RESPONSE SURFACE METHODOLOGY TO OPTIMIZE THE PRECOOKING TIME AND DRYING TEMPERATURE IN PRECOOKED FONIO PROCESSING

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Abstract
Fonio (Digitaria exilis) is a traditional cereal, mainly processed and marketed as precooked fonio of which processing yield is very low in spite of its nutritional and economic importance in many poor rural communities of Africa. Response Surface Methodology (RSM) is a set of statistical and mathematical methods used to develop, improve, and optimize of the processes. In the present study, Response Surface Methodology (RSM) was used to analyze the effects of precooking time and drying temperature on physical (size distribution and whiteness) and functional (hydration capacity and viscosity) characteristics of precooked fonio, the most popular derived product from fonio grains in West Africa. The aim was to optimize precooked fonio process. Fourteen samples of precooked fonio were produced by varying precooking time (15–90 min) and drying temperature (50–100 °C). Results showed that all the measured responses were significantly ($p < 0.05$) affected by the precooking time. The interaction of two variables had a significant effect upon the peak viscosity. Increase in precooking time was followed by an increase in particle size and hydration capacity, while whiteness and peak viscosity decreased. Optimal processing conditions generated from the models was precooking time, 35.44 min, and drying temperature, 86.54 °C, with a global desirability of 0.80.

Keywords: Fonio, precooking, drying conditions, physical and functional characteristics, optimization.

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1. INTRODUCTION

Fonio otherwise known as "acha" or hungry rice is an annual cereal crop indigenous to West Africa where it is cultivated for its straw and edible grains (Vietmeyer *et al.* 1996). It belongs to Poaceae family, sub-family of Panicoideae, tribe of Paniceae and genus of *Digitaria* Haller (Adoukonou-Sagbadja *et al.* 2006). Although, a large number of species of the genus *Digitaria* are recognized as weeds, *Digitaria exilis* (white fonio) and *Digitaria iburua* (black fonio) are cultivated as cereal crops and utilized as food.

Fonio has been reported as the oldest African cereal (Cruz, 2004). For thousands of years, West Africans have cultivated it across the savannah. It grows well on poor, sandy or ironstone soils in areas of low rainfall. This crop is important in areas scattered from Senegal to Lake Chad, but it is especially in Guinea that it is a main cereal crop and the basic food for several people (Cruz, 2004). Fonio, sometimes considered as "small seed with a big promise", provides food early in the season when other crops are not yet mature for harvest (Ibrahim, 2001). Indeed, the grains are very small (Length: 1.5 mm, Width: 0.9 mm) with an average of 1000 grains weighing 0.5 g (Cruz *et al.*, 2011). But fonio is one of the most nutritious and best-tasting of African cereals (Jideani, 1990). Its grains are rich in methionine and cystine, two vital amino acids in human nutrition that are lacking in some major cereals such as rice, wheat, sorghum, barley and rye (Jideani and Akingbala ,1993; Vietmeyer *et al.*, 1996). Fonio contains 10.5% protein, 1.89% fat and 75.0% carbohydrate (Temple and Bassa, 1991).

Fonio remains vital to the food security of millions of African farmers who use it in several ways. It is mainly consumed as paste, gruel or couscous (Jideani, 1999; Adoukonou-Sagbadja *et al.*, 2006). Therefore, in many West African countries, small enterprises processed fonio grain in various products such as husked fonio, milled fonio, roasted fonio, parboiled fonio and precooked fonio (Cruz, 2004; Ballogou *et al.*, 2012). Among these products, precooked fonio for couscous preparation is more appreciated by consumers. It is easier and quicker in cooking than either husked or milled fonio grain (Ballogou *et al.*, 2012).

Precooked fonio process implies two thermal treatment stages known as steaming of the milled fonio grains and drying of the precooked fonio. Both treatments have a great effect on the output of process as well as the nutritional qualities of the product. So, it becomes important to find the combination of precooking time and drying temperature which could improve the precooked fonio qualities.

The present study aims to optimize precooked fonio process by analyzing the effects of precooking time and drying temperature on physical and functional characteristics of precooked fonio.

2. MATERIAL AND METHODS

Plant material

Fonio (*Digitaria exilis*), mainly *Namba* landrace, very preferred by the housewives and processors for its good functional and culinary characteristics **(Ballogou *et al.*, 2012)**, was provided by the farmers of Boukoumbé in Northwest of Benin.

