Journal of Multidisciplinary Academic and Practice Studies (JoMAPS)
ISSN: 2656-2359, Vol 1, No 3, 2023, 179-196 https://doi.org/10.35912/jomaps.v1i3.1789

Investigation of functional and sensory properties of plantain flour in citric acid

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Article History
Received on 24 July 2023
1st Revision on 2 August 2023
2nd Revision on 4 August 2023
Accepted on 16 August 2023

Abstract

Purpose: This study investigated the effects of process variables on the proximate, functional, and sensory properties of plantain flour.

Research Methodology: The plantain fruit was sorted and hand-peeled using kitchen knives. It was then cut into various slices of 2 – 6 mm and steeped in citric acid solutions with concentrations ranging between 1 – 5 %. The steeping time varied between 30 – 120 min. The pretreated plantain slices were processed into flours. Process parameters were analyzed using the response surface methodology of Design Expert software.

Results: The proximate composition showed no significant differences ($p > 0.05$), but functional and sensory properties varied significantly ($p < 0.05$). Flour samples exhibited desirable bulk density, high water absorption capacity, and favorable swelling power, indicating potential for bakery and complementary foods. Sensory analysis revealed that citric acid pretreatment improved moldability, texture, and overall acceptability, with the best results at citric acid concentration of 2.79%, slice thickness of 5.63 mm, and steeping time of 50.41 minutes.

Conclusions: Citric acid treatment significantly enhanced functional and sensory properties of plantain flour, making it suitable for diverse food applications

Limitations: This study did not consider the application of other optimization methods, such as genetic algorithms and particle swarm optimization, to estimate the optimum points. Future studies could focus on these areas

Contribution: The validation of the optimization processes showed success in the application of citric acid in the production of novel plantain flour.

Keywords: *Functional Properties, Optimization, Process Variables, Proximate Analysis, Sensory Properties*

How to Cite: Ishiwu, C. N., Nnanwube , I. A., Nkem, J. O., & Ezegbe, C. C. (2023). Investigation of functional and sensory properties of plantain flour in citric acid. *Journal of Multidisciplinary Academic and Practice Studies*, 1(3), 179-196.

1. Introduction

Plantains (*Musa spp.*) are plants that produce starchy fruits at maturity Udomkun et al. (2021) that must be processed before consumption. They are one of the most important food crops consumed after rice and maize, and are grown in more than 120 countries worldwide, mainly for their fruits, leaves, and fibers (Abbade, 2021). It is estimated that 61% and 21% of plantain production worldwide comes from West and Central Africa, respectively, and approximately 70 million people in these regions derive more than 25% of their carbohydrates from plantains, making them one of the most important sources of carbohydrates throughout Africa.

It has been reported that Nigeria falls into the category of being one of the largest plantain-producing countries in the world. Plantain is low in protein and fat content but contains a high amount of starch and minerals (Arinola, Ogunbusola, & Adebayo, 2016). During storage, significant differences in color and among most functional characteristics were observed as a consequence of both storage duration and packaging materials (Tripetch & Borompichaichartkul, 2019). Findings have shown that in sub-Saharan Africa, bananas and plantains provide more than 25% of the energy needs of 70 million people. It has been reported that mature green plantain pulp is rich in sugar (2–31 %), micronutrients, such as potassium (440 mg/100 g), phosphorus (32 mg/100 g), and magnesium (32 mg/100 g), vitamin C (20 mg/100 g), and vitamin B (Daniells, Englberger, & Lorens, 2011; Sauco, 2010). Unripe plantain flour has been shown to contain resistant starch which makes the flour to be classified as rich fiber food (Olawuni, Uruakpa, & Uzoma, 2018) Muffin produced from composite flour of unripe plantain and breadfruit had s 10 % fiber content higher than the whole wheat muffin and increased in starch gelatinization temperature which could have structural benefits to baked muffins (Kemski, Cottonaro, Vittadini, & Vodovotz, 2022).

2. Literature review

According to research findings, plantains are a good source of vitamins A, B1, B2, B3, B6, and C, and minerals such as calcium, potassium, phosphorus, and iron. They are a major staple that contributes to the food security of millions of people. Their use may vary according to socio-cultural behaviors, population eating habits, and market demand (Enriquez & Archila-Godinez, 2022). There are various types of plantains cultivated in West Africa, including true horn, false horn, and French horn plantains (Ayim, Amankwah, & Dzisi, 2012). Danso, Adomako, Dampare, and Oduro (2006) argued that these varieties have different physicochemical and morphological properties. When harvested at the unripe green stage of maturity, plantain contains starch almost equivalent to the starch content of the endosperm of corn and pulp of white potato (Anyasi, Jideani, & McHau, 2017). All stages of plantain growth, from immature to overripe, are important sources of food (Amah, Stuart, Mignouna, Swennen, & Teeken, 2021).

Industrially, plantain fruits are converted to flour and then used as a composite in the making of baby food ('*Babena*' and '*Soyamusa*'), bread, biscuits, and other food products (Adeniji, 2015). Although large amounts of plantains are harvested yearly in Nigeria, 50-60% of them are subject to postharvest losses, which has necessitated the development of adequate technologies for their processing and preservation (Morris, Kamarulzaman, & Morris, 2019). One method to achieve this is by processing plantains into flour. After harvest at the mature stage and upon peeling, plantains undergo rapid respiration, microbial, physical, and biochemical changes, leading to their deterioration (Adi, Oduro, & Tortoe, 2019). One such reaction is enzymatic browning, which has undesirable effects on the color and flavor of processed fruits. To avert these changes, organic acids, such as citric acid, can be employed to reduce enzymatic activities (Singh et al., 2018). Although Emojorho and Akubor (2016) studied the effects of soaking and boiling on the chemical composition and functional properties of flour, additional information is required on the use of chemical, physical, and combined methods for the pretreatment of flour.

To the best of our knowledge, no information is available on how soaking time and slice size as processing variables can affect the quality of plantain flour (Adi et al., 2019). This knowledge is important when investigating the development of flour with desired properties. In spite of the fact that previous research has been made on the various methods of processing and production of plantain flour, there exists no tangible information on the effects of citric acid pretreatment as well as slice size and steeping time on the proximate compositions, functional, and sensory properties of plantain flour (Adegunwa, Adebowale, Bakare, & Ovie, 2014). This constitutes a gap in the research that this study is designed to fill. High-quality plantain flour will add value to its use in food systems (Honfo, Togbe, Dekker, & Akissoe, 2022). Therefore, this study aimed to investigate the effects of various process variables (citric acid pretreatment, slice size, and steeping time) on the functional and sensory properties of plantain flour (Udomkun et al., 2021).

3. Research methodology

3.1 Materials

The plantain cultivar (French plantain) was purchased from the Amansea market in Awka, Anambra State. The citric acid (analytical grade) was purchased from Head Bridge Market, Onitsha, Anambra State.

3.2 Methods

3.2.1 Production of plantain flour

Plantain flour was produced using the procedure described by Ijeoma, Osobie, Uzoukwu, Esther, and Emilia (2014) with some modifications. The plantain fruits were sorted to remove damaged ones, washed in clean potable water, and hand-peeled using stainless kitchen knives. It was then cut into slices of 2–6 mm and immediately steeped in citric acid solutions with concentrations of 1-5 %. The steeping time varied between 30 -120 minutes. The plantain slices were then drained and dried in an oven to achieve a constant moisture content (10 %). Afterward, it was milled using an attrition mill to a fine flour and tightly sealed in polyethylene bags to prevent moisture uptake and further damage before analysis.

3.2.2. Experimental design

A three-variable and three-level-variable face-centered central composite design (FCCCD) was performed in this study using Design Expert version 12 to optimize the process parameters for the production of plantain flour. The three independent variables were citric acid concentration (A or X_1), plantain slice thickness (B or X_2), and soaking time (C or X_3). This generated 15 treatments (Table 1). The levels chosen for the independent variables were based on a preliminary experiment. To minimize the unexplained variability in the results due to extraneous factors, the treatments were carried out in a randomized order during the production stage.

