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Process optimization of flour from Philippine purple-fleshed sweet potato (Ipomoea batatas (L.) Lam. var. SG18-150-01) using Response Surface Methodology

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ABSTRACT

Processing purple-fleshed sweet potato (PFSP) into flour minimizes post-harvest losses as it has a longer shelf-life and can be used for various food product applications. The anthocyanins naturally occurring in PFSPs also provide promising color with added health benefits to consumers. However, the stability of this phytonutrient depends on several factors, thus optimizing the process of flour production is crucial. The study aimed to determine the optimum processing conditions of the purple-fleshed sweet potato flour (PFSPF) using the SG18-150-01 variety. Response Surface Methodology (RSM) was employed using a three-level factorial design following Central Composite Design to assess the effects of pressure-cooking time (5-25 minutes) and drying temperature (50-80°C) on the response variables. The generated optimum process is composed of a time-temperature combination of 5 minutes and 50.36°C which then resulted in a 143 mg cyanide-3-glucoside (c3g)/100g of anthocyanin content and 5.26 mg Trolox equivalents (TE)/g antioxidant activity. The model used to predict the response is found to be dependable as the actual values were close to the predicted. The optimized and stable PFSPF can be used as a functional ingredient, particularly in the baking industry.

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INTRODUCTION

Purple-fleshed sweet potato (PFSP) is not as widely available as other cultivars, but it gained a lot of attention based on nutrition and has been used as a functional food for its high contents of dietary anthocyanin and phytochemicals known to have

KEYWORDS

optimization, anthocyanin content, purple-fleshed sweet potatoes, flour

beneficial effects on human health (Yang et al., 2011). The pigments extracted from purple-fleshed sweet potatoes are also used as natural colorants in food applications. Processing sweet potato roots into flour minimizes post-harvest losses and makes them more stable intermediate products to increase the utilization of copious fresh crops (Eleazu and Ironua 2013).

Current technical studies on sweet potato flour have concentrated on the development of sweet potato flour-based products rather than on investigating efficient methods to produce the flour (Van Hal 2000) and optimizing the process to improve its shelf-life and nutritive value. Determining the optimum condition is important to establish a process with minimal loss of bioactive components, nutrients, and discoloration in the final product. Optimizing the process of purple-fleshed sweet potato flour (PFSPF) production is highly desirable to obtain a product with high quality and maximum potential health benefits. Response surface methodology (RSM) is an efficient tool that can be used in optimizing complex processes and, therefore, can be applied to optimizing PFSPF production. Recently, the Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños has developed a promising variety of sweet potatoes with vibrant purple color flesh. The SG18-150-01 was chosen in this study, as based on its profile, it has high yield and exudes stable and distinct deep purple flesh compared to other developed genotypes, which can be utilized for PFSPF production in the Philippines. The objective of this study is to optimize flour production by RSM, utilizing purple-fleshed sweet potato variety (SG18-150-01) with maximum anthocyanin content, antioxidant capacity, and acceptable color quality for potential use as a functional food ingredient.

MATERIALS AND METHODS

A. Variable screening experiment

Different pre-treatment and processing conditions that may affect the quality attributes of purple-fleshed sweet potato flour (PFSPF) and reduce its anthocyanin content were used as input variables. These variables were subjected to screening to eliminate those that will not significantly affect the product. A two-level fractional factorial design was used to screen the factors that will influence the quality of PFSPF. Seven input variables including peeled/unpeeled, chemical treatment, blanched/unblanched, cooking pressure, cooking time, drying temperature, and packaging material were used. The response variables for the experiment were moisture content (MC), water activity (A_w), color, and total anthocyanin content. Table 1 shows the minimum and maximum values for the 7 variables- 8 runs screening experiment.

Table 1: Maximum and minimum values of variables used in the screening experiment for PFSPF.

Variables	Minimum Level (-)	Maximum Level (+)	References
Peeled/unpeeled	unpeeled	peeled	(Maruf et al., 2010)
Chemical treatment	0	0.5% $Na_2S_2O_5$ for 5 minutes	(Ruttarattanamongkol et al., 2016)
Blanch/unblanched	0	70°C for 5 minutes	(Olatunde et al., 2016)
Cooking pressure*	5 psi	15 psi	(Sinha et al., 2015) (Xu et al., 2015)
Pressure-cooking time*	5 minutes	15 minutes	(Xu et al., 2015)
Drying temperature**	50°C	70°C	(Ruttarattanamongkol et al., 2016)
Packaging material***	clear	opaque	(Van Hal 2000) (Kaur and Sandhu 2016)

*pressure cooking by steam using All American Pressure Cooker AA910, 10-quart capacity
**dried using Memmert Oven
***clear: clear: clear front/white back, PET/PE, glossy plastic lining, 70 microns, 10*15 cm
opaque: silver, PET/VMPET/PE, glossy metalized foil lining, 80 microns, 10*15 cm

B. Preparation of PFSPF

PFSP (SG18-150-01) was used in the optimization of flour. PFSPs were harvested and collected after 120 days after planting. Roots with uniform size and shape without any visual defects were selected. The experimental sample (500 g) is representative of the population. The roots were cleaned by washing and air-dried before processing. The pre-treatment processing condition was based on the 8 treatment runs of the variable screening experiment (Table 1). Then the samples were shred using a grater, evenly spread on trays and dried for 8 hours. Samples were ground and sieved with no. 70 mesh sieve. The PFSPF was stored in air-tight packaging until used.

