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Modeling and Optimization of Quality Attributes of Packaged Rice Flour

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ABSTRACT

OBJECTIVE

An optimization of process variables is important in food system design. This research was carried out to optimize some processes for rice flour packaging.

METHODS

Samples of the product were prepared in the moisture range of 3.8%-9.0% (wb) and stored for 2 weeks - 12 weeks. The quality parameters, such as carbohydrate and fungi count, were determined using standard methods. A randomized historical data design was used to model and optimize the responses with respect to the process conditions.

RESULTS

Results show that the models developed were valid and significant for response prediction ($p < 0.05$). An MSE <30% was obtained, and this suggests the models' ability to interpolate within the design criteria. The optimal process conditions were 4.7% (wb) moisture and 2 weeks storage period. This gave 56.7% carbohydrate and 2.04 × 106 cfu/g fungi count with a 66.7% desirability.

CONCLUSION

This information can be used for rice flour production and packaging in the food industry.

KEYWORDS

Modelling; Microbial loads; Modeling; Optimization; Proximate composition; Rice flour

INTRODUCTION

Rice flour can be obtained by milling rice grains into powder. It is distinct from rice starch, which is usually produced by removing the husk from rice or paddy to obtain the raw rice before grounding into flour. Rice flour is a proven substitute for wheat flour [1], which some people believe irritates their digestive systems [2]. The product has found application as a thickener in recipe since it inhibits liquid separation. Rice flour may be made from either white or brown rice. Numerous commercial applications of rice flour have been reported. It is also used for dusting confections in a manner like powdered sugar [1]. Brown rice flour can be combined with

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vermiculites for use as a substrate for the cultivation of mushrooms. Hard cakes of colonized substrate can then be fruited in a humid container. This method is often employed by growers of edible mushrooms, as it is a very simple and low-cost method of growing mushrooms.

A major problem of the industrial processing of the rice flour is the associated quality loss due to poor preservation. The natural shelf-life of the product is usually affected by transportation, packaging and process conditions. The reason for this may not be unconnected to an inadequate process condition (temperature, storage period and moisture content), which could lead to a reaction of the fatty acid in the flour with the atmospheric oxygen [3]. There is therefore the need for an adequate and proper rice flour packaging to ensure shelf-life extension and enhance economic value in the product processing. The packaging will also provide physical and barrier protections to the product against external agents like oxygen and microorganisms [4].

Although many empirical models have been described for predicting the quality and shelf-life of certain types of food products [5-13], the models might not be suitable for predicting the quality parameters of packaged rice products. Therefore, there is a need to model and optimize the optimum processing parameters of packaged rice flour for industrial practice. The objective of this research was to model and optimize the effects of the moisture content and period on the quality attributes of packaged rice flour.

MATERIALS AND METHODS

Experimental Procedure

A 20 kg of local paddy rice variety was obtained from the National Institute of Cereal Research, Bedegi, Niger state, Nigeria. The sample was then parboiled in hot water to soften the cotyledon and threshed to remove chaff from the lot. This was followed by a thorough cleaning with the help of a de-stoner, which removes stones, chaff and other foreign materials [14]. The product was thereafter milled into powder, and the particle size and moisture content were determined using a particle size analyzer and a moisture meter. The initial moisture content and particle size of the resulting rice flour were found to be 9.04% (wb) and 20 µm, respectively. The rice flour was then packaged in an air-tight container (Figure 1) and kept for analysis.

Figure 1: Samples of packaged rice flour.