3.2.3. Proximate analysis

The proximate analysis included moisture, ash, fat, crude fiber, crude protein, and carbohydrate content determinations. This was performed using the method described by previous researchers.

Table 1. Experimental design with codes and actual values

S/N	% Citric acid concentration (A or X_1)	Slice thickness in mm (B or X_2)	Steeping time in min. (C or X_3)
1	(0) 3	(0) 4	(+1) 120
2	(-1) 1	(0) 4	(0) 75
3	(+1) 5	(-1) 2	(+1) 120
4	(0) 3	(0) 4	(0) 75
5	(0) 3	(0) 4	(0) 75
6	(0)3	(+1) 6	(0)75
7	(-1) 1	(-1) 2	(-1) 30
8	(0) 3	(0) 4	(0) 75
9	(0) 3	(0) 4	(0) 75
10	(0) 3	(0) 4	(0) 75
11	(+1) 5	(-1) 6	(-1) 30
12	(-1) 1	(-1) 6	(+1)120
13	(+1) 5	(0)4	(0) 75
14	(0) 3	(0) 4	(-1) 30
15	(0) 3	(-1) 2	(0) 75

Values in brackets are the codes while values outside are the actual values

3.2.4. Functional property

The functional properties of the plantain flour were determined as follows: bulk density, water absorption capacity, gelation capacity, gelation temperature, emulsification capacity, solubility, swelling capacity, and pH. The methods used for the determination of these properties were those described by previous researchers.

3.2.5. Sensory evaluation
The processed plantain flour was subjected to sensory evaluations. Plantain flour (50 g) was stirred into 150 ml of boiling water to make a paste for each sample. A panel of 20 judges who were regular consumers of reconstituted plantain flour was used for the subjective sensory test. The panelists evaluated the samples using a questionnaire provided and scored the points based on taste, moldability, aroma, and overall acceptance using a 9-point hedonic scale with 1= like extremely, 2 = like very much, 3 = like moderately, 4 = like slightly, 5 = neither like nor dislike, 6 = dislike slightly, 7= dislike moderately, 8 = dislike very much, and 9= dislike extremely, as described by Adegunwa et al. (2014).

3.2.6 Statistical analysis
All data were subjected to Analysis of Variance (ANOVA) using SPSS version 23.00, and significant differences between the means were separated using Duncan's multiple range test at $p<0.05$. Design-Expert version 12.0 was used to analyze the responses to generate fit statistics, coefficients of the independent variables, P-values for each term, R^2 adj, and lack of fit, which were used to consider the adequacy of each response variable before fitting into a mathematical model and drawing the contours.

4. Results and discussions

4.1 Proximate analysis

The results of the proximate analysis are presented in Table 2. The moisture content ranged from 8.03 to 9.39 %. The moisture content of the plantain flour samples was not significantly different ($p>0.05$). Moisture content is an index of the perishability and storability of the treated plantain flour. Low moisture content is a requirement for the long-term storage of dried food products (Zakpaa, Mak-Mensah, & Adubofour, 2010). The moisture content of the laboratory samples was quite similar to the values obtained by Ayodele, Fagbenro, and Adeyeye (2019), whose values ranged from 7.80% to 9.66 %, but higher than the value of 5.43 % reported by Haytowitz et al. (2019). Run 12 (1 % citric acid, 6 mm slice thickness and 120 min steeping time) had the least moisture content (8.03 %), whereas run 15 (3 % citric acid, 2 mm slice thickness and 75 min steeping time) had the highest moisture content (9.39 %). The plantain flours analyzed in this study may be good binders and composite flours in the food and baking industries because of their low moisture content and stability under proper storage conditions.

The ash content of a food sample is an index of the mineral content of that food, and a high ash content suggests a high mineral content, provided that the food sample has not been contaminated with any foreign matter, such as sand (Ishiwu, Ukpong, & Fyne-Akah, 2020). The results of the ash content of the treated plantain flour showed no significant difference between the treatments ($p>0.05$). The ash content was higher in run 15 (3.92 %) than in run 12 (3.55 %). The results obtained from this analysis are higher than those reported by Oko, Famurewa, and Nwaza (2015), which varied from 0.55 to 2.53 %, and that of Zakpaa et al. (2010), which was 2.68 %. However, the ash content reported by was higher than that in this study, ranging between 7.10% and 8.20 %.

Crude fat determines the free fatty lipids (neutral fat triglycerides) of a product. This property can be used as the basis for determining processing temperatures and predicting auto-oxidation, which can lead to rancidity and hence adversely affect the flavor of the food Zakpaa et al. (2010). The results of this analysis showed a significant difference in the fat content of the treated plantain flours ($p<0.05$). The fat content ranged from 1.37% to 1.97 %, which is lower than the results obtained by Oko et al. (2015), whose values ranged between 2.05% and 4.07 %. Yarkwan and Uvir (2015) obtained similar results to ours for fat content in their products, which ranged from 1.37% to 1.55 %.

Crude fiber is the residual fiber left after the flour sample is dissolved in sodium hydroxide. Crude fiber measures the cellulose, hemicelluloses, and lignin content of food. Available data from research carried out by Oko et al. (2015), reported significantly different lower fiber content of the various unripe plantain variety ranging from 0.19 – 0.61 %. This is in contrast to the results obtained in the present study, with values ranging from 4.76% to 5.18%. These results are higher than those obtained by Fadimu et al. (2018) (2.56 – 3.21 %) in their study. The results of this analysis showed no significant difference ($p<0.05$) in the crude fiber content. Run 12 had the highest fiber content (5.18 %), while run 9 had fiber content of 4.76%, which was the lowest. Research has linked dietary and functional fibers to a healthy life. The known health benefits of dietary fiber intake are related to reduced blood cholesterol levels, slow absorption of glucose, and improved insulin sensitivity (Oko et al., 2015). The range of fiber content of the samples implies that plantain flour could supplement the major ingredient in complementary foods, provided that the fiber content is not greater than 5 % in the formulation.

The crude protein content of the plantain flour samples, as shown in Table 2, showed no significant difference ($p<0.05$). The protein content ranged from 2.89% to 3.26 %, as obtained in this study. This is similar to the values obtained by Fadimu et al. (2018), whose results were in the range of 2.89 – 3.62 %. Ayodele et al. (2019) in their research work, reported higher protein content with values ranging from 8.08 – 10.66 %.

The results of the analysis confirmed that plantain is a carbohydrate food product. As correctly stated by Zakpaa et al. (2010), the underlying factor is the overall energy value that can be supplied to the consumer. The carbohydrate content of the plantain flour samples did not differ significantly ($p<0.05$). Sample 12 had the highest carbohydrate content (78.77 %). The carbohydrate content obtained in this study was within the range of values obtained by Oko et al. (2015), whose values ranged from 69.69% to 81.1 %.

4.2 Functional properties

The results of the functional properties are presented in Table 3. The bulk density ranged from 0.70 to 0.84 g/ml and showed a significant difference ($p<0.05$) in the values. Samples 2 (1 % citric acid, 4 mm slice thickness, and 75 min steeping time) and 12 (1 % citric acid, 6 mm slice thickness, and 120 min steeping time) had the highest bulk density, whereas runs 8, 9, 10 (3 % citric acid, 4 mm slice thickness, and 75 min steeping time) and 11 (5 % citric acid, 6 mm slice thickness, and 30 min steeping time) had the lowest bulk density. These values are similar to those obtained by Ijeoma et al. (2014), which ranged from 0.66 to 0.84 g/ml. This is contrary to the result obtained by Oluwatonyin (2017), whose values ranged from 0.15 – 0.42 g/ml. The bulk density was affected by the particle size and initial moisture content of the plantain flour. The high bulk density of the plantain flour suggests its suitability in food preparation, but on the contrary, low bulk density would be an advantage in making complementary foods (Hasmadi, Noorfarahzilah, Noraidah, Zainol, & Jahurul, 2020).

