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Original Research Paper

Optimizing banana powder production: A quadratic approach using Box-Behnken Design for hot-air oven drying parameters

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ABSTRACT

Optimization of parameters in food product processing is essential for achieving high-quality output and efficient production. While the use of fresh green bananas is limited, drying them into powder expands their applications significantly. This study focuses on optimizing the production of banana powder, which has numerous applications in the food industry. Key parameters such as steaming time, citric acid concentration, and drying time need to be optimized using Box-Behnken design of response surface methodology (RSM), as they directly impact the quality of the banana powder. The moisture content of the sample was measured using the gravimetric method, while water activity was assessed with a digital water activity meter. Amylose content was determined using a calorimeter, while starch content of the sample was measured using the anthrone method and color characteristics were evaluated with a spectrophotometer. The quadratic model was found to be the best fit for most of the responses (R^2 = 0.96 – 1) and the linear model was fit for starch content (R^2 = 0.73). Results obtained using Box-Behnken Design of response surface methodology reveals that steaming time of 10 minutes, citric acid concentration of 0.5 % and a drying time of 7 hours are ideal conditions for enhance powder making. Under the optimized condition, the values of yield, moisture content, water activity, amylose, starch content and L* was predicted to be 19.99 %, 5.73%, 0.40 a_w, 23.43 g/100g, 86.72 g/100g and 50.82 of banana powder respectively, aligning with the experimental values using the desirability function.

Keywords: Banana powder, box-behnken design, food industry, numerical optimization, response surface methodology

INTRODUCTION

Banana powder is a high valued product in the food industry due to its rich nutritional profile, versatility and long shelf life. The main source of raw material for the production of powder is green banana (Musa spp.) which is cultivated globally around 130 countries (Kamble et al., 2022). It contains a wealth of essential vitamins and minerals like potassium and dietary fiber. It ranks 4th among the most important stable crops followed by rice, wheat and millet (Alzate et al., 2021). Unfortunately, the quality and quantity of banana production suffer greatly from post-harvest losses caused by improper handling, inadequate cold storage, and transportation challenges (Rajapaksha et al., 2021). After bananas are harvested, due to their climacteric nature, it undergoes physiological changes such as softening of the flesh, alterations in color, and loss of weight. Post-harvest losses in green bananas are mainly attributed to temperature and humidity during storage, as well as inadequate cultivation practices (Mebratie et al., 2015). To mitigate these losses, it is essential to ensure proper handling of green bananas after harvest, which includes appropriate storage, packaging, and marketing systems. Drying minimizes postharvest losses efficiently by lowering moisture content (%) and water activity (a_w) in banana powder. This decrease helps to slow down physical and biochemical reactions, which in turn minimizes microbial growth during the ripening process (Kamble et al., 2022). Convective tray drying is a widely recognized drying method which is accessible, user-friendly with less initial installation cost than other drying methods. However, the primary drawbacks of tray drying include the necessity of high drying temperatures, extended drying times, and increased energy consumption compared to more advanced drying methods (Zhao & Gao, 2016).

The optimization of various drying processes was examined by many researchers for several powder production processes such as sour cherry fruit powder, beetroot juice powder, tucupi powder etc. Recent studies have been conducted to optimize the drying parameters with respect to moisture content, water activity, solubility, hygroscopicity and bulk density. The spray drying conditions of sour cherry juice powder was optimized using RSM by Moghaddam et al. (2017), based on physiochemical properties. Similarly, Pires & Pena (2017) and Bhupinder et al. (2017) optimized the spray drying process of tucupi powder and beetroot powder. As of our knowledge, there is no in-depth study to optimize the hot-air oven drying process for banana powder production. Response surface methodology (RSM) not only plays a vital role in the design, development and formulation of new products but also helps in enhancing the existing product design. RSM utilizes various design for the optimization process, among that Box-Behnken design is the most popular, especially for 3-12 factors (Montgomery, 2017). These designs are specifically created as response surface designs and require only three levels, which are coded as -1, 0, and +1. This approach reduces the experimental repetition required to compare to a full three-level factorial design and simultaneously ensures desirable statistical properties. In case of three levels, quadratic model is appropriate which can be full-filled by the Box-Behnken design, which offers superior prediction accuracy, particularly at the centre of the factor space.

Therefore, the current study was conducted to evaluate the effect of a broad range of steaming time, citric acid concentration and drying time on the quality of banana powder using response surface methodology (RSM). The conditions laid to evaluate the quality of banana powder dried by hot-air oven includes yield, moisture content, water activity amylose content, starch content and L*. So, the aim of this work is to maximize the yield, amylose content, starch content and L* and to minimize the moisture content and water activity of the banana powder by studying the cumulative impact of hot-air oven drying parameters include steaming time, citric acid concentration and drying time.

MATERIALS AND METHODS

Data collection

The experiment was conducted at the Centre for Post Harvest Technology of the Tamil Nadu Agricultural University, Coimbatore, India and at ICAR – National Research Centre for Banana (NRCB), Trichy, India. All the experiments were replicated thrice and the mean value was reported.

Preparation of banana powder

Fresh and uniform size of green bananas of around 60 kgs were used for the experiments. Care should be taken to ensure that there was no smoking, cutting or any sign of physical injury. Before starting the production of banana powder, green bananas were washed in running water, cleaned properly and then used for the production process. The peel of the banana was removed manually using stainless knife and then it was sliced into circular form of 4 mm thickness using dicer. Then, the slices were immersed in water (1: 3 ratio) containing citric acid (0.01%) for 10 mins to arrest the enzymatic browning. The banana slices were then dehydrated at a temperature of 60°C using laboratory scale hot air forced electrical convection drier (NSW-143, Universal oven, Delhi) till the slices turned brittle. The dehydrated slices were ground in a commercial pulveriser for 120 sec and then sieved using 60 mesh sieves (ASTM: 60; 250 µm), collected, cooled and stored in a 250 g HDPE bags at room temperature for further analysis. The production process accomplished under steaming time (10, 20, 30 mins), citric acid concentration (0, 0.5, 1 %) and drying time (6, 7, 8 hrs) as presented in Table 1.

Experimental design and optimization

The optimal combination of hot-air oven drying conditions influencing the physicochemical properties of the dried powders were known using response surface methodology (RSM). A Box-Behnken design with three variables, steaming time (10, 20, 30 minutes), citric acid concentration (0, 0.5, 1 %) and drying time (6, 7, 8 hours) shown in Table 1 consisted of 17 runs. Yield, moisture content, water activity, amylose content, starch content and L* are the response variables. A second-order polynomial equation was used to relate the experimental data for each dependent variable.

