Philippine Journal of Science
152 (5): 1831-1846, October 2023
ISSN 0031 - 7683
Date Received: 22 Mar 2023

Utilization of Out-of-specification Unripe Cavendish Banana [*Musa acuminata* (AAA)] as Banana Powder

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Around 5–20% of the total banana crop in the Philippines is rejected because it does not meet the specifications for export as fresh fruit. This study aimed to utilize the out-of-specification unripe Cavendish banana of local exporters into banana powder. The effects of different pre-drying treatments such as blanching time and concentrations of citric acid and ascorbic acid on the properties of the resulting Cavendish banana powder in terms of moisture content, water activity, color, solubility, water absorption capacity, bulk density, water holding capacity, and % yield were determined using a central composite face-centered response surface methodology design. Significant mathematical models were generated that predicted the effects of individual and combined influences of pre-drying treatments. Results showed that ascorbic acid was the main factor that influence the lightness, water activity, swelling power, bulk density, and water absorption capacity of banana powder. Results of the optimization process suggested that the desirable pre-drying treatments for banana powder were a blanching time of 0–5 min, as well as soaking in ascorbic acid ranging from 0.01–0.10% and in citric acid ranging from 0.07–0.10%. The identified optimal treatment ranges for blanching time, ascorbic acid concentration, and citric acid concentration provide valuable insights for producing acceptable, safe, and high-quality banana powder. By utilizing out-of-specification bananas and transforming them into value-added intermediate products like powder, the banana industry can reduce waste, maximize resource utilization, and create a more environmentally friendly and economically viable approach to banana production.

Keywords: banana powder, Cavendish banana, optimization, out-of-specification, response surface methodology

INTRODUCTION

Banana is one of the major commodities in the Philippines with more than 5 million Filipino farmers that are depending on it as their major source of income and food (Ortiz 2012). Concurrently, the Philippines is among the top 10 banana-producing countries in the world and ranks as the second leading global banana exporter (FAO 2022). In 2020, the total volume of banana production in the Philippines is 9 million metric tons, which is mainly from Cavendish (52%), *Saba* (28%), and *Lakatan* (10%) cultivars (PSA 2022). Cavendish banana is primarily grown for export, whereas *Saba* and *Lakatan* are the most used cultivars for food processing and dessert, respectively (Gueco *et al*. 2020).

Consequential to the high production of Cavendish in the country, there is also an abundant supply of Cavendish banana that is wasted and rejected because it does not meet

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the specifications for export as fresh fruit (Calderon and Rola 2003). A similar scenario is happening worldwide, where around 5–20% of bananas amounting to 4–5 million tons in the export are getting rejected due to out-of-specifications or non-conformity on maturity, sizes (*e.g.* too small), shapes (*e.g.* nonuniformity and irregularity), deformation, and cracking. These non-compliant bananas for export are mostly discarded, resulting in environmental problems and significant losses for both farmers and processors (Suresh Kumar *et al*. 2019). It is estimated that 80% of these bananas rejected are still food grade, especially those rejected for size or shape requirements rather than for fruit internal quality. These bananas can still be used for food processing and for producing good-quality products (Stanley 2017).

One of the easiest and simplest ways to preserve bananas is by dehydration and processing them into powder or flour. The majority of the commercially available banana powder was produced out of unripe green *Saba* banana, but several studies have shown the feasibility of other varieties for producing banana powder or flour (Anyasi *et al* 2013). Cavendish banana – like other varieties used for banana powder production – contains high starch content, especially at the unripe maturity stage (Bezerra *et al.* 2013; Pragati *et al.* 2014; Anyasi *et al.* 2017). Processing bananas into powder or flour increases their shelf life, allowing for long-term storage. Additionally, this process simplifies packaging, making it easier to store and transport bananas (Yani *et al.* 2013). Banana powder is widely utilized as an additive and ingredient in various food products due to its excellent nutritional profile (Ranjha *et. al* 2022). Some of the product applications of banana powder in the literature include drinks (Yang *et al.* 2007), cookies (Pragati *et al.* 2014), and pasta (Biernacka *et al.* 2020).

To alleviate the distress and losses of local farmers and exporters, this study aimed to utilize the out-of-specification unripe Cavendish banana of exporters into banana powder. Given that the raw material to be used in this study is not the usual or standard banana for processing, characterization of the unripe Cavendish banana was conducted. In addition, treatment prior to dehydration, such as blanching time, and concentrations of citric acid and ascorbic acid were optimized using response surface methodology (RSM) based on the required characteristics of banana powder in terms of moisture content, water activity, color, solubility, water absorption capacity (WAC), bulk density, water holding capacity, and % yield. The banana powder examined in this research is intended as a potential replacement for flour. Unripe bananas, known for their bland flavor and "starchier" taste (Zhu *et al.* 2018), may be suitable for the said intended application.

Blanching pre-treatment plays a crucial role in preserving the quality of fruits and vegetables by deactivating enzymes and eliminating microorganisms (Cruz *et al*. 2006). Additionally, it has been found that blanching enhances the drying and dehydration rates by modifying the physical properties of the products, leading to improved quality attributes (Xiao *et al*. 2017). The increased permeability of cell membranes during blanching also facilitates faster moisture removal (Severini *et al.* 2005). Moreover, blanching has demonstrated positive effects on mass and heat transfer, as well as product characteristics such as color, texture, and vitamin retention (Taiwo and Adeyemi 2009). Similarly, the use of compounds like ascorbic acid and citric acid as pre-drying treatments and anti-browning agents is crucial in preventing enzymatic browning and preserving the color and quality of dried fruits (Alipoorfard *et al.* 2020). These studies collectively highlight the significance of considering blanching time and the concentrations of citric acid and ascorbic acid in optimizing the quality of banana powder in terms of its properties and attributes.

One widely utilized mathematical and statistical approach for modeling and analyzing processes is RSM, in which the response of interest is influenced by multiple variables (Aydar 2018). By employing RSM in this study, the impact of blanching time, citric acid concentration, and ascorbic acid concentration on banana powder properties can be comprehensively assessed. Mathematical modeling further enhances analysis, enabling systematic predictions and optimized pre-drying conditions for improved banana powder production.

MATERIALS AND METHODS

Materials

Unripe Cavendish banana [*Musa acuminata* (AAA Group)] samples were supplied by one of the well-known banana exporters in the Philippines, whose banana plantation is located at Magdalena, Laguna. The samples provided were rejects or out-of-specification for export due to defects in shape, smaller sizes than the required specification, and defects on the skin due to rubbing (not exceeding 10% of the total area). However, these defects did not affect the flesh of the fruit and it remained in good condition for food processing, as depicted in Figure 1. The quality of the samples is comparable to or slightly inferior to Class II, as described in the Philippine National Standard (PNS/BAFPS 64:2008). The maturity level of the Cavendish banana was 86 days from the shooting of the fruit.

Citric acid and ascorbic acid used for the pre-drying treatments of the Cavendish banana in this study were purchased from Alysons' Chemical Enterprises, Incorporated in Quezon City, Philippines.

Figure 1. Unripe cavendish banana samples.