Water absorption capacity (WAC) was highest in sample 7 (1 % citric acid, 2 mm slice thickness, and 30 min steeping time) (306.00 g/ml) and lowest in sample 5 (3 % citric acid, 4 mm slice thickness, and 75 min steeping time) (247.00 g/ml). These high WAC values are desirable in dough and baked goods, such as cookies, as they help to increase the size of the baked goods. These values are very much higher than those obtained by Arisa, Adelekan, Alamu, and Ogunfowora (2013) whose values ranged from 125.17 to 171.40 g/ml. The water absorption capacity was significantly different ($p < 0.05$). The water absorption capacity (WAC) signifies the ability of a substance to interact with water in an environment with a small amount of water (Ishiwu et al., 2020).

The least gelation concentration (LGC) indicates the gelation ability of flour. A lower gelation concentration suggests the gelling ability of the flour, even when the flour quantity is dispersed in water for reconstitution into the dough (Ishiwu et al., 2020). The flour samples formed gels at 6 g/ml except for runs 11 and 14, which had an LGC of 4 g/ml; consequently, runs 11 and 14 formed gels quickly. However, Fadimu et al. (2018) reported the least gelation concentration values of between 6 and 8 %. The least gelation temperature (LGT) was significant ($p<0.05$) and ranged from 71.5 – 76.00 ºC. Run 11 appeared to have the highest gelation while run 3 had the least gelation temperature. These values were similar to those obtained by Oko et al. (2015). The high amylase content of plantain may be responsible for the high gelatinization temperature of plantain flour.

Table 2. Proximate composition of some selected plantain flours from the samples

Run	CA (%)	SLT (mm)	SPT (min)	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)
1	3	4	120	8.38^{a}± 0.60	3.59^{a} ±0.29	3.17^{a} ±0.47	1.37^{a} ±0.23	4.85^{a} ±0.37	78.66^{a} ±0.02
9	3	4	75	9.17^{a}±0.74	3.62^{a} ±0.39	3.26^{a} ±0.53	1.58^{a} ±0.60	4.76^{a} ±0.47	77.62^{a} ±1.79
12	1	6	120	8.03^{a} ±0.21	3.55^{a} ±0.64	2.89^{a} ±0.04	1.59^{a} ±0.06	5.18^{a} ±0.83	78.77^{a} ±0.37
15	3	2	75	9.39^{a} ±0.59	3.92^{a}±0.31	3.12^{a} ±0.26	1.97^{a} ±0.24	4.77^{a} ±0.43	77.97^{a} ±1.15

Data are presented as mean ± standard deviation (n = 3). Means in the same column with different superscripts are significantly different ($p < 0.05$).

Table 3. Functional properties of the plantain flour

Run	CA (%)	SLT (mm)	SPT (min)	BD (g/ml)	WAC (g/ml)	LGC (g/ml)	LGT (ºC)	EC (%)	SOL (%)	SWP (%)	pH
1	3	4	120	0.82^{f} ±0.00	285.00^{cde} ±1.41	6.00 ±0.00	72.50^{ab} ±0.71	31.28^{a} ±0.39	5.64^{cde} ±0.06	11.82^{bcd} ±0.08	4.69^{n} ±0.00
2	1	4	75	0.84^{h} ±0.00	299.50^{ef} ±2.12	6.00 ±0.00	75.00^{de} ±0.00	39.40^{c} ±0.85	5.73^{def} ±0.35	11.08^{abc} ±0.53	4.20^{d} ±0.00
3	5	2	120	0.82^{f} ±0.00	290^{def} ± 1.41	6.00 ±0.00	71.50^{a} ±0.71	31.91^{ab} ±0.15	6.62^{f} ±0.13	12.17^{cd} ±0.61	3.59^{a} ±0.00
4	3	4	75	0.77^{c} ±0.01	249.50^{ab} ±4.95	6.00 ±0.00	73.50^{bc} ±0.71	39.75^{cd} ±1.77	5.28^{bcd} ±0.69	11.29^{abcd} ±0.89	4.11^{e} ±0.01
5	3	4	75	0.80^{e} ±0.00	247.00^{a} ±2.83	6.00 ±0.00	73.50^{bc} ±0.71	40.40^{cde} ±0.57	5.26^{bcd} ±0.71	11.48^{abcd} ±0.59	4.13^{f} ±0.00
6	3	6	75	0.72^{b} ±0.00	266.50^{bc} ±3.54	6.00 ±0.00	73.50^{bc} ±0.71	39.67^{cd} ±0.47	4.75^{abc} ±0.42	11.65^{bcd} ±0.09	4.25^{k} ±0.01
7	1	2	30	0.77^{c} ±0.01	306.00^{f} ±26.87	6.00 ±0.00	75.50^{e} ±0.71	41.90^{de} ±2.40	6.52^{ef} ±0.13	10.43^{a} ±0.28	4.52^{l} ±0.00
8	3	4	75	0.70^{a} ±0.00	288.50^{def} ±6.36	6.00 ±0.00	74.00^{cd} ±0.00	32.6^{ab} ±0.86	5.49^{bcd} ±0.13	12.26^{d} ±0.62	4.14^{g} ±0.01
9	3	4	75	0.70^{a} ±0.00	276.50^{cd} ±4.95	6.00 ±0.00	74.00^{cd} ±0.00	32.82^{ab} ±0.57	5.34^{bcd} ±0.62	12.24^{d} ±0.55	4.15^{g} ±0.00
10	3	4	75	0.70^{a} ±0.00	277.50^{cd} ±6.36	6.00 ±0.00	74.00^{cd} ±0.00	32.54^{ab} ±0.94	5.48^{bcd} ±0.14	12.25^{d} ±0.56	4.16^{h} ±0.00
11	5	6	30	0.70^{a} ±0.00	293.50^{def} ±4.95	4.00 ±0.00	76.00^{e} ±0.00	42.50^{e} ± 0.71	4.64^{ab} ±0.07	10.83^{ab} ±0.16	3.89^{c} ±0.00
12	1	6	120	0.84^{h} ±0.00	257.00^{ab} ±4.24	6.00 ±0.00	73.00^{bc} ±0.00	32.00^{ab} ±0.00	5.79^{def} ±0.13	10.77^{ab} ±0.15	4.65^{m}

											±0.01
13	5	4	75	0.79^{d} ±0.00	277.50^{cd} ±2.12	6.00 ±0.00	73.50^{bc} ±0.00	33.75^{b} ±1.06	4.98^{abcd} ±0.28	11.85^{bcd} ±0.22	3.62^{b} ±0.00
14	3	4	30	0.72^{b} ±0.00	277.50^{cd} ±3.54	4.00 ±0.00	75.50^{e} ±0.00	41.12^{cde} ±0.47	4.31^{a} ±0.40	11.95^{cd} ±0.18	3.98^{d} ±0.00
15	3	2	75	0.83^{g} ±0.00	285.50^{cde} ±2.12	6.00 ±0.00	73.50^{bc} ±0.00	32.94^{ab} ±0.09	6.46^{ef} ±0.64	11.24^{abcd} ±0.25	4.19^{i} ±0.00

Data are presented as mean ± standard deviation. Means in the same column with different superscripts are significantly different (p<0.0).

CA = Citric Acid, SLT = Slice Thickness, SPT = Steeping Time, BD = Bulk Density, WAC = Water Absorption Capacity, LGC = Least Gelation Capacity, LGT, =Least Gelation Temperature, EC = Emulsion Capacity, SOL = Solubility, SWP = Swelling Power.

