

## Optimization of orange-fleshed sweet potato (*SG 18-88-01*) flour preparation for maximum carotenoid retention using response surface methodology

<sup>1,\*</sup>Remigio, K.T., <sup>1</sup>Avorque, F.D., <sup>1</sup>Ancheta, L.B., <sup>1</sup>Santiago, D.O., <sup>1</sup>Galang, M.B.,  
<sup>1</sup>Sumague, M.V., <sup>1</sup>Felismino, R.M., <sup>2</sup>Abustan, M.M., <sup>2</sup>Crisostomo, S.D. and  
<sup>2</sup>Villavicencio, M.H.

<sup>1</sup>*Institute of Food Science and Technology, University of the Philippines Los Baños, College, Laguna, 4031, Philippines*

<sup>2</sup>*Institute of Plant Breeding, University of the Philippines Los Baños, College, Laguna, 4031, Philippines*

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### Abstract

Due to the nature of the flour processing methods, the nutritional content of sweet potatoes decreases. Knowing the optimal flour processing conditions is important to maximize the nutrition that one can obtain from sweet potato flour. In this study, optimized flour preparation conditions for maximum  $\beta$ -carotene retention of orange-fleshed sweet potato (*SG 18-88-01*) (OFSP) were determined using response surface methodology. A two-level randomized Box-Behnken design was utilized to assess the effects of blanching temperature (60 to 100°C), blanching time (1 to 3 mins), and drying temperature (50 to 70°C). The optimal conditions were blanching for one minute at 97.75°C and drying at 66.30°C. Using the said conditions, the experimental vitamin A content was reported to be 373.95 IU/g, antioxidant activity was 0.55 mg TE/g, and color values were 82.81 L\*, 6.40 a\*, 24.92 b\*, and 1.32 radians hue angle. The predicted and experimental values were compared using paired t-test and showed no significant differences at  $p > 0.05$  and  $p > 0.01$ . Hence, the model was adequate and had good predicting capacity. The optimized OFSP flour has 5.50±0.80% moisture, 2.14±0.22% ash, 2.51±0.24% crude protein, 3.07±0.09% crude fiber, 0.47±0.03% crude fat, and 86.31% nitrogen-free extract content. The flour has a water absorption index (WAI) of 5.90±0.15 g/g, water solubility index (WSI) of 55.26±0.03%, and swelling power of 13.23±1.34 g/g. Given the results, the generated OFSP flour is ideal to use for food production, particularly in bakery products. It was also revealed that consuming 4-10 g of the flour can meet the Recommended Nutrient Intake in all Filipino age groups.

## 1. Introduction

Sweet potato (*Ipomoea batatas* Lam) is a perennial dicotyledonous plant that belongs to the botanical family of Convolvulaceae. It has large and edible storage roots and palmate-lobed leaves. The color of its skin typically varies between yellow, orange, red, purple, brown, and cream with flesh color ranging from white to red, purple, cream, yellow, and orange. Sweet potato (SP) contains substantial amounts of carbohydrates, proteins, carotenoids, polyphenols, vitamins, and minerals depending on its variety. Thereby it is highly regarded as a “three-in-one” root crop given that it contains high amounts of starch like cereals, high vitamin and pectin content like fruits, and significant amounts of minerals like vegetables which are all necessary to the human diet (Padmaja, 2009).

Sweet potatoes have varying nutritional composition, physicochemical and functional properties, and sensory attributes depending on their variety. Orange-fleshed sweet potato (OFSP) is a biofortified root crop that contains high levels of  $\beta$ -carotene which is a precursor of vitamin A.  $\beta$ -carotene is one of the most important naturally occurring carotenoids, commonly found in yellow and orange-colored fruits and vegetables, due to its promising antioxidant and provitamin A activity (Kopeck *et al.*, 2014). Carotenoids are important to maintain normal vision, growth, reproduction, and immunity and reduce susceptibility to cancer, diabetes, and cardiovascular disease (National Institutes of Health, 2022). Furthermore, Tumuhimbise *et al.* (2019) reported that raw OFSP may provide as much as 276.98  $\mu$ g/g  $\beta$ -carotene. Aside from being an excellent source of  $\beta$ -carotene, OFSP is also known to contain considerable

\*Corresponding author.

Email: [ktremigio@up.edu.ph](mailto:ktremigio@up.edu.ph)

amounts of minerals (Fe, Zn, Mn, Mg, Ca, Na, K), vitamins (B and C), and fiber (Haskell *et al.*, 2004). In terms of physicochemical properties, OFSP is reported to contain 8.80% moisture, 2.90% protein, 2.80% ash, 1.00% fat, and a total carbohydrate content of 82.30% (Obomeghei *et al.*, 2020).

Nutrient deficiency is still a problem that each country faces daily, particularly the developing and underdeveloped countries. As such, researchers and scientists seek ways to resolve the said problem and one of the solutions is the utilization of abundant nutritious raw materials. According to FAOSTAT (2016), about 105 million metric tons was the total annual sweet potato production in 2016 alone, with around 95% of sweet potatoes produced in developing countries. In the Philippines, OFSP has a considerable yield, however its cultivation is hindered given the limited availability of OFSP varieties (Quindara *et al.*, 2020). Given this, there has been a growing number of studies conducted to produce more OFSP varieties and assess the properties and potential benefits of sweet potatoes in resolving nutrient deficiency and food shortage problems.

Due to its abundance and year-round availability, sweet potatoes are now utilized and processed into flour to be added or substituted in usual flour-based products such as bread, noodles, pasta, crackers, and more to extend their shelf-life, address issues with discoloration, and increase the nutritional content. Production of sweet potato flour often involves different unit operations such as washing, peeling, slicing, drying, milling, packaging, and storage (Kaur and Sandhu, 2016). Some of these processing steps, if not all, can change color and reduce the carotenoid content of sweet potatoes due to exposure to heat, light, and oxygen which can cause single- and double-bond structure alteration leading to degradation (Tao *et al.*, 2021). Because of this, conditions during processing must be monitored and the process of flour production must be optimized to achieve maximum retention of nutrients and carotenoids in the flour. In this study, the *SG18-88-01* variety was utilized in flour production. Response surface methodology (RSM) was used to determine the optimal conditions to generate flour with maximum carotenoid retention.