Experimental Design

In this investigation, moisture content and storage or packaging period were used as the processing condition while keeping other obvious variables constant. The sample of the rice flour was divided into four portions, and the moisture content of three of the portions was varied using the air circulated oven dry method [15]. This was done by drying the rice portion in the oven at 60 RH and 105°C; and computing the moisture content after 0 hour, 24 hours, 48 hours and 72 hours of drying per rice portion. Thus, the moisture contents of the four rice portions were found to be 9.04%, 7.78%, 5.22% and 3.8% (wb) with respect to the drying time. A 25 µm thick low- density polyethylene (LDPE), with a negligible vapor and gas permeability, was used for the packaging of the four portions of the rice flour samples. The LDPE was chosen instead of the other packaging materials because of its higher quality retention ability. Each of the rice flour portions was stored in an incubator and the temperature maintained at 30°C over a period of 12 weeks. At the end of every 2 weeks, samples of the rice flour were taken from each of the portions for the quality parameter investigations. A total of 24 samples of the rice flour, six samples from each portion were obtained (Table 1).

S/n	Period (week)	Moisture content (wb)
1	2.0	9.04
2	4.0	9.04
3	6.0	9.04
4	8.0	9.04
5	10.0	9.04
6	12.0	9.04
7	2.0	7.78
8	4.0	7.78
9	6.0	7.78
10	8.0	7.78
11	10.0	7.78
12	12.0	7.78
13	2.0	5.22
14	4.0	5.22
15	6.0	5.22
16	8.0	5.22
17	10.0	5.22
18	12.0	5.22
19	2.0	3.80
20	4.0	3.80
21	6.0	3.80
22	8.0	3.80
23	10.0	3.80
24	12.0	3.80

Table 1: Samples of packaged rice flour.

Determination of Quality Attributes

A standard analytical procedure reported for the investigation of the nutritional properties of food products was used to determine the quality parameters of the packaged rice flour. Ash content was determined by placing the 2 g of the rice flour in a clean crucible and heating in a muffle furnace for 1 hour at 600°C. This was followed by cooling in a desiccator to obtain ash. The protein content was determined using the kjeldahl method while the fat content was determined by extraction method using a soxhlet apparatus. The procedure outlined by AOAC [15] was used to determine the crude protein, dry matter and the carbohydrate content of the packaged rice flour samples. The plate count method was used to determine the total bacteria and fungi present in the cultured samples. A 0.1 ml of each of the samples was diluted and pipette into the center of the dish, which contains a solution of nutrient agar and potato dextrose agar each separately and in duplicate. The dish which contained the solution was allowed to set followed by inversion and then incubated at 37°C for 72 h. The developed colonies on the plate were observed under microscope, counted and recorded.

Quality Parameter Modeling

Model structure development

In this method, 67% (16 samples) of the data obtained from the 24 samples were used for the training exercise leading to the model development. The remaining 33% (8 samples) of the data were kept for verification. A cubic polynomial regression model was assumed for predicting (Y) response variable, as shown in Equation (1) [4]. The model test statistics of all individual response parameters were test against the cubic model; and the best model was established as shown in Table 2.

$$Y = \beta_o + \beta_1 p + \beta_2 m + \beta_{11} p^2, \dots \dots \dots, + \beta_{222} m^3 + \epsilon \quad (1)$$

Where, p = storage period (weeks), m = moisture content (%, wb), β_o, β_1, β_2, ……., β_{222} = model constants, ϵ = experimental error.

Parameter	Model	Std	R^2	R^2_{adj}	R^2_{pred}	Press
Ash	Quadratic	0.4366	0.5061	0.2592	-0.3337	5.150
Fat	Cubic	0.5600	0.9278	0.8196	0.2452	19.67
Crude fiber	Linear	0.5258	0.5992	0.5375	0.4432	4.990
Crude protein	Linear	1.1700	0.6341	0.5778	0.4714	25.74
CHO	Quadratic	1.1200	0.9369	0.9053	0.821	35.60
Dry-Matter	2FI	1.0700	0.5594	0.4493	0.0437	29.81
Bacteria Count	Quadratic	1.9800	0.6092	0.4139	0.0974	90.35
Fungi count	Quadratic	0.3122	0.926	0.889	0.824	2.320

Table 2: Response model characteristics for quality parameter prediction.

