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OPTIMISATION OF PROCESS VARIABLES FOR THE PRODUCTION OF COOKIES FROM WHEAT, FONIO, PIGEON PEA FLOUR BLENDS USING D–OPTIMAL DESIGN

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Abstract: Optimisation of the production of composite flour from wheat, fonio and pigeon pea flours using D–optimal design of response surface methodology was carried out. The independent variables were wheat flour (20–50), fonio flour (20–70) and pigeon pea flour (10–35); while the dependent variables were moisture content, fat content, texture and colour. Analysis of variance and regression analysis were used to analyse the data. The moisture content ranged from 4.95 to 5.39%, oil content (15.03 to 15.55%), texture (15.50–33.00 N), and colour difference (30.95–48.54). The flour blends have a significant effect on moisture content, oil content, texture, and colour difference at $p<0.05$. The coefficient of determination (R^2) of the generated model ranged from 0.78 to 0.99. The result of the study shows that 27.50 g of wheat flour, 62.50 g of fonio flour and 10 g of pigeon pea flour were the optimal conditions for the production of cookies from the blend. At this condition, moisture content was 4.99%, fat content was 15.1%, texture was 29.77 and the colour difference was 48.54. The desirability of optimization was 0.86.
Keywords: cookies, optimization, wheat–fonio–pigeon pea flour, response surface methodology, quality attributes

1. INTRODUCTION

Cookies are popular snacks throughout the world. It is made primarily from flour, sugar, butter and eggs. It is a sweet, crunchy dough made of wheat flour, and other customary baking items. It has a soft texture and low moisture content when compared with biscuit, they are high in carbohydrates, fat, and calorie (Awolu et al., 2015). Fonio (Digitaria exilis and Digitaria iburua) is one of the oldest African cereals. For thousands of years, West Africans have cultivated it across the dry savannas and it was once their major food. Fonio is also one of the most nutritious but underutilized cereals. Its seed is rich in methionine and cystine which are amino acids vital to human health and deficient in other major cereals such as wheat, rice, maize, sorghum, barley, and rye (Jideani and Jideani, 2011).

Food legumes form an important component of the diets of people in many developing countries of Africa (Gopalan et al., 2006). They are cheaper source of proteins when compared to animal proteins. Pigeon pea (Cajanus cajan L.) also called red gram or tuar (known locally in South–west of Nigeria as ewa otili); is a member of the family Leguminasea. Pigeon pea protein is a rich source of lysine, but is usually deficient in sulphur–containing amino acids, methionine and cystine; it thus supplements the essential amino acids in cereals (Gopalanet al., 2006). Protein–deficient foods are common for a large portion of Nigeria's population. Protein content in carbohydrate–based foods can be increased to improve nutritional quality. Vegetable protein calories have been proposed as a solution to this problem (Abioye et al., 2011), because legume proteins are high in lysine, an essential amino acid that is limited in most cereals (Alain et al., 2007).

Response Surface Methodology (RSM) is an important tool in process and product improvement (Altan et al., 2008). RSM is a set of mathematical and statistical procedures that can be used to investigate relationships between one or more responses (dependent variables) and a variety of factors (independent variables) (Diniz and Martin, 1996). Through the literature search, we discovered that no studies have been conducted using RSM to investigate the composite flour made from wheat, fonio, and pigeon pea in the production of cookies. The purpose of this study is to investigate the possibility of improving the nutrient quality of cookies made from composite flour of wheat, acha, and pigeon pea flour, as well as to optimise the processing conditions for the quality attributes of the cookies.

2. MATERIALS AND METHODS

Seeds of pigeon pea (*Cajanus cajan*) were purchased at a local market in Ilesa, Osun State while grains of Fonio (*Digitaria exilis*) were obtained from a local market in Jos, Plateau State. Other ingredient for the production of cookies such as eggs, baking powder, nutmeg, milk, sugar, margarine and vegetable oil were purchased at a local market in Ogbomoso, Oyo state.

— Processing of Pigeon Pea into Flour

Four kilogram of each pigeon pea seed was weighed and sorted to remove dirt. The weighed and sorted pigeon pea was then boiled in water for 60 min to reduce the presence of anti–nutritional factor. The seeds were dehulled with the use of mortal pestle and dried using solar drier for 12 hours. The dried seeds was milled using hammer mill after which the flour was sieved using a 1mm sieve size. The flour was packed in a polyethylene bag (Enwere et al., 2003).