Experimental design

Precooking time (PT) and drying temperature (DT) are the two quantitative controllable factors (independent variables) used in this study. So, a central composite design for two factors (K=2) was used to estimate the simultaneous effect of independent variables on precooked fonio particle size distribution, whiteness, hydration capacity and peak viscosity in a quadratic function. After preliminary precooking tests, the upper and lower limits for the independent variables were established. The precooking time varied from 15 min to 90 min and drying temperature varied from 50 °C to 100 °C. The three levels of process variables were coded as -1, 0 and 1. Five (05) levels of each variable were chosen and fourteen (14) precooked fonio production trials (Table 1) were performed for the evaluation of the optimized process. The design matrix and variable combinations are presented in table 1.

Precooked fonio processing

Approximately 200±0.1 g of fonio (12.32% water content) first dehusked and milled are steamed on a hotplate at 300 °C during the time predefined in the experimental design. Then, the wet precooked fonio grains were oven-dried. Drying was done until the moisture content of precooked fonio was less than 13.5% according to Codex Standard 202-1995 **(**Codex Alimentarius, 2007). The dried precooked fonio were packed in polythene bag and stored at room temperature until analyses.

Particle size distribution

The granularity of the precooked fonio was determined by sieving method. Each sample (100 g) was sieved through a system of screens with decreasing mesh ranging from 3150 µm to 630 µm (3150 µm, 2500 µm, 1250 µm and 630 µm). The sieving was applied for 10 min in an electric sifter (RETSCH AS 200, digit, Haan, Germany). The size distribution was reported as the weight of precooked fonio remaining on a specified sieve after sieving and expressed as a percentage.

Whiteness

Precooked fonio sample whiteness was measured using a Minolta CR-400 Chroma Meter (Konica Minolta Sensing, Inc., Osaka, Japan). Before measurement, the apparatus was calibrated with a standard white tile (Y=88.7, x=0.3181 and y=0.3353). Whiteness (L) value was recorded.

Hydration capacity

Hydration capacity of the precooked fonio was measured according to the AACC International Method 56-20.01 **(AACC, 2000)**. Precooked fonio flour (2.0 ± 0.005 g) was weighed into 100 ml centrifuge tube and 40 ml of distilled water was added. The tube was shaken vigorously and the suspension was let stand for 10 min. Then, the suspension was centrifuged for 15 min at 1000 x gravity. After centrifugation, supernatant was carefully poured and the tube was weighed again. The hydration capacity was calculated and expressed as g water absorbed per g sample.

Table 1: Design matrix and variable combinations

Treatment No.	Coded levels of variables		Actual Levels of variables	
	PT	DT	PT, min	DT, °C
1	-1	-1	25.98	57.32
2	-1	1	25.98	92.68
3	1	-1	79.02	57.32
4	1	1	79.02	92.68
5	0	0	52.50	75.00
6	0	0	52.50	75.00
7	0	0	52.50	75.00
8	-1.41	0	15.00	75.00
9	+1.41	0	90.00	75.00
10	0	-1.41	52.50	50.00
11	0	+1.41	52.50	100.00
12	0	0	52.50	75.00
13	0	0	52.50	75.00
14	0	0	52.50	75.00

Legend: PT= Precooking Time ; DT= Drying Temperature

Viscosity analysis

Rapid Visco Analyser (RVA, Series 4V, Newport Scientific, Australia) was used to determine the pasting properties, mainly peak viscosity of the precooked fonio flour. Thus, 3 grams of sample was mixed with 25 ml distilled water. A heating and cooling cycle were programmed in the following ways. The mixture was heated to 50°C and held at that temperature for 1 min, heated to 90 °C and held at 90 °C for 2 min and cooled to 50 °C and held at that temperature for 2 min.

Data analysis

The data obtained from the experiment were analyzed using the statistical program Minitab. A second order polynomial model was used to establish the relationship between the responses (Y) and variables (X) as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{12} X_1 X_2$$

in which β_0 is a constant, β_1 and β_2 are the linear effect coefficients, β_{11} and β_{22} are the quadratic effect coefficients and β_{12} is the interaction effect coefficient. Thus, β_0 can be interpreted as the estimated value of the response at the central point.