Characterization of Cavendish Banana

Color determination. Fresh unripe cavendish bananas were analyzed for color in terms of *CIE L**, *a**, *b** using Konika Minolta CR-300 Chromameter (Minolta Corp., Osaka, Japan). Representative banana samples were peeled and cut into three equal portions (bottom portion-near stem end, middle, and top portion near blossom end) and directly analyzed (both internal and external surfaces) using the chromameter. The instrument was initially calibrated against a white tile before measuring the *L**, *a**, *b** parameters of banana samples (Syazwani *et al*. 2013). Measurements were carried out in triplicates with six internal replicates and the mean value from each treatment was recorded.

Texture profile analysis (TPA). The textural properties of the Cavendish banana used for the production of powder in this experiment were measured using a texture analyzer (TA Plus, Lloyd Instruments, Ametek Inc., UK) fitted with a 2-mm cylinder probe. The probe is attached to a creep meter equipped with the software (NEXYGENTMMT v. 4.5, Lloyd Instruments, Ametek Inc., UK) for automatic analysis using a computer. Banana samples were cut into cylinders with sizes of approximately 20 mm diameter by 20 mm long. Each sample was placed on the stationary platform and punctured in two different points (longitudinal and horizontal axes) both at the central position of the fruit with a minimum distance of 40 mm from each point. The TPA was carried out using the following operating conditions: 2 mm/s test speed; 0.005 kgf trigger; 50% sample compression. The following TPA parameters were then measured and recorded by the instrument: sample height, hardness (1, 2), area (1,2), cohesiveness, springiness, springiness index, gumminess, chewiness, fracture force, adhesive force, adhesiveness, and stiffness. All measurements were taken at room temperature (30 °C ± 2 ℃). At least two replicate measurements with three internal replicates were conducted and the mean value from each treatment was recorded.

Total soluble solids (TSS). The TSS of the Cavendish banana was measured using a refractometer (Atago, Tokyo, Japan). The unit was calibrated with distilled water before measuring the actual sample. Three representative banana samples were randomly selected and pureed. A drop of pureed banana was placed in the daylight plate of the refractometer and the measured value was recorded and expressed as °Brix (°Bx).

pH. The pH of fresh bananas was determined following the Association of Official Analytical Chemists (AOAC) Official method 970.21 (2000) using a pH meter (LAQUA PH1100 HORIBA Bench meter, Kyoto, Japan), calibrated with standard buffer solutions 4 and 7.

Moisture content. The moisture content of fresh bananas was determined following the AOAC Official Method 925.09 (2000) using Vacuum Oven Method (Binder Vacuum Oven Model VD 23, Germany). Percent Moisture content was calculated using the following formula:

$$MC_{wb} = \frac{(W_i\text{-}W_f) \times 100\%}{W_i\text{-}W_a} \quad (1)$$

where MC_{wb} (%) is the moisture content on a wet basis, W_i (g) is the initial weight of samples before drying plus aluminum dish and lid, W_f (g) is the final weight of dried samples plus aluminum dish and lid, and W_a (g) is the weight of aluminum dish and lid (Dame and Sahu 2016).

Banana Powder Preparation

Newly supplied unripe bananas were stored in a well-ventilated room and were processed the following day. Unripe bananas were weighed, washed, sanitize in 200 ppm chlorinated water, and drained. Sanitized fruits were then pre-treated by blanching in boiling water before peeling and/or addition of organic acids (citric and/or ascorbic) after peeling based on the experimental design shown in Table 1. Pre-treated bananas were cut uniformly into slices (approximately 1 cm thick), dried in a cabinet dryer at 60 °C (Santos *et al*. 2022) for 16 h, and pulverized using a stone mill. The temperature and drying time for banana drying were determined based on previous trials conducted in the cabinet dryer at the DOST-ITDI (Deparment of Science and Technology–Industrial Technology Development Institute), where the achieved moisture content was 7.5% or lower. Banana powder without pre-drying treatment was also prepared as the control and was analyzed along with the banana powder samples with pre-drying treatments.

Physicochemical Analysis for Banana Powder

The analyses of the physicochemical properties of each banana powder sample were conducted in triplicates as follows:

Moisture content (MC). The moisture content of banana powder samples was determined using the Vacuum Oven Method (AOAC Official Method 925.09 2000), and computation was performed using Equation 1.

Water activity (a_w). The water activity of the banana powder was measured in Novasina Water Activity Meter AWC503 RS-C.

Color determination. Color characteristics of the banana powder were analyzed by measuring lightness (*L**), redness (*a**), and yellowness (*b**) using a chromameter (Minolta Chromameter Model CR-300, Japan).

Bulk density. The bulk densities of the powders were determined by weighing 2 g of the sample and placing it in a 50-mL graduated cylinder. The bulk density was calculated by dividing the mass of the powder by the volume occupied in the cylinder (Kurozawa *et al.* 2009).

Swelling capacity. Swelling capacity was determined by weighing 0.1 g into pre-weighed test tubes containing 10 mL distilled water, which was then heated in a water bath at 60 °C for 30 min with intermittent agitation after 5, 15, and 25 min for 5 s. Subsequently, the tubes were centrifuged at 1,000 xg for 15 min. The resulting supernatant was decanted. Swelling power was calculated as the weight of starch paste divided by the weight of dry starch (Onyango *et al.* 2013).

Water absorption capacity (WAC). WAC was done by weighing 5 g of banana powder into pre-weighed 50-mL

Table 1. Experimental design for production of banana powder using mature unripe Cavendish.

Run	Blanching time (min)	Citric acid (%)	Ascorbic acid (%)
1	5	0.1	0.05
2	10	0	0.1
3	0	0.05	0.05
4	5	0.05	0.05
5	10	0.05	0.05
6	5	0.05	0.05
7	10	0.1	0
8	10	0	0
9	5	0.05	0
10	0	0.1	0.1
11	5	0	0.05
12	0	0.1	0
13	0	0	0
14	5	0.05	0.05
15	0	0	0.1
16	5	0.05	0.1
17	10	0.1	0.1

centrifuge tubes. Each tube containing the sample was added with 25-mL distilled water, securely sealed with a cap, and vigorously shaken using a vortex mixer for 5 s to allow the powder particles to settle. The suspended particles were shaken every 5 min for 20 min to solvate and swell prior to centrifugation at 1,000 xg for 15 min. The supernatant was then decanted and drained by carefully touching the pellet with an adsorbent paper towel. WAC was computed as the difference between the weight of the drained tube and the weight of the original empty tube divided by the weight of the dry sample (Onyango *et al.* 2013).

Solubility. The solubility of banana powder was determined following the procedure of Pragati and others (2014). The supernatant obtained from WAC analysis was weighed (M_1) and transferred into a moisture dish. It was then placed in a hot air oven at 105 °C for 4 h and subjected to further drying until a constant weight was achieved. After drying, the samples were then transferred to a desiccator to cool. Cooled samples were weighed (M_2). The weight difference between M_1 and M_2 was expressed as the solubility of the powder (%).

% yield. The percentage yield of banana powder was calculated by comparing the final weight of banana powder and the initial weight of the banana as the raw material (Wibowo *et al.* 2021).