Model validation and calibration

A cross validation technique was used to test the validity of the model for predicting the response variables. The models were validated by comparing the verification data, which were the 33% experimental data, with those obtained from the resulting model equations at $p < 0.05$. An accurate model will closely match the verification data. The model calibration was done by adjusting the parameters within the margins of the uncertainties to obtain a model representation of the processes of interest that satisfies the predesigned criteria. This involves finding the parameters which give the best fit to the quality parameters response. To test the fitness of the models generated, the coefficient of determination R^2, R^2_{adj} and mean square error (MSE) were determined using Equation (2) - Equation (4) [4].

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y - Y_i)^2 \quad (2)$$

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{Y}-\bar{Y})^2}{\sum_{i=1}^{n}(Y-\bar{Y})^2} \quad (3)$$

$$R^2{}_{\text{adj}} = 1 - \frac{(1-R^2)(n-1)}{n-p-1} \quad (4)$$

Where, Y = response from the experiment, $\hat{Y}$ = model estimated response, $\bar{Y}$ = mean response, n = sample size, 16, p = number of predictors

Quality parameter optimization

In this investigation, a response surface Randomized Historical Data Design (RHDD) was used to carry out the optimization of the quality parameters of the packaged rice flour. The RHDD was built because it allows for flexibility in the choice of the variables, levels and constraints. The optimal process parameters, which approach the desirability index, were determined with respect to the response variables. A numeric character was assigned to all the variables since their levels are in discrete terms. The goal of the optimization closer to the desirability index is presented as constraints shown in Table 3. The individual desirability for maximizing ash, fat, crude fibre, crude protein, carbohydrate and dry matter contents of the packaged rice flour was computed using Equation (5) [12,16,17].

$$d_i(\hat{Y}) = \begin{cases} 0 \; if \; \hat{Y}_i(x) < L_i \\ \left(\frac{\hat{Y}_i(x)-L_i}{T_i-L_i}\right)^s \; if \; L_i < \hat{Y}_i(x) \le T_i \\ 1.0 \; if \; \hat{Y}_i(x) < T_i \end{cases} \quad (5)$$

T_i= large enough value for the responses;

The components *s* and *t* as used in this case, determine how important it is to hit the target value. If and t = 1, the function of desirability will increase linearly towards T_i; If s <1, t <1, the function is convex, and concave for s >1, t >1.

Also, the individual desirability for minimizing bacteria and fungi counts of the packaged rice flour was computed using Eq. (6) [16].

$$d_i(\hat{Y}) = \begin{cases} 1.0 \; if \; \hat{Y}_i(x) < U_i \\ \left(\frac{\hat{Y}_i(x)-U_i}{T_i-U_i}\right)^s \; if \; T_i < \hat{Y}_i(x) \le U_i \\ 0 \; if \; \hat{Y}_i(x) < U_i \end{cases} \quad (6)$$

Where, T_i = small enough value for the bacteria and fungi counts

				Allowable Range			
Process variable	**Unit**	**Level**	**Nature**	**min**	**max**	**std**	**Goal**
Storage period	week	4	discrete	2.00	8.00	0.00	in range
Moisture content	%, wb	4	discrete	3.80	9.04	0.00	in range
Ash	%	16	discrete	2.88	4.78	0.44	maximize
Fat	%	16	discrete	3.91	7.59	0.56	maximize
Crude fiber	%	16	discrete	1.11	3.18	0.53	maximize
Crude protein	%	16	discrete	22.0	28.4	1.18	maximize
Carbohydrate	%	16	discrete	50.9	62.8	1.12	maximize
Dry matter	g	16	discrete	91.0	96.2	1.07	maximize
Bacteria count	$\times 10^3$ cfu/g	16	discrete	1.90	9.00	1.98	minimize
Fungi count	$\times 10^6$ cfu/g	16	discrete	1.10	4.00	0.31	minimize

Table 3: Objective function of the quality parameter optimization. **Note:** Std = standard deviation; min = minimum value; max = maximum value.

