Optimized Supplementation Ratio of Wheat Flour and African Yam Bean Flour for Best Possible Bread Specific Volume and Crumb Hardness in Nigeria

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Abstract— *An optimized substitution mix ratio for of Wheat flour and African Yam Bean flours (AYB) was developed in this study. Wheat flour was substituted with African Yam Bean flours at different mix ratios of 90% to 100% of wheat flour and 0% to 10% of AYB flour. The experiment was conducted in I-Optimal mixture design by Design-Expert Software version 12. The dough Composite was prepared in different mix ratios according to the design matrix and subsequently baked under the same conditions and analysed for the following loaf quality attributes: Loaf Specific Volume and Bread Crumb Hardness as response variables. The objective functions were to maximize Loaf Specific Volume and minimize Bread Crumb Hardness to obtain the most acceptable product to consumers. Predictive models for the response variables were developed with the coefficient of determination (R^2) of 0.7500 for Loaf Specific Volume (LSV) and 0.8734 for Bread Crumb Hardness (BCH) at 95% confidence interval (CI). The predicted optimal substitution ratio was obtained as 96.833% Wheat flour and 3.167% AYB flour to yield Loaf Specific Volume was 2.106cm^3/g, Bread Crumb Hardness was 24.778N. With this result, it is inferred that substituting up to 3.167% of AYB flour into wheat dough formulation would optimise the LSV and BCH of the Wheat-AYB bread at the resulting mix ratio of 96.833:3.167. The benefit of the results of this study to bread industries is the reduction in the cost of bread by consequent reduction in the quantity of imported wheat flour utilization.*

Keywords— Bread, wheat, African Yam Bean, Flour, Dough, Specific Volume, Hardness.

I. INTRODUCTION

Bread is the most widely consumed food by all social classes around the world. It represents about 80% of the baked products sub-sector in Nigeria (KPMG, 2016). However, bread is relatively expensive in tropical countries where wheat is imported for bakery industries (Eleazu et. al, 2014). This is because wheat is a temperate crop that will not do well under tropical conditions as a result of unfavourable soil and climatic conditions (Abdelghafor, 2011).Whole-wheat grain consists of the entire grain, and, unlike refined grains, they still contain bran and germ, which are rich in dietary fibre and micronutrients (Kyro and Tjonneland, 2016).Whole-grain foods are associated with reduced risk of several chronic diet-related diseases and it contains a lot of compounds with reputed health benefits (Dalton *et al.*, 2012).

The bread industry commands a large market share in Nigeria. According to KPMG (2016), the bread industry is worth ₦122.1 billion and about 72% market share is allocated to the small and medium-sized bakeries. Majority of the bread consumed in Nigeria are baked by small and medium scale bakeries and come in different sizes that suit the consumer’s need, whose standard could be compromised by inadequate quality control. There is a large market for bread in Nigeria with population of over 200 million people with an estimated national population growth rate of 5.7% per annum, and an average economic growth rate of 3.5% per annum in the past 5 years with all social classes consuming it as a staple food.

Nigeria, being a tropical country in sub-Saharan Africa, does not have the agronomic variables that support profitable and economical production of wheat. This circumstance causes bakeries to depend highly on imported wheat for bread and other confectionaries. Foreign Agricultural Service (FAS) Lagos under the United States Department of Agriculture forecasts that wheat imports in Marketing Year (MY) 2019/20 is estimated to be 5.6 million metric tons, which is up by almost 4% compared to MY 2018/19. The rise in wheat consumption is attributable to the population growth of about 2.54% (2015-20), with Nigerians increasingly consuming greater amounts of wheat-flour based products (USDA-FAS, 2019). Successive governments in Nigeria, in a bid to reduce the increasing cost of wheat importation, enacted wheat control policies ranging from a complete ban in the years 1987 to 1991, via composite flour approach, which included 5% cassava inclusion from 2007 to 2010, 10% cassava inclusion from 1979 to 2007 and up to 40% cassava inclusion in 2012 (Ohimain, 2015). These policies have not been successful due to the undesired physical quality of wheat-cassava bread.