Table 1 : Box-behnken design: Experimental response values for banana powder

Runs No.	ST (min)	CAC (%)	DT (hrs)	Yield (%)	MC (%)	WA (a_w)	AC (g/100g)	SC (g/100g)	L*
1	20	0.5	7	21.56	7.02	0.4565	19.07	82.93	35.4
2	20	0.5	7	21.56	7.02	0.4565	19.07	82.93	35.4
3	10	0.5	6	21.88	10.29	0.5524	23.22	85.32	47.5
4	20	0	6	24.22	12.32	0.703	18.31	84.19	50.2
5	30	0	7	20.01	7.36	0.4444	15.52	80.19	44.9
6	20	1	6	23.98	12.02	0.6966	18.62	83.64	44.4
7	30	0.5	6	22.68	11.29	0.6981	16.07	83.71	51.3
8	10	0	7	19.86	6.01	0.4166	23.54	87.99	51.6
9	10	0.5	8	17.72	4.40	0.2202	22.30	88.56	46.8
10	20	0.5	7	21.58	7.05	0.4406	19.05	85.18	35.5
11	30	0.5	8	19.04	6.86	0.2305	17.00	82.19	32.4
12	20	0.5	7	21.58	7.05	0.4406	19.05	85.14	35.5
13	20	1	8	18.72	6.82	0.2526	18.65	87.37	34.3
14	30	1	7	21.78	7.82	0.4732	17.45	83.18	39.0
15	20	0.5	7	21.54	7.00	0.4634	19.02	84.71	35.3
16	20	0	8	18.86	5.53	0.2598	18.08	85.08	37.4
17	10	1	7	20.00	6.32	0.4166	21.95	87.66	45.1

ST - steaming time; CAC - citric acid concentration; DT - drying time; MC - moisture content; WA - water activity, AC – amylose content; SC – starch content; L* - lightness.; min - minutes, % - percentage, hrs – hours

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_0 x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k=1} \sum_{i=2}^{k} \beta_{ij} x_i x_j \text{ ——— (1)}$$

where, Y – Predicted response; β_0 – constant; β_i- linear coefficient; β_{ii} - squared coefficient; and β_{ij} - cross-product coefficient (first-order interaction between x_i and x_j) respectively.

The main purpose of optimizing the hot-air oven drying process of banana powder was to regulate the optimal levels of steaming time, citric acid concentration and drying time that would achieve maximum yield, amylose content, starch content & L* and minimum moisture content & water activity in the banana powder. To achieve this goal, criteria were established by selecting lower and upper limits for each parameter to maximize overall desirability. The predicted values and the observed values were compared for each parameter using this approach and the model's desirability was determined. Different parameters such as steaming time, citric acid concentration, and drying time, corresponding to the maximum desirability, were recorded.

Powder tests

Yield

The yield of the banana powder was calculated using the following formula

Yield (%) =

$$\left(\frac{Weight\ of\ the\ dried\ banana\ powder}{Weight\ of\ the\ fresh\ banana}\right) X\ 100 \text{ ——(2)}$$

Chemical composition

The moisture content of the banana powder was measured by using gravimetric method. It involves drying the sample in hot-air oven at 80 ± 5°C. The results were expressed in percentage (%) (Kumar et al., 2019). Digital water activity meter (Aqua Lab, METER Group, Inc. USA) was used for measuring Water activity (a_w) of the banana powder and for estimating the unbound water vapor pressures, at an accuracy of ± 0.003. It was pre-calibrated with milli-Q-water at 25°C (Kamble et al., 2022). The amylose content was determined by suspending 100 mg sample with 1 mL absolute ethanol and 10 mL 1 N NaOH and incubation for overnight. It was measured colorimetrically (UV-3200 spectrophotometer, Lab India, New Delhi) at 590 nm. Anthrone method was used to determine the starch content as per the standard procedure with some minor alteration (AOAC, 1996). Resuspension of sugar extracted samples with distilled water and 52% perchloric acid was done. Colour intensity was measured using UV spectrophotometer at 630 nm. The starch content was calculated as glucose*0.9 (Kumar et al., 2019).

Colour values

The colour characterization of the banana powder was carried out using a tintometer (Lovibond LC 100 SV 100 Kit). The colour value is measured in terms of L* (lightness to darkness) in the range of 0 to 100.

Statistical Analysis

Design expert statistical software (Version 13.0.5.0, Stat-Ease Inc., Minneapolis, MN) to assess the effect of various process parameters on measured responses at 5% level of significance. The analysis of variance (ANOVA) was used to evaluate the model's statistical significance. Model analysis, lack-of-fit tests and R^2 (coefficient of determination) were applied to evaluate the effectiveness of the models. Using the β coefficient values, the contribution of independent variables to predicting the dependent variables was evaluated. A higher positive β value for a parameter indicates a stronger effect of that parameter, and vice versa. By using response surface plots like contour plots and 3D surface plots, the relations between any two independent variables were illustrated, keeping the values of the third and fourth variables constant.

RESULT AND DISCUSSION

The influence of steaming time (10, 20, 30 minutes), citric acid concentration (0, 0.5, 1 %) and drying time (6, 7, 8 hours) on the yield, moisture content, water activity, amylose content, starch content and L* of the banana powder were assessed using Box-Behnken design of response surface methodology, as shown in Table 1.

Diagnostic evaluation of fitted models and response surfaces

The second-order response surface model results, analysed using analysis of variance (Table 2). These results showed that the fitted quadratic models explained over 90% of the variation in the experimental data, demonstrating a high level of significance ($R^2 > 0.90$) and the linear model explained over 70% of the variation in the experimental data, demonstrating a high level of significance ($R^2 = 0.73$).

Yield (%)

The yield of banana powder is the ratio of the final powder weight to the initial raw banana weight, reflecting the efficiency of the drying and processing methods. A higher yield is desirable as it indicates minimal losses during processing and maximizes the use of raw material. The yield of hot-air oven-dried banana powder ranged between 17.72 % and 24.22%. The interaction effect between independent factors on the yield of hot-air oven-dried banana powder is depicted in a three-dimensional response surface plot for quality banana powder (Fig. 1). Increasing the drying time had a substantial ($p<0.05$) favourable influence on the linear drop in yield, making it easier to remove unattached water molecules. The experimental results on the yield were used to build a polynomial equation. This model explains how hot-air oven drying parameters has impacts on the yield of banana powder (Equation 3). ANOVA showed that the quadratic model accurately predicted yield (%), with a significant ($p<0.05$) F-value of 23.98 (Table 2). The yield model is well-fitted, with a coefficient of determination (R^2) value of 0.96 and reduced coefficients of variance (CV = 2.32%) and standard deviation (SD = 0.48) (Table 2, Equation 3). The main effects of steaming time and drying time (A and C) and the quadratic effects of steaming time (A^2) significantly ($p<0.05$) influenced the yield of banana powder (Table 2).

Moisture content (%)

Moisture content measures the total quantity of water in food, while water activity indicates the quantity of free water available for biochemical reactions, impacting storage life (A. Shrivastava et al., 2021). The moisture content of hot-air oven-dried banana powder ranged between 4.4% and 12.32%. The interaction effect between independent factors on the moisture content of hot-air oven-dried banana powder is depicted in a three-dimensional response surface plot for quality banana powder (Fig. 2). Increasing the drying time had a substantial ($p<0.05$) favourable influence on the linear drop in moisture content,

Table 2 : Variable effects & prediction model coefficients for yield, MC, WA, AC, SC and L* of the banana powder