C. Experimental Design for Optimization Experiment

The optimization experiment used two variables that are observed to have significant effects on the PFSPF based on the results of the screening experiment. The optimum processing conditions were determined using 3^2 fractional factorial experiments following a Central Composite Design with 13 experimental combinations with a replicate run (Table 2). The identified independent variables and the different levels were as follows: pressure-cooking time (A) (5, 15 and 25 minutes), drying temperature (B) (50°C, 65°C, 80°C). All other variables were set constant; peeled, untreated with chemicals, unblanched, cooking pressure (10 psi), dried for 16 hours, and packaging material used is opaque as suggested in the screening experiment results. The identified 13 experimental combinations were subjected to total anthocyanin content, antioxidant capacity, color L*, a*, b*, chroma, and hue angle analyses which are represented as R_1, R_2, R_3, R_4, R_5, R_6, and R_6, and R_7, correspondingly. Mathematical models were evaluated for each response using multiple regression analysis. The polynomial equation is as follows:

$$\alpha = \beta_0 + \beta_1 A + \beta_2 B + \beta_{12} AB + \beta_{11} AA + \beta_{22} BB + \beta_1{}^2{}_2 AB + \beta_{12}{}^2 AB$$

where α is the response variable, β_0 is the intercept, β_1, β_2, β_{12}, β_{11}, β_{22}, $\beta_1{}^2{}_2$ and $\beta_{12}{}^2$ are the linear, cross-product, quadratic coefficients, respectively. Lastly, A and B are the independent variables.

Table 2: Five levels of the identified variable for optimization experiment.

Variable	Symbols	-α	-1	0	+1	+α
Pressure-cooking time (minutes)	A	0.86	5	15	25	29.14
Drying temperature (°C)	B	43.79	50	65	80	86.21

D. Fitting the Model

Model fitting is performed to evaluate the significance of the model and the quality of the model can be determined by the application of Analysis of Variance (ANOVA). In this study, the response variables (TAC, AA, and color) were employed in a multiple regression analysis to fit the second-order polynomial equation because there is a curvature in the system.

E. Quality Assessment of PFSP Flour

Color measurement

The color of PFSPF was determined using Konica Minolta, Inc. Chroma Meter CR-400 with three parameters (CIE L*, a*, b*) established by the International Commission on Illumination. The L* value represents lightness and chromatic color is represented by a* and b* values. The a* value indicates the redness (+a*) and greenness (-a*), and the b* value indicates the yellowness (+b*) and blueness (-b*). Chroma and hue angle were determined using the a* and b* values and are measures of color intensity and actual color tone in the color system, respectively. All measurements were in triplicates.

Extraction of PFSPF samples

PFSPF extracts were extracted using the methods of Hong and Koh (2015) and Siegalman and Hendricks (1958) with modifications. Each sample (0.5g) was weighed and extracted using 10 mL of aqueous methanol containing 1 % HCl at room temperature in an orbit shaker (Lab-Line Instruments, Inc.) using a reciprocating motion for 1 h. Then, it was centrifuged using a high-speed centrifuge (IEC International Centrifuge) for 15 min. The residue was re-extracted under the same conditions. The combined supernatants were stored at -4°C until used.

Total anthocyanin content (TAC) Analysis

Total monomeric anthocyanin content was measured by the pH differential method according to Giusti and Wrolstad (2005). The spectrophotometer (Shimadzu UV-1900 UV-VIS spectrophotometer) was warmed up for 30 minutes before the measurements. Appropriate dilution of the sample was determined with potassium chloride buffer (pH 1.0) wherein the absorbance falls in the linear range of the spectrophotometer. Total anthocyanin content was determined using two buffer systems: potassium chloride buffer (0.025 M, pH=1.0) and sodium acetate buffer (0.4 M; pH=4.5). The determined dilution of the samples was prepared in triplicates and equilibrated for 15 minutes. Extracts were mixed with the corresponding buffer, and the absorbance of each dilution at 530 nm ($\lambda_{vis\text{-}max}$) and 700 nm was measured against a blank cell filled with distilled water (to correct for haze). Visible spectra were recorded by scanning the absorbance between 530 and 700 nm using quartz cuvettes of 1 cm path length. All the measurements were done in triplicates.

Pigment content was calculated as equivalents of cyanidin-3-glucoside (MW= 449.2 g/mol, ε=34,300 L/mol/cm). The total anthocyanin content (as cyanidin-3-glucoside equivalents), was calculated using the following formula:

$$\text{TAC} = \frac{A \times MW \times DF \times 1000}{\varepsilon \times l}$$

where TAC is total anthocyanin content (mg/L); MW is molecular weight (g/mol); DF is dilution factor; l is pathlength (cm); ε is molar absorptivity; 1000 is the conversion factor from milligram; A is absorbance and was calculated as follows:

$$A = (A_{530\ nm} - A_{700nm})_{\ pH1.0} - (A_{530\ nm} - A_{700nm})_{\ pH\ 4.5}$$

Antioxidant Activity (AA) Analysis by DPPH scavenging activity assay

The DPPH assay was used to evaluate the free radical scavenging activity of PFSPF extracts. A modified method was used according to Pisoschi and Negulescu (2012). DPPH was dissolved in methanol at a concentration of 0.1 mM. About 1 ml of methanol was added to a tube. Then 1 mL of diluted extract solution was mixed and vigorously shaken with 1 ml of freshly prepared DPPH solution. The mixture was incubated in a dark room for 25-30 minutes at room temperature. After incubation, the absorbance of the sample was read at 517 nm in a spectrophotometer. Methanolic solutions of Trolox (1-10 µg/ml) were used as standards. All the measurements were done in triplicates.