RESULTS AND DISCUSSION

Prediction of Quality Parameters of Packaged Rice Flour

A prediction of the quality parameters of the packaged rice flour is essential to influence the effect of the process conditions on the shelf-life of the product. The coefficient of the model terms for predicting the quality parameters of the packaged rice flour is shown in Table 4. The contributions of the storage period and moisture content on the overall acceptability of the models can be seen to depend on the linearity and fitness of the polynomial. A quadratic empirical model equation was developed for predicting the ash content, carbohydrate and dry matter of the product. Analysis of variance of the models showed that the carbohydrate and dry matter parameters have significant effect on the responses at $p < 0.05$ (Table 5). The model is generally associated with a negative individual effect and positive interaction or quadratic effects (Table 4). It is likely that the ash and carbohydrate contents of the packaged product will increase due to the positive effects of the quadratic and interaction model terms. Similar results were reported by Madhuresh et al. [8] in their study on the optimization of gluton free bread formulation containing hydrocolloid, modified starch and rice flour. In another related investigation, Raharja et al. [1] developed a quadratic regression polynomial model for predicting the quality parameters of rice flour cross-linked with gluten. This is also in line with the findings of Hussain ad Uddin [18] who reported quadratic fit models for the optimization of the functional properties of wheat flour. Hence, the quadratic models generated can be used for predicting the ash content, carbohydrate and dry matter of the packaged rice flour.

The model for predicting the bacteria count was not significant, while that for predicting fungi count has significant effect on the process conditions at $p < 0.05$ (Table 5).

	model term									
Q	**β_o**	**p**	**m**	**Pm**	**p^2**	**m^2**	**p^2m**	**pm^2**	**p^3**	**m^3**
Ash	6.68	-0.89	-0.35	0.04	0.07^*					
Fat	-35.2	-3.61	22.3^*	0.28	0.57	-3.5	-0.002	-0.03	-0.03	0.2
CF	2.63	-0.24^*	0.11							
CP	21.1	0.03	0.67^*							
CHO	68.9	3.10^*	-5.08	0.09	-0.3	0.26				
DM	101	-0.99	-1.15	0.18^*						
B_c	-3.88	5.48	-1.04	-0.23	-0.39^*	0.16				
F_c	1.07	-0.43^*	0.57	0.04	0.06^*	-0.06				

Table 4. Actual models for predicting quality parameters of packaged rice flour. **Note:** *Significant at $p < 0.05$; CF = Crude Fibre%; CP = Crude Protein%; CHO = Carbohydrate%; DM = Dry Matter, g; B_c = Bacteria Count cfu/g; F_c = Fungi Count cfu/g; β_o = Intercept; p = Period (week); m = Moisture Content%, wb; Q = Quality Parameter.

The interaction effect between the processes was lower in the model predicting the bacteria counts, whereas the quadratic effect was higher in the model predicting the fungi counts (Table 4). This implies that the microbial loads are likely to increase when the process conditions are combined. Reason may be attributed to the fact that interaction between period and moisture can cause the rice flour to cake and grow molds, and this may in turn increase the activity of the microorganisms. An interaction model equation was found to predict the dry matter content of the product at $p < 0.05$ (Table 5). The contributing effect of the moisture term of the model was lower than the period and the interaction terms.

Source variation	**Ash**	**Fat**	**CF**	**CP**	**DM**	**CHO**	**B_c**	**F_c**
Model	0.1564^n	0.0083^*	0.003^*	0.0015^*	0.0169^{ns}	$< 0.0001^*$	0.059^n	$< 0.0001^*$
p-Period	0.5080	0.5524	0.001	0.807	0.2476	0.0004	0.615	< 0.0001
m-Moisture	0.4186	0.0095	0.107	0.0004	0.0611	< 0.0001	0.701	0.1261
Pm	0.0962	0.0524	-	-	0.0100	0.1741	0.062	0.0629
p^2	0.0392	0.1849	-	-	-	0.0015	0.010	0.0161
m^2	0.8772	0.0117	-	-	-	0.0373	0.415	0.0604
p^2m	-	0.9210	-	-	-	-	-	-
pm^2	-	0.3162	-	-	-	-	-	-
p^3	-	0.2452	-	-	-	-	-	-
m^3	-	0.0017	-	-	-	-	-	-
R^2	0.5061	0.9278	0.5992	0.6341	0.5594	0.9369	0.6092	0.9260
R^2_{adj}	0.2590	0.8196	0.5375	0.5778	0.4493	0.9053	0.4139	0.8890
MSE	0.1121	0.1176	0.2241	0.1132	0.2838	0.2587	0.2112	0.0609