## 2. Materials and methods

### 2.1 Materials

The orange-fleshed sweet potatoes (SG 18-88-01) were provided by the Institute of Plant Breeding located at the University of the Philippines Los Baños. The sweet potatoes that were utilized in this study came from the same batch to ensure uniformity of the source of the raw materials and its maturity.

### 2.2 Sample preparation

The soil residues were removed by washing the samples thoroughly. The damaged portions of the sweet potatoes were removed by cutting. Afterwards, the screened sweet potatoes were thoroughly washed again before it was peeled. The peeled sweet potatoes were sliced into 2 mm slab thickness using a manual food slicer and were immediately soaked in water to prevent browning reactions. The sliced samples were then subjected to blanching for three varying periods (1 min, 2 mins, and 3 mins) and temperatures (60°C, 80°C, and 100°C). Subsequently, the blanched samples were dried using a cabinet drier using different processing temperatures (50°C, 60°C, and 70°C) which lasted for at least 12-16 hrs. The dried sweet potato samples were ground until the resulting material could pass through an 80-mesh US Standard sieve. The resulting flour was then placed in an aluminum standup pouch. Afterwards, the packaged flour samples were placed in a cool and dark place to avoid exposure to direct sunlight and heat.

### 2.3 Color measurement

The color of the orange-fleshed sweet potato flour samples was determined using a hand-held chroma meter (Konika Minolta, model CR-400) following the CIELAB Color System with parameters L\*, a\*, and b\* (Nielsen, 2010). The color determination was done three times. The L\* values corresponded to lightness. On the other hand, the a\* values accounted for the components on the red-green axis. Lastly, the b\* values represented the components on the yellow-blue axis.

The chroma (C\*ab) and hue angle (h degrees) were determined to further expound the color of the optimized yellow sweet potato flour. The chroma and hue angle of the sample were calculated using the following equations:

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}}$$

$$h \text{ degrees} = \left( \frac{a^*}{b^*} \right)$$

Where C\*ab refers to chroma, a\* refers to the values of the components on the red-green axis, and b\* refers to the values of the components on the yellow-blue axis.

### 2.4 Determination of vitamin A content

#### 2.4.1 Extraction of pro-vitamin A

A total of 0.5 g of the sample was weighed and placed in a 250-mL Erlenmeyer flask. Afterwards, 30 mL of acetone hexane with the ratio of 3:7 were added to the flask to extract the pro-vitamin A present in the sample. The extract was then refluxed for 1 hr. Subsequently, the sample was allowed to cool before being stored inside a cabinet away from the sunlight for

at least 15 hrs. The extract was then filtered into a 50-mL volumetric flask and the residue was washed and diluted to mark using acetone hexane (1:9). The extraction of pro-vitamin A was done in triplicates.

#### 2.4.2 Preparation of standard curve

In a 100-mL volumetric flask, 20 mg of  $\beta$ -carotene was dissolved using 2 mL of chloroform. After dissolving the said sample, it was diluted to mark (100 mL) with acetone hexane (1:9). From the prepared stock solution, solutions containing 0.2, 0.4, 0.6, 0.8, 1.2, 1.6, and 2.0  $\mu\text{g}$  carotene/mL were prepared. The prepared samples were then placed in separate test tubes wrapped with aluminum foil.

#### 2.4.3 Spectrophotometry

The absorbance of the sample and the prepared standard solutions were measured at 440 nm using a UV Vis Spectrophotometer with acetone hexane (1:9) as blank three times. The concentration of carotene ( $\mu\text{g}/100$  g sample) was then calculated using the standard curve. Furthermore, the  $\beta$ -carotene content of the sample was noted and was interpreted as vitamin A value using the conversion value of 0.6  $\mu\text{g}$  carotene  $\approx$  1 IU (international unit) vitamin A. The vitamin A content in IU/g was then converted to  $\mu\text{gRE}$  by dividing the resulting value by 3.33.

### 2.5 Determination of antioxidant activity

#### 2.5.1 Preparation of sweet potato extract

A total of 0.5 g of powdered sample was weighed and placed in a 50-mL beaker. The sample was extracted with 15 mL MetOH-H<sub>2</sub>O (50:50, v/v; acidified with 1% HOAc) solution in a stirrer for 1 hr at room temperature. The sample was then transferred in 15 mL/50 mL centrifuge tubes and centrifuged for 15 mins. The supernatant liquid was collected, and its concentration was recorded. Finally, it was transferred in an amber bottle glass and was stored at 0 to 4°C prior to further analysis.

#### 2.5.2 Scavenging effect on DPPH

The antioxidant activity of the extracts was measured using the DPPH radical scavenging assay as described by Castillo-Israel *et al.* (2020). An aliquot (1 mL) absolute methanol was pipetted into a test tube. Then, 1 mL of the diluted sample and 1 mL of DPPH solution were added into the test tube and were incubated for 25-30 mins at room temperature in a dark place. The absorbance of the sample was read at 517 nm using a UV Vis Spectrophotometer with 2 mL Absolute MetOH + 1 mL DPPH as control. The absorbance of the sample was then corrected to account for possible interference of sample

color by subtracting the absorbance of a sample blank (Absolute MetOH). The process was done in triplicates and the results were expressed in  $\mu\text{g}$  Trolox equivalents (TE)/g.

### 2.6 Experimental design

Response surface methodology (RSM) was used to determine the optimum processing conditions for orange-fleshed sweet potato flour production. The experimental design and statistical analysis were performed using Stat Ease software (Design-Expert 13, Version 13.0.8.0 64-bit). A two-level randomized Box-Behnken design (BBD) was utilized to assess the effects of the three independent variables: blanching time ( $X_1$ ) blanching temperature ( $X_2$ ) and drying temperature ( $X_3$ ). As shown in Table 1, the minimum and maximum values for blanching time were set between 1 and 3 mins, with blanching temperature between 60 and 100°C, and drying temperature between 50 and 70°C. The response variables were vitamin value (IU/g), antioxidant activity ( $\mu\text{g}$  TE/g), and color ( $L^*$ ,  $a^*$ ,  $b^*$ , and hue angle) which were represented as  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$ ,  $R_5$ ,  $R_6$  correspondingly. The complete design model consisted of 15 runs. Mathematical models were evaluated for each response using multiple regression analysis. The polynomial equation used is as follows:

$$\alpha = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1 X_1 + \beta_{22} X_2 X_2 + \beta_{33} X_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3$$

Where  $\alpha$  is the response variable,  $\beta_0$  is the intercept  $\beta_1$ ,  $\beta_2$ ,  $\beta_3$ ,  $\beta_{11}$ ,  $\beta_{22}$ ,  $\beta_{33}$ ,  $\beta_{12}$ ,  $\beta_{13}$  and  $\beta_{23}$  are the linear, quadratic, and interaction coefficients, respectively. Lastly,  $X_1$ ,  $X_2$  and  $X_3$  are the independent variables.