Statistical Analyses

Statistical analyses and modeling of response variables were performed using the Design-Expert Version 7.0 (Stat-Ease, Minneapolis, MN, USA). A central composite face-centered RSM, consisting of three independent variables – the concentration of citric acid, the concentration of ascorbic acid, and the blanching time – was employed in the study. The design required 17 experimental runs as shown in Table 1. The response variables measured included moisture content, water activity, color (*L**, *a**, *b**), bulk density, swelling capacity, solubility, WAC, and % yield. Models for the response variables were generated using the multiple regression analysis that fits the second-order equation given below:

$$y = \beta_o + \sum \beta_i x_i + \sum \beta_{ii} x_i^2 + \sum \sum \beta_{ij} x_{ij} \quad (2)$$

where y is the predicted response, β_o is the regression coefficient for intercept, β_i is the linear coefficient, β_{ii} is the quadratic coefficient, and β_{ij} is the interaction coefficient.

The adequacy of mathematical models was evaluated and verified according to model significance ($p \leq 0.05$), lack of fit test, and other measures of adequacy such as R^2, adjusted R^2, and prediction error sum of squares, among others.

Another statistical treatment used was the descriptive statistical analysis using mean and standard deviation for describing the physicochemical characteristics of raw banana and banana powder. It was executed using the IBM Statistical Packages for Social Sciences (SPSS) Statistics 22 (SPSS, Inc. 2013, New York, USA) software.

Optimization and Validation

The objective of the optimization is to develop a banana powder subjected to applicable pre-drying treatment capable of giving a minimum quality and safety characteristics that is acceptable to the market requirements. Specifications of criteria for the optimization of independent and response variables for banana powder are shown in Table 2. Optimization of the process variables was performed using the desirability function. The desirability scores were generated by the

Table 2. Specifications of criteria for the optimization of independent and response variables for banana powder.

Factors		Optimization criteria			
		Goal	Limits	Weights	Importance
A.	**Independent variables**				
	Blanching time, min	In range	0–5	1	+++
	Concentration of citric acid, % (w/w)				
	Concentration of ascorbic acid, % (w/w)	In range	0.0– 0.10	1	+++
		In range	0.0–0.10	1	+++
B.	**Response variables**				
	Moisture content (%)	Target = 5	4.0–7.5	1	+++
	Water activity	Minimize	0.3–0.523	1	+++
	Color (*L**)	Target = 77	70–85	1	+++
	Yield (%)	Maximize	10–18.5	1	+++
	Swelling power (%)	Maximize	4–7	1	+++
	Bulk density (g/mL)	Maximize	0.65–0.80	1	+++
	Water absorption Capacity (%)	Minimize	2–5.75	1	+++

Design-Expert Version 7.0 software from the different combinations of process parameters. Only scores with > 0.70 were considered in the reported optimum range for each response. Validation experiments of two optimal pre-drying treatments were conducted in triplicates to estimate the predictive capacity of the generated models. The model is considered valid once the experimental values of responses were within the confidence and/or prediction interval of 95%.

RESULTS AND DISCUSSION

Physicochemical Properties of Mature-Unripe Cavendish Banana

Table 3 shows the physicochemical properties of the mature-unripe Cavendish banana obtained from those graded as unacceptable or out-of-specification for export. Results showed that the physicochemical characteristics of the unripe Cavendish banana are comparable to those acceptable for export and those reported in several studies. Ernesto and his colleagues (2018) reported a moisture content and TSS of green cavendish bananas collected from different regions in Mozambique ranging from 70.98–76.99% and 10–12%, respectively. According to Ahmed and others (2020), low pH (< 5), low %TA (< 0.50), and low TSS (< 10%) values are expected in fresh fruit bananas harvested as mature green. The firmness of the outer section of the banana in the current study is within the range of the firmness of the Cavendish banana described in the study of Siriwardana and colleagues (2016). This shows that in terms of the physicochemical characteristics of the pulp of the mature-unripe Cavendish banana in the present study, the raw material can still be used and suitable for food processing.

Table 3. Physicochemical properties of unripe Cavendish banana.

Physicochemical characteristics	Mean ± SD
pH	4.91 ± 0.32
TSS, °Brix	8.67 ± 4.06
% titratable acidity	
% citric acid	0.21 ± 0.02
% malic acid	0.22 ± 0.02
% moisture content	78.27 ± 3.12
Color (inner section)	Inner section
*L**	72.44 ± 3.97
*a**	–2.42 ± 0.74
*b**	16.53 ± 14.95
Color (outer section)	
*L**	78.21 ± 0.54
*a**	–3.42 ± 0.42
*b**	24.32 ± 1.31
Firmness, kg • m/s^2 (inner section)	0.7488 ± 0.450
Firmness, kg • m/s^2 (outer section)	0.4077 ± 0.0217

Effects of the Pre-drying Treatments on the Physicochemical Properties of Mature-Unripe Cavendish Banana Powder

Table 4 presented the mean values of response variables obtained from mature unripe banana powder processed with varying pre-drying treatments (blanching time, concentration of citric acid, and concentration of ascorbic acid). The effects of the pretreatments on the moisture content, water activity, color (*L**, *a**, *b**), yield, solubility, swelling power, bulk density, and WAC were analyzed by fitting the model on the second-order Equation 2. The effects of pre-drying treatments on each response variable are discussed below and generated models that were significant are summarized in Table 5.

Moisture content (%). The moisture content of unripe banana powder produced with different pretreatments ranged from 4.50–7.52%. Linear regression revealed that the generated model (Equation 3) for this response is significant. The factor that greatly affects the moisture content of unripe banana powder was the blanching time, as shown in Table 5. It can be observed in Figure 2 that as the blanching time increased the moisture content decreased. This result concurred with the findings of Taiwo and Adeyemi (2009), wherein blanched banana samples lost higher amounts of moisture compared to unblanched ones. This phenomenon may be attributed to the increased permeability in the cell walls of blanched fruits, which favors faster migration of water to the surface for removal (Wang *et al.* 2022; Deng *et al.* 2018).

$$MC = 7.115 - 0.188(BT) – 7.768 (CA) – 8.714 (AA) \quad (3)$$

Water activity. The water activity of unripe banana powder samples ranged from 0.319–0.523. Linear terms of citric acid and ascorbic acid, as well as the interaction effects of blanching time and ascorbic acid, are the factors that significantly affected the water activity of banana powder (Table 5). Among them, ascorbic acid is the factor that greatly influenced the changes in water activity. The generated model for water activity is shown in Equation 4. 3-D surface plot (Figure 3) showed that at lower blanching time and controlling the concentration of citric acid at 0.05%, water activity decreased as ascorbic acid increased. Similarly, the linear effect of citric acid, as shown in Figure 4, revealed that water activity decreased as the citric acid increased. According to Abano and Sam-Amoah (2011), ascorbic acid pretreatment tends to loosen the water molecules in the banana slices when exposed

Table 4. Mean values of response variables obtained from different pre-drying treatments applied in the processing of unripe banana powder.