Source	Yield (%)		MC (%)		WA (a_w)		AC (g/100 g)		SC (g/100 g)		L*	
	F value	p-value	F value	p-value	F value	p-value	F value	p-value	F value	p-value	F value	p-value
Model	23.98	0.0002	160.81	<0.0001	129.28	<0.0001	1514.11	<0.0001	11.90	0.0005	156.43	<0.0001
A: ST	8.67	0.0216	86.44	<0.0001	22.48	0.0021	12327.72	<0.0001	31.18	<0.0001	135.90	<0.0001
B: CAC	1.24	0.3027*	6.72	0.0358	0.0899	0.7731*	29.43	0.0010	1.47	0.2468*	112.60	<0.0001
C: DT	179.37	<0.0001	1080.55	<0.0001	1106.96	<0.0001	0.7138	0.4261*	3.05	0.1041*	448.30	<0.0001
AB	2.81	0.1376*	0.0977	0.7637*	0.6452	0.4482*	489.96	<0.0001	-	-	0.1787	0.6852*
AC	0.2859	0.6094*	9.26	0.0188	14.26	0.0069	135.34	<0.0001	-	-	164.42	<0.0001
BC	0.0106	0.9210*	10.98	0.0129	0.0005	0.9828*	2.67	0.1461*	-	-	3.62	0.0989*
A^2	22.87	0.0020	22.65	0.0021	14.49	0.0067	536.76	<0.0001	-	-	334.72	<0.0001
B^2	0.0059	0.9408*	12.05	0.0104	4.95	0.0614*	74.63	<0.0001	-	-	96.79	<0.0001
C^2	0.1807	0.6835*	221.01	<0.0001	0.6493	0.4469*	60.84	0.0001	-	-	63.34	<0.0001
Lack of fit	1969.14	0.0735*	284.52	0.0971*	5.65	0.0637*	33.79	0.0854*	1.34	0.4155*		0.0642*
R^2	0.96		0.99		0.99		0.99		0.73		0.99	
Adj. R^2	0.92		0.98		0.98		0.98		0.67		0.98	

*non significance at 5% level

making it easier to remove unattached water molecules. The experimental results on moisture content were used to build a polynomial equation. This model explains how hot-air oven drying parameters has impacts on moisture content of banana powder (Equation 4). ANOVA showed that the quadratic model accurately predicted moisture content (%), with a significant ($p<0.05$) F-value of 160.81 (Table 2). The moisture content model is well-fitted, with a coefficient of determination (R^2) value of 0.99 and reduced coefficients of variance (CV = 3.09%) and standard deviation (SD = 0.24) (Table 2, Equation 4). The main effects of steaming time, citric acid concentration & drying time (A, B and C) and the interaction effects of steaming time & drying time (AC) and citric acid concentration & drying time (BC) and the quadratic effects of steaming time (A^2), citric acid concentration (B^2) and drying time (C^2) significantly ($p<0.05$) influenced the moisture content of banana powder (Table 2).

Water activity (a_w)

Water activity (a_w) is an indispensable factor in preventing non-microbial reactions and inhibiting microbial growth. Reducing the water activity of food through drying is a usual method for preserving food and creating various types of shelf-stable products (Kamble et al., 2022). The water activity of hot-air oven-dried banana powder ranged between 0.2202 and 0.7030 a_w. The interaction effect between independent factors on the water activity of hot-air oven-dried banana powder is depicted in a three-dimensional response surface plot for quality banana powder (Fig. 3). Increasing drying time had a substantial favourable effect ($p<0.05$) on the linear decline in water activity, making it easier to remove unbound water (free water molecules). Based on the experimental results on water activity, a model is developed through polynomial equation. This model explains how hot-air oven drying parameters influence the water activity of banana powder (Equation 5). ANOVA indicated that the quadratic model provided a better prediction of water activity, with F-value of 129.28 ($p<0.05$) which is significant (Table 2). The water activity mode was found to be suitable, as shown by a coefficient of determination (R^2) of 0.99 and reduced coefficients of variance (CV =4.00%) and standard deviation (SD = 0.01) (Table 2, Equation 5). The main effects of steaming time and drying time (A and C) and their

$$\text{Yield (\%)} = 21.56 + 0.5063*A + 0.1913*B - 2.30*C + 0.4075*AB + 0.1300*AC + 0.0250*BC - 1.13*A^2 - 0.0182*B^2 - 0.1008*C^2;\ (R^2 = 0.96). \quad (3)$$

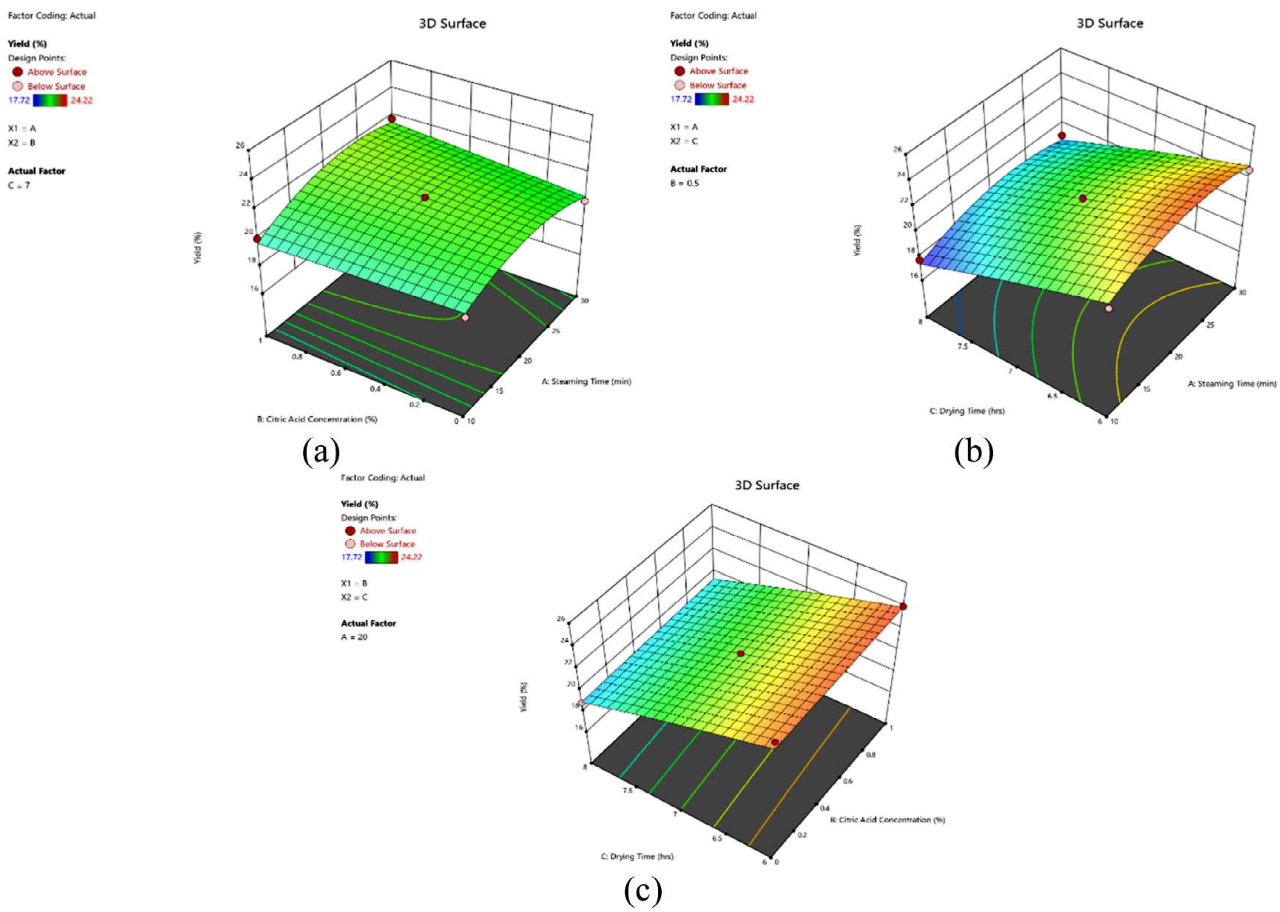

Fig. 1 : Response surface plot showing the effect of a) steaming time and citric acid concentration b) steaming time and drying time and c) citric acid concentration and drying time on the yield of banana powder

interaction (AC), together with the quadratic effect of steaming time (A^2), significantly ($p<0.05$) influenced the water activity of banana powder (Table 2).