The adequacy of the models was determined using model analysis, lack-of-fit test and R^2 (coefficient of determination) analysis **(**Weng *et al*., 2001). The lack-of- fit is a measure of the failure of a model to represent data in the experimental domain, especially for those points which were not included in the regression or variations in the models and which, therefore, cannot be accounted for by random error (Montgomery 2001). A model is adequate in describing the response if the lack-of-fit is insignificant ($p > 0.05$). The R^2 is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit. If the R^2 value for a model is more than 80 % then it can be considered for further analysis (Myers and Montgomery, 2002). The effect of variables at linear, quadratic and interactive level on the response was described using significance at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Numerical optimization techniques of the Minitab 14.10 software were used for simultaneous optimization of the multiple responses. The desired goal for each response was chosen. In order to search a solution, the goals are combined into an overall composite function, called the desirability function (Myers and Montgomery, 2002). The numerical optimization finds a point that maximizes the desirability function. In the desirability function, each response can be assigned an importance in relation to the other response. The importance varies from the least important (a value of 0.1), to the most important (a value of 10). In the present study, all the responses were assigned an importance of 1, as per the default settings of the software. The response surfaces help to understand the effect of varying the processing parameters upon the response, i.e. in which direction the response is increasing or decreasing.

3. RESULTS AND DISCUSSION

Responses of different studied physical and functional characteristics

Response surface analysis was applied to the experimental data and the second order response surface model was fitted to the size distribution, the whiteness, the hydration capacity and the peak viscosity. The statistical significance of the model terms was examined with the help of regression analysis and analysis of variance (ANOVA).

Table 2: Response values for size distribution, whiteness, hydration capacity and peak viscosity

Treatment code	Size distribution					Whiteness	Hydration Capacity	Peak Viscosity , cP
	< 630 µm, %	] 630-1250 µm], %	] 1250-2500 µm], %	] 2500, 3150 µm], %	>3150 µm, %			
1	11.02	69.71	14.61	1.95	3.50	62.22	3.31	1001.50
2	2.84	49.51	36.31	4.91	6.87	56.33	4.74	50.00
3	10.11	69.34	15.00	2.17	3.91	62.02	3.75	567.50
4	4.46	59.50	30.66	2.17	4.58	57.80	4.90	61.00
5	5.32	59.00	30.35	2.27	3.40	58.14	4.69	131.50
6	5.96	59.77	25.39	3.66	5.64	59.19	4.61	262.00
7	6.23	61.58	23.25	3.31	5.84	58.98	4.14	282.50
8	22.21	70.09	6.29	1.01	0.61	67.35	2.99	1354.50
9	4.68	56.50	31.89	2.95	4.07	58.55	5.01	105.50
10	5.22	53.86	31.53	4.26	5.51	57.27	4.57	149.00
11	5.97	60.56	25.94	3.03	4.75	58.06	4.38	162.50
12	5.44	55.27	28.17	4.14	7.22	57.81	4.79	139.50
13	4.72	54.86	29.84	3.85	6.93	58.62	4.48	224.00
14	4.63	56.50	31.33	3.33	4.46	58.40	4.84	147.00

Table 3: Regression analyses of the second order polynomial models for the various responses

	Size distribution, %		Whiteness	Hydration capacity	Peak viscosity, cP
	] 630-1250 µm]	] 1250-2500 µm]			
Intercept	57.83	28.06	58.52	4.60	197.7
X_1	- 8.71***	13.00***	- 3.99***	0.96***	- 570.0***
X_2	3.38*	-2.33	0.42	0.06	- 71.4
X_1^2	6.35*	-8.85**	4.07***	- 0.63**	520.8***
X_2^2	0.26	0.80	- 1.21*	- 0.15	- 53.4
X_1X_2	5.18	-3.02	0.84	- 0.14	222.5*
ANOVA					
Lack-of-Fit (P-value)	0.48	0.99	0.22	0.66	0.15
R-sq, %	88.7	94.4	97.0	91.0	96.9
R-sq(adj), %	81.7	90.9	95.2	85.4	95.0

Legend: ** = Significant at P<0.05, ** = Significant at P<0.01, ***= Significant at P<0,001.*

It was observed that the lack-of-fit test for all the models were insignificant ($p > 0.05$), implying that the models were accurate enough to predict the responses. The variability explained by all the models was more than 80 per cent ($R^2 > 0.80$) for] 630-1250 µm] and] 1250-2500 µm] size distribution, whiteness, hydration capacity and peak viscosity. Thus, all the models exhibited statistically adequacy and were hence used to study the effect of processing parameters on the various responses. The response values for the different treatments are presented in Table 2 and the result of the regression analysis and analysis of variance (ANOVA) for all the models is reported in Table 3.