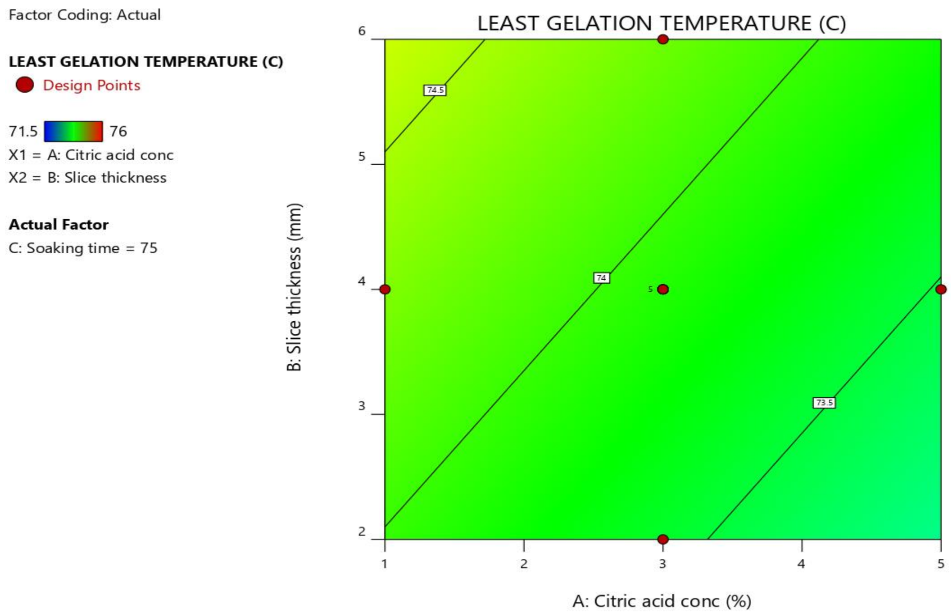


Figure 1. Contour plot for least gelation temperature of the plantain flour sample

The least gelation temperature was modeled as follows (Equations 1 and 2):

$$LGT = \alpha + \beta 1A + \beta 3C \quad (1)$$
$$LGT = 73.90 - 0.42A - 1.67C \quad (2)$$

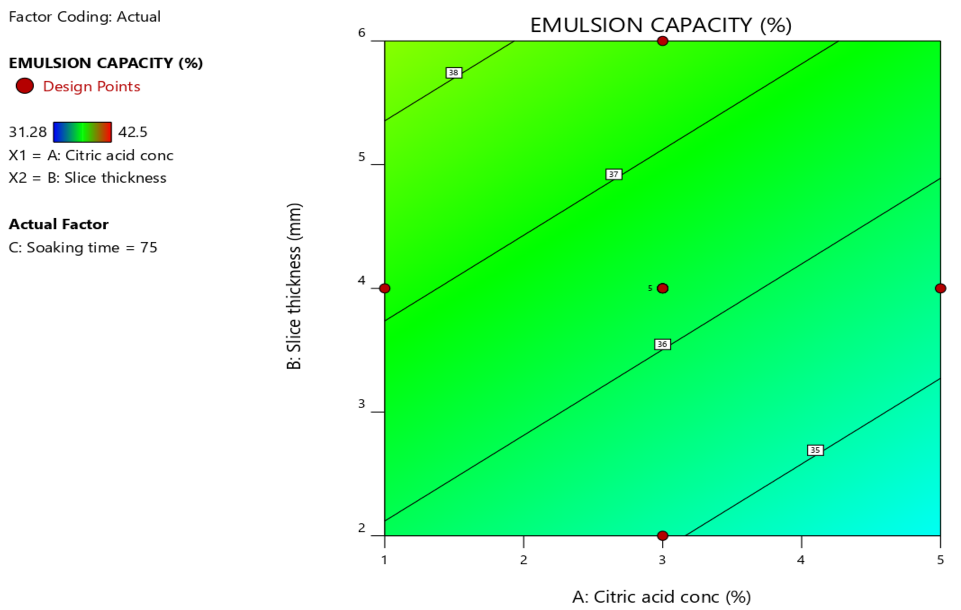
α is the intercept, and A and C represent citric acid concentration and soaking time, respectively. Figure 1 shows the contour plot of the least gelation temperature (LGT). Equations 1 and 2 explain the least gelation temperature as a function of citric acid concentration (A) and soaking time (C). β_1 and β_3 are the coefficients of A and C, respectively. Eq. 1 is the ideal regression model, whereas Eq. 2 is the actual value substituted in Eq.1.

Both citric acid concentration and soaking time influenced the least gelation temperature. The model showed that increasing both the citric acid concentration and soaking time would decrease the least gelation temperature and vice versa. However, a change in the soaking time had a greater effect than citric acid concentration. From Eq. 2, C would cause a higher reduction in the LGT than A, since β_3 is higher in value than β_1. The R^2 adjusted is very high (89.08 %), which makes the model adequate because it can explain 89.08 % of the changes in LGT resulting from the interaction effect of A and C. There is a positive relationship because R^2 adjusted suggests a high interpretation that the model is a true representation of the relationship between the least gelation temperature and, citric acid concentration, and steeping time. From Fig. 1, when the citric acid concentration is increased from 1.7 – 4.2 %, and the slice thickness is reduced from 5.1 – 2.1 mm, the least gelation temperature decreases from 74.5 – 74.0 °C

The emulsion capacity of the treated plantain flour was significantly different among the samples ($p<0.05$), with values ranging from 31.28 % for sample 1 to 42.50 % for sample 11. From the results, it can be deduced that a lower steeping time resulted in a higher emulsion capacity and vice versa.

From the analysis of Oluwatonyin (2017), whose values ranged from 17.86 to 39.84 %, the emulsion capacity and stability of the blanched samples were generally lower than those of the unblanched control sample, and hence decreased with increasing heat. This could be a result of the heat generated during blanching.

The regressions for the emulsion capacity are shown in Equations 3 and 4. Figure 2 shows the contour plot of the emulsion capacity.



The model equations for emulsion capacity are presented in Equations 3 and 4. Eq.3 is the ideal model, while Eq. Table 4 shows the model with the coefficient of C substituted for β_3. The equations showed that only steeping time (C) had a significant effect on emulsion capacity. From Equation 4, increasing the steeping time decreases the emulsion capacity.

$$Emulsion\ capacity = \alpha + \beta 3C \quad (3)$$
$$Emulsion\ capacity = 36.31 - 5.06C \quad (4)$$
R^2 adjusted = 53.39 %.

From the contour plot (Fig. 2), when the citric acid concentration increased from 1.8% to 4.3 % and the slice thickness reduced from 5.3 mm to 3.8 mm, the emulsion capacity decreased from 37 to 38 %. The R^2 adjusted is moderately high (53.39 %), suggesting that 53.39 % of changes in the emulsion capacity are caused by the steeping time, indicating that the model is a true representation of the relationship between the emulsion capacity and the steeping time.

The solubility of the plantain flour samples differed significantly ($p < 0.05$). The solubility of the plantain flour ranged from 4.31% to 6.62 %, with samples 14 and 3 having the least and maximum values, respectively. The results obtained in this study are similar to those obtained by Arisa et al. (2013), whose values ranged from 4.67% to 6.80 %, and Oluwatonyin (2017), whose values ranged from 4.14% to 5.89 %. Equations 5 and 6 show the regressions for the solubility. Figure 3 shows the contour plot of the solubility of the plantain flour samples.

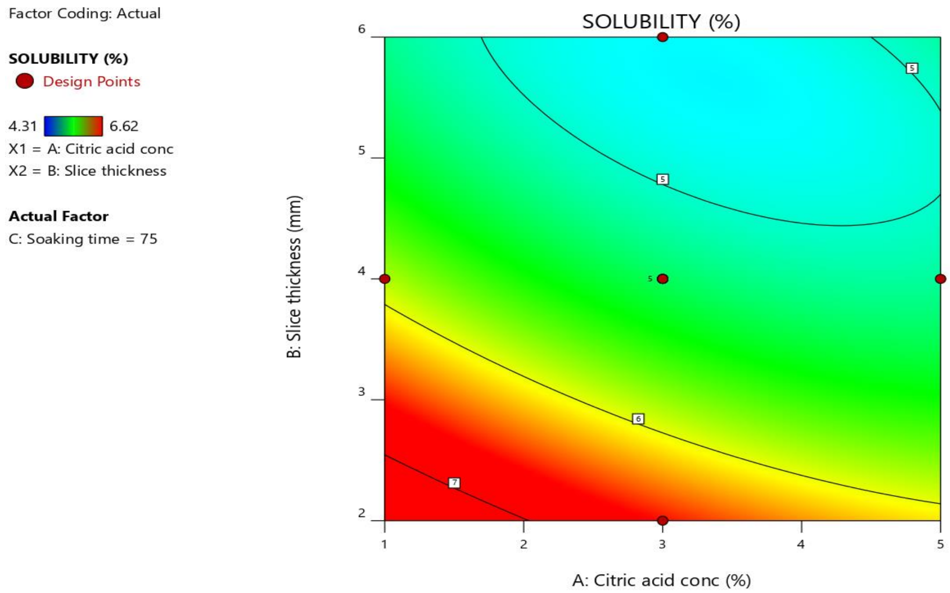


Figure 3. Contour plot for solubility for the plantain flour samples

An increase in both the slice thickness and steeping time increased the solubility of the plantain flour samples, as shown in equations 5 and 6.