— Processing of Fonio into Flour

Seven kilogram of fonio grains was weighed and sorted to remove dirt. The grains was washed repeatedly in portable water, dried and milled with hammer mill after which the flour was sieved using 1 mm sieve size. The flour was packed in a polythene bag (Olapade et al., 2010).

— Experimental Design

The experimental design employed was the response surface methodology using a D–optimal. This generated fourteen experimental runs. Three independent variables was used; flour ratio of fonio (20–50%), wheat (35–70%) and pigeon pea (10–35%). Four dependent variables were selected as responses for representing the main parameter of cookies quality; colour, texture, fat content and moisture content. The experimental data for each response variable was fitted to the quadratic model. The regression parameters for the equation was generated.

— Production of cookies

The cookies samples were produced from flour, salt, baking powder, egg, margarine, sugar, milk, vanilla. Margarine and sugar were allowed to cream using an electric mixer at a medium speed for 5 min. Eggs and milk were added and then mixed for 30 min. Vanilla, flour, baking powder and salt were mixed thoroughly and added to the cream mixture where they were mixed together to form dough. The dough was kneaded to uniform thickness of 0.5 cm and a circular cut of 5 cm diameter. It was allowed to bake at 180°C for 30 min.

3. DETERMINATION OF THE QUALITY ATTRIBUTES OF COOKIES

— Moisture content

Two grams of each flour was weighed and transferred into weighed crucibles. The crucibles was then placed into the drying oven at 105 °C for 5 hours. After this, they were removed and placed in a desiccator to cool. The cooled crucibles were reweighed. The loss in weight after drying was calculated as the percentage moisture (AOAC, 2010).

— Oil content

The oil content was determined using the AOAC (2010) method. A grinder was used to grind the samples. Five grams of sample were weighed into thimbles for fat extraction using a solvent extractor (SER 148, VelpScientifica, Usmate, Italy). The oil content was obtained by dividing the mass of extracted fat by the dry matter of the sample.

— Colour determination

The surface colour of the samples were measured with a colourimeter (Nippon Denshoku Σ90 colour difference meter, Japan) and expressed as Hunter L (lightness), a (redness) and (yellowness) values (Krokida *et al*., 2001a). Colour difference (Hunter ΔE) was calculated according to Eq. (1):

$$\text{Colour difference (Hunter } \Delta E) = [(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2]^{1/2} \quad (1)$$

where L_0, a_0 and b_0 are the L, a, and b values of cookies cut, respectively.

— Texture Measurement

Texture measurement of the cookies which was measured in hardness was performed by using puncture test. The measurement was performed by using penetrometer. The penetrometer needle was fitted and the cookies sample was placed underneath it with the tip of the needle touching the surface of the sample. The pointer shaft of the die was set to zero. The plunger of the penetrometer was released to make a free penetration on the sample for 15 sec. The depth of penetration was measured by gently depressing the pointer shaft until it again touches the top of the plunger. The penetration distance was measured (Sancho *et al*., 2010).

— Optimisation and Statistical Analysis

Optimum conditions for cookies that produce the best result was obtained using computer software package (Design expert version 6.0.1 Stat. Ease Minneapolis, USA). This was achieved by minimizing the moisture content, oil content, and moderate texture and colour. The coefficients of determination, R^2 were fitted into the regression equation.

4. RESULTS AND DISCUSSION

— Quality Attribute of Cookies

Table 1 displays the quality characteristics of cookies made from a blend of wheat, fonio, and pigeon pea flours. The moisture content of the cookies ranged between 4.94 and 5.39 percent. This result was consistent with Omah and Okafor's (2015) findings on cookies made from wheat and millet–pigeon pea flour blends, as well as Adebayo and Okoli (2017) findings on flour samples made from germinated lima bean and sorghum. Because the moisture content values obtained are less than 10%, cookies made from composite flour (wheat, fonio, and pigeon pea) have a stable shelf life. The moisture content range obtained in this study is similar to that obtained by Awolu *et al*. (2016) and Adeyanju *et al*. (2021).