Amylose content (g/100g)

The amylose content in banana powder plays a significant role in determining its functional properties, such as gelatinization and retrogradation behaviour. Higher amylose levels contribute to increased resistance to digestion, making banana powder a potential source of resistant starch. The amylose content of hot-air oven-dried banana powder ranged between 15.52 and 23.54 g/100g. The interaction effect between independent factors on the amylose content of hot-air oven-dried banana powder is depicted in a three-dimensional response surface plot for quality banana powder (Fig. 4). A significant ($p<0.05$) positive effect on the linear increase in amylose content with decreased steaming time was observed. Based on the experimental results on amylose content, a model is built through a polynomial equation. This model explains how hot-air oven drying parameters influence the amylose content of banana powder (Equation 6). ANOVA indicated that the quadratic model provided a better prediction of amylose content (g/100g), with a significant ($p<0.05$) F-value of 1514.11 (Table 3). The amylose content model was found to be suitable, with a coefficient of determination (R^2) value of 0.99 and lower coefficients of variance (CV = 0.41%) and standard deviation (SD = 0.07) (Table 3, Equation 6). The main effect of steaming time (A) and citric acid concentration (B), the interaction effect of steaming time & citric acid concentration (AB) and steaming time & drying time (AC), and the quadratic effects of steaming time (A^2), citric acid concentration (B^2) and drying time (C^2) significantly ($p<0.05$) influenced the amylose content of banana powder (Table 3).

$$\text{Moisture Content (\%)} = 7.03 + 0.7888{*}A + 0.2200{*}B - 2.79{*}C + 0.0375{*}AB + 0.3650{*}AC + 0.3975{*}BC - 0.5565{*}A^2 + 0.4060{*}B^2 + 1.74{*}C^2;\ (R^2 = 0.99). \quad \text{———}(4)$$

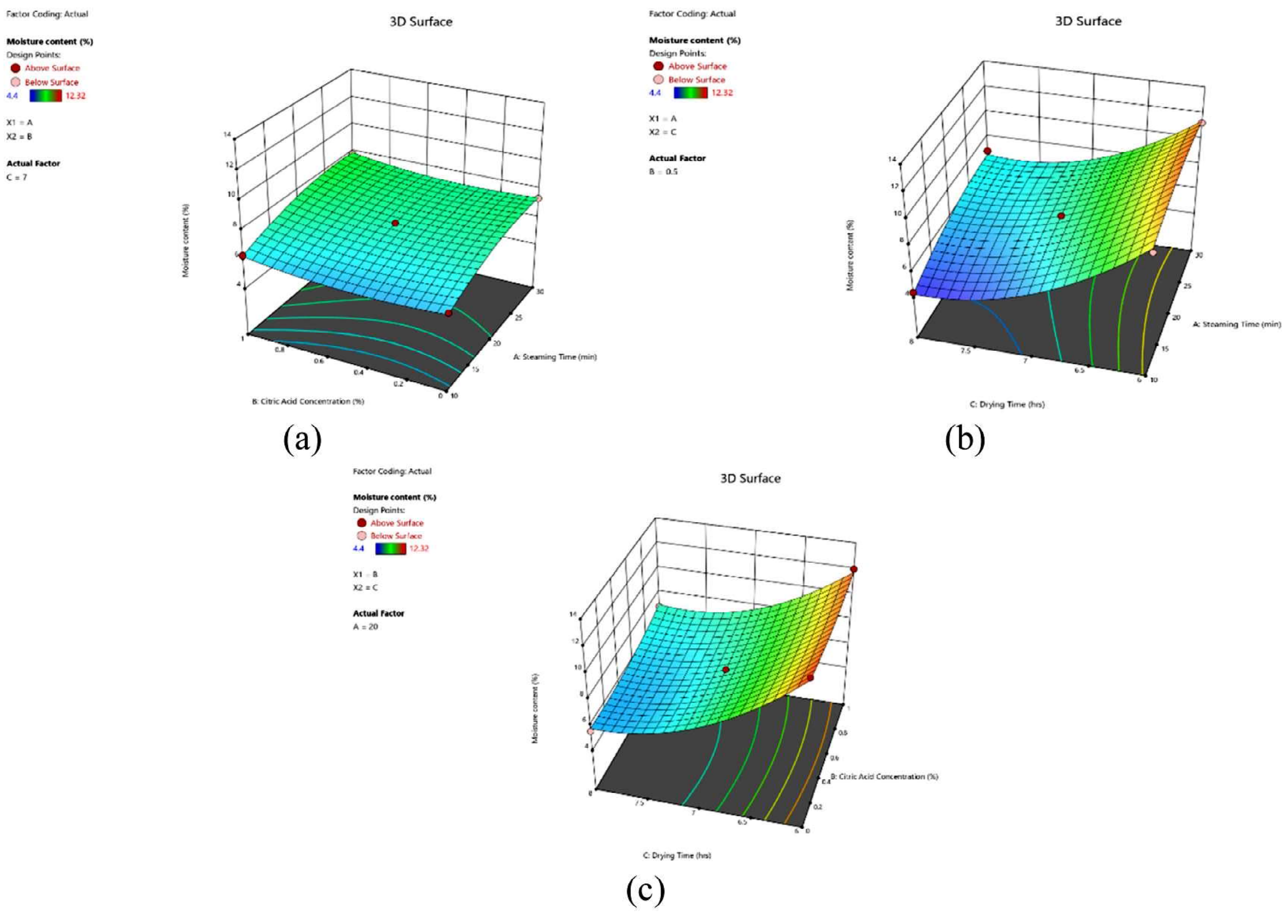

Fig. 2 : Response surface plot showing the effect of a) steaming time and citric acid concentration b) steaming time and drying time and c) citric acid concentration and drying time on the moisture content of banana powder

Strach content (g/100 g)

Starch is a polysaccharide carbohydrate composed of numerous glucose units linked by glycosidic bonds. It is widely present in various foods, including bananas. The starch content of hot-air oven dried banana powder ranged between 80.19 and 88.56 g/100g. The interaction effect between independent factors on the starch content of hot-air oven-dried banana powder is depicted in a three-dimensional response surface plot for quality banana powder (Fig. 5). A significant ($p<0.05$) positive effect on the linear increase in starch content with decreased steaming time was observed. Based on the experimental results on starch content, a model is built through a polynomial equation. This model explains how hot-air oven drying parameters influence the starch content of banana powder (Equation 7). ANOVA indicated that the quadratic model provided a better prediction of starch content (g/100g), with a significant ($p<0.05$) F-value of 11.90 (Table 3). The starch content model was found to be suitable, with a coefficient of determination (R^2) value of 0.73 and lower coefficients of variance (CV = 1.51%) and standard deviation (SD = 1.28) (Table 3, Equation 7). The main effect of steaming time (A) significantly ($p<0.05$) influenced the starch content of banana powder (Table 3).