Impact of processing parameters on size distribution

Among different treatments, the highest values of size distribution were ranged within] 630-1250 µm] and]1250-2500 µm]. These values varied from 49.51 to 71.08 % and 6.29 to 36.31 % respectively for] 630-1250 µm] and] 1250-2500 µm] (table 2). The size distribution of precooked fonio particle was mainly affected by the precooking time. The linear term of this processing parameter was found to be highly significant ($p < 0.001$) for both size distribution ranged within] 630-1250 µm] and] 1250-2500 µm] (table 3). Besides, the quadratic term of precooking time significantly affected ($p < 0.05$) these size distributions. The linear term coefficient of drying temperature is significant only for] 630-1250 µm] size distribution. Figure 1 showed that whatever the drying temperature,] 630-1250 µm] size distribution decreases when the precooking time increases while Figure 2 showed that increasing in precooking time results in an increase of] 1250-2500 µm] size distribution.

The size distribution of precooked fonio is in relationship with the lump formation during the precooking process. As the precooking time increases, fonio starch gelatinization got the amylose out of grains **(**Buléon *et al.*, 1990). Consequently, it can be argued that it is amylose which permits the aggregation of grains, causing the increase of] 1250-2500 µm] size distribution and reducing the] 630-1250 µm] size distribution.

Impact of processing parameter on the whiteness

The highest value of whiteness was obtained from treatment 8 (table 2) which involved the lowest precooking time (15 min). According to the table 3, both precooking time and drying temperature significantly affected the whiteness. The linear and quadratic terms of precooking time are found to be highly significant ($p < 0.001$) on the whiteness. For the drying temperature, only the quadratic term significantly ($p < 0.05$) contributed to the whiteness. Figure 3 shows that an increase of precooking time leads to a decrease of whiteness.

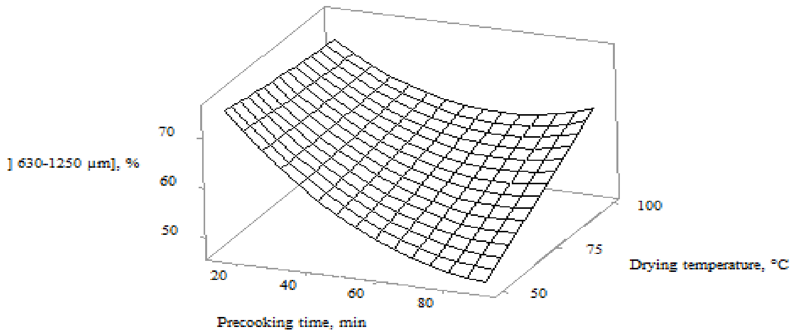

Fig. 1: Response surface representing the effect of precooking time and drying temperature on [630-1250 µm] granularity part of precooked fonio

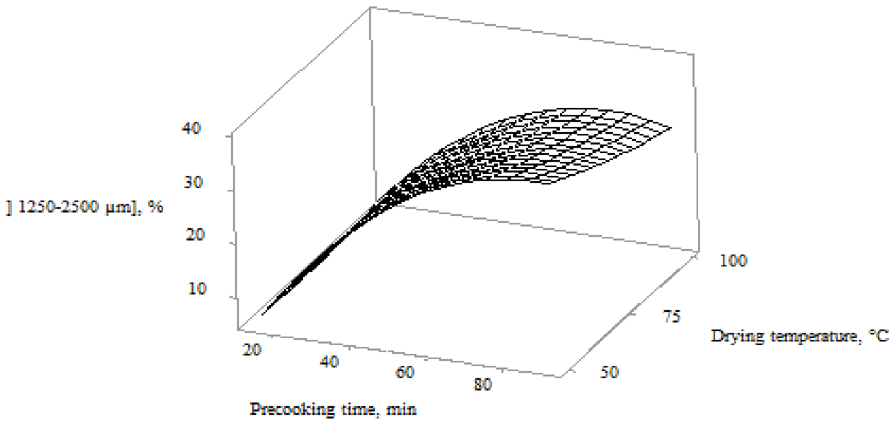

Fig. 2: Response surface representing the effect of precooking time and drying temperature on [1250-2500 µm] granularity part of precooked fonio