F. Determination of Optimum Processing Combination

Response Surface Regression Analysis

The response surface regression analysis was employed using the Stat-Ease software (Design-Expert 13, Version 13.0.8.0 64-bit) in the analyses of the color, TAC, and AA for all the processing combinations of the product. The software was used for the graphical presentation of the response surface plots and predicted response of each treatment.

Attainment of Optimum Combination

The values for all response variables were set to specific constraints [(color L* = goal: none); (color a* = goal: in range, limits :14.23-18.46); (color b* = goal: in range, limits: -9.16 - -6.97); (hue angle = goal: in range, limits: 359.435-359.603); (chroma= goal: in range, limits: 16.0102-20.6077); (TAC= goal: maximize, limits: 71.7388- 143.917, importance: +++); (AA= goal: maximize, limits: 2.80343- 7.2915, importance: +++)] as influenced by independent variables (pressure-cooking time, and drying temperature). The desirability profiling was done by using Stat-Ease software (Design-Expert 13, Version 13.0.8.0 64-bit).

Verification of the Optimized Model

Two solutions generated from desirability profiling were rerun to verify the model used in determining the values of the parameters considered. Color, TAC, and AA analyses were conducted. Point prediction and confirmation were used as post-analysis run by using Stat-Ease software (Design-Expert 13, Version 13.0.8.0 64-bit) to confirm whether the experimental values are within the range of predicted values from the model using prediction intervals (PI). Among the solutions, the highest desirability was selected as the optimum processing condition for PFSPF production.

RESULTS AND DISCUSSION

A. Preliminary Experiment: Variable Screening

Screening experiments are a vital step in process optimization. It is used to eliminate non-significant variables and determine the significant ones to improve the overall process (Taguchi 2002). Many factors could influence the response in a process, making it difficult to single out the main factors to optimize. Finding the effect of every single factor is time-consuming, wasteful, and often unable to determine interactions between parameters (Boateng and Yang 2021). To address these problems, screening designs such as fractional factorial designs are used and later followed by optimization experiments such as Response Surface Methodology.

A 2^{7-4} Fractional Factorial Design with resolution III, 7 factors, and 8 runs with a single replicate was employed to determine the factors significantly affecting the quality of PFSPF. Table 3 shows the summary of standardized effects for the different quality attributes of PFSPF. The negative effect estimates suggest that using the low value of the factor decreases the value of the response variable while the positive effect estimates enhance it. The results show that blanching has no significant influence on all the attributes of the PFSPF. This predicts that at any level between the “high” and “low” values, the responses will not be affected. The moisture content (MC) of PFSPF was not significantly affected by the factors used, along with the

water activity (A_w) except for the drying temperature and packaging material.

Table 3: Summary of standardized effects of variable screening experiment using Two-Level Factorial Design showing variables that are significantly affecting the quality of PFSPF.

Factors	Range of Values		Responses					
	Low (-)	High (+)	MC	A_w	Color L*	Color a*	Color b*	TAC
Peeling	unpeeled	peeled	-1.09027^{ns}	-0.02042^{ns}	3.1325*	-0.6815^{ns}	0.2545^{ns}	-54.6713**
Chemical treatment	0	0.5% $Na_2S_2O_5$ for 5 mins.	0.83670^{ns}	-0.00325^{ns}	-1.2005^{ns}	-1.6725^{ns}	1.5345*	-103.313**
Blanching	0	70°C for 5 mins.	-1.34295^{ns}	-0.02392^{ns}	0.2395^{ns}	0.5475^{ns}	-0.6895^{ns}	-0.55102^{ns}
Cooking pressure	5 psi	15 psi	-0.87239^{ns}	0.01625^{ns}	1.6095*	1.4855^{ns}	-0.7705*	27.0602*
Pressure-cooking time	5 mins.	15 mins.	1.65606^{ns}	0.02692^{ns}	0.1155^{ns}	-0.7645^{ns}	1.7195*	-26.7216*
Drying temperature	50°C	70°C	-4.75855^{ns}	-0.15425*	1.5985*	0.8145^{ns}	-0.0585^{ns}	-14.0949*
Packaging material	clear	opaque	2.33611^{ns}	0.04325*	-0.2715^{ns}	-1.0395^{ns}	1.1305*	23.6004*

^{ns}–no significant difference at p >0.05; * -significant at p <0.05; **-highly significant at p <0.