Though Wheat gluten plays a vital role in the quality and structure of baked bread, a small fraction of the flour matrix can be replaced with other non-wheat flour without affecting its final bread quality.

The use of local and available flours which could produce similar characteristics as gluten or support the available gluten strands during fermentation, proofing and baking would make the applicability of composite flour technology successful. Shittu *et al.* (2007) defined composite flours as either binary or ternary mixtures of flours from some other crops with or without wheat flour. The reason for considering composite flours in various food products has been to exploit the economic advantage of reducing or even eliminating the cost of imported wheat in bakery and pastry products by partial or complete use of domestically grown products instead of wheat.

African yam bean (AYB) (*Sphenostylis sternocarpa L.*) is a drought-tolerant legume crop grown primarily as a food in West Africa, especially southern Nigeria. It grows well even on acidic and highly leached sandy soils. It is the second biggest and one of the most economically important within the legume family. Despite its abundant yielding potentials, the crop is still largely under-exploited and under-utilized (IITA, 2010). It is expected that its successful inclusion in bakery products will enhance the value and importance to the crop.

In spite of huge investments made by the Federal Government in the cassava bread initiative over a period of 34 years, the project has not achieved (Punch Newspaper, December 19, 2016). According to Eduardo *et al.* (Eduardo *et al*., 2013) commercial production of wheat-cassava bread is still difficult due to the impaired bread structure. Consequently, research has been in progress to enhance the specific volume and texture of wheat-cassava bread by adding bread enhancement substances such as hydrocolloids, enzymes, and emulsifiers (Shittu *et al.*, 2009; Serventi, 2020; Eduardo *et al*., 2014). *Shittu et al., (2007)* has shown that bread with improved specific volume and crumb softness can be made from composite cassava-wheat flour with added xanthan gum. But very little has been done by utilizing this native and underutilized crop of Nigerian origin to improve the quality of wheat-cassava bread. Also, utilizing a non-gluten protein may help compensate for some lost protein by substituting more fraction of wheat flour and therefore can help in proper shaping of the bread structure and texture (Ziobro *et al*., 2016). The specific volume of a loaf is a good indicator of bread quality. It represents the ability of gluten strands to retain enough gas released during fermentation and dough proofing. Higher gas retention ability will lead to a higher specific volume (Nada and Hasan, (2015); (Franco *et al.*, 2020). It has been reported in the literature as a definite measure of loaf size (Shittu *et al.*, 20017; Purna *et al*., 2011). It is also used by the Standard Organization of Nigeria (SON) as a measure of standard bread quality (NIS, 2004). It is the ratio of loaf volume (cm^3) to loaf weigh (g). The objective of this paper therefore to develop an optimized substitution mix ratio of wheat flour and AYB flour production of an acceptable bread quality.

II. MATERIALS AND METHODS

2.1 Materials

A creamy variegated African Yam Bean (AYB) seed (*Sphenostylis stenocarpa*) and Commercial grade hard wheat grain were purchased at a local commodity market in Kubwa, Federal Capital Territory Abuja in Nigeria. Dough preparation and bread baking were done in the food Science Department of Federal University of Technology, Abeokuta in Nigeria.

The flour of the two crops was prepared as shown in the process flow charts of Figure 1.

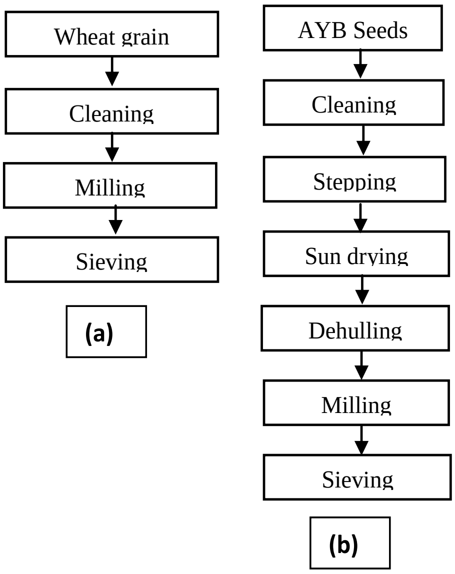

FIGURE 1: Process Flow process for the flours production: (a) Wheat, (b) AYB

2.2 Methods

The process flow chat for the Bread baking was shown in Figure 2. The composite flour was mixed intimately to attain uniform distribution of flour particle for a period of 10 minutes, while kneading was done manually for 7 minutes to develop the gluten structure of the dough when hydrated. Dough proofing was done in a proofing chamber set to 37°C for 30min between 78–80% Relative Humidity before baking in a preheated oven at about 220°C for 20 minutes.