Table 5. Analysis of variance of model for quality parameter predicting. ^{n} = Not Significant at $p<0.05$; * = Significant at $p < 0.05$; CF = Crude Fibre%; CP = Crude Protein%; CHO = Carbohydrate%; DM = Dry Matter, g; B_c = Bacteria Count cfu/g; F_c = Fungi Count cfu/g; MSE = Mean Square Error.

Moreover, the models used for predicting the crude fibre, protein and fat contents of the packaged rice flour were linear and cubic with significant effects on the process conditions ($p < 0.05$) (Table 5). A positive effect of the process condition was observed on the model predicting the crude protein; whereas the effect was less pronounced on the model predicting the crude fibre, as was shown in Table 4. The interaction of the process conditions may cause an increase in the concentration of the mineral nitrogen in the flour, thereby increasing the fat and crude protein content of the product with time.

Correlation between Actual and Interpolated Quality Parameters

The validation of the models for predicting the quality parameters of the packaged rice flour is a necessary step to follow prior to the optimization, failure of which may lead to misleading results [16]. The relationship between the actual and the interpolated quality parameters of the packaged rice flour are show in Figure 3 and Figure 4. The results obtained are close to the data interpolated from the model equations ($p < 0.05$), with a mean square error of less than 30%. The reason for this may not be unconnected to the high values of the coefficient of determination (R^2 and R^2_{adj}) which exceeds acceptable limit (75%-80%) for fitting regression models describing biological process [13,14,19]. At that level, the R^2 better fit the experimental data even with the period and moisture variability. A similar finding was reported by Jalgaonkar et al. [20] in their work on the optimization of the extrusion process parameters of pasta product. Also, Danbaba et al. [12], who developed model equations for predicting the color characteristics and consumer acceptability of rice snacks, corroborates this finding. This implies that the models are valid, fit and may be used to interpolate quality parameter values outside the limit of the process conditions.