The analysis of variance for moisture content revealed that the quadratic model and model term, i.e. the interaction between wheat and pigeon pea flour, fonio and pigeon pea flour (AC, BC), were significant, whereas the interaction between wheat and fonio (AB) flour was not significant at $p<0.05$. The values for the coefficient of determination, R^2, and adjusted R^2 were 0.904 and 0.844, respectively. This indicates that the model is well–fit and suitable for predicting MC. Table 2 shows the MC response for regression coefficients and the dependent variables analysis of variance. The regression equation representing the effect of the variables on moisture content is depicts in Eq. (2).

$$MC = 0.099992A + 0.050118B - 0.1271C - 0.00121AB + 0.001656AC + 0.003192BC \quad (2)$$

Table 1: Quality attributes of composite blends from wheat, fonio and pigeon pea flour

Runs	A (%)	B (%)	C (%)	MC (%)	FC (%)	T (N)	ΔE
1	35.00	35.00	30.00	5.06	15.07	26.00	40.16
2	20.00	50.00	30.00	5.26	15.40	25.25	41.32
3	27.50	47.50	25.00	5.19	15.34	29.75	34.43
4	35.00	45.00	20.00	5.33	15.43	15.50	35.65
5	27.50	42.50	30.00	5.14	15.37	29.16	34.05
6	27.50	62.50	10.00	4.95	15.03	33.00	48.54
7	23.75	61.25	15.00	5.39	15.55	25.50	41.09
8	35.00	55.00	10.00	5.01	15.09	18.50	37.05
9	20.00	50.00	30.00	5.26	15.40	25.25	41.32
10	35.00	55.00	10.00	5.00	15.09	18.50	37.05
11	20.00	70.00	10.00	5.19	15.13	21.50	30.95
12	35.00	35.00	30.00	5.06	15.07	26.00	40.16
13	27.50	52.50	20.00	5.39	15.55	25.50	41.09
14	20.00	70.00	10.00	5.10	15.13	21.50	30.95

A= wheat flour, B= fonio flour, C= pigeon pea, FC= fat content, MC= moisture content, T= Texture, ΔE= colour difference

Table 2: Moisture content response for regression coefficients and ANOVA

Responses	Sources of Variance	Sum of Squares	DF	Mean Squares	F–value	p–value
MC	Model	0.253124	5	0.050625	15.10859	*0.0007
	Linear Mixture	0.060092	2	0.030046	8.96699	*0.0091
	AB	0.010666	1	0.010666	3.183167	0.1122
	AC	0.020619	1	0.020619	6.153497	*0.0381
	BC	0.179779	1	0.179779	53.6537	* 0.0001
	Residual	0.026806	8	0.003351		
	Lack of Fit	0.026806	4	0.006701		
	Pure Error	0	4	0		
	Cor Total	0.27993	13			
R^2= 0.904; adjusted R^2= 0.844						

*p<0.05 indicates statistical significance

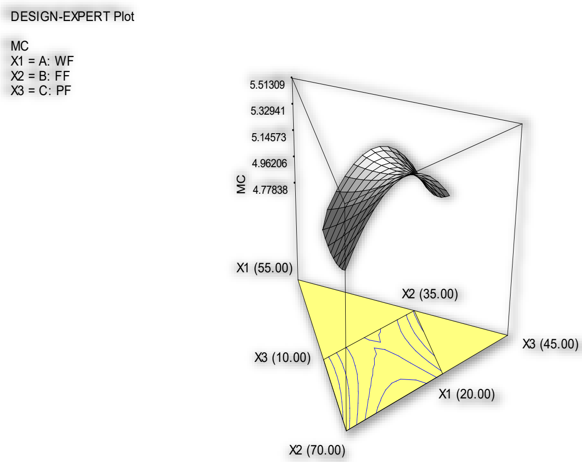

Figure 1: Response surface plot showing the interaction between the variables and moisture content

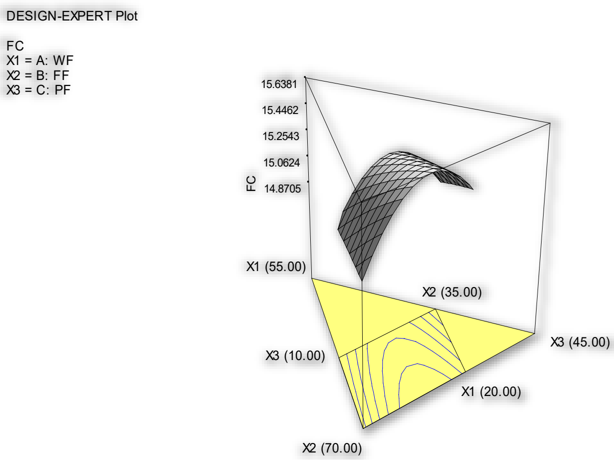

Figure 2: Response surface plot showing the interaction between the variables and fat content