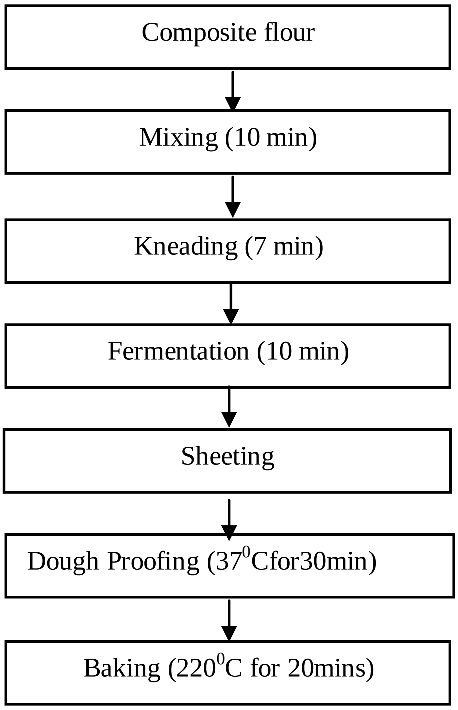

FIGURE 2: Process Flow chart for bread production

2.3 Modeling and Optimization

The experiment was designed in I-Optimal, 2-Mixture design using Design Expert version 12.0BL2 (2017-2015). The design matrix is shown in Table 1.

TABLE 1
THE DESIGN MATRIX OF THE EXPERIMENT

Run	Component 1 A: Wheat %	Component 2 A: AYB %	Response 1 Crumb Hardness N	Response 2 Specific Volume cm^3/g
1	100	0		
2	95	5		
3	95	5		
4	90	10		
5	100	0		
6	90	10		
7	97	3		
8	95	5		
9	95	5		

Equation 1 represents the model used in the optimization study to express the behaviour of the system responses which are the crumb hardness (N) and specific volume (cm^3/g), each as a function of the mix ratios (Wheat **:** AYB).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (1)$$

Where, β_0 is the offset term or model constant; β_1, β_2, are the linear or first order terms, is the random error term that allows uncertainties between the experimental and predicted values.

Therefore, by using this design, a total of nine (9) experimental runs were conducted. The experiments were performed in random order to avoid systematic error.

The acceptability of the models depended on the p-value of the analysis of variance and the value of the correlation coefficient (R^2) as shown in Equation 3.

The goodness of fit of the model, which was estimated by the coefficient of determination (R^2), was obtained from Equation 3.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_{i,pre} - Y_{i,exp}\right)^2}{\sum_{i=1}^{n}\left(Y_{i,exp} - Y_m\right)^2} \quad (3)$$

Where $Y_{i,pre}$ is predicted value of the response variable, $Y_{i,exp}$ is the expected (experimental) value of the same variable, n is the number of experiments and Y_m is he mean value f the variable.

I-optimal Mixture design (custom) method of Design Expert (version12, 2007-2015, Stat-Ease Co., USA) was used for the modelling and optimization of response variables using experimental data. Substitution levels of the mix components ranged from 90% to 100% for wheat flour and from 0% to 10% for AYB flour. Proofing and baking periods were constant for all the experimental samples. Baker's ingredients percentages by the total mass of flour used in this study is shown in Table 2.