$$Solubility = \alpha + \beta 2B + \beta 3C + \beta 22B2 \quad (5)$$
$$Solubility = 5.26 - 0.86B + 0.67C + 0.48B2 \quad (6)$$

The R^2 adjusted was very high (89.72 %). This implies that the model is adequate and explains the true relationship between solubility, slice thickness, and steeping time. From the equation, increasing the slice thickness would reduce the solubility; however, increasing the square of the slice thickness and the steeping time would increase the solubility of the plantain flour sample, with the steeping time having a greater effect on the solubility.

The unripe plantain flours had good swelling powers, which were in accordance with the range of values for flour samples. The range of values for swelling power of the treated plantain flour samples was 10.43 – 12.26 %. The results of this analysis show that the different process variables caused slight aggregation of the starch granules to different levels, and hence affected the level of its exposure and swelling power. Run 8 (3 % citric acid, 4 mm slice thickness and 75 min steeping time) had the maximum value while run 7 (1 % citric acid, 2 mm slice thickness and 30 min steeping time) had the least value for swelling power. The values obtained in this study were higher than those obtained by Ijeoma et al. (2014), whose values ranged from 2.07% to 5.20 %. In contrast, Arisa et al. (2013) and Fadimu et al. (2018) obtained much higher values ((38.18 – 48.89 %) and (31.85 – 39.54 %)) in their studies.

The pH values, as indicated by the results, ranged from 3.59 to 4.69. There were significant differences ($p<0.05$) in the pH values of the flour samples. Run 1 had the highest pH value of 4.69 while run 3 had the lowest pH value. These values indicate a low level of acidity in the treated plantain flour sample, which is a result of the citric acid pretreatment. However, the pH results obtained in this study were lower than those reported by Ijeoma et al. (2014), who observed values ranging from 6.24 to 6.88. The regressions for pH are shown in Equations 7 and 8, respectively.

$$pH = \alpha + \beta 1A + \beta 3C + \beta 12AB + \beta 13AC + \beta 23BC + \beta 11A2 + \beta 22B2 + \beta 33C2 \quad (7)$$

$$pH = 4.14 - 0.29A + 0.36C + 0.39AB - 0.08AC + 0.13BC - 0.24A2 + 0.07B2 + 0.19C2 \quad (8)$$

R^2 adjusted = 99.65 %

Figure 4 shows the contour plot of pH for the plantain flour samples. Citric acid concentration, slice thickness, and steeping time affected the pH. The pH was also influenced by the interactions between citric acid concentration and slice thickness, citric acid concentration and steeping time, and slice thickness and steeping time. From the equation model, increasing the citric acid concentration, the interaction of the citric acid concentration and steeping time, and the square of the citric acid concentration would decrease the pH of the plantain flour samples, with the citric acid concentration having a greater effect. Conversely, increasing the steeping time, the interaction between citric acid concentration and slice thickness, slice thickness and steeping time, and the squares of slice thickness and steeping time increased the pH of the plantain flour samples, with the steeping time having a greater effect.

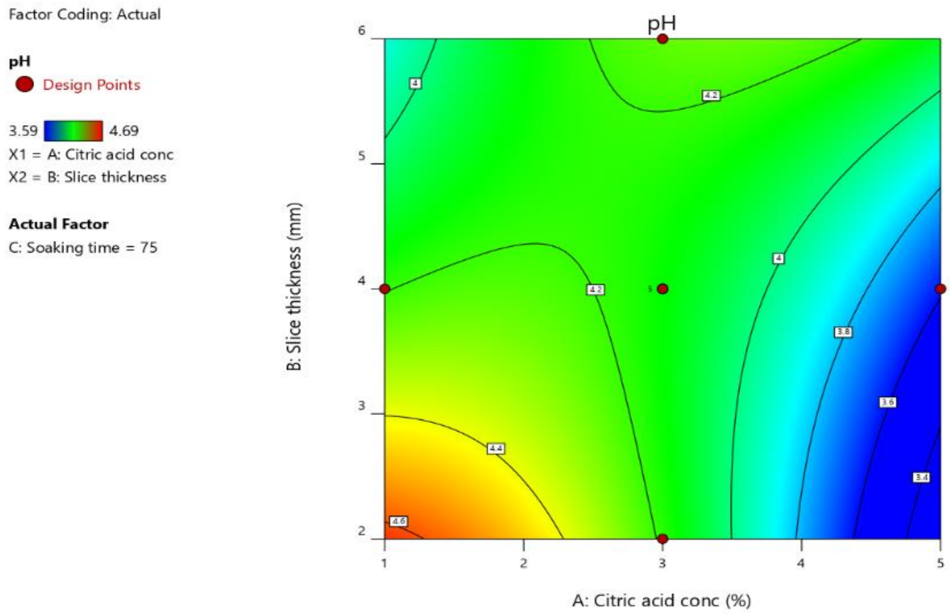


Figure 4. Contour plot of pH for the plantain flour samples

From the contour plot, in case 1, when the citric acid treatment increased from 1.3% to 2.3 % and the slice thickness increased from 2.1 mm to 2.95 mm, the pH decreased from 4.6 to 4.4. In case 2, when the citric acid was increased from 3.9% to 4.4 % and the slice thickness was decreased from 4.8 mm to 3.9 mm, the pH decreased from 3.8 to 3.6. Although this is contrary to the first case, it still had the same decreasing effect on the pH of the plantain flour sample. The R^2 adjusted has a very high percentage (99.65 %). This makes the model adequate and explains the relationship between citric acid concentration, slice thickness, and steeping time. There is a positive relationship because the R^2 adjusted is suggesting a high interpretation that the model is a true representation of the relationship between pH and the interaction effect.

4.3 Sensory properties

The results of the mean scores obtained for the different parameters are presented in Table 4. The results showed significant differences ($p<0.05$) in the mean scores for all sensory attributes as scored by the panelists. The majority of the panelists preferred the taste of sample 9 (3 % citric acid, 4 mm slice thickness, and 75 min steeping time) to other samples. The rating was similar to that of Adegunwa et al. (2014).

Table 4. Sensory properties of the reconstituted plantain meal eaten with soup

Run	CA (%)	SLT (mm)	STP (min)	Taste	Aroma	Moldability	Texture	Colour	Overall acceptability
1	3	4	120	3.40[a]	3.20[abc]	3.20[ab]	3.20[ab]	3.40[a]	3.20[ab]
2	1	4	75	4.30[abc]	2.90[ab]	4.30[abc]	3.80[abc]	4.00[ab]	3.80[ab]
3	5	2	120	3.50[a]	3.90[abc]	4.70[abcd]	5.20[cd]	5.50[b]	4.80[bc]
4	3	4	75	5.80[bc]	4.50[abc]	3.90[ab]	4.10[abcd]	3.10[a]	4.00[abc]
5	3	4	75	6.10[c]	4.00[abc]	5.00[bcd]	4.10[abcd]	4.00[ab]	4.60[bc]
6	3	6	75	4.50[abc]	3.50[abc]	6.70[d]	5.70[d]	4.80[ab]	5.60[cd]
7	1	2	30	6.10[c]	4.90[c]	6.10[cd]	4.40[bcd]	7.40[c]	6.50[d]
8	3	4	75	5.30[abc]	4.50[abc]	3.90[ab]	3.90[abc]	3.90[ab]	4.30[abc]
9	3	4	75	3.30[a]	3.70[abc]	4.90[bcd]	3.60[abc]	3.40[a]	3.70[ab]
10	3	4	75	3.60[a]	4.30[abc]	5.30[bcd]	3.60[abc]	4.20[ab]	4.40[abc]
11	5	6	30	4.90[abc]	4.20[abc]	4.70[abcd]	4.30[abcd]	4.20[ab]	4.60[bc]
12	1	6	120	3.90[ab]	2.80[abc]	3.70[ab]	4.30[abcd]	3.70[ab]	3.60[ab]
13	5	4	75	5.80[bc]	4.60[bc]	4.10[abc]	4.20[abcd]	4.80[ab]	4.90[bc]
14	3	4	30	5.70[bc]	4.50[abc]	4.60[abcd]	3.60[abc]	3.70[ab]	4.60[bc]
15	3	2	75	3.50[a]	3.60[abc]	2.70[a]	2.60[a]	3.40[a]	2.80[a]

Data are presented as mean ± standard deviation. Data in the same column with different superscripts are significantly different (p<0.05).