— Fat content (FC)

The cookies fat content ranged from 15.04 to 15.55 percent. The fat content of cookies rises as pigeon pea flour is substituted. These values agreed with the findings of Olapade *et al.* (2010) and Okpala (2010). Because of oxidative activity, the fat content of cookies affects their shelf life (Awolu *et al.*, 2015). At $p<0.05$, the ANOVA result for fat content revealed that the quadratic model and model terms (AC, BC) were significant, while AB was not. The values for R^2 and adjusted R^2 were 0.888 and 0.818, respectively. This indicates that the model is suitable for predicting fat content and fit because R^2 values closer to 1.0 provide the best fit. The regression equation is depicted in Eq. (3).

$$FC = 0.13888A + 0.137963B - 0.03824C + 9.15E5AB + 0.002655AC + 0.003468BC \quad (3)$$

Table 3: Fat content response for regression coefficients and ANOVA

Responses	Sources of Variance	Sum of squares	DF	Mean Squares	F–value	p–value
FC	Model	0.408925	5	0.081785	12.75498	*0.0012
	Linear Mixture	0.106527	2	0.053263	8.306824	*0.0112
	AB	6.13E–05	1	6.13E–05	0.009563	0.9245
	AC	0.053013	1	0.053013	8.267748	*0.0207
	BC	0.2123	1	0.2123	33.10975	*0.0004
	Residual	0.051296	8	0.006412		
	Lack of Fit	0.051296	4	0.012824		
	Pure Error	0	4	0		
	Cor Total	0.460221	13			
R^2 = 0.888; adjusted R^2 = 0.818						

*p<0.05 indicates statistical significance

— Texture (T)

The texture of the cookies ranged from 15.5 to 33 N. Increased incorporation of fonio and pigeon pea flour had a significant impact on this. It has been reported that the textural properties of food products are affected by processing conditions and raw materials (Krokida *et al*., 2001b; Nourian and Ramaswamy, 2003). The texture results for cookies agreed with the findings of Ishiwu *et al*. (2014) on optimizing the taste and texture of biscuits made from a blend of plantain, sweet potato, and malted sorghum flour. The texture analysis of variance revealed that the quadratic model and model terms (AC, AB, and BC) were significant at p<0.05. The values for R^2 and adjusted R^2 were 0.866 and 0.782, respectively. The regression equation representing the effect of the variables on texture is depicted in Eq. (4).

$$T = 2.548785C - 8.18759A - 0.66209B + 0.159452AB + 0.116017AC - 0.05619BC \quad (4)$$

Table 4: Texture response for regression coefficients and analysis of variance

Responses	Sources of Variance	Sum of squares	DF	Mean Squares	F–value	p–value
T	Model	259.7443	5	51.94886	10.36469	*0.0024
	Linear Mixture	63.68277	2	31.84138	6.352905	*0.0223
	AB	186.3935	1	186.3935	37.18872	*0.0003
	AC	101.1906	1	101.1906	20.18927	*0.0020
	BC	55.72583	1	55.72583	11.11826	*0.0103
	Residual	40.09679	8	5.012098		
	Lack of Fit	40.09679	4	10.0242		
	Pure Error	0	4	0		
	Cor Total	299.8411	13			
R^2 = 0.866; adjusted R^2 = 0.782						

*p<0.05 indicates statistical significance

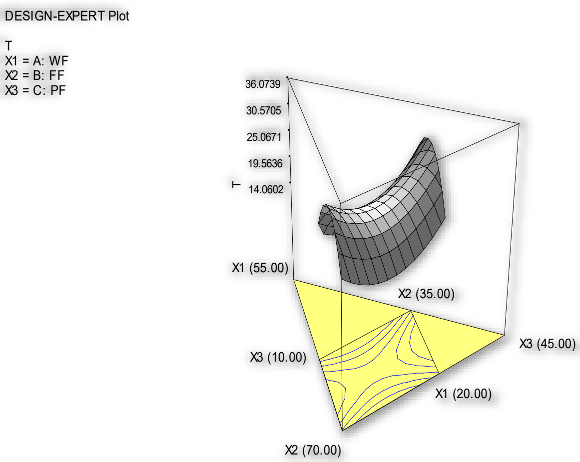

Figure 3: Response surface plot showing the interaction between the variables and texture