Table 1. Independent variables used in the analysis of optimum processing conditions.

Independent Variables	Symbols		Coded Variable Levels		
	Coded	Uncoded	-1	0	1
Blanching Time (mins)	$X_1$	BTi	1	2	3
Blanching Temperature (°C)	$X_2$	BTe	60	80	100

### 2.7 Verification of the optimized model

The data acquired from the responses was analyzed by the Stat-Ease software. Solutions with varying desirability on top of the corresponding predicted values for the responses were generated. The combination of the factors described by the solution with the highest desirability was used and another solution was also used to verify the integrity of the model. Lastly, to ensure the applicability and predicting capacity of the generated optimized model, the experimental values were compared to the predicted or existing literature values

and a paired t-test using Minitab 19 was also employed to determine if the differences were significant or not.

### 2.8 Proximate analysis

The generated flour sample was then sent to the Lipa Quality Control Center in Lipa, Batangas for proximate analysis. The moisture, ash, fat, fiber, protein, and carbohydrate content of the sweet potato flour obtained from the optimized process were determined according to the standard methods (Association of Official Analytical Collaboration (AOAC) International, 2000).

### 2.9 Determination of functional properties

The water absorption index (WAI), water solubility index (WSI), and swelling power (SP) of the optimized sweet potato flour were determined following the methods used by Ruales *et al.* (1993) with modifications. Sweet potato flour (2.5 g) was mixed with 30 mL distilled water at 30°C. After mixing, the solution was left to stand for 30 mins and was then centrifuged at 4900 $\alpha$ ×g for 10 mins. The supernatant liquid was carefully decanted, and the residue was weighed. With this, the water absorbance index (WAI) was calculated using the equation:

$$WAI \left( \frac{g}{g} \right) = \frac{\text{weight gain by the sample}}{\text{dry weight of the sample}}$$

The decanted supernatant liquid was then evaporated on a hot plate and was subjected to oven drying overnight. The residue left after the said process was weighed again and the percentage of water solubility index (%WSI) and swelling power (SP) were determined using the following equations:

$$\%WSI = \frac{\text{weight of dry solid in supernatant}}{\text{dry weight of the sample}}$$

$$SP = \frac{\text{weight gain by the sample}}{\text{dry weight of sample} - \text{weight of dry solid}}$$

## 3. Results and discussion

### 3.1 Model description

Design Expert 13 generated a total of 18 solutions (Table 2) with an optimal flour preparation condition composed of blanching for 1 min at 98.365°C and drying at 65.956°C with desirability of 0.635. Another set of optimum conditions composed of 1 min blanching at 97.751°C and drying temperature at 66.302°C with desirability of 0.635 was also used to verify the integrity of the said model.

The analysis of variance (ANOVA) was conducted using Stat-Ease Design Expert Version 13 to determine the significance of the model and its linear, quadratic, and cross-product terms (Table 3), and lack of fit of the independent variables on vitamin A, antioxidant activity, L\*, a\*, b\*, and hue angle of the OFSP flour. The design quadratic polynomial models for each response variable had a p-value of 0.0001 indicating that the model terms were significant. In terms of the lack of fit test, Montgomery and Runger (1998) pointed out that it is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the design. The results presented in Table 3 showed that all parameters exhibited no significant lack of fit which indicates that the model fits the functional relationship between the experimental factors and the response variables. On the other hand, the coefficient of

Table 2. Generated optimal conditions for OFSP (SG 18-88-01) flour preparation using response surface methodology.

RUN	$X_1$	$X_2$	$X_3$	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$	$R_6$	Desirability
1	98.36	1.00	65.96	357.88	0.51	81.36	5.40	28.59	1.38	0.63
2	98.34	1.00	65.87	357.10	0.51	81.35	5.41	28.58	1.38	0.63
3	98.31	1.00	66.03	357.94	0.51	81.35	5.39	28.58	1.38	0.63
4	98.35	1.00	66.08	357.81	0.51	81.36	5.39	28.59	1.38	0.63
5	98.37	1.00	65.76	357.99	0.51	81.35	5.42	28.59	1.38	0.63
6	98.63	1.00	65.93	357.32	0.52	81.42	5.42	28.65	1.38	0.63
7	98.10	1.00	65.67	358.64	0.51	81.28	5.41	28.53	1.37	0.63
8	98.90	1.00	65.70	356.89	0.52	81.48	5.46	28.70	1.38	0.63
9	98.70	1.00	65.35	357.55	0.52	81.42	5.48	28.66	1.37	0.63
10	97.75	1.00	66.30	358.92	0.50	81.22	5.33	28.46	1.38	0.63
11	99.05	1.00	65.92	356.40	0.52	81.52	5.45	28.74	1.38	0.63
12	98.41	1.00	66.70	357.25	0.50	81.39	5.34	28.60	1.38	0.63
13	99.07	1.00	65.38	356.72	0.53	81.51	5.50	28.74	1.37	0.63
14	98.44	1.00	66.97	356.98	0.51	81.41	5.32	28.61	1.38	0.63
15	98.04	1.00	64.96	359.22	0.51	81.25	5.47	28.50	1.37	0.63
16	99.29	1.00	64.98	356.48	0.53	81.56	5.55	28.78	1.37	0.63
17	99.98	1.00	65.85	354.34	0.54	81.76	5.51	28.95	1.38	0.63
18	96.68	1.00	64.78	362.10	0.49	80.94	5.40	28.21	1.37	0.63

determination ( $R^2$ ) of the model ranged from 0.8701 to 0.9906 which was significantly high as according to Omolola *et al.* (2015), the value closer to 1 is the better fit for a regression model. Therefore, the model was adequate given that it contained no significant lack of fit and had exemplary levels of  $R^2$ .