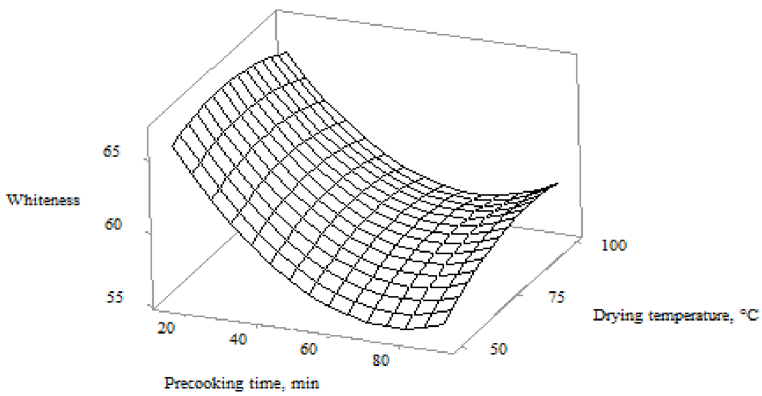

Fig. 3: Response surface representing the effect of precooking time and drying temperature on the whiteness of precooked fonio

It has been reported that lower steaming temperature and time were favorable to produce a better quality of parboiled brown rice **(Islam *et al.*, 2002).** Besides, Parnsakhorn and Noomhorm (2008) have noticed that the whiteness value of parboiled rice decreased with increasing steaming time. So, our results are similar to those obtained by these authors. The decrease of whiteness with increasing precooking time can be explained by the browning of precooked fonio grains.

Impact of processing parameters on hydration capacity and peak viscosity

Viscosity and hydration capacity are indicators of functional characteristics of cereal based products. The values of hydration capacity for different treatments are ranged between 2.99 and 5.01 (Table 2). The hydration capacity was affected only by the precooking time. The linear and the quadratic terms of this processing parameter were significant coefficients in the model (table 3). With the increasing of the precooking time, hydration capacity of precooked fonio increases significantly to reach its highest values at the maximal precooking time (figure 4). The peak viscosity of the processed precooked fonio was also significantly affected by the precooking time. The linear and the quadratic terms were found to be highly significant ($p < 0.001$). From Figure 5, it is clear that precooking time had a decreasing effect on the peak viscosity. The minimum peak viscosity was obtained from treatment 4 which involved a high precooking time (79.02 min) and high drying temperature (92.68 °C). Thus, the interaction term significantly contributes to viscosity response in the model ($p < 0.05$).

The increase of hydration capacity and the fall of viscosity in processed cereal products have been reported to be influenced by the pre-gelatinization of starch (Majzoobi *et al*., 2011). So, with the increasing of precooking time, the native starch of fonio is more pre-gelatinized. These results are similar to those obtained by Lai (2001) on pre-gelatinized rice flour.

Optimization

Based on the results described above, it can be asserted that the quality of the precooked fonio is not dependent on a single main factor and that both independent variables were important in defining the characteristics of the product. So, the next stage involved the detection of the best combination of factors that are able to produce the expected characteristics in the final product. All comments arising from the response surface plots were taken into account in the optimization, considering that the optimal solution arises from a compromise among the different responses. Thus, the criteria of optimization must be selected; that is, a variable response may either be maximized or minimized. Table 4 shows the constraints assigned upon the measured responses and the optimum predicted responses generated from the model with its desirability.

As a result of the optimization stage, the optimum processing condition generated from the models was, precooking time, 35.44 min and drying temperature, 86.54 °C. The corresponding responses of the optimum processing condition are 62.42, 20.04, 60.94, 4.045 and 283.68 respectively for] 630-1250 µm] and] 1250-2500 µm] size distributions, whiteness, hydration capacity and peak viscosity (Table 4).