Run	Factors			Responses										
	BT (min)	CA (%)	AA (%)	MC (%)	A_w	Color (L^*)	Color (a^*)	Color (b^*)	Yield (%)	Solubility (%)	Swelling power (%)	Bulk density (g/mL)	WAC (%)
1	**5.0**	**0.05**	**0.05**	6.375	0.434	67.45	1.68	16.43	13.33	15.33	8.23	1.00	2.54
2	**5.0**	**0.00**	**0.00**	5.537	0.407	76.75	0.38	20.32	13.67	14.53	11.02	0.98	2.57
3	**2.5**	**0.05**	**0.05**	5.280	0.333	77.25	1.45	12.32	12.14	13.56	5.25	0.76	1.99
4	**2.5**	**0.10**	**0.05**	5.245	0.363	68.84	1.49	16.49	13.24	14.59	9.81	1.00	2.56
5	**5.0**	**0.00**	**0.10**	5.170	0.386	76.43	0.29	19.50	13.51	20.00	9.87	0.93	2.59
6	**5.0**	**0.10**	**0.00**	4.503	0.319	68.51	1.67	14.94	13.69	11.70	10.50	0.91	2.76
7	**2.5**	**0.00**	**0.05**	6.297	0.458	75.86	0.46	18.88	14.08	20.32	10.65	0.88	2.48
8	**2.5**	**0.05**	**0.05**	7.277	0.372	78.02	0.27	18.10	14.15	12.42	11.91	0.91	2.72
9	**0.0**	**0.00**	**0.00**	7.520	0.523	55.74	2.66	17.29	14.55	19.25	9.01	0.96	2.55
10	**0.0**	**0.00**	**0.10**	5.327	0.334	76.76	1.38	13.11	14.94	12.09	5.93	0.72	1.98
11	**0.0**	**0.05**	**0.05**	6.663	0.476	63.75	3.23	24.68	13.59	30.50	7.93	0.90	2.11
12	**2.5**	**0.05**	**0.10**	5.104	0.321	76.33	1.40	12.77	13.33	12.21	6.26	0.78	1.98
13	**5.0**	**0.10**	**0.10**	4.721	0.353	75.82	1.14	14.11	11.77	23.04	5.55	0.85	1.83
14	**2.50**	**0.05**	**0.00**	6.539	0.433	62.14	2.59	14.45	15.18	13.10	8.71	1.00	1.56
15	**0.00**	**0.10**	**0.10**	5.459	0.351	77.53	12.59	1.00	13.21	14.51	6.31	0.78	1.96
16	**2.50**	**0.05**	**0.05**	5.901	0.431	68.38	2.02	2.02	14.09	17.73	8.03	1.02	2.52
17	**0.00**	**0.10**	**0.00**	6.039	0.427	74.79	1.31	25.89	13.17	21.75	8.26	0.95	1.64

Table 5. Effects of blanching time, citric acid, and ascorbic acid on the moisture content, water activity, color (L), color (a), % yield, swelling power, bulk density, and water absorption capacity on banana powder as their corresponding coefficients in the predictive quadratic models.

Factor	Responses							
	Moisture content (*p*-value)	Water activity (*p*-value)	Color (L^*) (*p*-value)	Color (a) (*p*-value)	% Yield (*p*-value)	Swelling power (*p*-value)	Bulk density (*p*-value)	Water absorption capacity (*p*-value)
Constant	+7.115	+0.517	+67.291	+1.785	+14.893	+9.008	+0.938	+2.581
Blanching time (BT)	–0.188 (0.050)	–0.022 (0.130)	–	–0.109[a] (0.031)	–0.139 (0.140)	+0.310 (0.181)	+0.014 (0.160)	+0.042 (0.173)
Citric acid (CA)	–7.768 (0.098)	–0.590[a] (0.043)	–	–4.240 (0.069)	–11.347[a] (0.024)	–	+0.052 (0.914)	–0.820 (0.586)
Ascorbic acid (AA)	–8.714 (0.0667)	–1.423[a] (0.016)	+89.880[a] (0.026)	+12.630 (0.232)	–6.987 (0.140)	-27.154 (0.027)	–1.500[a] (0.008)	–5.464[a] (0.003)
BT x CA	–	–	–	–	–	–	–	–
BT x AA	–	+0.278[a] (0.034)	–	–10.620 (0.094)	–	–	–	–
CA x AA	–	–	–	+606.000 (0.060)	–	–	–	–
BT^2	–	–	–	–	–	–	–	–
CA^2	–	–	–	–	–	–	–	–
AA^2	–	–	–	–	–	–	–	–

Table 5. Continued . . .

Measures of fit of models								
Model	(0.033)[a]	(0.011)[a]	(0.026)[a]	(0.028)[a]	(0.036)[a]	(0.041)[a]	(0.030)[a]	(0.012)[a]
R^2	0.477	0.639	0.288	0.640	0.469	0.366	0.485	0.556
R^2 adj	0.356	0.519	0.241	0.476	0.346	0.275	0.366	0.453
Pred R^2	0.115	0.311	0.071	–0.812	0.140	0.166	0.188	0.227
Adequate Precision	7.749	9.006	4.547	9.452	7.432	5.836	6.210	7.463
CV (%)	11.83	10.43	8.03	96.62	5.15	20.65	8.32	9.78
Lack of fit	(0.897)	(0.744)	(0.549)	(0.146)	(0.945)	(0.989)	(0.972)	(0.942)
Transformation	None	None	None	None	None	None	None	None

[[a]] Coefficients significant (95% confidence level)

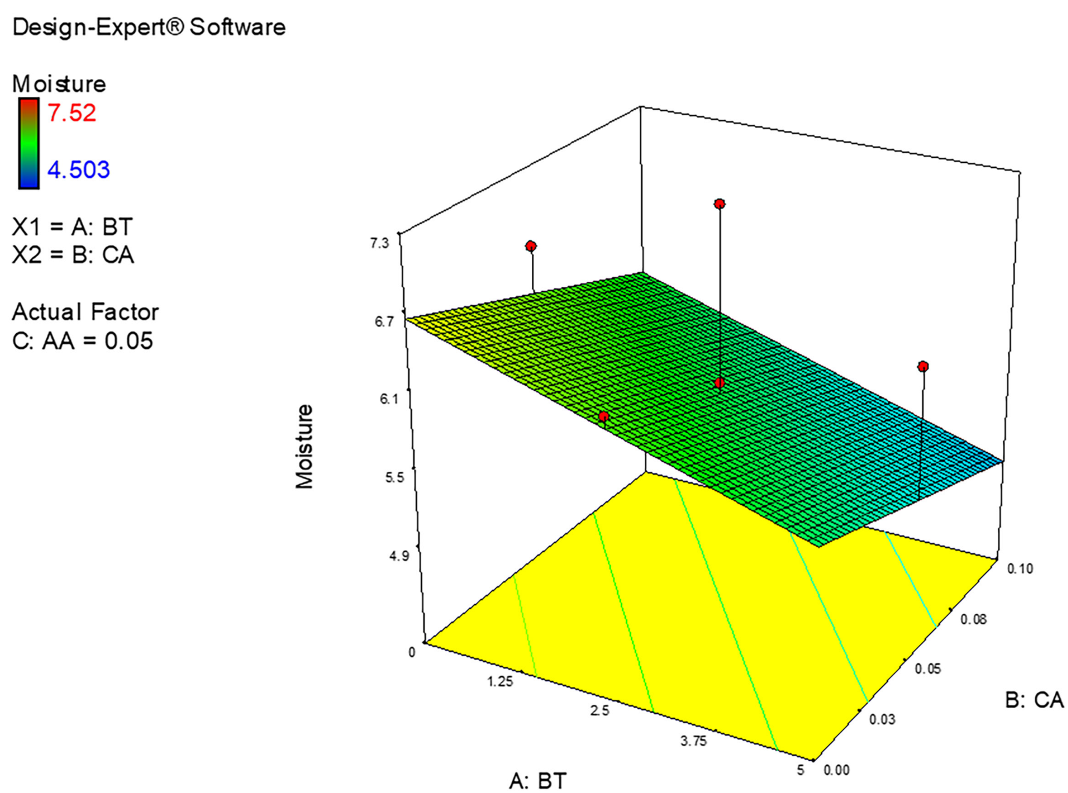

Figure 2. Effects of blanching time as the pre-drying treatment on the moisture content of the unripe banana powder.