The results of the analysis showed a significant difference (p<0.05) in the aroma of the flour samples. The results for aroma ranged from 2.80 to 4.90. Figures 5 and 6 show the aroma contour plots. The regression models are represented by Equations 9 and 10.

$$Aroma = \alpha + \beta 3C \quad (9)$$
$$Aroma = 3.91 - 0.7C \quad (10)$$

R^2 adjusted = 53.13 %

Only the steeping time affected the aromas. Increasing the stepping time reduced the aroma of the plantain flour sample. The R^2 adjusted was moderately high, thus showing a true representation of the relationship between aroma and steeping time in the model. As shown in Figure 5, when the citric acid concentration increased from 1.8% to 4.0 % and the slice thickness increased from 3.1 to 5.6 mm, the aroma decreased from 4.4 to 4.0.

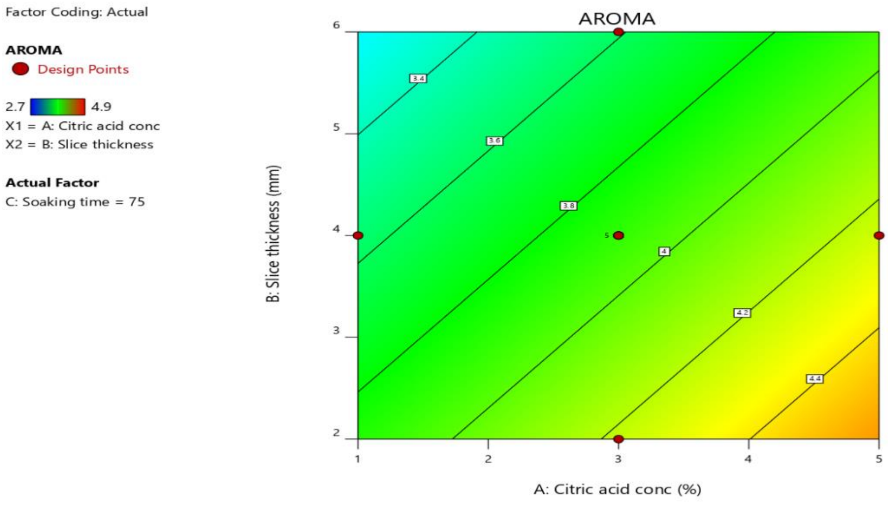


Figure 5. Contour plot for the aroma of the plantain flour samples; case 1

However, from the contour plot (Figure 6), when the steeping time is increased from 78 to 112 min and the citric acid concentration is reduced from 4.7 to 1.8%, the aroma decreases from 3.5 to 3.0. This suggests that increasing the citric acid concentration increases the aroma and vice versa.

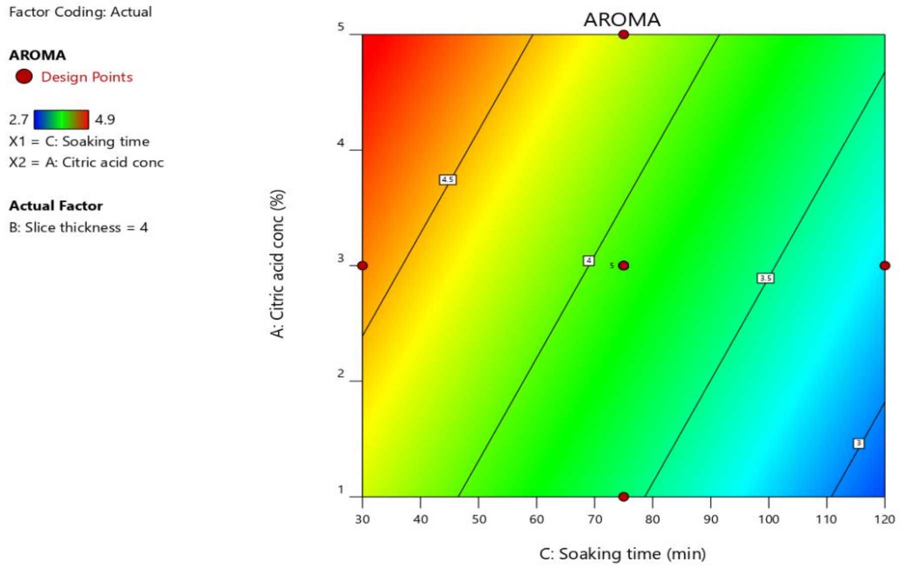


Figure 6. Contour plot for the aroma of the plantain flour samples; case 2

Sample 15 had the best moldability value, whereas sample 6 ranked the lowest. This could be a measure of how compact the flour samples would be when constituted into dough. The results of Adegunwa et al. (2014) for moldability (2.60 – 5.30) are within the range obtained in this study. The regressions for moldability are represented by Equations 11 and 12.

$$Moldability = \alpha + \beta 2B + \beta 13\, AC \quad (11)$$
$$Moldability = 4.52 + 2.00B + 2.60AC \quad (12)$$

The regression equation showed that both the slice thickness and interaction between citric acid concentration and steeping time had a significant effect on the moldability of the plantain flour. Increasing both factors increases the moldability. However, the interaction between citric acid concentration and steeping time had a greater effect on moldability than the slice thickness. As shown in Figure 7, when the citric acid concentration is increased from 1.7% to 2.4 % and the steeping time is increased from 44 min to 70 min, the moldability is reduced from 7 to 5.

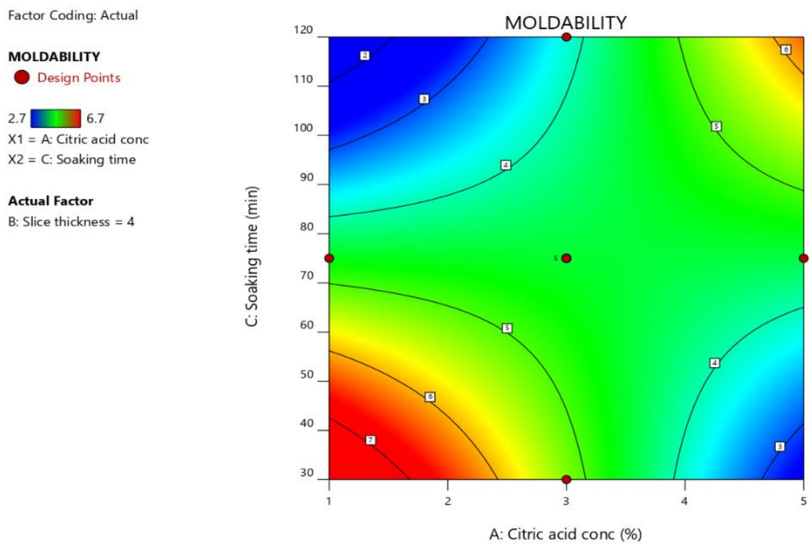


Figure 5. Contour plot for the aroma of the plantain flour samples; case 1

When the citric acid concentration is increased from 1.5% to 3.2 % and the steeping time increased from 84 to 112 min, the moldability increases from 2 to 4. When the citric acid concentration is increased from 3.9% to 4.6 % and the steeping time is reduced from 64 min to 42 min, the moldability is reduced from 4 to 3. The results of the texture analysis showed a significant difference ($p<0.05$) in the texture of the plantain flour samples. The variation in texture could be a result of the difference in particle size. Scores for texture ranged from 2.60 to 5.70. Sample 12 had the best score for texture, indicating a smaller particle size than the others. However, this is contrary to the report of Adegunwa et al. (2014), whose values ranged from 3.15 to 4.15 for 100 % instant breadfruit paste.