$$\text{Starch content (g/100)} = 84.70 - 2.53{*}A + 0.5500{*}B + 0.7925{*}C;\ (R^2 = 0.73). \quad \text{——}(7)$$

L* value

The L* value of banana powder represents its lightness, with higher L* values indicating a lighter or whiter appearance. This parameter is important in evaluating the visual quality of the powder, as it can

$$\text{Water activity } (a_w) = 0.4515 + 0.0301{*}A + 0.0019{*}B - 0.2109{*}C + 0.0072{*}AB - 0.0339{*}AC - 0.0002{*}BC - 0.0333{*}A^2 + 0.0194{*}B^2 + 0.0070{*}C^2;\ (R^2 = 0.99). \qquad (5)$$

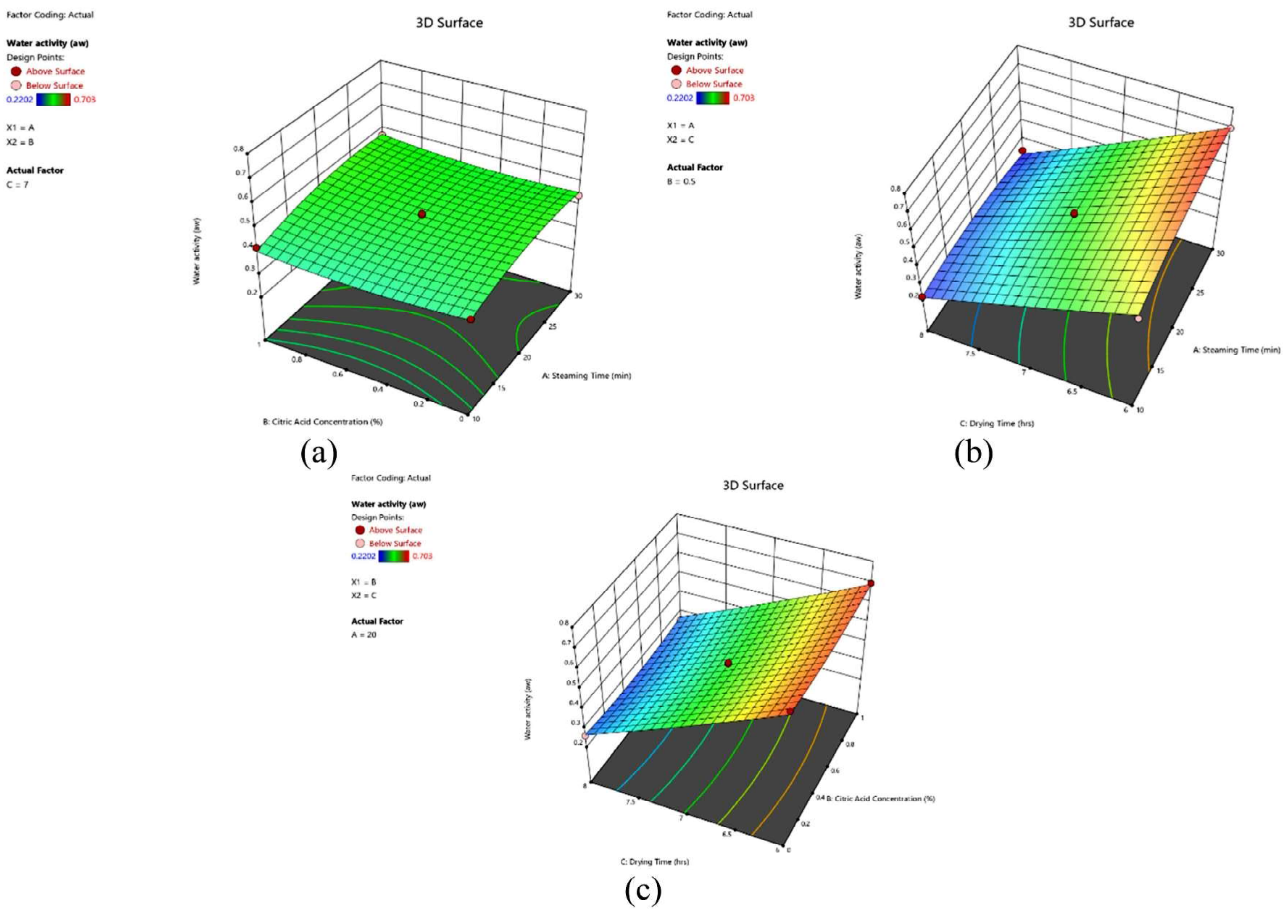

Fig. 3 : Response surface plot showing the effect of a) steaming time and citric acid concentration b) steaming time and drying time and c) citric acid concentration and drying time on the water activity of banana powder

influence consumer acceptance and perceived product freshness. The L* value of hot-air oven-dried banana powder ranged between 32.4 and 51.6. The interaction effect between independent factors on the L* value of hot-air oven-dried banana powder is depicted in a three-dimensional response surface plot for quality banana powder (Fig. 6). A significant ($p<0.05$) positive effect on the linear increase in L* value with decreased drying time was observed. Based on the experimental results on L* value, a model is built through a polynomial equation. This model explains how hot-air oven drying parameters influence the L* of banana powder (Equation 8). ANOVA indicated that the quadratic model provided a better prediction of L*, with a significant ($p<0.05$) F-value of 156.43 (Table 3). The L* value model was found to be suitable, with a coefficient of determination (R^2) value of 0.99 and lower coefficients of variance (CV = 1.72%) and standard deviation (SD = 0.70) (Table 3, Equation 8). The main effect of steaming time (A), citric acid concentration (B) and drying time (C) and the interaction effect of steaming time & drying time (AC), and the quadratic effects (A^2, B^2 and C^2) significantly ($p<0.05$) influenced the L* value of banana powder (Table 3).

Selection of optimum conditions

A numerical optimization method was applied to optimize the hot-air oven drying process of banana powder, assigning equal importance of “3” to all process parameters, including steaming time, citric acid concentration and drying time. The important criteria for constraint optimisation are to minimise moisture content and water activity while maximizing

$$\text{Amylose content (g/100g)} = 19.05 - 3.12*A + 0.1525*B - 0.0238*C - 0.8800*AB - 0.4625*AC + 0.0650*BC + 0.8978*A^2 - 0.3347*B^2 - 0.3022*C^2; (R^2 = 0.99). \text{———————}(6)$$