to prolonged heat and thereby aid drying. This may have contributed to the lower water activity of banana powders pre-drying treated at higher concentrations of organic acids and when combined with blanching.

$$a_w = 0.517 - 0.022(BT) - 0.590(CA) - 1.423(AA) + 0.278(BT)(AA) \quad (4)$$

Color (L*, a*, b*). Color in terms of lightness (*L**) of unripe banana powder ranges from 55.74–78.02. A significant linear model was generated (Equation 5), whereby ascorbic acid is the only factor that significantly affects lightness. It is illustrated in Figure 5a that as the ascorbic acid concentration increased from 0 to 0.10%, the lightness of unripe banana powder also increased. Ascorbic acid has long been used to arrest the enzymatic browning of fruits (Ali *et al.* 2020) by inhibiting the activities of polyphenol oxidase and peroxidase enzymes (Sikora and Świeca 2018).

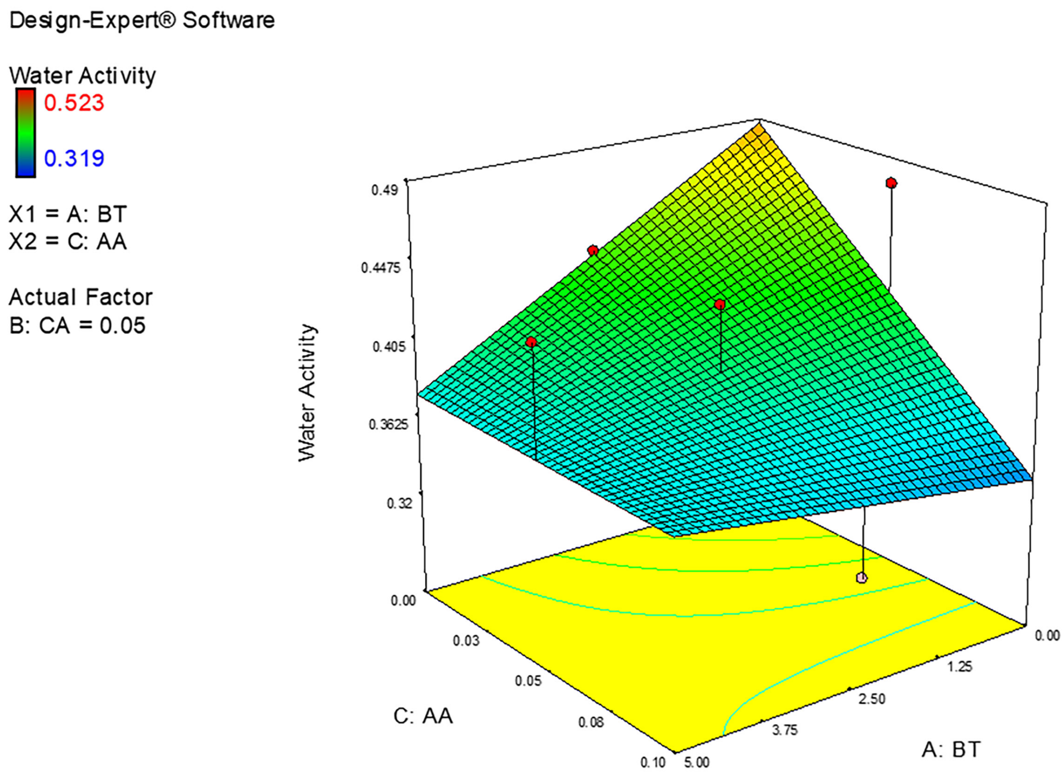

Figure 3. Effects of blanching time and ascorbic acid concentration as the pre-drying treatment on the water activity of unripe banana powder.

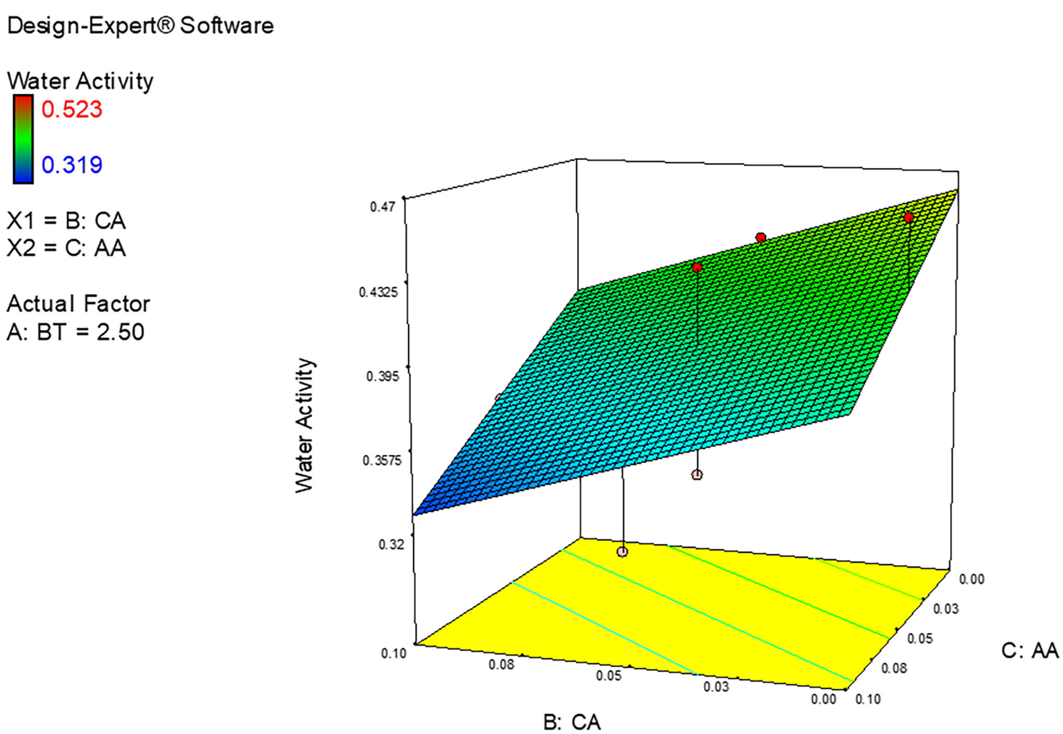

Figure 4. Effects of citric acid as the pre-drying treatment on the water activity of unripe banana powder.