Table 3. Analysis of variance for the response surface model for vitamin A, antioxidant activity, L\*, a\*, b\*, and hue angle.

Source	DF	Sum of squares	Mean square	F-Value
<b>Vitamin A</b>				
Lack of Fit	15	2230.1200	148.67	0.90 <sup>a</sup>
Pure Error	4	664.0700	166.02	
Total Error	19	2894.1900	314.69	
<b>Antioxidant</b>				
Lack of Fit	15	0.0028	0.0002	3.02 <sup>a</sup>
Pure Error	4	0.0002	0.0001	
Total Error	19	0.0030	0.0003	
<b>L*</b>				
Lack of Fit	15	5.0400	0.3362	0.59 <sup>a</sup>
Pure Error	4	2.2800	0.5700	
Total Error	19	7.3200	0.9062	
<b>a*</b>				
Lack of Fit	15	4.1600	0.2772	0.78 <sup>a</sup>
Pure Error	4	1.4200	0.3543	
Total Error	19	5.5800	0.6315	
<b>b*</b>				
Lack of Fit	15	13.3000	0.8865	2.33 <sup>a</sup>
Pure Error	4	1.5200	0.3804	
Total Error	19	14.8200	1.2669	
<b>Hue angle</b>				
Lack of Fit	15	0.0033	0.0002	0.58 <sup>a</sup>
Pure Error	4	0.0015	0.0004	
Total Error	19	0.0048		

<sup>a</sup> insignificant lack of fit

The significant coefficients were noted, and necessary model reduction was done. The resulting final predicted model for each response variable in terms of

coded factors is presented in Table 4.

### 3.2 Vitamin A content

The  $\beta$ -carotene content of the OFSP flour was 22436.70  $\mu\text{g}/100\text{g}$ , DW. The value obtained was much higher than that of the hot air-dried and drum-dried OFSP flour samples in the study of Amajor *et al.* in 2014 which only ranged from 2398 to 19017  $\mu\text{g}/100$ , DW. The  $\beta$ -carotene content of the sample was converted into vitamin A and showed that the OFSP flour had a vitamin A content of 373.95 IU/g, DW. The said value was higher than the reported value of a raw sweet potato which only contained 141.87 IU/g, DW (Mohanraj and Sivasankar, 2014). With this, the flour generated using SG 18-88-01 orange-fleshed sweet potato variety with the optimized conditions showed exemplary levels of vitamin A. The results of the multiple regression analysis exhibited that the vitamin A content of the flour was significantly affected by linear ( $p < 0.0001$ ) and interaction coefficient ( $p < 0.05$ ) of blanching time and drying temperature and quadratic terms ( $p < 0.005$ ) of blanching temperature and time. The final predictive model of vitamin A content is shown in Table 4.

The relationship between vitamin A content and blanching temperature, blanching time, and drying temperature is presented in Figure 1. As observed, the  $\beta$ -carotene content decreased with increasing blanching and drying temperature which can be accounted for by the volatility of the vitamins particularly vitamin A at higher temperatures (Ruttarattanamongkol *et al.*, 2016). In addition, van Jaarsveld *et al.* (2016), also seconded that thermal processing can cause significant loss to the total amount of  $\beta$ -carotene in OFSP varieties as it can

Table 4. Final predicted model equation per response variable.

Response variable	Model equation	$R^2$
Vitamin A	$386.45 + 20.96X_2 + 16.32X_3 - 24.91X_1^2 + 15.43 X_2^2 - 10.56X_2X_3$	0.8701
Antioxidant Activity	$0.46 + 0.17 X_1^2 - 0.06X_2^2 - 0.07 X_3^2 + 0.01X_1X_3$	0.9906
L*	$78.88 - 1.19X_1 - 0.50X_3 + 3.23X_1^2$	0.9352
a*	$4.78 + 1.30X_1 - 0.29X_2 - 0.89X_3$	0.8861
b*	$25.61 - 2.78X_1 + 0.89X_3 + 1.20 X_1^2 - 0.76X_2^2$	0.9146
Hue angle	$1.39 - 0.03X_1 + 0.01X_2 + 0.04X_3 + 0.03X_1^2 - 0.02X_1X_3$	0.9143

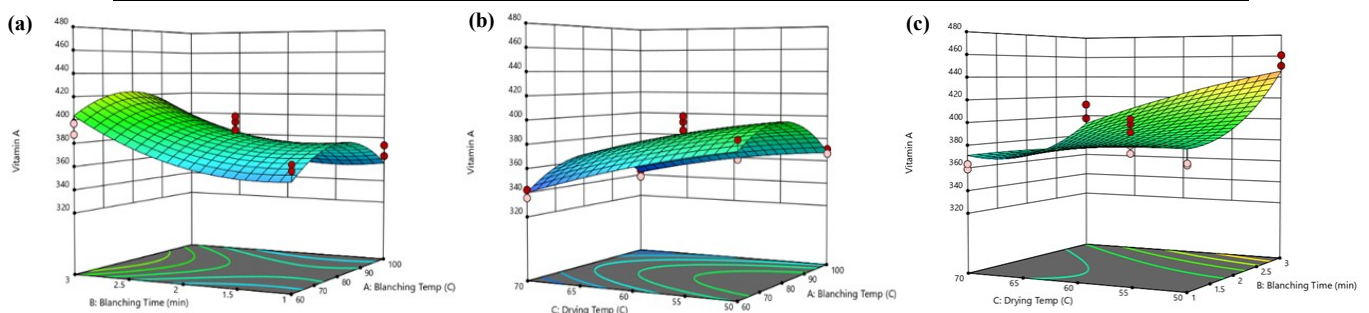


Figure 1. Response surface plots of the effect of blanching temperature, blanching time, and drying temperature on the OFSP flour.

lead to oxidative or non-oxidative changes, epoxide formation, and cis-trans isomerization of carotenoids. On the other hand, the  $\beta$ -carotene content increased with increasing blanching time. This is because blanching inactivates the activity of peroxidases and lipoxygenases which highly contributes to the degradation of  $\beta$ -carotene.

