory properties of African yam bean (*Sphenostylis stenocarpa*) and cowpeas (*Vigna uniguiculata*). *Plant Food for Human Nutrition,* 11, 71 – 81.

Acquarone, V. M., & Rao, M. A. (2003). Influence of sucrose on the rheology and granule size of cross-linked waxy maize starch dispersions heated at two temperatures. *Carbohydrate Polymers*, 51(4), 451 – 458.

Agboola, S. O., Akingbala, J. O., & Oguntimehin, G. B. (1990). Production of low substituted cassava starch acylates and citrates. *Starches* 43 (1), 13 – 15.

Akpa, J. G., & Dagde, K. K. (2012). Modification of Cassava Starch for Industrial Uses. *International Journal of Engineering and Technology*, 2 (2), 3 – 10.

Amandikwa, C. (2012). Proximate and functional properties of open air, solar and oven dried cocoyam flour. *International Journal of Agriculture and Rural Development* 15(2), 988 – 994.

Association of Official and Analytical Chemists (2005). Official methods of analysis (18th ed.). AOAC International.

Awolu, O.O., Oyebanji, O.V., & Sodipo, M.A. (2017). Optimization of proximate composition and functional properties of composite flours consisting wheat, cocoyam *(Colocasia esculenta)* and bambara groundnut *(Vigna subterranea)*. *International Food Research Journal,* 24(1), 268 – 274.

Bertolini, A.C., Mestres, C., Lourdin, D., Della Valle, G., & Colonna, P. (2001). Relationship between thermomechanical properties and baking expansion of sour cassava starch (*Polvilho azedo*). *Journal of Science, Food and Agriculture,* 81, 429-435.

Chen, M.J., & Lin, C.W. (2002). Factors affecting the water-holding capacity of fibrinogen, plasma protein gels optimized by response surface methodology, *Journal of Food Sciences*, 67, e2579.

Coulson, J. M., & Richardson, J. F. (2004). Chemical Engineering, Vol. 1 (6^{th} Eds.), Butterworth – Heinemann, Woburn, M. A.

Elemuo, G.K.., & Obasi, N. E. (2022). Evaluation and optimization of the physical and sensory properties of enhanced bread produced from wheat flour and chemically modified African yam bean and cassava starches, International Journal of Research and Scientific Innovation, 9(4), 110 – 123

Grace, M. R. (1977). Cassava Processing, FAO Plant Production and Protection Series No. 3, 2.

Gunarantne, A., & Corke, H. (2007). Functional properties of hydroxy propylated cross linked tuber and root starches, Cereal Chemistry, 84, 30 – 37.

Hirsch, J. B., & Kokini, J. L. (2002). Understanding the mechanism of cross-linking agents (POCl3, STMP, and EPI) through swelling behavior and pasting properties of cross-linked waxy maize starches, Cereal Chemistry, 79, 102 – 107.

Hoover, R., & Sosulski, F. (1986). Effect of cross-linking on Functional properties of legume starches, Starch, 38(5): 149-155.

Houson, P., & Ayenor, G.S. (2002). Appropriate processing and food functional properties of maize flour. African Journal of Science and Technology 3, 126 – 131.

Kaur, B., Ariffin, F., Bhat, R., & Karim, A. A. (2012). “Progress in starch modification in the last decade,” Food Hydrocolloids, 26(2), 398–404.

Langan, R. E. (1986). Food Industry in Modified Starches. In O. B. Wurzburg (Eds.), Properties and uses (pp. 199 – 212). Boca Raton, Florida, CRC Press.

Malomo, O., Ogunmoyela, O.A.B., Adekoyeni, O.O., Jimoh, O., Oluwajoba, S.O., & Sobanwa, M.O. (2012). Rheological and functional properties of soy-poundo yam flour. International Journal of Food Science and Nutrition Engineering 2(6), 101 – 107.

Maninder, K., Kawaljit, S.S., & Narpinder, S. (2007). Comparative study of functional, thermal and pasting properties of flours from different field pea and pigeon pea cultivars. Food Chemistry 104. 259 – 267.

Moorthy, S. N., Wenhem, J. P., & Blanshard, J. M. V. (1996). Effects of solvent extraction on the gelatinization properties of flour and starch of five cassava varieties, Journal of Science Food and Agriculture, 72, 329-336.

Myers, R. H., Montgomery, D. C., & Anderson – Cook, C. M. (2009). Response surface methodology: Process and product optimization using designed experiments, 3rd ed., John willey $ sons, New Jersey, USA.

Nnam, N. M. (2003). Evaluation of the nutrient and sensory properties of porridges from African yam bean (Sphenostylis stenocarpa) and maize (Zea mays L.) flours. Nigeria Research in Education, 9, 49-54.

Ojinaka, M.C., Akobundu, E.N.T., & Iwe, M.O. (2009). Cocoyam starch modification effects on functional, sensory and cookies qualities. Pakistan Journal of Nutrition 8, 558 – 567.

Okoye, J.I., Ene, G.I., & Ojobor, C.C. (2017). Chemical composition and functional properties of Sorghum-African yam bean flour blends. Sky Journal of Food Science 6(2), 021 – 026.

Olaoye, O. A., Onilude, A. A., & Idowu, O. A. (2006). Quality characteristics of bread produced from composite flours of wheat, plantain and soya beans. African Journal of Biotechnology, 5(11), 1102 – 1106.

Onimawo, I.A., & Akubor, P.I. (2012). Food Chemistry: Integrated Approach with Biochemical background. (2nd Ed.), Joytal Printing Press, Agbowo, Ibadan, Nigeria.

Sathe, A.K., Deshphande, S.S., & Salunkhe, D.K. (1982). Functional properties of lupin seed (Lupinus mutabillia) protein and protein concentrates. Journal of Food Science, 47, 491 – 497.

Sathe, S.K., & Salunkhe, D.K. (1981). Isolation, partial characterization and modification of the Northern bean (Phaseous vulgarris L.) starch. Journal of Food Science. 46, 617 – 621.Tester, R.F., Karkalas, J., & Qi, X. (2004). “Starch-composition, fine structure and architecture,” Journal of Cereal Science, 39(2), 151–165.