It is shown in the results that using unpeeled PFSP decreases TAC while peeled samples increase it. The peeling condition creates a significant influence over the color L* which represents the lightness of PFSPF. Unpeeled PFSP flour tends to be darker in color compared to peeled samples. The addition of an anti-browning agent significantly decreases TAC while increasing color b*. Subsequently, using a higher level of cooking pressure enhances TAC and lightens the color of PFSPF but lowers the color b* value. Negative effect estimates of cooking time to TAC imply that less cooking time is preferable to achieving higher TAC. Moreover, to achieve a darker color and higher TAC of PFSPF, a lower drying temperature must be used. The type of packaging material additionally has a significant influence over TAC and color b*. The positive effect estimates revealed that an opaque type of packaging is better for achieving higher TAC.

Blanching is found to have no significant effect on the response variables. The pressure-cooking time and drying temperature were selected for the process optimization of PFSPF. The use of chemical treatment and blanching step was eliminated in the process since the results gave negative effects on the attributes of PFSPF. The packaging material that was used is opaque to maintain dark color and higher TAC, and cooking pressure was held constant at 10 psi using unpeeled samples. It is expected that with these processing conditions, PFSPF will have better quality attributes.

B. Model Fitting

Based on the obtained results, the suggested model for predicting the value of the response variables (TAC, AA, color) is quadratic, as expected, because response surface designs such as CCD are used to fit the second-order regression model (Asghar et al., 2014). Model modification is necessary if there are model terms that have no significant effect on the response. This is done by manual removal of insignificant model terms and adding a cubic term that was not aliased with other terms which resulted in generating a reduced cubic model with better fit and precision. In general, cubic models are not considered for analysis due to the risk of being aliased, and fitting response surface design in a cubic model is considered overfitting such as in the study conducted by Deng et al. (2019). However, there are previous studies that have considered adding cubic terms into the quadratic model to obtain a better model fit for their response. For instance, Aghbashlo et al. (2011) selected a reduced cubic model for model fitting in their study due to having insignificant lack-of-fit and a high coefficient of determination (R^2) values. Therefore, after modifying the model, a reduced cubic model was chosen as the best fit for the response variables, except for the color L and b values, which are best fitted with a reduced quadratic model. According to the results, the reduced quadratic and cubic polynomial models for the response variables had a p-value of < 0.0001, which indicates that the model terms were significant and can be used to navigate the design space.

Another way to evaluate the model is the goodness-of-fit test. A model is well fitted to the experimental data if it obtains a significant regression, and the lack of fit is insignificant (Montgomery 2012). Table 4 shows that all experimental factors have no significant lack of fit, which means that the model is well fitted to the response variables. Another determinant of the model quality is the coefficient of determination (R^2) which measures how well the model can predict an outcome. The model obtained R^2 of 0.5905 to 0.9512 (Table 6) and a value closer to 1 is the better fit for a regression model. The model was found to be adequate in predicting the response as it obtained significant lack-of-fit and satisfactory levels of R^2, except for color L* which is relatively lower and can be attributed to several factors such as the sensitivity of the test. The significant regression coefficients were presented in Table 5 with necessary model reduction, and the final predicted model for each response variable in terms of coded factors is shown in Table 6.

Table 4: Summary of Lack of Fit test of Analysis of Variance (ANOVA) for the designated response variables.

Response Variables	Source	df	Sum of Squares	Mean Square	F-value	p-value
TAC	Lack of Fit	42	833.58	19.85	1.72	0.0800^{ns}
	Pure Error	24	277.56	11.57		
	Total Error	66	1111.14	31.42		
AA	Lack of Fit	42	3.11	0.0741	0.7756	0.7695^{ns}
	Pure Error	24	2.29	0.0955		
	Total Error	66	5.40	0.1696		
Color L*	Lack of Fit	44	67.99	1.55	0.3750	0.9977^{ns}
	Pure Error	24	98.89	4.12		
	Total Error	68	166.88	5.67		
Color a*	Lack of Fit	41	6.83	0.1667	0.4770	0.9820^{ns}
	Pure Error	24	8.39	0.3494		
	Total Error	65	15.22	0.5161		
Color b*	Lack of Fit	43	3.31	0.0770	0.6918	0.8564^{ns}

	Pure Error	24	2.67	0.1113		
	Total Error	67	5.98	0.1883		
	Lack of Fit	41	9.42	0.2298	0.5752	0.9416[ns]
Chroma	Pure Error	24	9.59	0.3994		
	Total Error	65	19.01	0.6292		
	Lack of Fit	41	0.0019	0.0000	0.2573	0.9999[ns]
Hue angle	Pure Error	24	0.0044	0.0002		
	Total Error	65	0.0063	0.0002		

[ns] insignificant lack of fit, p >0.05

Table 5: Regression coefficients of the predicted reduced quadratic and cubic polynomial for the response of TAC, AA, color L*, color a* and color b*, chroma, and hue angle.

Coefficient	TAC	AA	Color L*	Color a*	Color b*	Chroma	Hue Angle
Intercept	110.63	5.44	58.05	16.61	-7.66	18.29	359.57
A	-9.56	0.2291	2.14	-0.4808	0.5174	-0.6131	0.0080
B	-4.37	0.0882	-0.1238	-0.1856	0.3613	-0.3377	0.0146
AB	-2.66	-0.0370	0.3429	-0.7146	0.3871	-0.7876	0.0000
AA	1.83	-0.1130	-0.6249	-0.0221	-0.4061	0.1641	-0.0205
BB	-5.66	-0.2304		-0.6933	-0.1803	-0.5350	-0.0265
A^2B	-16.79	-0.8258		1.29		1.16	0.0320
AB^2				0.4196		0.2677	0.0229

A-Pressure-cooking time (mins.), B-Drying temperature (°C)

Table 6: Final predicted model equation for each response variable.