The Philippine Dietary Reference Intakes (PDR) (2015) has set a Recommended Nutrient Intakes (RNI) per day for vitamin A as presented in Table 5. The OFSP (SG 18-88-01) flour generated from the optimal conditions has a total vitamin A value of 112.30  $\mu$ g retinol equivalent ( $\mu$ gRE) or 11229.60  $\mu$ gRE per 100 g. This entails that the flour has exemplary levels of vitamin A content and can meet the daily recommended nutrient intakes (RNI) established by PDR in all Filipino age groups by only consuming 4.00 to 10.00 g of flour.

Table 5. Recommended Nutrient Intakes per day for Vitamin A as set by Philippine Dietary Reference Intakes (2015).

Age group (years old)	Vitamin A ( $\mu$ gRE)	
	Male	Female
1-2	400	400
3-5	400	400
6-9	400	400
10-12	500	500
13-15	700	500
16-18	800	600
19-29	700	600
30-49	700	600
50-59	700	600
60-69	700	600
> 70	700	600
Pregnant		900
Lactating		1000

### 3.3 Antioxidant activity

The antioxidant activity of the OFSP flour was  $0.55 \pm 0.00$  mg TE/g, DW. The obtained data was considerably lower than that of the paste generated from the Beaugard variety of OFSP which had  $1.24 \pm 0.20$  mg TE/g, DW (Gabilondo *et al.*, 2022). The results of the multiple regression analysis showed that the

antioxidant activity was significantly affected by quadratic ( $p < 0.0001$ ) terms of blanching temperature, blanching time, and drying temperature and interaction coefficient ( $p < 0.05$ ) of blanching temperature and drying temperature. The final predictive model of antioxidant activity is shown in Table 4.

The response surface plots in Figure 2 illustrate the relationship between antioxidant activity and blanching temperature, blanching time, and drying temperature. It can be observed that the antioxidant activity slightly decreased with increasing blanching and drying temperature. The decrease in antioxidant activity due to blanching was also observed in the blanched sweet potato leaves in the study of Bellail *et al.* (2012) and in Irish York cabbage according to Abu-Ghannam and Jaiswal (2015). Bellail *et al.* (2012) explained that the reduction of antioxidant activity can be attributed to the degradation of antioxidants or their interaction with other compounds during thermal processing. Li *et al.* (2007) likewise observed that drying processes at high temperatures and longer drying times destroyed some of the phenol compounds leading to a decrease in antioxidant properties. Furthermore, Méndez-Lagunas *et al.* (2017) also observed that the antioxidant activity and phenolic content significantly decreased with increasing drying temperature and attributed it to the thermal decomposition of the antioxidants and partial degradation of lignin which leads to the release of phenolic acid derivatives to be released in the system. Finally, a longer blanching time resulted in a slight increase in the antioxidant activity of the flour. The observed trend was also in agreement with the study of Dibanda *et al.* (2020) and may be attributed to the gradual inactivation of polyphenol oxidase and the possible presence of heat-stable antioxidant components during blanching (Amin and Lee *et al.*, 2005).

### 3.4 Color

The color description of the OFSP flour sample was determined using chromameter and was expressed in CIELAB color system values ( $L^*$ ,  $a^*$ , and  $b^*$ ). The value of  $L^*$  indicates the lightness of a sample. On the other

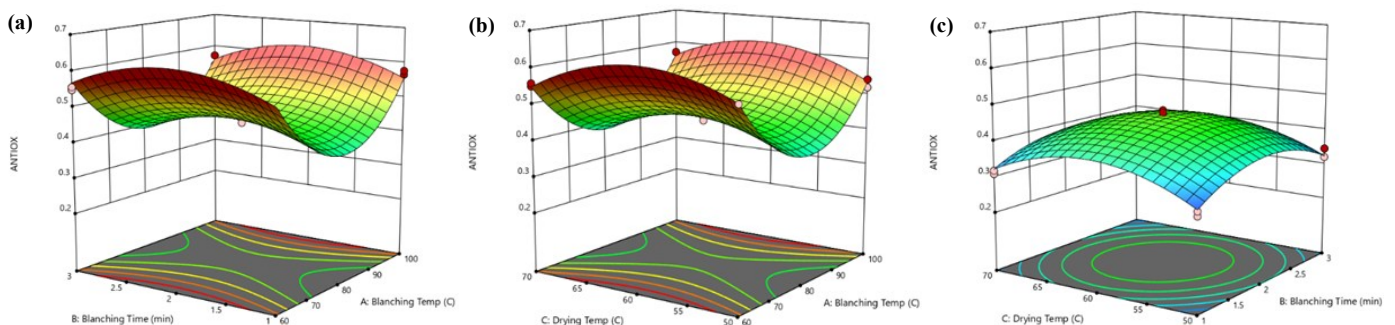


Figure 2. Response surface plots of the effect of blanching temperature, blanching time, and drying temperature on antioxidant activity.

hand,  $a^*$  and  $b^*$  are the chromaticity coordinates where the positive values of  $a^*$  and  $b^*$  represent redness and yellowness, respectively. The negative values of  $a^*$  and  $b^*$  illustrate greenness and blueness, respectively (Ly et al., 2020). Based on the results, the OFSP flour showed tristimulus values at 82.81  $L^*$ , 6.40  $a^*$ , and 29.92  $b^*$ . These values indicated that the flour was lighter with more yellow tone and less red color. Furthermore, the chroma, which represents the saturation and vividness of color, and hue angle, which orientates the proportion of redness and yellowness for this study, were determined. Based on the calculations, the OFSP flour has a hue angle of 75.60° which can be found near the middle of the red-yellow quadrant and a chroma value of 25.73 which indicates that the color of the flour is unsaturated.