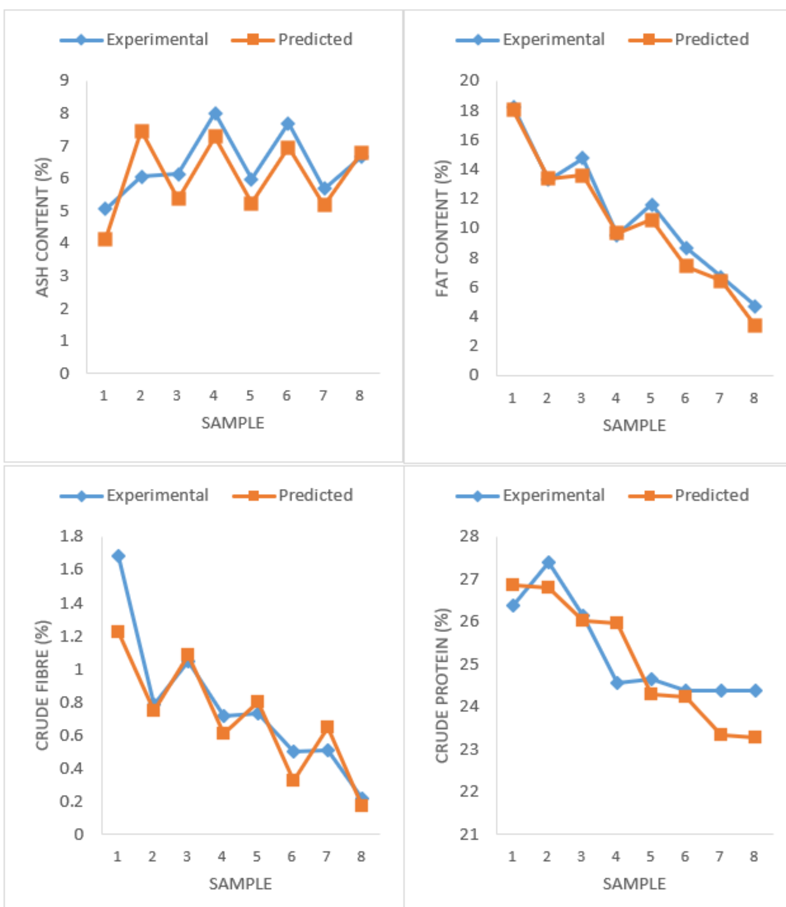

Figure 3. Validation of the actual and interpolated ash, fat, crude fibre and protein contents.

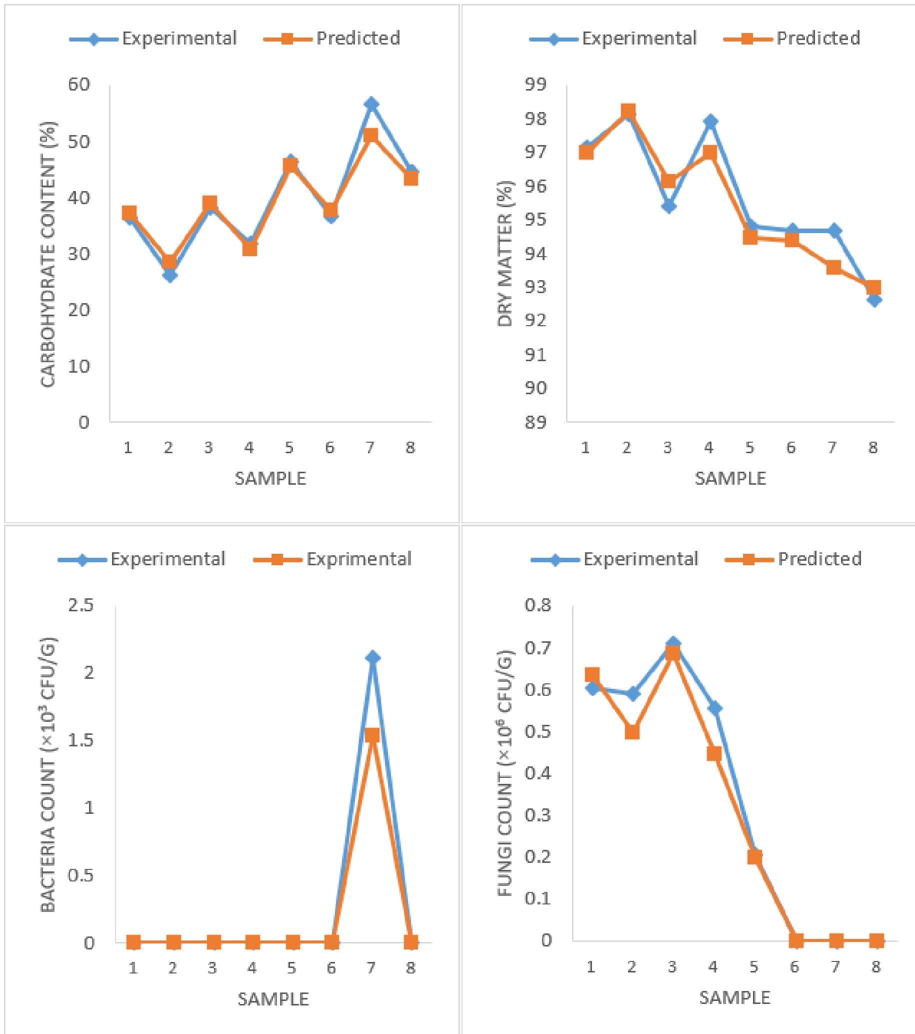

Figure 4: Validation of the actual and interpolated carbohydrate, dry matter, bacteria and fungi counts.