Response Variable	Model Equation	R^2
TAC	$110.63 - 9.56A - 4.37B - 2.66AB + 1.83A^2 - 5.66B^2 - 16.79A^2B$	0.9399
AA	$5.44 + 0.02291A + 0.0882B - 0.0370AB - 0.1130A^2 - 0.2304B^2 - 0.8258A^2B$	0.7721
Color L*	$58.05 + 2.14A - 0.1238B + 0.3429AB - 0.6249A^2$	0.5905
Color a*	$16.61 - 0.4808A - 0.1856B - 0.7146AB - 0.0221A^2 - 0.6933B^2 + 1.29A^2B + 0.4196AB^2$	0.8180
Color b*	$-7.66 + 0.5174A + 0.3613B + 0.3871AB - 0.4061A^2 - 0.1803B^2$	0.8351
Chroma	$18.29 - 0.6131A - 0.3377B - 0.7876AB + 0.1641A^2 - 0.5350B^2 + 1.16A^2B + 0.2677AB^2$	0.7590
Hue angle	$359.57 + 0.0080A + 0.0146B + 0.0000AB - 0.0205A^2 - 0.0265B^2 + 0.0320A^2B + 0.0229AB^2$	0.9512

A-Pressure-cooking time (mins.), B-Drying temperature (°C), R^2-coefficient of determination

For TAC as response variable, it was noted that the model is found to be significant ($p < 0.01$, R^2: 0.9339), indicating its predictive capacity. The lack of fit was insignificant with a p-value of 0.0800 and the model was found to fit well with the reduced cubic model to predict the TAC of the PFSPF. Moreover, the reduced cubic model is the best fit in predicting AA and it has an insignificant lack of fit ($p > 0.05$) with an R^2 of 0.7721. The models for each color response value are significant at $p < 0.01$, with an insignificant lack of fit ($p > 0.05$), meaning they can predict the values experimentally.

C. Effect of pressure-cooking time and drying temperature on the Response Variables

Total Anthocyanin Content (TAC)

Anthocyanins belong to the phenolic compounds that are abundant in purple-rich colored root crops, such as purple-fleshed sweet potatoes. The TAC of PFSPF using SG18-150-01 variety was quantified using the pH differential method. Figure 1 shows that the TAC is at maximum at the lowest level of pressure-cooking time (5 minutes) and drying temperature (50°C). Higher drying temperature and longer pressure cooking decrease the TAC of the PFSPF. After subjecting to different levels of pressure-cooking time and drying temperature, the TAC of the PFSPF ranges from 71.74 to 143.92 mg/100g dry basis. Using the optimized conditions derived from the model (Table 9), an experimental mean of 142.996 mg/100g dry basis was obtained. The obtained value is higher than the TAC of drum-dried, purple-fleshed sweet potato flour, which ranged from 25.01-27.91 mg/100g dry basis from the study conducted by Soison et al. (2014) using a drum temperature of 120-140°C. In this study, cabinet drying using a lower temperature of 50-70°C was explored. It has been supported by the results that using lower drying temperature and exposure to shorter pressure-cooking time exhibited better retention of anthocyanins in the PFSPF.

The stability of anthocyanins depends on many factors, such as their structure, concentration, the presence of enzymes, oxygen, pH, or temperature (Musilova et al., 2020). There have been previous studies reported the degree of degradation and stability of anthocyanins during the heat treatment process using different processing conditions. For instance, using minimal heat treatment can retain more anthocyanin in purple sweet potato powder (Wang et al., 2014; Xu et al., 2015). However, the study conducted by Musilova et al. (2020) shows that a higher degree of heat treatment enhances the stability of anthocyanin due to their protective reaction, resulting in the condensation of monomers and formation of more stable oligomeric pigments. Moreover, differences in the obtained TAC value might also be due to several factors such as the variety, solvent for extraction used, and the pH conditions. The purple sweet potato SG18-150-

01 variety used in this study exhibited high amounts of anthocyanins, which makes it a good source of flour that can be utilized as a natural food colorant with stable bioactive components and used as a functional ingredient. It is therefore essential to optimize the process for PFSPF production with maximum TAC retention to achieve a higher-quality product.