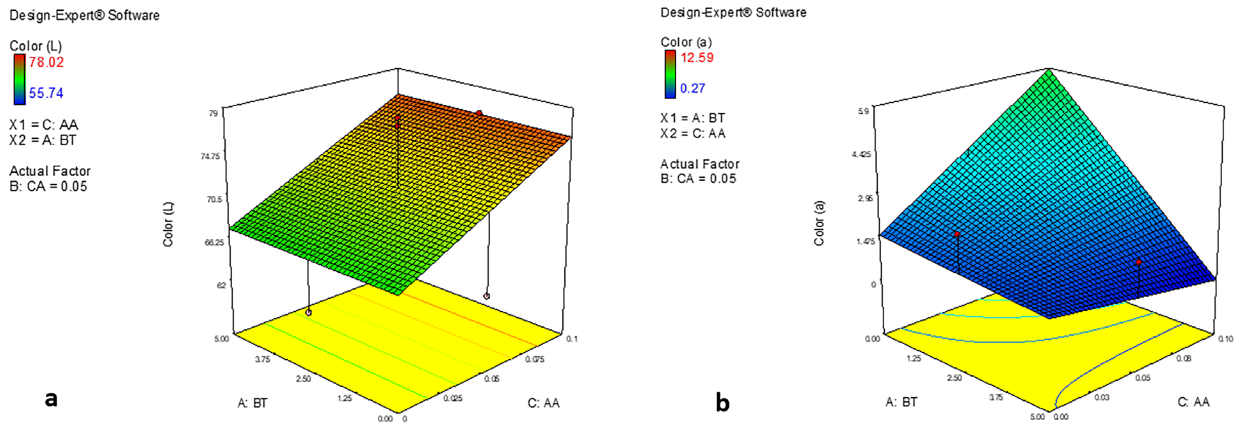

Figure 5. Effects of ascorbic acid as the pre-drying treatment on the color (a) L^* and (b) a^* of unripe banana powder.

$$L^* = 67.291 + 89.88(AA) \quad (5)$$

Color a^* (greenness to redness) values of unripe banana powder ranged from 0.27–12.59. The model generated by fitting the color (a*) values in the second-order Equation 2 is significant (Equation 6). Blanching time is the only factor that affected the redness of unripe banana powder. Figure 5b shows that redness decreased as the blanching time increased from 0 to 5 mins. On the other hand, the color in terms of blueness to yellowness (b^*) of unripe banana powder samples ranged from 1.00–25.89. The generated model (equation not shown), however, was not significant – indicating that pretreatments did not affect the color b^* values of unripe banana powder.

$$\text{Color } (a^*) = 1.785 - 0.109(BT) - 4.24(CA) + 12.63(AA) - 10.62(BT)(AA) + 606(CA)(AA) \quad (6)$$

To appreciate and visualize the degree of lightness and chromaticity of each sample, a photographic representation of unripe banana powder samples is shown in Figure 6.

% yield. The % yield of unripe banana powder samples ranged from 11.77–15.18%. The generated model (Equation 7) was significant, wherein the linear term of citric acid was the only factor that influences the % yield of unripe banana powder. As shown in Figure 7, the % yield decreased as the citric acid increased. There is a limited study on the effect of the pre-drying treatment using citric acid on the % yield of banana powder and other fruit powder. In the study of Setyawan and colleagues (2021), it was mentioned that pre-drying treatments caused the loss of water-soluble compounds that may be responsible for weight loss. In another study conducted by Toldrá and Flores (2004), it was reported that pH can greatly affect the drip loss of coated food materials. In the present study, the addition of citric acid may cause to lower pH of bananas, resulting in higher drip loss and lower % yield.

$$\% \text{ yield} = 14.893 - 0.139(BT) - 11.347(CA) - 6.987 (AA) \quad (7)$$

Solubility. The solubility of unripe banana powder samples ranged from 11.70–30.50. The generated model (equation not shown) was not significant, which indicates that blanching time, the concentration of citric acid, and the concentration of ascorbic acid do not affect the solubility of unripe banana powder. This result is consistent with the findings of Rosidi and others (2021) in their study on the effect of blanching on the water solubility of dragon fruit powder. The non-significant effect of the pre-drying treatments on the solubility of banana powders may be due to the relatively short duration of exposure during blanching, which is not sufficient to cause degradation of the starch component of banana powder (Sengkhamparn *et al.* 2013). Additionally, it could be attributed to the high availability of soluble components and minimal starch degradation (Roisidi *et al.* 2021).

Swelling power. The swelling power of different samples of unripe banana powder ranges from 5.21–11.95 %. Table 5 shows that the generated model for the selling power of unripe banana powder is significant (Equation 8). The factor that mainly causes significant changes in swelling power is ascorbic acid. As shown in Figure 8a, swelling power decreases as the ascorbic acid increases from 0–0.10%. This may be attributed to the higher depolymerization of the starch by ascorbic acid. In comparison with citric acid, ascorbic acid has a lower molecular weight; therefore, at similar concentrations, ascorbic acid would have a larger number of acid molecules than citric acid (Trithavisup and Charoenrein 2016). This might be the reason for the significant effect of the ascorbic acid treatment on the swelling power of the banana powder.

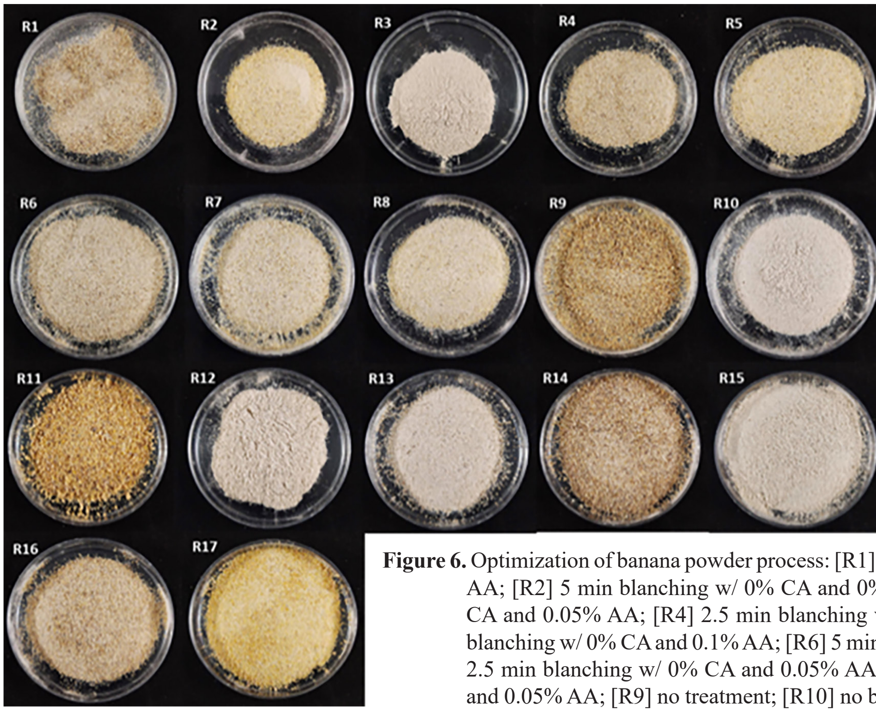

Figure 6. Optimization of banana powder process: [R1] 5 min blanching w/ 0.05% CA and 0.05% AA; [R2] 5 min blanching w/ 0% CA and 0% AA; [R3] 2.5 min blanching w/ 0.05% CA and 0.05% AA; [R4] 2.5 min blanching w/ 1.0% CA and 0.05% AA; [R5] 5 min blanching w/ 0% CA and 0.1% AA; [R6] 5 min blanching w/ 0.1% CA and 0% AA; [R7] 2.5 min blanching w/ 0% CA and 0.05% AA; [R8] 2.5 min blanching with 0.05%CA and 0.05% AA; [R9] no treatment; [R10] no blanching w/ 0% CA and 0.1% AA; [R11] no blanching w/ 0.05% CA and 0.05% AA; [R12] 2.5 min blanching w/ 0.05% CA and 0.1% AA; [R13] 5 min blanching w/ 0.1% CA and 0.1% AA; [R14] 2.5 min blanching w/ 0.05% CA and 0.1% AA; [R15] no blanching w/ 0.1% AA and 0.1%CA; [R16] 2.5 min blanching w/ 0.05% CA and 0.0.5% AA; [R17] no blanching w/ 0.1% CA and 0% AA.