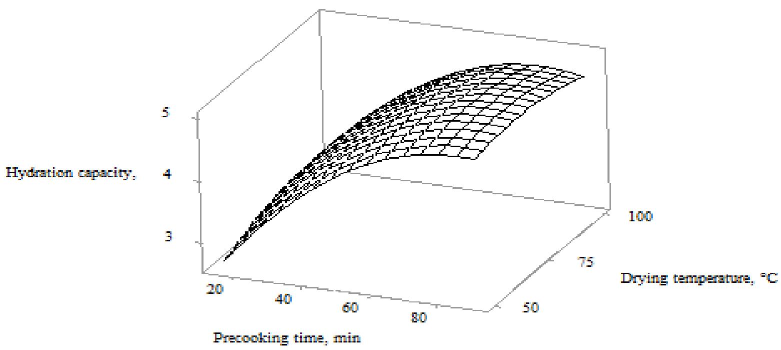

Fig. 4: Response surface representing the effect of precooking time and drying temperature on the hydration capacity of the precooked

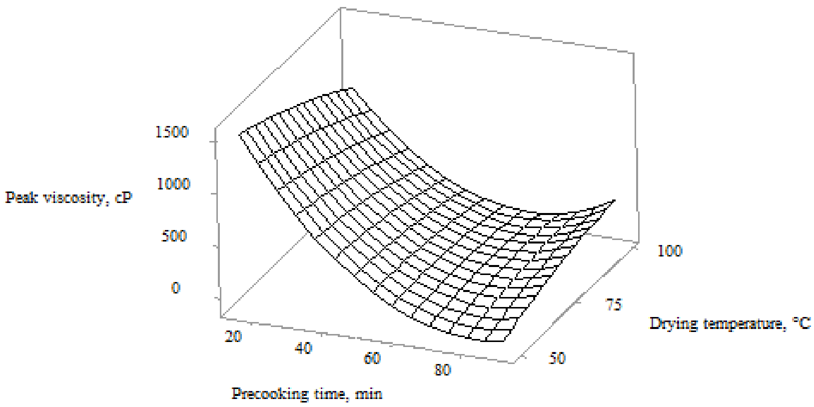

Fig. 5: Response surface representing the effect of precooking time and drying temperature on the peak viscosity of the precooked fonio

Table 4: Constraints applied to the responses for numerical optimization and optimum predicted values

Response	Goal	Lower Limit	Upper Limit	Optimum value	Desirability
] 630-1250 µm], %	Maximize	60	70	62.42	0.76
] 1250-2500 µm], %	Minimize	15	25	20.04	0.99
Whiteness	Maximize	58	65	60.94	0.91
Hydration capacity	Maximize	3	5	4.05	0.87
Peak viscosity, cP	Minimize	200	500	283.68	0.53
Optimum processing condition					
Precooking time, min			35.44		
Drying temperature, °C			86.54		
Global desirability			0.80		

Table 5 Verification of the models by comparing the experimental values with the predicted values

Response	Predicted value	Actual value*
] 630-1250 µm], %	62.42a	65.98 ± 2.42a
] 1250-2500 µm], %	20.04b	21.17 ± 1.62b
Whiteness	60.94c	63.16 ± 1.52c
Hydration capacity	4.05d	4.50 ± 0.07d
Peak viscosity, cP	283.68e	272.00 ± 1.41e

*Values are expressed as mean ± standard deviation S.D. of two replications
The mean with the same letter than the predicted value on each line is not significantly different from this predicted value ($p < 0.05$) by 1-Sample t test.

This formulation had a calculated desirability of 0.80 and the resulted precooked fonio exhibited good quality, which was subsequently analyzed in order to compare predicted response to measured values. Perusal of table 5 showed that the predicted values had non-significant ($p < 0.05$) difference from experimental values.

4. CONCLUSION

Response surface methodology was effective in optimizing processing parameters for the precooked fonio process. The regression analysis yielded models that were used for obtaining optimum conditions for desired responses within the range of conditions applied in this study. Model analysis, which included checking the validity of the model with the help of various relevant statistical aids, such as lack-of-fit and coefficient of determination, revealed that all the models were statistically adequate. The precooking time was found to have a significant effect upon all the responses while the drying temperature significantly affected the size distribution and the whiteness. Optimum values for the processing parameters were obtained via numerical optimization, which also satisfied the criterion of constraints of the responses.

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