TABLE 2
PROPORTION OF INGREDIENTS USED FOR ALL FORMULATION

Ingredient	Baker's Percentage	Composition
Composite flour	100%	151.6 (g)
Water	62%	94 (ml)
Yeast	3%	4.5 (g)
Salt	2%	3.0 (g)
Sugar	4%	6.1 (g)
Margarine	3%	4.5 (g)

(Source: NIS-470, 2004)

2.4 Determination of Loaf Specific Volume

The weights (g) of baked bread samples were taken after sufficiently cooling in desiccators by using a digital balance (0.01 g accuracy). The bread loaf volume (cm^3) was determined using a modified standard seed displacement method (AACC, 2000). Millet seeds were used for volume displacement experiment. The container used for measurements was a pan of 14.9cm × 9.3cm × 7.8cm. The loaf was placed in the container of known volume (1080.846 cm^3) into which millet seeds were poured until the container was filled to the brim and levelled off by a straight-edged baton moving in the direction of the container's length axis.

The volume of seed displaced poured into the container subtracted from the volume of the container gives the loaf volume (cm^3) as shown in Eqn. (4).

$$Loafvolume\ (cm^3) = vol.ofcontainer(cm^3) - vol.ofpouredgrain(cm^3) \quad (4)$$

The loaf specific volume was calculated by dividing volume (cm^3) by loaf weight (g) taken 24 hrs after baking as expressed in Eqn.(5).

$$L\text{oafSpecificVolume}, LSV\,(\text{cm}^3/g) = \frac{Loafvolume\ \ (\text{cm}^3)}{Loafweig\ ht\ (g)} \quad (5)$$

The minimum acceptable specific loaf volume for whole wheat bread as specified by Standard Organization of Nigeria (SON) is 2.0 cm^3/g (NIS, 2004).

2.5 Bread Crumb Hardness

The textural analysis was carried out to determine crumb softness/hardness. The textural analysis of the bread crumb was done using a Perten Instrument (TVT-300XPM) by double-cycle compression Texture Profiles Analysis (TPA) method. The bread loaf was sliced into a cube of 25mm thickness using a stainless kitchen bread knife. The extreme sides (back) of each loaf were discarded. For the TPA a 25mm-diameter probe was inserted into the prepared sample cube at 40% strain, speed of 2mm/s and trigger force of 5g (Dvorakova et al., 2012). The TPA data were used to determine the crumb hardness.

III. RESULTS AND DISCUSSION

3.1 Bread Crumb Hardness

In this study, Bread Crumb Hardness (BCH) ranged from 22.35 to 34.09 N. The crumb with 100% wheat flour and 0% AYB has the least BCH which is not within the optimization objectives. This result can be explained by the fact that more gluten strands contained in wheat are available for raising the dough during fermentation/proofing which, will eventually form a light textured and less compact crumb (Nwatu *et. al.*, 2020). BCH was at maximum when the mix proportion of wheat flour and AYB flour was 90% and 10% respectively. This can also be interpreted as a result of insufficient gluten strand available for rising, therefore forming a more compact and impaired bread structure (Nwatu *et. al.*, 2020).

Models were developed to predict each of the studied response variables (Bread Crumb hardness and Loaf Specific Volume) for any selected mix ratio with coefficient of determination (R^2) of 0.8734. The analysis of variance (ANOVA) table for BCH data is presented in table 3. The **Model F-value** of 48.31 implies that the model is significant. There is only a 0.02% chance that an F-value this large could occur due to noise. **P-values** less than 0.0500 indicates that model terms are significant. In this case the linear terms of Wheat (A) and AYB (B) in the model are significant. P-Values greater than 0.1000 indicate the model terms are not significant.

TABLE 3
ANOVA TABLE FOR BREAD CRUMB HARDNESS

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	206.74	1	206.74	48.31	0.0002	significant
Linear Mixture	206.74	1	206.74	48.31	0.0002	
Residual	29.95	7	4.28			
Cor Total	236.70	8				

The predictive equation for BCH in terms of actual factors for the bread specific volume is presented in Eqn. 6.

$$BCH\ (N) = 0.2106 * Wheat\ (\%) + 1.385 * AYB\ (\%) \tag{6}$$

The coefficient of determination (R^2) of 0.8734 represents a good fit at p<0.01, which indicates the suitability of the model to predict the response with a good degree of accuracy. The response plots are shown in Figure 3(a,b,c).