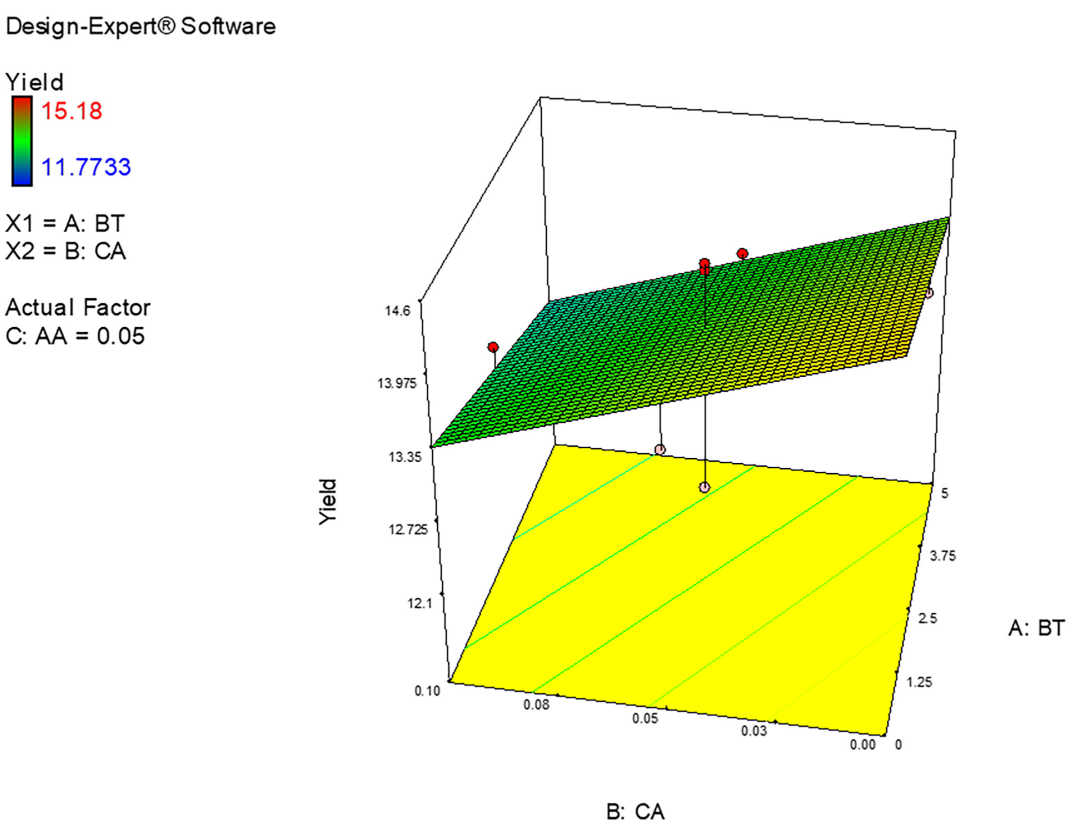

Figure 7. Effects of citric acid as the pre-drying treatment on the Yield of unripe banana powder.

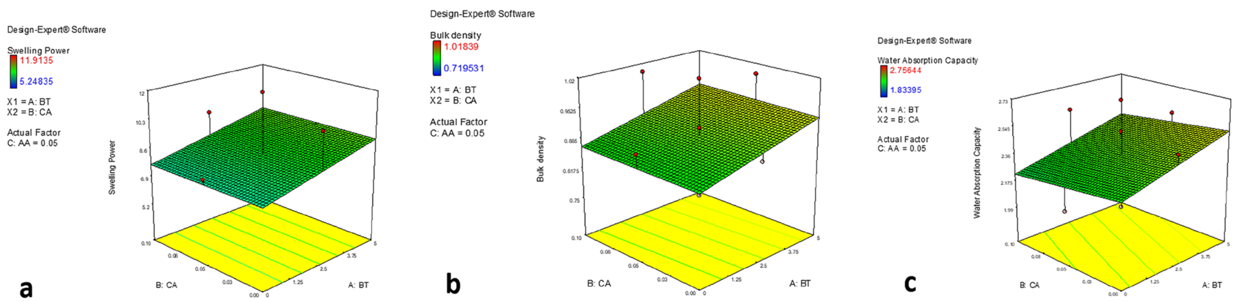

Figure 8. Effects of ascorbic acid as the pre-drying treatment on the [a] swelling power, [b] bulk density, and [c] water absorption capacity of unripe banana powder.

$$\text{Swelling power} = 9.008 + 0.310(\text{BT}) - 27.153(\text{AA}) \tag{8}$$

Bulk density. The bulk density of unripe banana powders was within the range of 1.72–1.02 g/mL. Similar to the result of swelling power, the linear term of ascorbic acid was the only factor that significantly affects the bulk density of the produced banana powder samples, on which the increase in the concentration of ascorbic acid from 0 to 0.1% decreased the bulk density (Figure 8b). The generated model is shown in Equation 9:

$$\text{Bulk density} = 0.938 + 0.014(\text{BT}) + 0.052(\text{CA}) - 1.500(\text{AA}) \tag{9}$$

The bulk density obtained in this study closely matched the findings of Alsiddig and Osman (2018), who investigated the characteristics of banana powders at various stages of maturity. They reported a bulk density of 1.05 g/mL for unripe Cavendish banana powder. The reported bulk density value for the said study was the highest among semi-ripe and ripe counterparts which may be attributed to their fine texture.

The bulk density is a valuable parameter that offers insights into the particle packing, arrangement, and compaction profile, as well as the porosity of the product (Shimbhanao 2016), which is crucial in determining the appropriate packaging material. When it comes to flours or powders, those with lower bulk densities require less dense packing materials (Akubor and Ike 2012).

Water absorption capacity (WAC). The WAC of unripe banana powder was found to follow a similar trend as the bulk density and swelling power of the samples, wherein the concentration of ascorbic acid is the only significant factor that mainly affects WAC, as shown in Table 5 and in the generated model in Equation 10. The concentration of ascorbic acid was observed to have a significant impact on decreasing the WAC of the powder samples (Figure 8c).

The WAC of unripe banana powder in this study ranged from 1.83–2.76%. These values are higher compared to other unripe banana varieties in the study of Hasmadi and others (2021). Generally, unripe banana powder has also a higher WAC than flour from ripe bananas (Singh *et al.* 2017; Pragati *et al.* 2014). WAC represents the ability of a product to associate with water under conditions where water is limited (Singh *et al.* 2017). The physical state of starch, dietary fiber, and protein in the flour contributed to its WAC, with the release of amylose playing a significant role in effectively binding water molecules and yielding a higher WAC (RodrÍguez-Ambriz *et al.* 2008).

$$\text{WAC} = 2.581 + 0.042(\text{BT}) - 0.820(\text{CA}) - 5.464(\text{AA}) \tag{10}$$

Optimization and Validation of the Pre-drying Treatment for Mature-Unripe Cavendish Banana Powder

The results obtained by the central composite face-centered response surface design (Table 5) showed that the predicted models for moisture content, water activity, color (L^*), yield, swelling power, bulk density, and WAC were the significant models that were affected by pre-drying treatments. Hence, optimization of the blanching time, ascorbic acid, and citric acid pre-drying treatment for banana powder were performed by using the desirability function and considering the criteria set in Table 2 that will result in a banana powder capable of giving a minimum quality characteristic that is acceptable to the market standards.