The results of the multiple regression analysis showed that the  $L^*$  values were significantly affected by the linear ( $p < 0.05$ ) terms of blanching and drying temperature and the quadratic ( $p < 0.0001$ ) term of blanching temperature. In terms of  $a^*$  values, it can be seen from the multiple regression analysis that the values were significantly affected by the linear ( $p < 0.05$ ) terms

of blanching temperature, blanching time, and drying temperature. With respect to  $b^*$  values, linear ( $p < 0.001$ ) terms of blanching and drying temperature along with the quadratic ( $p < 0.05$ ) terms of blanching temperature and time significantly affected it. Lastly, the hue angle was significantly affected by the linear ( $p < 0.05$ ) terms of blanching temperature, blanching time, and drying temperature, quadratic ( $p < 0.005$ ) term of blanching temperature, and interaction coefficient ( $P < 0.005$ ) term of blanching and drying temperature. The final predictive model equations for  $L^*$ ,  $a^*$ ,  $b^*$ , and hue angle are presented in Table 4.

As shown in Figure 3, the  $L^*$  value decreased with increasing blanching temperature and increased with increasing drying temperature. As exhibited in Figure 4,  $a^*$  values decreased with increasing blanching time and drying temperature and increased with increasing blanching temperature. Figure 5 illustrates that  $b^*$  values increased with increasing blanching and drying temperature and slightly decreased with increasing blanching time. Lastly, the hue angle (Figure 6) increased with increasing drying temperature, slightly

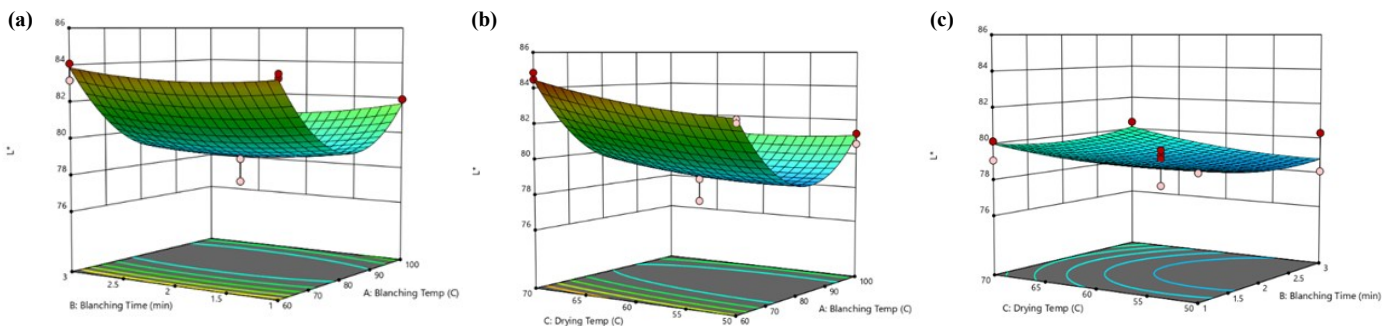


Figure 3. Response surface plots of the effect of blanching temperature, blanching time, and drying temperature on  $L^*$  values.

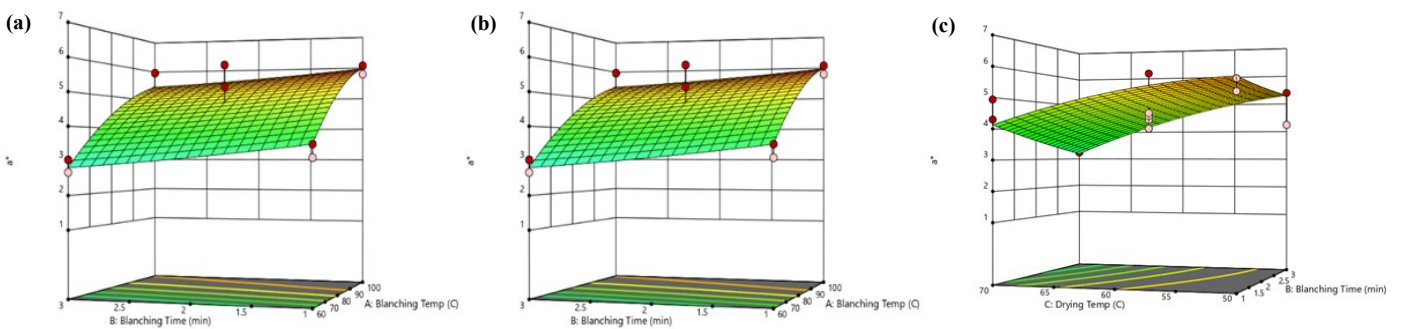


Figure 4. Response surface plots of the effect of blanching temperature, blanching time, and drying temperature on  $a^*$  values.

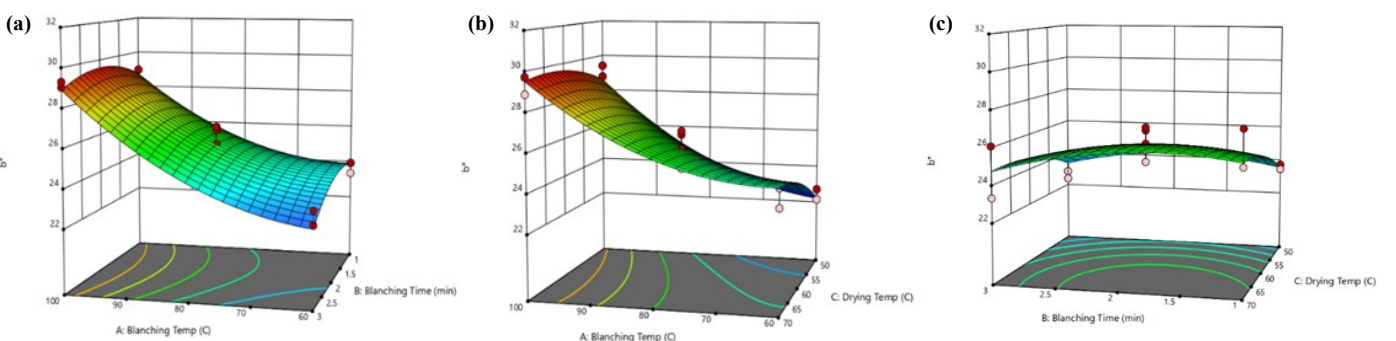


Figure 5. Response surface plots of the effect of blanching temperature, blanching time, and drying temperature on  $b^*$  values.