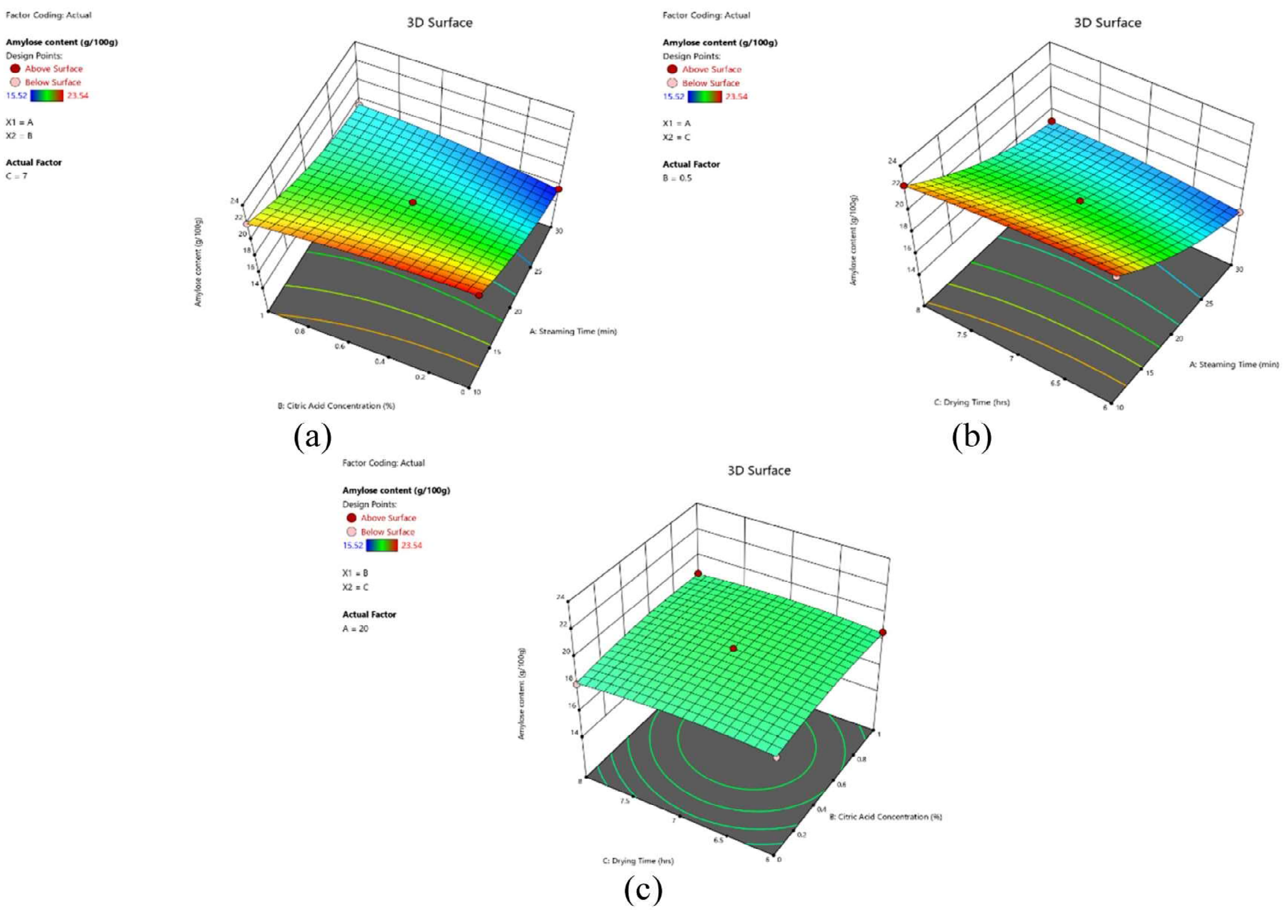

Fig. 4 : Response surface plot showing the effect of a) steaming time and citric acid concentration b) steaming time and drying time and c) citric acid concentration and drying time on the amylose content of banana powder

yield, amylose content, starch content and L*. Criteria and outputs of the numerical optimization of the responses for banana powder was given in Table 3. All of these aspects play a vital role in the overall acceptability of the finished product. Therefore, based on their relative contribution to quality, the importance assigned to the six responses such as yield, moisture content, water activity, amylose content, starch content and L* was "3" for each. The optimal parameters for preparing banana powder were determined to be a steaming time of 10 minutes, a citric acid concentration of 0.5 %, and a drying time of 7 hours.

Verification of optimized conditions

The suitability of the model equations for predicting optimal response values was evaluated under the conditions of a steaming time of 10 minutes, a citric acid concentration of 0.5 %, and a drying time of 7 hours considered optimal by the RSM optimization approach. To validate these optimised conditions, experiments were carried out to compare the experimental results with the expected values. The experiments were carried out three times. Under these optimal conditions, the predicted values for yield, moisture content, water activity, amylose content, starch content and L* were 19.99 % yield, 5.73% moisture content, 0.40 a_w water activity, 23.43 g/100g amylose, 86.72 g/100 g starch content and 50.82 L* compared to the experimental values of 20.02 %, 4.99 %, 0.38 a_w, 23.42 g/100g, 85.98 g/100g and 49.86, respectively. The optimized data and results were shown in Table 4. For achieving the optimal conditions for the production of banana powder, yield, amylose content, starch content and L* must reach maximum level while

$$L^* = 35.42 - 2.93*A - 2.66*B - 5.31*C + 0.1500*AB - 4.55*AC + 0.6750*BC + 6.33*A^2 + 3.40*B^2 + 2.75*C^2;\ (R^2 = 0.99). \quad (8)$$