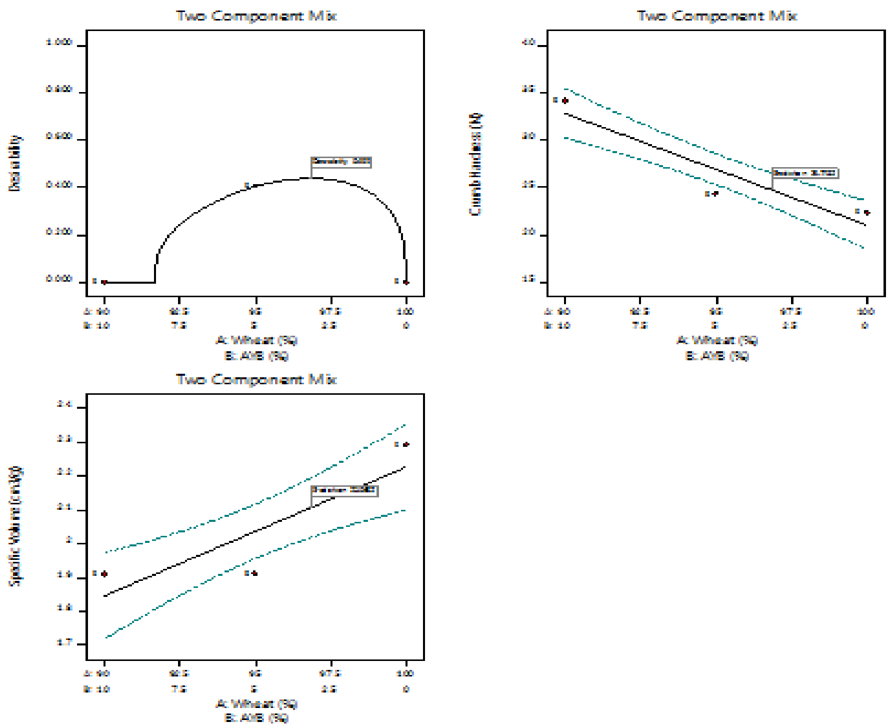

FIGURE 3: Graph of two component mix: Desirability, Bread Crumb Hardness and Specific volume vs wheat-AYB mix ratios.

To demonstrate how well the models can predict the response variables, the observed data were plotted against the model predicted data as shown in Fig. 4.

The predictive model was tested for validity by plotting the predicted value against the observed data. If the scatter points lie closely along the trend line the model is considered adequately valid to predict the data.

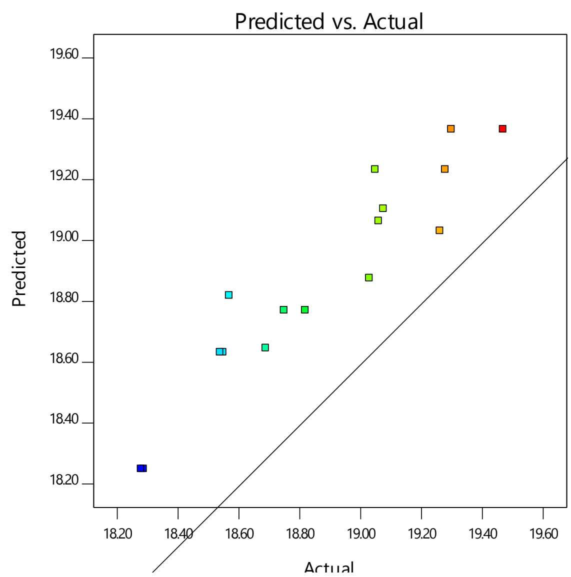

FIGURE 4: Graph of predicted against observed data for Crumb hardness

From Figure 4, the points lie very closely to the trend line showing reasonable agreement between the predicted and observed data. This shows that the prediction of BCH from the mix components percentage, by the model, was good. The summary of solution of the optimization process is presented in Table 4.