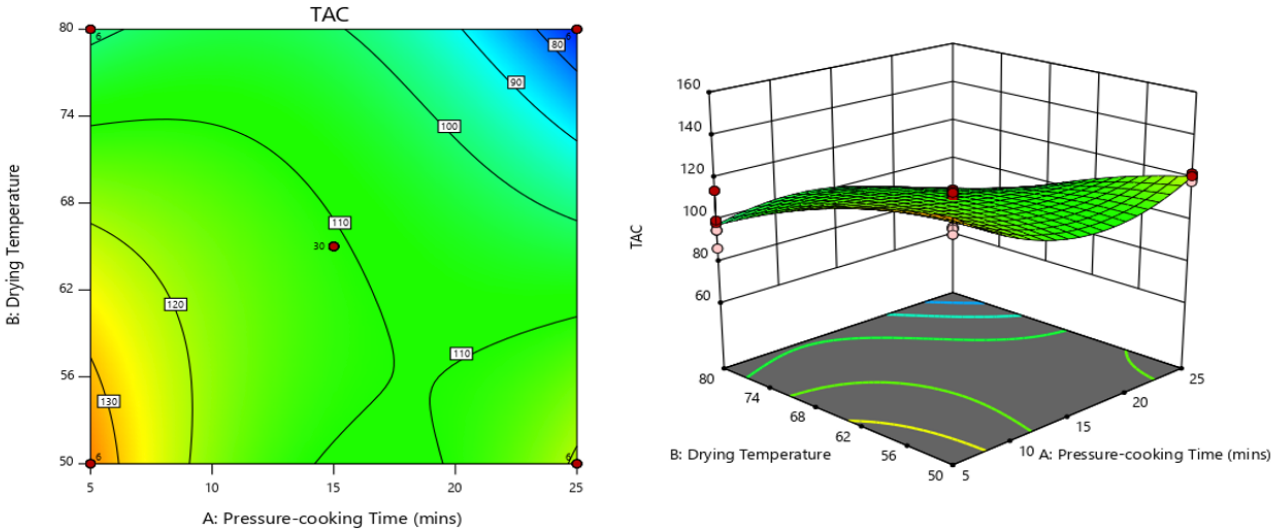

Figure 1: Contour and 3-D response surface plots showing the effect of pressure-cooking time and drying temperature on the TAC of PFSPF

Antioxidant Activity (AA)

The antioxidant activity of PFSPF was assessed by the DPPH scavenging activity assay. The phenolic compounds, mainly the anthocyanins, present in purple-fleshed sweet potatoes, contribute to their antioxidant capacity. Results from several studies showed that the antioxidant activity of flour is affected by cooking methods such as boiling, steaming, pressure-cooking, and drying (Huang et al., 2006; Kim et al., 2015; Ruttarattanamongkol et al., 2016; Sinha et al., 2015). The antioxidant activity of the PFSPF ranges from 2.80 to 7.29 mg trolox/g dried extract. At optimized conditions, the AA is found to be 5.255 mg/g (Table 9). As shown in Figure 2, there is minimal change in the AA of the PFSPF when subjected to the levels of factors used. However, it can be observed that longer pressure-cooking time at low drying temperature slightly increases the AA. According to Ruttarattanamongkol et al. (2016), heat treatment could result in cell structure damage of the sweet potato flesh tissues, thereby, causing easier extraction of the antioxidant components. It is also supported by the increased antioxidant capacity of several products during the cooking process, such as microwave cooking, steaming, or boiling, as reported by Halvorsen et al. (2006). Moreover, different drying conditions used in flour production also cause variations in the antioxidant activity, hence, it is important to optimize the overall drying process for maximum retention. Varietal differences could also result in differences in the obtained antioxidant properties of flours. For this reason, the selection of sweet potato varieties, such as the PFSP SG18-150-01 variety with considerable amounts of beneficial phytochemical components, such as anthocyanins, is important.

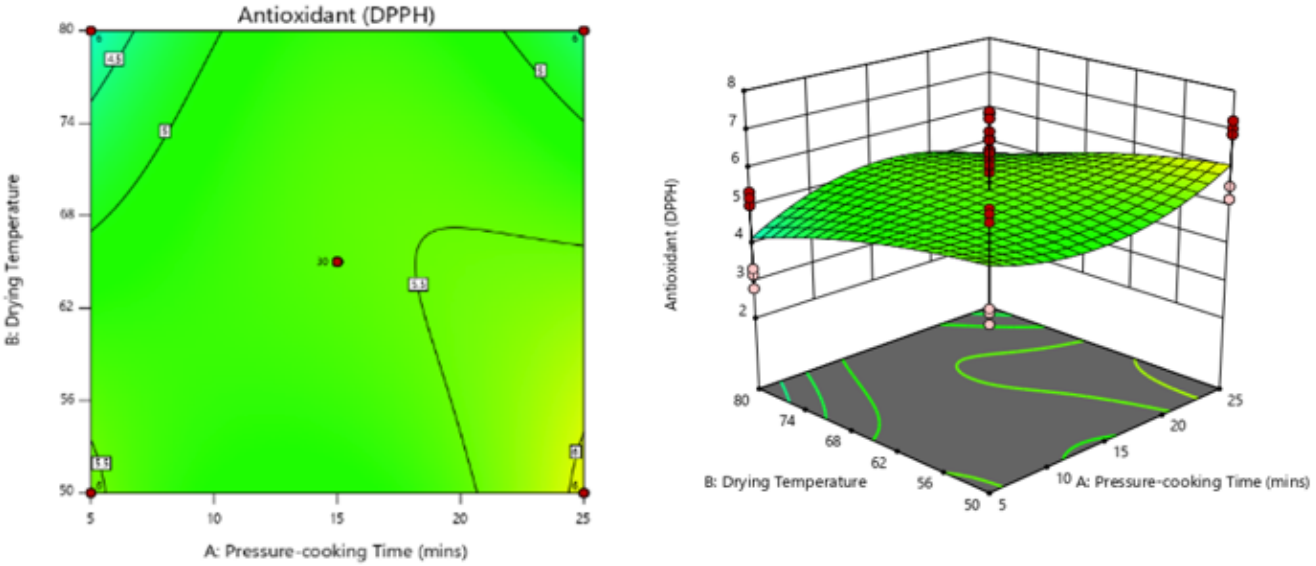

Figure 2: Contour and 3-D response surface plots showing the effect of pressure-cooking time and drying temperature on the antioxidant activity (AA) of PFSPF.