Optimal Quality Parameters of Packaged Rice Flour

Optimization is a process of finding the maximum or minimum values of the quality parameters with respect to the process conditions. The goal here is to develop a simple method for preliminary process design of the rice flour packaging, so other variables not used in the system development can be added, for industrial applications. The results of the optimal quality parameters of the packaged rice flour and their interaction effect on the process condition are shown in Figure 5. Also, perturbation effects of quality parameters for optimal process conditions are shown in Figure 6. This gives approximate values for each of the quality parameters lying at the nodal points of interaction of the process conditions. The optimum values were 4.09% ash, 7.09% fat, 2.7% crude fibre, 24.3% crude protein, 56.7% carbohydrate, 95.3 g dry matter, 2.01 × 10^3 cfu/g bacteria and 2.04 × 10^6 cfu/g fungi count with 66.7% desirability. A further analysis of the objective function revealed that these values occur for rice flour with 4.7% (w.b.) moisture content at 2 weeks storage period. Thus, the presence of moisture in the rice flour will likely enhance its quality parameters through the formation of disulfide and electrovalent bonds between protein components [1,21,22-24]. The water absorption capacity may reduce if the moisture present in the rice flour exceeds the interaction between the process conditions, and this may affect its later applications. It is therefore possible to enhance the shelf-life and quality parameters of the packaged rice flour with the combination of process conditions. The period and moisture content conditions selected in this analysis should give a reasonable estimate for the quality parameters of the packaged rice flour. However, different assumptions should be made for different processes, and the choice of these factors is an area where design experience is needed.

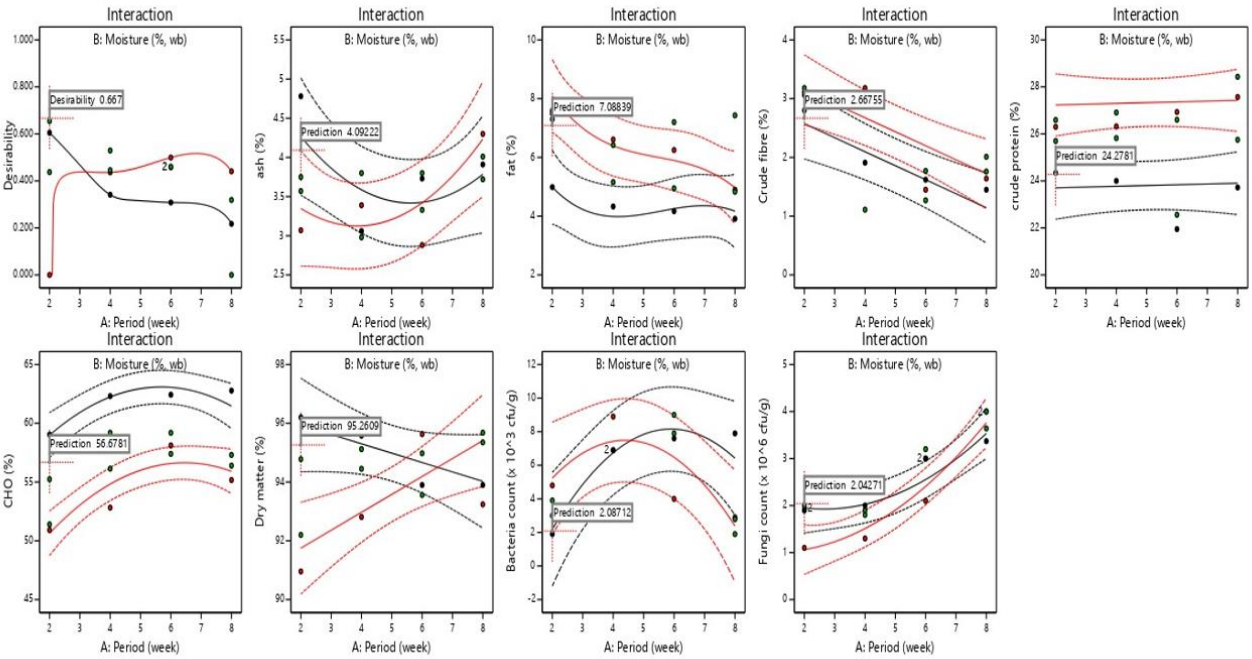

Figure 5: Optimal parameters of the packaged rice flour.