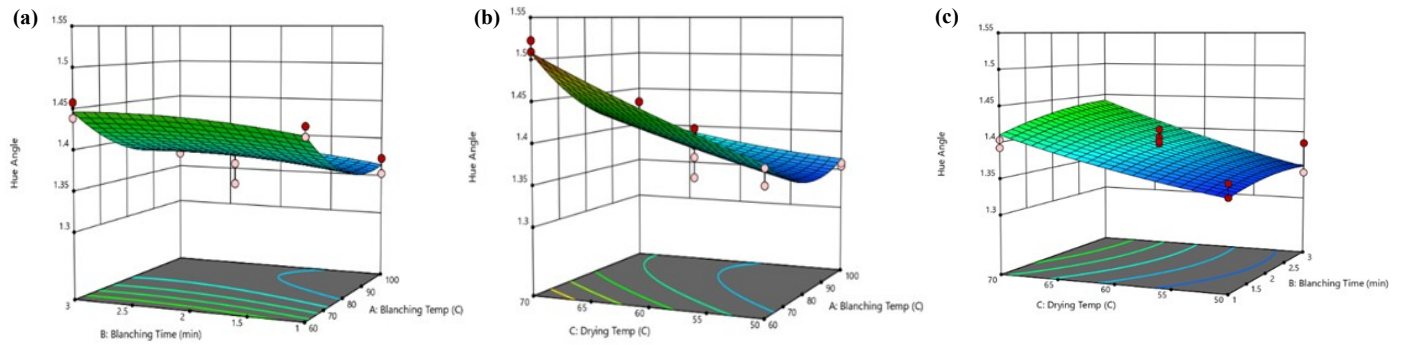


Figure 6. Response surface plots of the effect of blanching temperature, blanching time, and drying temperature on hue angle. increased with increasing blanching time, and decreased with increasing blanching temperature.

As observed, the color values were significantly affected by the independent variables. According to Suh *et al.* (2003), color pigments are easily oxidized by thermal processing. Ahmed *et al.* (2010) seconded this observation and affirmed that high drying temperatures increase pigment degradation which often leads to more variation in the color of dried or dehydrated foods. On the other hand, blanching, in general, aids in the retention of the color by inactivating lipoxygenase and polyphenol oxidase enzymes which are known to be responsible for enzymatic browning and color changes in fruits and vegetables (Sumonsiri *et al.*, 2014).

### 3.5 Verification of the model

To verify the optimized model generated by the Design Expert, flour preparation was carried out using the conditions from the model and the predicted and experimental values were noted. The comparison of predicted and experimental values of the response variables of the two solutions along with their respective percent differences was presented in Table 6. Based on

the results, vitamin A,  $L^*$ , and hue angle have low percent differences which entails that the model can predict the actual values of the said response variables. On the other hand, antioxidant activity,  $a^*$ , and  $b^*$  values have high percentage differences. Hence, paired t-tests were employed to determine if the difference was significant.

The results of the paired t-test for OC1 (Table 7) revealed that the predicted vitamin A and color ( $a^*$  and  $b^*$ ) values were not significantly ( $p>0.05$ ) different to the experimental value. Furthermore, the predicted antioxidant activity,  $L^*$ , and hue angle values were not significantly different from the experimental values at  $p>0.01$ .

As presented in Table 8, the predicted vitamin A and color ( $L^*$  and  $a^*$ ) values obtained using OC2 were not significantly ( $p>0.05$ ) different to the experimental value. Furthermore, the predicted antioxidant activity,  $b^*$  and hue angle values were not significantly different from the experimental values at  $p<0.01$ . The results of the paired t-test further verify the acceptability and predicting the capacity of the model.

Table 6. Comparison of predicted and experimental values of the two optimum conditions (OC) for the response of vitamin A, antioxidant activity (AA),  $L^*$ ,  $a^*$ ,  $b^*$ , and hue angle.

Response variable	Predicted value		Experimental value		Percentage Difference (%)	
	OC1	OC2	OC1	OC2	OC1	OC2
Vitamin A (IU/g)	357.88	358.92	348.36	373.95	2.66	4.18
AA (mg TE/g)	0.51	0.50	0.57	0.55	10.39	10.04
$L^*$	81.36	81.22	82.03	82.81	0.82	1.95
$a^*$	5.40	5.33	5.93	6.40	9.79	20.07
$b^*$	28.59	28.46	24.88	24.92	12.97	12.42
Hue angle	1.38	1.38	1.34	1.32	2.85	4.18

Table 7. Paired T-test result for the comparison of the predicted and experimental vitamin A content, antioxidant activity, and color values ( $L^*$ ,  $a^*$ ,  $b^*$ , and hue angles) of the optimized OFSP (SG 18-88-01) flour using OC1.

Response variable	Predicted value and SD	Experimental value and SD	T-value	P-value
Vitamin A (IU/g)	357.88±12.34	348.36±0.00	1.34	0.3130 <sup>c</sup>
AA (mg TE/g)	0.51±0.01	0.57±0.00	-6.36	0.0240 <sup>d</sup>
$L^*$	81.36±0.62	82.03±0.19	-4.33	0.0490 <sup>d</sup>
$a^*$	5.40±0.57	5.93±2.96	0.71	0.5520 <sup>c</sup>
$b^*$	28.59±0.88	24.88±06	2.37	0.1410 <sup>c</sup>
Hue angle	1.38±0.02	1.34±0.01	5.41	0.0330 <sup>d</sup>

<sup>c</sup>not significant at  $p>0.05$ , <sup>d</sup>not significant at  $p<0.01$ .

Table 8. Paired T-test result for the comparison of the predicted and experimental vitamin A content, antioxidant activity, and color values (L\*, a\*, b\*, and hue angles) of the optimized OFSP (SG 18-88-01) flour using OC2.

Response variable	Predicted value	Experimental value	P-value
Vitamin A (IU/g)	358.92±12.34	373.95±0.00	0.1700 <sup>cd</sup>
AA (mg TE/g)	0.50±0.01	0.55±0.00	0.0240 <sup>d</sup>
L*	81.22±0.62	82.81±0.25	0.0850 <sup>cd</sup>
a*	5.33±0.57	6.40±0.15	0.0560 <sup>cd</sup>
b*	28.46±0.88	24.92±0.37	0.0190 <sup>d</sup>
Hue angle	1.38±0.02	1.32±0.20	0.0360 <sup>d</sup>

<sup>c</sup>not significant at p>0.05, <sup>d</sup>not significant at p<0.01.