Color

The color of PFSPF represented by color coordinates L*, a*, and b* was measured following the CIELAB color system. Experimental means for color L* range from 52.11 to 62.43; color a*, 14.23 to 18.46; color b*, -9.16 to -6.97; chroma, 16.01 to 20.61; hue angle, 359.435 to 359.603. Figure 3 shows the color generated by the Nix™ color sensor using the color values (color L*: 55.070, color a*: 13.800, color b*: -7.750) of optimum condition. Based on the results, the PFSP flour has a slightly darker color with a more red tone and less blue tone. Optimized PFSPF has a hue angle value of 359.490 and a chroma value of 15.822, which indicates that the color falls between the red to blue quadrant with an unsaturated color tone.

Figure 3: Color of optimized PFSPF as generated by the Nix™ Color Sensor using the color values (L*, a*, b*)

As shown in Figure 4, the color L* value increases as the pressure-cooking time and drying temperature increase, resulting in lighter color. The color a* value is at minimum at the lowest level of pressure-cooking time and drying temperature, which means that less red color is attained at this condition. While at the highest level of pressure-cooking time and drying temperature, the color b* value increases, resulting in a bluer color tone. Also as exhibited in the figure, chroma reaches its maximum value, which means color becomes more intense, at a low level of pressure-cooking time and a high level of drying temperature. Lastly, hue angle tends to increase in value at the highest levels of pressure-cooking time and drying temperature. According to Collado et al. (1997), the genotype of sweet potato mainly influences the color of sweet potato flour, and cultivars can be selected for their use as flour containing natural colorants (greens, bright orange, and purple pigments). The drying of sweet potato flour using elevated temperatures causes color changes (Kaur and Sandhu 2016). Increasing drying temperature was observed to decrease the visual appearance color of purple-fleshed sweet potato powder (Wang et al., 2014). Optimizing the process for flour production is essential to obtain a better color quality of product.

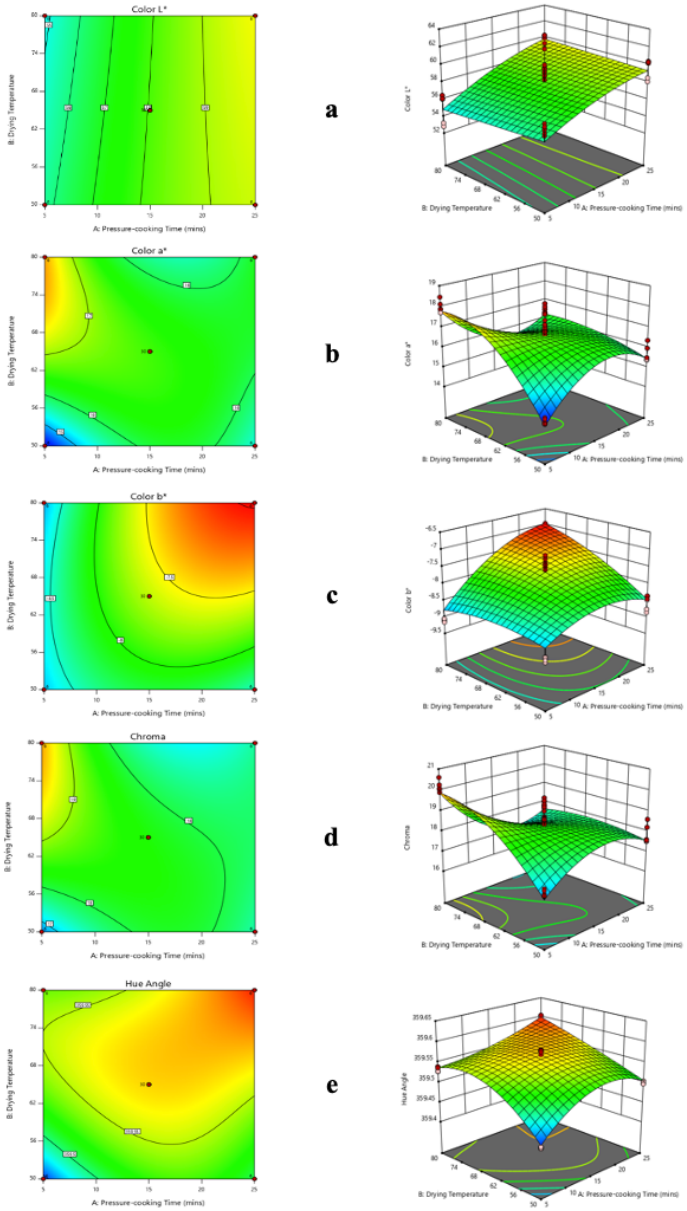

Figure 4: Contour and 3-D response surface plots showing the effect of pressure-cooking time and drying temperature on the color values; a) color L*, b) color a*, c) color b*, d) chroma, and e) hue angle of PFSPF.