TABLE 4
SUMMARY OF THE OPTIMIZATION PROCESS

Number	Wheat	AYB	Crumb Hardness	Specific Volume*	Desirability	Desirability (w/o Intervals)	
1	96.833	3.167	24.778	2.106	0.439	0.506	Selected

From Table 4, the optimal solution was located at the mixture ratio of 96.833% Wheat flour and 3.167 % AYB flour , which gave a Bread Crumb Hardness of 24.778 N.

3.2 Loaf Specific Volume (LSV)

In this study, loaf specific volume (LSV) ranged from 1.89 to 2.31cm^3/g. The lowest value of LSV occurred when the mixture was 90% wheat and 10% AYB while the maximum occurs at the mixture of 100% wheat flour and 0% AYB for the same reason as in crumb hardness. A loaf specific volume for whole-wheat bread should not be less than 2.0cm^3/g (NIS, 2004). Ngozi (2014) reported specific volume which ranged from 2.16 to 3.51cm^3/g for bread made by substituting parts of wheat flour with whole-wheat flour. Malomo *et al.*, (2011) reported a specific volume of bread that ranged from 2.08 to 3.39cm^3/g with 5% breadnut flour substitution level and 95% wheat bread significantly different from others. The result of the ANOVA for LSV is presented in Table 5.

TABLE 5
ANOVA TABLE FOR LSV

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.2166	1	0.2166	21.00	0.0025	significant
Linear Mixture	0.2166	1	0.2166	21.00	0.0025	
Residual	0.0722	7	0.0103			
Lack of Fit	0.0722	1	0.0722			
Pure Error	0.0000	6	0.0000			
Cor Total	0.2888	8				

P-value less than 0.0025 indicates that model terms are significant. The predictive equation of LSV in terms of the mixture ratios of the two flours is given in Eqn. (4).

Specific volume=0.02227*wheat-0.015733*AYB 4

The coefficient of determination (R^2) is 0.7500 and F-value is 21.00 at 95% confidence interval, which is an indication of a good fit. The coefficients of the Equation 4 show that LSV was negatively affected by the AYB flour component. From Table 3, the optimal solution of the optimization occurs at the mix ratio of 96.833% of wheat and 3.16% AYB for specific volume of 2.106 cm^3/g

The validation plot of predicted against observed values of LSV is presented in Figure 5. The points lie very close to the trend line showing good agreement between the predicted and observed data. This shows that the prediction of LSV was very good.

This trend as explained earlier shows a very good prediction given that the entire points lie almost on the trend line.

IV. CONCLUSION

Response Surface Methodology (Mixture Design) algorithm was used for optimization of the wheat-AYB substitution ratio in this study. The optimised composite flour of Wheat and AYB was developed for improved loaf specific volume and bread crumb hardness. The objective function was to obtain the most suitable substitution ratio that will maximize Loaf Specific Volume and minimize Bread Crumb Hardness by minimizing %wheat flour component and maximizing %AYB flour component. Based on the composite desirability index of 0.428, the predicted optimal composite mix formulation for enhanced quality of composite bread were 95.328% of wheat flour and 4.672 AYB flour respectively. At this formulation, the predicted loaf specific volume was 2.049cm^3/g and bread crumb hardness was 26.545N, whereas the coefficient of determination (R^2) for loaf specific volume was 0.7500, and that for bread crumb hardness was 0.8734. The predicted optimal loaf specific volume complies with Standard Organization of Nigeria (SON) standard on the quality specifications given on the loaf specific volume of whole-wheat bread as 2.0cm^3/g minimum. Increasing the substitution level of AYB flour and consequently reducing the wheat flour impacts the quality of the composite bread physically by reducing loaf specific volume and increasing crumb hardness. This agrees with Yaver and Bilgiçli (2018) that Cereal-Legume Flour Blend (CLFB) in bread formulations lowered the volume in Commercial Bread (CB) and increased the hardness of bread.

This study proves that an acceptable physical attributes of bread can be achieved by supplementing wheat with AYB flour up to 4.672%, based on Nigerian standard. It can be more in other countries based on their standards.

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