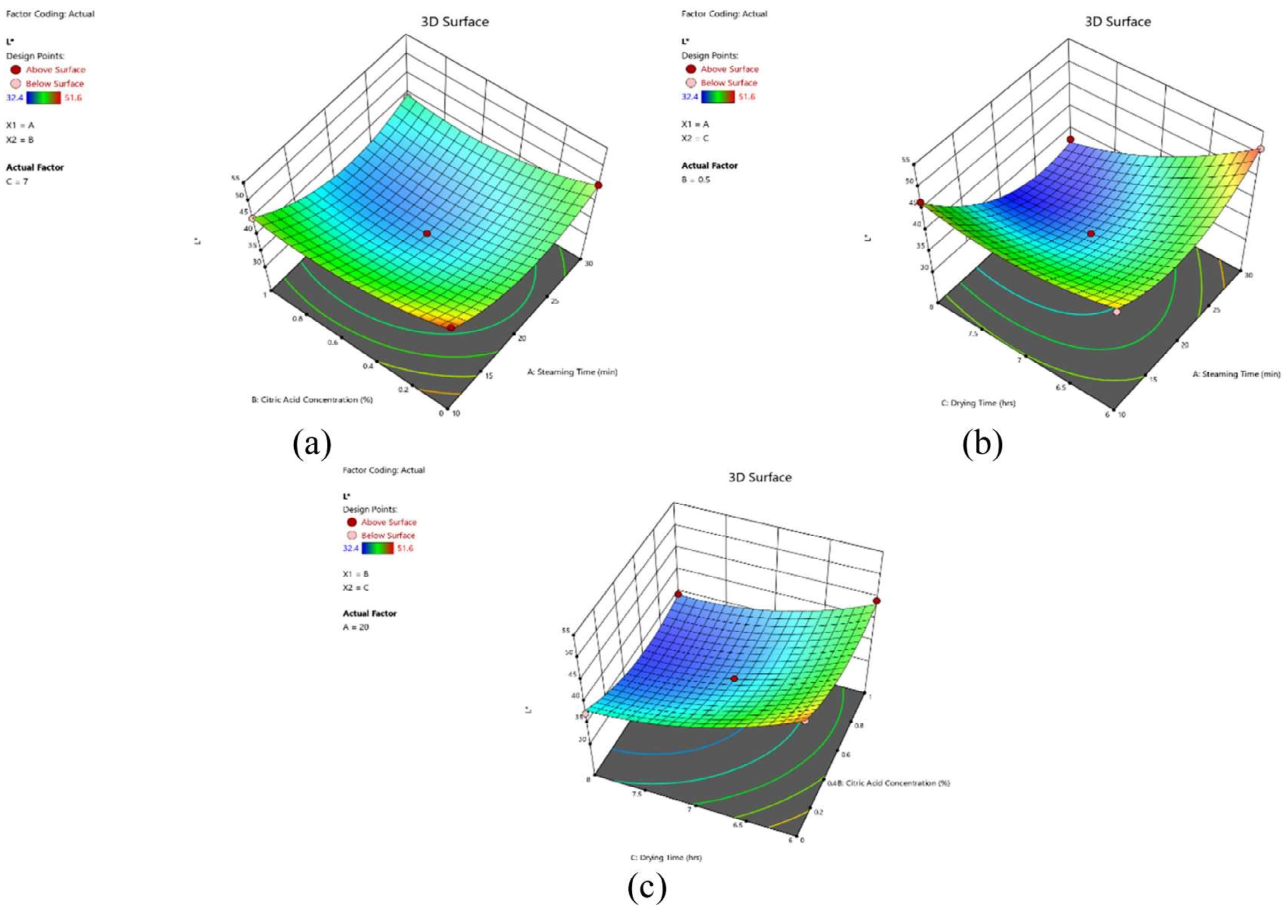

Fig. 5 : Response surface plot showing the effect of a) steaming time and citric acid concentration b) steaming time and drying time and c) citric acid concentration and drying time on the L* of banana powder

Table 3 : Criteria and outputs of the numerical optimization of the responses for banana powder

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: Steaming time	is in range	10	30	1	1	3
B: Citric acid concentration	is in range	0	1	1	1	3
C: Drying time	is in range	6	8	1	1	3
Yield	Maximize	17.72	24.22	1	1	3
Moisture content	Minimize	4.4	12.32	1	1	3
Water activity	Minimize	0.22	0.70	1	1	3
Amylose content	Maximize	15.52	23.54	1	1	3
Starch content	Maximize	80.19	88.56	1	1	3
L*	Maximize	32.4	51.6	1	1	3

Table 4 : Optimized combination and results

Result	Process variables			Responses					
	ST (min)	CAC (%)	DT (hrs)	Yield (%)	MC (%)	WA (aw)	AC (g/100 g)	SC (g/100 g)	L*
Pre. results	10	0.5	7	19.99	5.73	0.40	23.43	86.72	50.82
Exp. results	10	0.5	7	20.02	4.99	0.38	23.42	85.98	49.86

moisture content and water activity must reach minimum level. The obtained findings of yield agreed with those of Bazaria et al. (2018). It reported the highest yield of 44.35% spray dried beetroot juice powder at an optimized drying condition 160 °C inlet air temperature and 400 ml/h feed flow rate and a maltodextrin concentration of 15%, which is higher than the present study reporting yield at an optimized condition. Gloria I. Giraldo-Gómez et al. (2019) reported that the moisture content and water activity of the extrude banana powder was in the range between 3.75 to 6.34% and 0.33 to 0.48 a_w. The observed result of moisture content was nearer to the range and water activity was within the range. The observed results of amylose content and starch content confirmed the results of Kumar et al. (2019). The obtained result of L* confirmed the result of Omolola et al., (2018). Pawan et al. (2015) reported that effect of blanching on the dehydration characteristics of unripe banana slices blanched and dried at different temperatures to produces good quality banana flour. Those Experimental procedures were similar to the results of our obtained optimal condition. The mean values obtained from these experiments were within 95% of the predicted values, demonstrating that the optimal conditions are valid within the specified range of process variables.

CONCLUSION

The hot-air oven drying process for banana powder was carefully optimized using the Box-Behnken design of Response Surface Methodology. Key factors involved steaming time (10-30 minutes), citric acid concentration (0-1%), and drying time (6-8 hours) were found to significantly affect the yield, moisture content, water activity, amylose content, starch content and L* of the banana powder. The optimal conditions of the process were a steaming time of 10 minutes, a citric acid concentration of 0.5 %, and a drying time of 7 hours which were assessed by the application of desirability functions and numerical optimization. Under these optimal conditions, the resulting banana powder achieved a yield of 19.99 %, moisture content of 5.73%, a water activity of 0.40 a_w, amylose content of 23.43 g/100g, starch content of 86.72 g/100g and L* of 50.82. At 20 to 30 min steaming time, the starch content in the banana powder starts to reduce, so the decreased starch content of banana powder will not be efficient. At 6 hrs of drying time, the moisture content of the banana powder will be more and it will lead to increase of microbial activity and at 8 hrs drying inversely affect the quality of the banana powder. In order to increase the shelf-life of the banana powder, a preservative must be added, so the steaming time of 10 min, 0.5% citric acid concentration and 7 hrs drying time would be the optimal condition for the production of high-quality banana powder. Future research should investigate additional process variables, such as drying temperature and steaming temperature, as well as variations in citric acid concentrations. These studies could offer a more comprehensive understanding of factors affecting banana powder quality and lead to further improvements and innovations in the drying process. Exploring these additional parameters could help further optimize banana powder production, enhancing both quality and efficiency.

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REFERENCES

Akonor, P. T., Atter, A., Owusu, M., Ampah, J., Andoh Odoom, A., Overå, R., ... & Kolding, J. (2021). Anchovy powder enrichment in brown rice based instant cereal: a process optimization study using response surface methodology (RSM). *Food Science & Nutrition*, *9*(8), 4484-4496. https://doi.org/10.1002/fsn3.2424

Alam, M. S., Pathania, S., & Sharma, A. (2016). Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings. Lwt, *74*, 135-144. https://doi.org/10.1016/j.lwt.2016.07.031

Alzate Acevedo, S., Díaz Carrillo, Á. J., Flórez-López, E., & Grande-Tovar, C. D. (2021). Recovery of banana waste-loss from production and processing: a contribution to a circular economy. *Molecules*, *26*(17), 5282. https://doi.org/10.3390/molecules26175282

Bazaria, B., & Kumar, P. (2018). Optimization of spray drying parameters for beetroot juice powder using response surface methodology (RSM). *Journal of the Saudi Society of Agricultural Sciences*, *17*(4), 408-415. https://doi.org/10.1016/j.jssas.2016.09.007

Bezerra, M. A., Santelli, R. E., Oliveira, E. P., Villar, L. S., & Escaleira, L. A. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. *Talanta*, *76*(5), 965-977. https://doi.org/10.1016/j.talanta.2008.05.019

Bhaskar, J. J., S, M., Chilkunda, N. D., & Salimath, P. V. (2012). Banana (Musa sp. var. elakki bale) flower and pseudostem: dietary fiber and associated antioxidant capacity. *Journal of Agricultural and Food Chemistry*, *60*(1), 427-432. https://doi.org/10.1021/jf204539v

Borges, L. L., Martins, F. S., Conceição, E. C., & Silveira, D. (2017). Optimization of the spray drying process for developing jabuticaba waste powder employing response surface methodology. *Journal of Food Process Engineering*, *40*(1), e12276. https://doi.org/10.1111/jfpe.12276

Famuwagun, A. A., Taiwo, K., Gbadamosi, S. O., & Oyedele, D. (2016). Optimization of production of bread enriched with leafy vegetable powder. http://dx.doi.org/10.4172/2157-7110.1000605

Giraldo-Gómez, G. I., Rodríguez-Barona, S., & Sanabria-González, N. R. (2019). Preparation of instant green banana flour powders by an extrusion process. *Powder Technology*, *353*, 437-443. https://doi.org/10.1016/j.powtec.2019.05.050