The contour plot of the texture is shown in Figure 8. The regression equations for the texture are presented in Equations 13 and 14.

$$Texture = \alpha + \beta 2B + \beta 13AC + \beta 22B2 \quad (13)$$
$$Texture = 3.75 + 1.55B + 1.80AC + 0.54B2 \quad (14)$$
R^2 adjusted = 83.73 %.

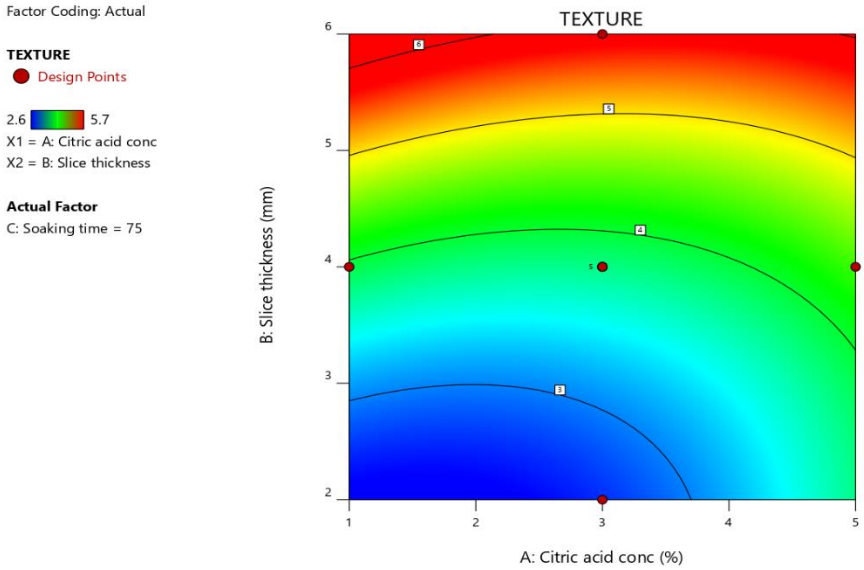


Figure 8. Contour plot for the texture of the plantain flour samples

The texture was influenced by the slice thickness and the interaction between the citric acid concentration and steeping time, with the interaction between the citric acid concentration and steeping time having a greater effect. Increasing both parameters increased the texture of the plantain flour sample. The R^2 adjusted is very high, which makes the model adequate, hence validating the relationship between the texture, slice thickness, and the interaction between the citric acid concentration and the steeping time. By increasing the citric acid concentration from 2.2% to 3.7 % and reducing the slice thickness from 5.7 mm to 2.8 mm, the texture decreased from 6 to 3.

The test scores for the color of the plantain flour samples ranged from 3.10 – 5.70. The color may be a result of the processing procedures. There were no significant differences ($p>0.05$) between samples 1, 4, 9, and 15. Sample 7 was the least accepted sample. The regression equation is represented by Equation 15, and Figure 9 shows the contour plot for color.

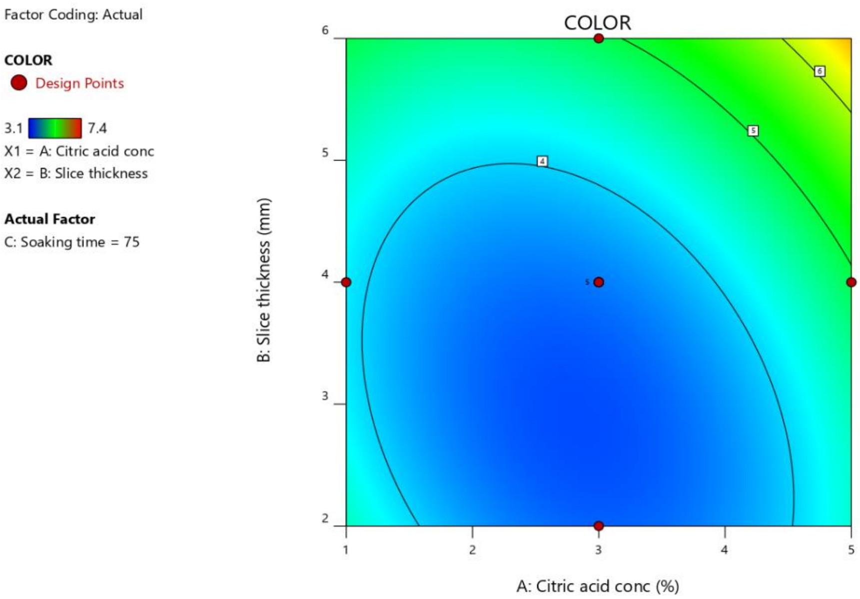


Figure 9. Contour plot for the color of the plantain flour samples

$$Colour = \alpha + \beta 13AC + \beta 11B2 \quad (15)$$

The model showed that both the interaction between citric acid concentration and steeping time and the square of citric acid concentration influenced the color of the plantain flour sample. From the contour plot, when the citric acid concentration is increased from 3.2% to 4.5 % and the slice thickness is increased from 4.1 mm to 5.4 mm, the color increases from 5 to 6.

The results obtained from the analysis showed a significant difference ($p<0.05$) in overall acceptability. The values ranged from 2.80 to 6.50. Sample 15 (3 % citric acid, 2 mm slice thickness, and 75 min steeping time) had the best overall acceptability, whereas sample 7 (1 % citric acid, 2 mm slice thickness, and 30 min steeping time) had the least overall acceptability. Adegunwa et al. (2014) obtained values for overall acceptability ranging from 2.9 – 4.65 which is within the range of values obtained in this research work. The regression equations for the overall moldability are represented by Equations 16 and 17. The contour plot of the overall acceptability is shown in Figure 10.

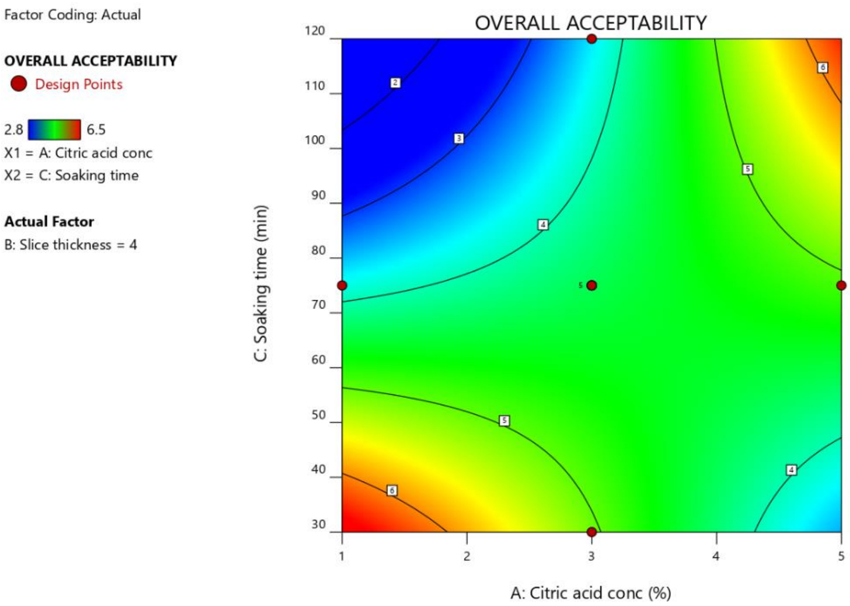


Figure 10. Contour plot for overall acceptability for the plantain flour sample

$$Overall\ acceptability\ =\ \alpha\ +\ \beta 13AC \qquad (16)$$
$$Overall\ acceptability\ =\ 4.36\ +\ 2.17AC \qquad (17)$$
R^2 adjusted = 68.49.