D. Optimization and Verification of the Model

A total of five solutions were generated after setting the goals in the criteria for optimizing the process using Design Expert. Based on the suggested solution runs, the optimal PFSPF processing condition with the highest desirability (0.732) is composed of a pressure-cooking time of 5 minutes and a drying temperature of 50.364°C, resulting in TAC of 134.698 mg (c3g)/100g, 5.561 mg (TE)/g AA, 14.320 color L*, -8.725 color a, 16.734 color b, 16.734 chroma and 359.447 hue angle values (Table 7). To further verify the integrity of the model, another set of optimum conditions (lowest desirability, 0.708) with a 25-minute pressure-cooking time and drying temperature at 50°C was used. The two processing conditions were rerun and subjected to the same response variables (TAC, AA, color properties) to test model adequacy (Table 8).

Table 7: Generated optimal conditions for PFSPF preparation using response surface methodology.

Run	A	B	R_1	R_2	R_3	R_4	R_5	R_6	R_7	Desirability
1	5.000	50.364	134.698	5.561	55.732	14.230	-8.725	16.734	359.447	0.732
2	5.000	51.597	134.046	5.539	55.694	14.551	-8.700	16.990	359.458	0.725
3	5.000	52.000	133.817	5.531	55.681	14.652	-8.692	17.071	359.462	0.723
4	25.000	50.000	121.059	6.099	59.344	15.439	-8.472	17.541	359.505	0.708
5	5.000	56.500	130.698	5.420	55.541	15.677	-8.622	17.898	359.497	0.690

A-Pressure-cooking time (mins.), B-Drying temperature (°C), R_1- TAC, R_2- AA, R_3-color L*, R_4- color a*, R_5 -color b*, R_6 -chroma, R_7 -hue angle

Table 8: Optimum conditions from the two selected solutions generated from the model.

Solution	Symbol	Pressure-Cooking Time (mins.)	Drying Temperature (°C)	Desirability
1*	OC1	5.00	50.364	0.732
3	OC2	25.00	50.000	0.708

*selected optimized condition

To check the predictive ability of the optimized model, a verification test was conducted. The prediction interval of the two optimum conditions was noted and presented in Table 9. The prediction interval denotes the range in which the experimental values will likely fall within the point of an estimate of 95 percent, as influenced by the specified predictor. If the observed value is within the prediction interval, then the model is verified. It can be observed that the experimental values for TAC and antioxidant activity for both optimum processing conditions fall between the prediction interval range, except for color L*, a*, b*, chroma, and hue angle values, notably in OC2. This means that the model can effectively be used to predict TAC and AA but is weak in predicting the color. Observed deviations in color measurement might be attributed to the sensitivity of the test or variations from the source of raw material used in the experiment.

Table 9: Prediction interval (PI) of the two optimum conditions (OC) generated from the model at a 95% confidence interval.

Response Variable	OC1			OC2		
	Experimental Value	95% PI		Experimental Value	95% PI	
		Low	High		Low	High
TAC	142.996±3.00*	126.03	143.37	112.527±1.70*	112.37	129.75
AA	5.255±0.17*	4.96	6.17	5.711±0.14*	5.49	6.71
color L*	55.070±0.71*	52.46	59.01	55.085±0.55	56.07	62.62
color a*	13.800±0.28*	13.20	15.26	16.700±0.48	14.40	16.47
color b*	-7.750±0.14	-9.35	-8.10	-9.653±0.26	-9.10	-7.85
chroma	15.822±0.30*	15.58	17.89	19.289±0.54	16.39	18.70
hue angle	359.490±0.00	359.43	359.47	359.476±0.00	359.48	359.53

OC1-(Solution 1), OC2- (Solution 3); *-value falls within the PI range

The main objective of the optimization experiment was to develop a process with maximum TAC and antioxidant activity with acceptable color quality. Based on the results, OC1 obtained higher TAC (142.996 mg c3g/100g) although lower AA (5.255 mg TE/g) compared with OC2. This optimum condition was used as the final optimum process, given it has the highest desirability and is the most suitable, cost-effective, and time-efficient.

CONCLUSION

Post-harvest losses of fresh, purple-fleshed sweet potatoes can be minimized by processing these crops into flour, as it is in a more stable form and can be used as an intermediate product for many food applications. The vibrant purple color contributed by its natural bioactive components called anthocyanins can also be used as a natural colorant and functional food ingredient as it possesses health-promoting benefits. The current challenge, however, is to develop a process of flour production with maximum retention of anthocyanins and overall quality.

In consideration of the main objective of the optimization experiment, which is to develop a process of PFSPF production with maximum TAC and antioxidant activity with acceptable color quality, OC1 (pressure-cooking time: 5 minutes and drying temperature: 50.36°C) was chosen as the final optimum process, given it has the highest desirability, and it is the most suitable, cost-effective, and time efficient way. The optimum process for PFSPF can be used as a basis for upscale production of the flour, thereby, also encouraging farmers to cultivate, and other stakeholders to utilize the developed, purple-fleshed sweet potato variety (SG18-150-01), increasing its commercial value.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

MBBG conceived and designed the optimization experiments, carried out the analysis, interpreted the data, and wrote the manuscript. FLDA conducted optimization experiments and analyzed the data. DMOS secured the funding, supervised the experiments, and provided critical revisions of the manuscript. All authors approved the final version of the manuscript.

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