The prediction interval (PI) of both optimum conditions from the model was also noted. Prediction interval sets a range of values within which a response is likely to fall given the specified values of a given size or predictor. As seen in Table 9, considering the standard error of prediction and standard deviation, all experimental values of the response variables fall within the prediction interval generated using Design Expert 13. This entails that the model has a good predicting capacity for all the response variables. Lastly, the second optimum condition involving blanching for 1 min at 97.75°C and drying at 66.30°C had the highest  $\beta$ -carotene content amounting to 22436.70  $\mu\text{g}/100$ .

### 3.6 Proximate analysis

The results of proximate analysis showed that the optimized OFSP flour has a moisture content of 5.50±0.80% which was lower than the drum-dried OFSP flour (6.22±0.04%) from the study of Ruttarattamongkol *et al.* (2016). The flour has low moisture content which is ideal for longer shelf-life (Neela *et al.*, 2019). In terms of crude ash content which denotes the minerals in a product, the generated flour has 2.14±0.22% which is in harmony with the values (2.40±0.42%) obtained by Amajor *et al.* (2014) from sun-dried CIP 44029 flour. In terms of crude protein content, the flour has 2.51±0.24% which is within the range of 1.91-5.83% crude protein range of OFSP as reported by Mohammad *et al.* (2016). Furthermore, the flour has a crude fiber content of 3.06±0.09% which was higher than that of the reported values (2.67 to 2.90±0.28%) of OFSP flour in the study of Amajor *et al.* (2014). On the other hand, the optimized OFSP flour contained 0.47±0.03% crude fat content which was

slightly higher than the reported fat content (0.39±0.03%) of the OFSP flour in the same study by Rodrigues *et al.* (2016). Lastly, the flour is reported to contain a nitrogen free extract content of 86.31%.

### 3.7 Functional properties

#### 3.7.1 Water absorption index

The generated flour using the optimum conditions has a water absorption index of 5.90±0.15 g/g. The obtained value is close to the reported WAI value (5.42 g/g) of pre-gelatinized sweet potato starch from the study of Marta and Tensiska (2017). Ahmed *et al.* (2010) explained that WAI, which is a good indicator of the availability of molecules of the hydrophilic group to interact with water molecules, is greatly affected by temperature. Tortoe *et al.* (2017) also observed the said trend and concluded that the higher the temperature used in processing, the higher the WAI values. This index is useful to estimate the behavior of the material if further processed for other usages such as in baked and other food systems (Oikonomou and Krokida, 2012).

#### 3.7.2 Water solubility index

The optimized flour has a water solubility index (WSI) of 55.26±0.03%. The obtained WSI values of the sample were higher than that of the reported WSI value (38.87 to 38.90%) of OFSP flour in the study of Rodrigues *et al.* (2016) and close to the recorded WSI values (18.20 to 52.00%) of the extruded YFSP and OFSP flours from the study of Shih *et al.* (2009). The difference in values can be attributed to the different flour preparation conditions used to generate flour. Higher values of the water solubility index of the OFSP flour can be accounted for by the highly soluble material,

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

Response variable	OC1			OC2		
	Experimental value	95% PI		Experimental value	95% PI	
		Low	High		Low	High
Vitamin A	348.36±0.00*	327.26	388.50	373.95±0.00*	329.03	389.84
AA	0.57±0.00*	0.48	0.57	0.55±0.00*	0.47	0.55
L*	82.03±0.19*	79.82	82.90	82.81±0.25*	79.65	82.81
a*	5.93±2.96*	4.13	6.67	6.40±0.15*	4.08	6.61
b*	24.88±06*	24.40	30.80	24.92±0.37*	24.25	30.60
Hue angle	1.34±0.01*	1.34	1.42	1.32±0.20*	1.32	1.42

\*value falls within the PI range

increase in the amount of amylase leaching, and greater starch granules decomposition (Shih *et al.*, 2009). Given that the OFSP flour has a higher water solubility index, it can be ideal to be used in the production of bakery products and pastas (Kusumayanti *et al.*, 2015).

### 3.7.3 Swelling power

The optimized flour has a swelling power (SP) of  $13.23 \pm 1.34$  g/g which is higher than the reported SP values (4.65 to 5.89 g/g) of the flour generated from orange-fleshed sweet potato in the study of Tortoe *et al.* (2017). Although the flours were all generated from orange sweet potato, the differences in SP values were still noticeable. The said differences may be due to the different starch granular structure and morphology, the presence of components such as salts and proteins, and the varying amount of amylose and amylopectin which are all part of the differences in the genetic makeup of sweet potatoes (Tortoe *et al.*, 2017). Furthermore, Jangchud *et al.* (2003) reported that factors such as temperature and blanching also affected the swelling power values of flour as blanching prior to flour processing and increased drying temperatures resulted in an increase in swelling power. This functional property is considered an important quality measure in flour application as bakery products (Awuchi *et al.*, 2019).

## 4. Conclusion

This study established the optimum model for preparing OFSP (SG 18-88-01) flour to maximize  $\beta$ -carotene retention using response surface methodology. The optimal conditions involved blanching for 1 minute at  $97.75^\circ\text{C}$  and drying at  $66.30^\circ\text{C}$ . The analysis confirmed the model's adequacy with no significant lack of fit and high coefficient of determination levels. Verification showed no significant differences between predicted and experimental values with the latter consistently falling within the prediction interval. The resulting flour has high vitamin A content, meeting daily RNI for all Filipino age groups with consumption of 4.00 to 10.00 grams. Physicochemical and functional property analyses indicate the flour's suitability for the production of bakery goods. To enhance the study, suggestions include estimating shelf-life, verifying final specifications post-packaging, exploring its application in food products, and further characterizing starch-related parameters such as granule size, damaged starch content, swelling behavior and other rheological properties for better assessment. Additionally, investigating the retention of vitamin A, antioxidant activity, and color values in developed food products post-processing is recommended.

## Conflict of interest

The authors declare no conflict of interest.

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