Overall acceptability was influenced by the interaction between citric acid concentration and steeping time. As this interaction increases, the overall acceptability also increases. The model was adequate because the R^2 adjusted was high.
As shown in Figure 10, when the citric acid content is increased from 1.8% to 3.1 % and the steeping time is increased from 41 min to 56 min, the overall acceptability decreases from 6 to 5. When the citric acid content is increased from 1.8% to 3.3 % and the steeping time is reduced from 104 min to 73 min, the overall acceptability increases from 2 to 4. When the citric acid concentration was increased from 4.0% to 4.7 % and the steeping time from 78 to 107 min, the overall acceptability increased from 5 to 6.

4.4 Graphical optimization
The main criteria for constraints optimization of process parameters for the functional and sensory properties of the plantain flour production were minimum possible citric acid concentration and maximum slice thickness which generated the solution with the desirability of 100 % used to plot figures 11, 12 and 13.

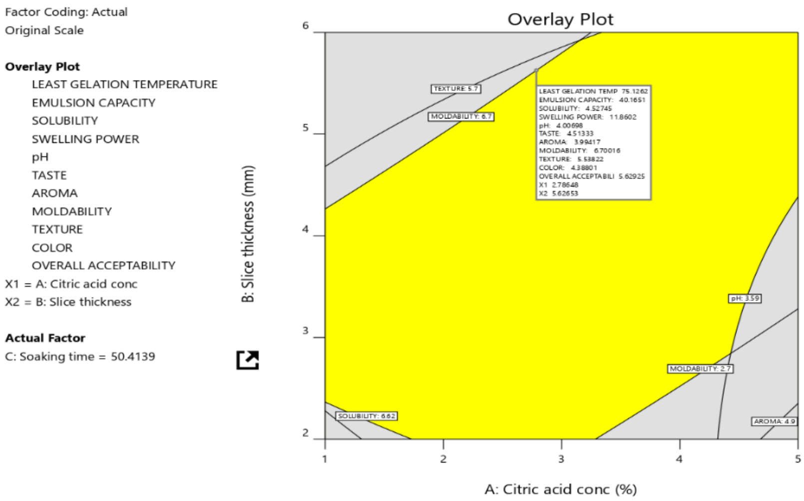


Figure 11. Optimization plot at the soaking time of 50.41 min

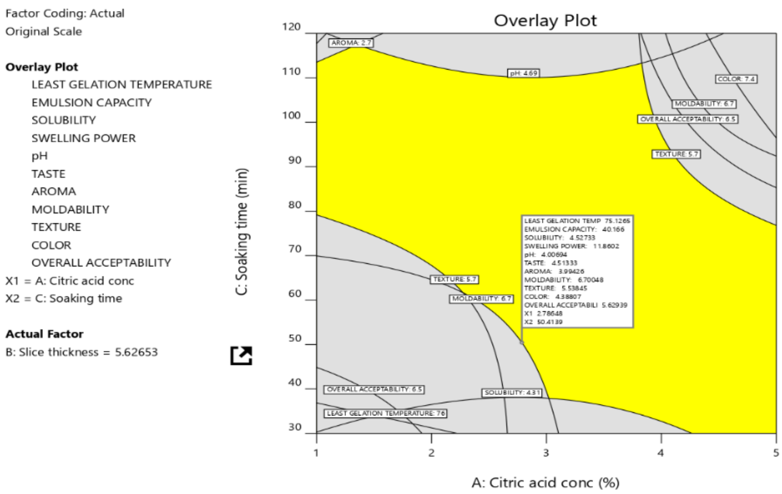


Figure 12. Optimization plot for slice thickness of 5.63 mm

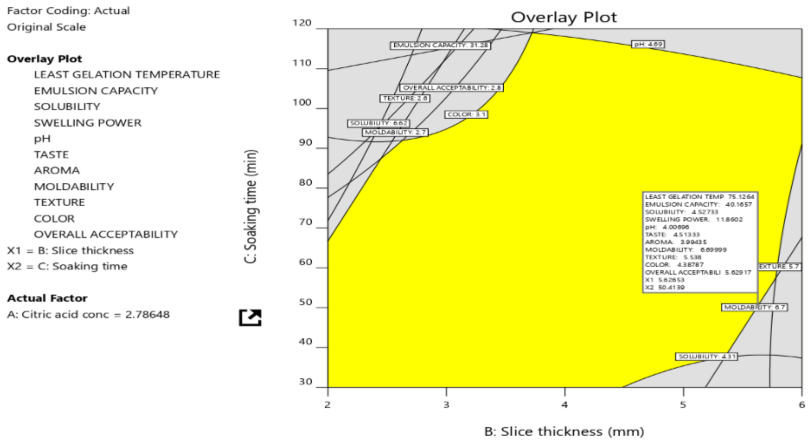


Figure 13. Optimization plot for the citric acid concentration of 2.79 %

This shows that if the selected optimum critical values of citric acid concentration of 2.77 %, slice thickness of 5.63 mm, and soaking time of 50.41 min are employed in the production of plantain flour, the flour would be moderately liked for moldability and would be slightly liked generally (Fig. 11). To optimize the response variables (LGT, EC, solubility, SWP, pH, taste, aroma, moldability, texture, color, and overall acceptability) that exhibited significant models, graphical representation was deployed. All responses that exhibited significant models and were expressed in the form of a mathematical model were included and assigned equal importance based on their desired effect on the quality of the plantain flour by either maximizing or minimizing the values of the properties. The selected value then provided the process variable combinations that would result in the optimized properties of plantain flour. The obtained results showed the following properties: least gelation temperature = 75. 12 °C, emulsion capacity = 40.76 %, solubility = 4.53 %, swelling power = 11.86 %, pH = 4.00, taste = 4.51, aroma = 3.99, moldability = 6.70, texture = 5.54, color = 4.39, and overall acceptability = 5.63, at selected optimum process variables of citric acid concentration = 2.79 %, steeping time = 50.41 min, and slice thickness = 5.62 mm. The optimization plots are shown in Figures 11, 12, and 13 for fixed soaking time, slice thickness, and citric acid concentration, respectively.

5. Conclusion

This study showed that the pretreatments given to the plantain slices had significant effects on the flours produced ($p<0.05$). The functional properties of all plantain flour samples were significantly different ($p<0.05$). The results of the functional properties showed high values for water absorption capacity, bulk density, and swelling power in samples 1, 2, 15, and 3, making them highly suitable for plantain dough production. Lowering the steeping time lowered the gelation concentration, and hence the high gelling ability of the flour, which is a good property. As the steeping time increased, the gelation temperature decreased. The sensory scores showed that sample 15 had the best scores based on moldability, texture, and overall acceptability, and was the most preferred sample for the production of plantain dough and possibly other plantain flour-based products. The proximate composition of the plantain flour samples showed that sample 12 can be stored better than the others because of its low moisture content compared to the other samples. Sample1 has low fat content and relatively high ash content, making it a desirable alternative for people seeking low-calorie foods. The low protein content of sample 12 makes it suitable for people with a renal condition that do not easily metabolize proteins

Therefore, it is recommended that the optimum critical values of citric acid concentration, slice thickness, and soaking time are 2.77 %, 5.63 mm, and 50.41 min, respectively, for the production of plantain flour with the flour should exhibit optimal functional and sensory properties. Future studies should investigate the impact of packaging materials on the stability of citric acid-processed plantain flour. The variety of the plantain fruit and the drying equipment used during the production of the flour could influence the quality of the plantain flour and these factors could be studied by future researchers

5.1 Limitations and Study Forward

This study did not consider the application of other optimization methods, such as genetic algorithms and particle swarm optimization, to estimate the optimum points. Future studies should focus on these areas.

Acknowledgments

The authors are grateful to Mrs. Nneka Mofunanya, a senior technologist at the Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, for her assistance in analyzing the samples.

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