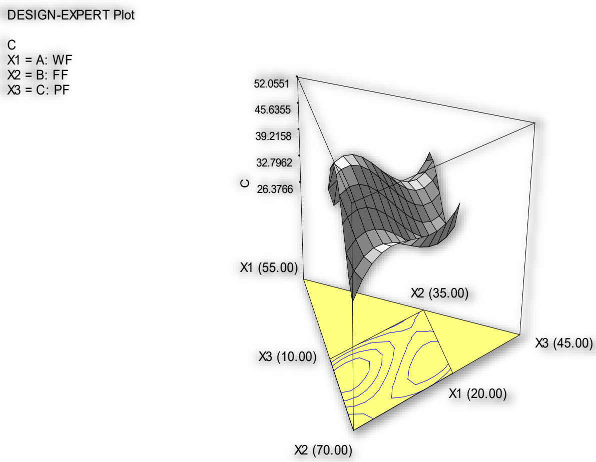

Figure 4: Response surface plot showing the interaction between the variables with colour difference

— Colour difference (ΔE)

The result of colour difference of the cookies ranged from 30.96 – 48.54. It was discovered that as baking progresses, a significant amount of brown product is formed. A colour change in cookies is usually caused by non–enzymatic browning at higher temperatures (Shyu, and Hwang, 2001). Moreira et al. (2009) obtained comparable results when vacuum frying potato chips. The cubic model and model term (AC, AB, BC ABC, AB(A–B), AC(A–C), BC(B–C)) were significant at $p<0.05$ in the analysis of variance for the colour difference. The values for R^2 and adjusted R^2 were 0.999 and 0.985, respectively. The regression equation is given in Eq. (5).

$$\Delta E = -127.5352A + 1.5862B - 51.9045C + 2.3337AB + 1.6090AC - 0.6431BC - 0.0309ABC + 0.0139AB(A-B) + 0.0256AC(A-C) + 4.1234E-3BC(B-C) \quad (5)$$

Table 5: Colour response for regression coefficients and analysis of variance (ANOVA) for the dependent variables of the D–optimal mixture design

Responses	Sources of Variance	Sum of squares	DF	Mean Squares	F–value	p–value
ΔE	Model	296.4082	9	32.93425	63660000	*0.0001
	Linear Mixture	11.47146	2	5.735729	63660000	*0.0001
	AB	5.867853	1	5.867853	63660000	*0.0001
	AC	5.350529	1	5.350529	63660000	*0.0001
	BC	4.726836	1	4.726836	63660000	*0.0001
	ABC	5.348712	1	5.348712	63660000	*0.0001
	AB(A–B)	3.410945	1	3.410945	63660000	*0.0001
	AC(A–C)	9.392159	1	9.392159	63660000	*0.0001
	BC(B–C)	5.564251	1	5.564251	63660000	*0.0001
	Pure Error	0	4	0		
	Cor Total	296.4082	13			
R^2= 1.000; adjusted R^2= 1.000						

*p<0.05 indicates statistical significance

— Optimization

Using the software package, four appropriate solutions for the optimization process were discovered. That is, four different combinations of wheat, fonio, and pigeon pea flour could be used to minimise moisture, fat content, texture, and colour. The desirability ranged from 0.76 to 0.86. The preferred point that was of highest desirability process parameters for cookies of acceptable quality attributes were 27.5% wheat flour, 62.5% fonio flour, and 10% pigeon pea flour, which gave moisture content of 4.99%, fat content of 15.1%, texture of 29.78 N, and colour difference of 48.54.

5. CONCLUSIONS

The quality characteristics of cookies made from a blend of wheat, fonio, and pigeon pea flour were influenced. To accurately predict the quality attributes of cookies at any given baking temperature and time, model equations were developed. The models' good fit was confirmed by high coefficients of determination R^2 of 0.90, 0.88, 0.86, and 0.99 for moisture content, fat content, texture, and colour, respectively. The optimal process parameters are 27.5% wheat flour, 62.5% fonio flour, and 10% pigeon pea flour, which results in a moisture content of 4.99%, fat content of 15.1%, texture of 29.78 N, and a colour difference of 48.54. Modelling of the experimental data generated useful equations for predicting the quality attributes of cookies made with wheat–fonio–pigeon pea flour blend.

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