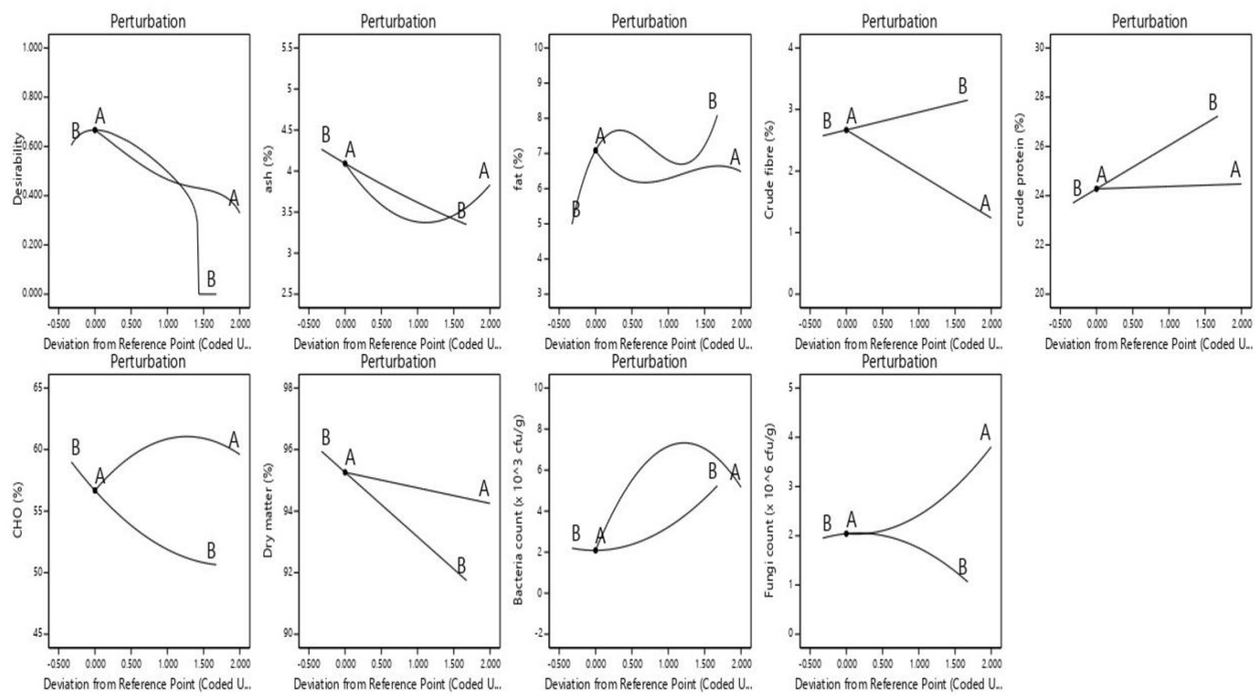

Figure 6: Perturbation effect of quality parameters for optimal process condition.

CONCLUSION

The model equations developed for predicting the quality parameters of packaged rice flour were fit, valid and significant for predicting the quality parameters ($p < 0.05$). Also, the mean square error of less than 30% obtained suggests that the models can be used for interpolating within the design criteria. The optimum values of the quality parameters were found to be 4.09% ash, 7.09% fat, 2.7% crude fibre, 24.3% crude protein, 56.7% carbohydrate, 95.3 g dry matter, 2.01×10^3 cfu/g bacteria and 2.04×10^6 cfu/g fungi count with 66.7% desirability. This value occurred at 4.7% (w.b.) moisture content at 2 weeks storage period.

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