Immanuel, G. (2015). Effects of blanching on the dehydration characteristics of unripe banana slices dried at different temperature. *Agricultural Engineering International: CIGR Journal*, *17*(2), 168-175. https://cigrjournal.org/index.php/Ejounral/article/view/2994

Kamble, M., Singh, A., Singh, S. V., Chinchkar, A., & Pareek, S. (2022). Optimization of convective tray drying process parameters for green banana slices using response surface methodology and its characterization. *Journal of Food Quality*, *1*, 8208572. https://doi.org/10.1155/2022/8208572

Kashyap, P., Riar, C. S., & Jindal, N. (2021). Optimization of ultrasound assisted extraction of polyphenols from Meghalayan cherry fruit (*Prunus nepalensis*) using response surface methodology (RSM) and artificial neural network (ANN) approach. *Journal of Food Measurement and Characterization*, *15*, 119-133. https://doi.org/10.1007/s11694-020-00611-0

Kumar, P. S., Nambi, E., Shiva, K. N., Vaganan, M. M., Ravi, I., Jeyabaskaran, K. J., & Uma, S. (2019). Thin layer drying kinetics of banana var. Monthan (ABB): Influence of convective drying on nutritional quality, microstructure, thermal properties, color, and sensory characteristics. *Journal of Food Process Engineering*, *42*(4), e13020. https://doi.org/10.1111/jfpe.13020

Kumar, P. S., Saravanan, A., Sheeba, N., & Uma, S. (2019). Structural, functional characterization and physicochemical properties of green banana flour from dessert and plantain bananas (*Musa* spp.). *Lwt*, *116*, 108524. https://doi.org/10.1016/j.lwt.2019.108524

Mahfoudhi, A., Baaka, N., Haddar, W., Mhenni, M. F., & Mighri, Z. (2015). Development and optimization of the extraction process of natural dye from *Tamarix aphylla* (L.) Karst. Leaves using response surface methodology (RSM). *Fibers and Polymers*, *16*, 1487-1496. https://doi.org/10.1007/s12221-015-4772-5

Mebratie, M. A., Haji, J., Woldetsadik, K., Ayalew, A., & Ambo, E. (2015). Determinants of postharvest banana loss in the marketing chain of central Ethiopia. *Food Sci. Qual. Manag*, *37*, 52-63. https://iiste.org/Journals/index.php/FSQM/article/view/20609

Moghaddam, A. D., Pero, M., & Askari, G. R. (2017). Optimizing spray drying conditions of sour cherry juice based on physicochemical properties, using response surface methodology (RSM). *Journal of Food Science and Technology*, *54*, 174-184. https://doi.org/10.1007/s13197-016-2449-8

Montgomery, D. C. (2017). *Design and analysis of experiments*. John wiley & sons.

Morshedi, A., & Akbarian, M. (2014). Application of response surface methodology: design of experiments and optimization: a mini review. *Indian Journal of Fundamental and Applied Life Sciences*, *4*(4), 2434-2439. https://www.cibtech.org/sp.ed/jls/2014/04/jls.htm

Olusegun-Omolola, A., Obiefuna-Jideani, A. I., Francis-Kapila, P., & Adaora-Jideani, V. (2018). Optimization of oven drying conditions of banana (*Musa* spp., AAA Group, cv 'Luvhele' and 'Mabonde') using response surface methodology. *Agrociencia*, *52*(4), 539-551. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-31952018000400539

Pires, F. C. S., & da Silva Pena, R. (2017). Optimization of spray drying process parameters for tucupi powder using the response surface methodology. *Journal of Food Science and Technology*, *54*, 3459-3472. https://doi.org/10.1007/s13197-017-2803-5

Powthong, P., Jantrapanukorn, B., Suntornthiticharoen, P., & Laohaphatanalert, K. (2020). Study of prebiotic properties of selected banana species in Thailand. *Journal of Food Science and Technology*, *57*, 2490-2500. https://doi.org/10.1007/s13197-020-04284-x

Rajapaksha, L., Gunathilake, D. M. C. C., Pathirana, S. M., & Fernando, T. (2021). Reducing post-harvest losses in fruits and vegetables for ensuring food security—Case of Sri Lanka. *MOJ Food Process Technologies*, *9*(1), 7-16. https://doi.org/10.15406/mojfpt.2021.09.00255

Shana, U. S., Devi, M. N., Ramesh, D., Kannan, B., & Djanaguiraman, M. (2023). Biochemical process optimization via statistical methods: a mini review. *Int J Stat Appl Math*, *8*, 30-38. https://doi.org/10.22271/maths.2023.v8.i5Sa.1164

Shende, A. S., Joshi, J., & Rao, P. S. (2024). Process optimization of microwave-assisted aqueous extraction of tannins and saponins from Malabar Spinach (*Basella alba*) leaves using ANN-GA and RSM methodology. *Measurement: Food*, *13*, 100117. https://doi.org/10.1016/j.meafoo.2023.100117

Shrivastava, A., Tripathi, A. D., Paul, V., & Rai, D. C. (2021). Optimization of spray drying parameters for custard apple (*Annona squamosa* L.) pulp powder development using response surface methodology (RSM) with improved physicochemical attributes and phytonutrients. *Lwt*, *151*, 112091. https://doi.org/10.1016/j.lwt.2021.112091

Singh, B., & Hathan, B. S. (2017). Process optimization of spray drying of beetroot Juice. *Journal of Food Science and Technology*, *54*(8), 2241-2250. https://doi.org/10.1007/s13197-017-2659-8

Surendra, T. V., Roopan, S. M., Arasu, M. V., Al-Dhabi, N. A., & Rayalu, G. M. (2016). RSM optimized *Moringa oleifera* peel extract for green synthesis of *M. oleifera* capped palladium nanoparticles with antibacterial and hemolytic property. *Journal of Photochemistry and Photobiology B: Biology*, *162*, 550-557. https://doi.org/10.1016/j.jphotobiol.2016.07.032

Taiwo, K. A., & Adeyemi, O. (2009). Influence of blanching on the drying and rehydration of banana slices. *African Journal of Food Science*, *3*(10), 307-315. https://doi.org/10.5897/AJFS.9000166

Tavares, R. M. D. O., Assis, C. F. D., Lima, P. D. O., Lima, P. D. S. D., Lima, R. R. C., & Damasceno, K. S. F. D. S. C. (2022).

Blanching effect on the quality and shelf-life characteristics of fresh cowpea grains [*Vigna unguiculata* (L.) Walp.]. *Foods*, *11*(9), 1295. https://doi.org/10.3390/foods11091295

Varsha, G. D., Chirag, D., Jilen, M., & Sahu, A. K. Standardization of blanching and sulphitation technique on physico-chemical parameters for dehydration of banana pseudo stem central core for powder making using cabinet dryer. https://doi.org/10.33545/26174693.2023.v7.i2Sg.255

Vivek, K., Mishra, S., & Pradhan, R. C. (2021). Optimization of spray drying conditions for developing nondairy based probiotic sohiong fruit powder. *International Journal of Fruit Science*, *21*(1), 193-204. https://doi.org/10.1080/15538362.2020.1864567

Zhao, R., & Gao, T. (2016). Research article research progress of hot air drying technology for fruits and vegetables. *Advance Journal of Food Science and Technology*, *10*(3), 160-166. http://dx.doi.org/10.19026/ajfst.10.2045

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