Based on the independent and response variable criteria, the optimum pre-drying treatments for unripe banana powder with desirability of > 0.70 were as follows: [a] blanching time of 0–5 minutes, [b] ascorbic acid of 0.01–0.10%, and [c] citric acid of 0.07–0.10%. A contour plot for the most desirable point (desirability = 0.818) of pretreatment in unripe banana powder with a blanching time of 2.28 min, citric acid of 0.10%, and ascorbic acid of 0.10% is shown in Figure 9.

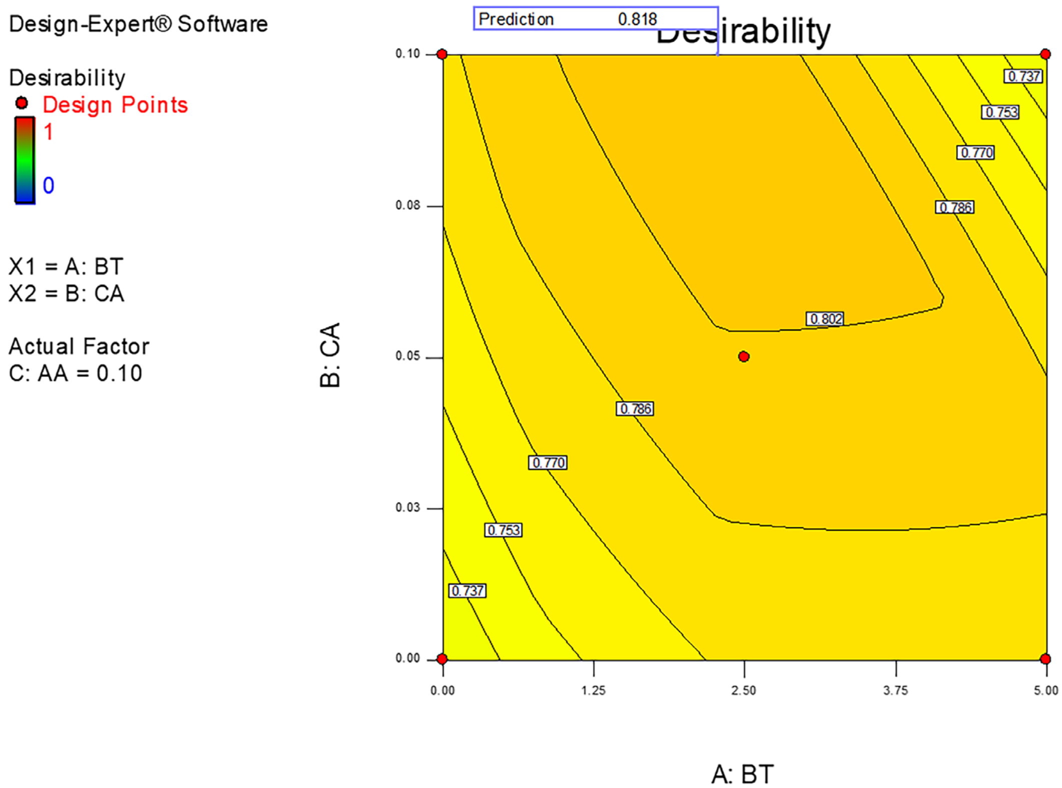

Figure 9. Most desirable pre-drying treatment combinations for unripe banana powder.

Table 6. Predicted and actual values of moisture content, water activity, color (L), % yield, swelling power, bulk density, and water absorption capacity of "optimal" unripe banana powder.

Response	Optimal 1[a]			Optimal 2[b]		
	Actual value	Confidence interval	Predicted interval	Actual value	Confidence interval	Predicted interval
MC (%)	3.90 ± 0.29[c]	4.28–5.80	3.37–6.71	4.01 ± 0.61[c]	5.23–6.79	4.33–7.69
A_w	0.24 ± 0.01[c]	0.28–0.37	0.23–0.43	0.26 ± 0.01[c]	0.30–0.41	0.25–0.46
Color (*L)**	75.28 ± 0.64	71.38–81.17	63.06–89.50	77.00 ± 0.64	71.38–81.17	63.06–89.50
% yield	13.18 ± 2.55	11.97–13.51	11.04–14.44	13.45 ± 5.33	13.06–14.65	12.14–15.57
Swelling Power (%)	6.13 ± 0.85	5.51–8.49	2.98–11.02	6.19 ± 0.42	4.39–8.19	2.11–10.48
Bulk density (g/mL)	0.69 ± 0.03[c]	0.74–0.91	0.64–1.01	0.66 ± 0.02[c]	0.70–0.87	0.61–0.97
WAC (%)	2.03 ± 0.02	1.79–2.30	1.49–2.61	2.00 ± 0.02	1.75–2.27	1.44–2.58

[a] Conditions: blanching time (min) = 2.28; citric acid (%) = 0.10; ascorbic acid (%) = 0.10
[b] Conditions: blanching time (min) = 0.0; citric acid (%) = 0.03; ascorbic acid (%) = 0.10
[c] Denotes significant difference ($p < 0.05$) between predicted and actual values for each sample

Optimal results were validated by performing an experiment on the optimal point. Two optimal samples of unripe banana powder were produced based on the optimum range combinations of blanching time, the concentration of citric acid, and ascorbic acid. For Optimal Sample 1, the pretreatment combination used was 2.28 min blanching time, 0.10% ascorbic acid, and 0.10% citric acid. For Optimal Sample 2, the pre-treatment combination used was 0 min blanching time, 0.03% ascorbic acid, and 0.10% citric acid. The validation experiment, as shown in Table 6, demonstrated that in general, the actual values of moisture content, water activity, color (*L**), % yield, and swelling power of the optimal samples are within the confidence and/or prediction intervals of the predicted values.

CONCLUSION

The central composite face-centered RSM design was successfully used to determine the appropriate pre-drying techniques, particularly on blanching time and the use of organic acids such as ascorbic acid and citric acid to produce an optimum banana powder that is acceptable in terms of quality and safety. Banana with the most optimum pre-drying treatments produced a banana powder with a moisture content of 3.90 ± 0.29%, water activity of 0.24 ± 0.01, color lightness of 75.28 ± 0.64, yield of 13.18 ±2.55%, swelling power of 6.13 ± 0.85%, bulk density of 0.69 ± 0.03 g/mL, and WAC of 2.03 ± 0.02%.

Based on the experimental runs conducted, mature unripe Cavendish bananas from out-of-specification for export can be processed into powder, which may be used in various applications. Further research on the starch property, microbiological quality, nutritional component, and food application of the produced banana powder are highly recommended.

ACKNOWLEDGMENTS

The authors would like to acknowledge the full cooperation and support to the study of the following: Mr. Gabriel Igot of Techgreen who provided the raw material, particularly the out-of-specification Cavendish banana for export, used in the experimental runs in the study, as well as Mr. Ronald Balderama and Mr. Romnick Enriquez of Food Processing Division for their assistance in the production and experimental runs.

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