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

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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 parameters of the flour samples showed no significant difference ($p > 0.05$), but there were significant effects ($p < 0.05$) on the functional and sensory properties of the flour samples. The functional properties were found to differ significantly.
Limitation: This study did not consider the application of other optimization methods such as genetic algorithm and particle swarm optimization in estimating 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: *Process variables, proximate analysis, functional properties, sensory properties, optimization*
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1. Introduction

Plantains (*Musa spp*) are plants producing fruits that are starchy at maturity (Akinyemi, S, O, & Akyeampong, 2010) and need to be processed before consumption. They are one of the most important food crops consumed after rice and maize, grown in more than 120 countries of the world, mainly for their fruits, leaves and fibers (Newilah, Tchango, Fokou, & Etoa, 2005). It is estimated that 61% and 21% of plantain production worldwide comes from West and Central Africa respectively and about 70 million people in these regions derive more than 25% of their carbohydrates from plantains, hence 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. Findings have shown that in sub-Saharan Africa, bananas and plantain provide more than 25% of the energy needs of 70 million people. It was 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 also 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, C and minerals like calcium, potassium, phosphorus, and iron. They are a major staple that contributes to food security for millions of people. Their uses may vary according to socio-cultural behaviors, eating habits of the population, and market demand (Newilah et al., 2005). There are various types of plantain cultivated in West Africa, and these include; true horn plantain, false horn plantain, and French horn plantain (Ayim, Amankwah, & Dzisi, 2012). Danso, Adomako, Dampare, and Oduro (2006) argued that these varieties have different physicochemical and morphological properties. Plantain when harvested at its unripe green stage of maturity contains starch almost equivalent to the starch content of endosperm of corn and pulp of white potato. All stages of plantain growth from the immature to the overripe are important sources of food.

Industrially, plantain fruits are converted to flour and then used as composite in the making of baby food ('*Babena*' and '*Soyamusa*'), bread, biscuit, and other food products (Akinyemi et al., 2010). In as many as large tons of plantains are harvested yearly in Nigeria, 50-60% of it is subject to postharvest losses and this has necessitated the need to develop adequate technologies for its processing and preservation. One of the methods to achieve this is by processing plantain into flour. After harvest at the matured stage and upon peeling, plantains undergo rapid respiration, microbial, physical and biochemical changes and this leads to its deterioration. One such reaction is enzymatic browning which has undesirable effects on the color and flavor of the processed fruit. To avert these changes, organic acids like citric acid can be employed to reduce these enzymatic activities (Nielsen & Arneborg, 2007; Theron & Lues, 2010). Although Emojorho and Akubor (2016) studied the effect 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 in the pretreatment of flour hence, the focus of this study.

To the best of our knowledge, no information is available on how soaking time and slice size as a processing variable can affect the quality of plantain flour. This knowledge is important when the development of flour with desired properties is investigated. 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. This constitutes the gap in research that this study is designed to fill. High-quality plantain flour successfully produced will add value to its use in the food system. Therefore, this research seeks 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.

3. Methodology

3.1 Materials

The plantain cultivar; (French plantain) was purchased from Amansea market in Awka, Anambra state. The citric acid (analytical grade) used was purchased from Head bridge market Onitsha, Anambra state.

3.2 Methods

3.2.1 Production of plantain flour

The plantain flour was produced using the procedure described by Ijeoma, Osobie, Uzoukwu, Esther, and Emilia (2014) with some modifications. The plantain fruit was 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 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 a set of 15 treatments (Table 1). The levels chosen for the independent variables were based on the preliminary experiment performed. To minimize the unexplained variability in the results due to extraneous factors, the treatments were carried out in randomized order during the production stage.

3.2.3. Proximate analysis

The proximate analysis carried out include moisture, ash, fat, crude fiber, crude protein and carbohydrate content determinations. This was done 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 determined were: bulk density, water absorption capacity, gelation capacity, gelation temperature, emulsification capacity, solubility, swelling capacity and pH measure. The methods used for the determination of these properties were the ones described by previous researchers.

3.2.5. Sensory evaluation
The processed plantain flour was subjected to sensory evaluation. Plantain flour (50 g) was stirred into 150 ml of boiling water to make a paste for each sample. A panel consisting of 20 judges who are regular consumers of reconstituted plantain flour was used for the subjective sensory test. The panelists evaluated the samples using a questionnaire provided and they 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, Adebowale, Bakare, and Ovie (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 such into a mathematical model and drawing the contours.

4. Results and Discussions

4.1 Proximate analysis

The results of the proximate analysis are shown in Table 2. The moisture content ranged from 8.03 to 9.39 %. It was observed that the moisture content of the plantain flour samples was not significantly different ($p>0.05$). Moisture content is an index of perishability and storability of the treated plantain flour. Low moisture content is a requirement for the long storage life 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 – 9.66 % but higher as compared to a 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 as binders and composite flour in food and baking industries due to low moisture content and would be stable under proper storage conditions.

The ash content of a food sample is an index of the mineral content of that food, and high ash content suggests high mineral content provided the food sample has not been contaminated with any foreign matter like sand (Ishiwu, Ukpong, & Fyne-Akah, 2020). The result of the ash content of the treated plantain flour showed no significant difference between the treatments at ($p>0.05$). Ash content was shown to be higher in run 15 (3.92 %) than in run 12 (3.55 %). The results obtained from this analysis are higher than the one 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 Ayodele et al. (2019) was higher than the one from this research and the values ranged between 7.10 – 8.20 %.

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

Crude fiber is the residual fiber left after the flour sample has been 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 this present research with values ranging from 4.76 – 5.18%. These results are higher than those obtained by Fadimu et al. (2018) (2.56 – 3.21 %) in his research. The results of this analysis showed no significant difference ($p<0.05$) in the crude fiber content. Run 12 had the highest fibre content (5.18 %), while run 9 had fibre content of 4.76%, hence being the lowest. Research has linked dietary and functional fibers to healthy life. The known health benefits of dietary fiber intake have been related to reducing blood cholesterol levels, slow absorption of glucose, and improving insulin sensitivity (Oko et al., 2015). The range of fiber content of the samples implies that the 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 the result in Table 2 shows that there is no significant difference ($p<0.05$). The protein content ranged from 2.89 – 3.26 % as obtained in this research. This is similar to the values obtained by Fadimu et al. (2018) in the result of his analysis being 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 result of the analysis confirmed the fact that plantain is a carbohydrate food product. As correctly stated by Zakpaa et al. (2010), the underlying factor is the overall energy value it can supply 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 from this research work is within the range of values obtained by Oko et al. (2015) whose values ranged from 69.69 – 81.1 %.

4.2 Functional properties

The results of the functional properties are shown in Table 3. The bulk density ranged from 0.70 to 0.84 g/ml and it showed a significant difference ($p<0.05$) in the values. Sample 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) were the highest in bulk density, while 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 value. These values are similar to the values obtained by Ijeoma et al. (2014), ranged from 0.66 to 0.84 g/ml. This is contrary to the result obtained by Oluwatonyin (20 who's value 17) whose values ranged from 0.15 – 0.42 g/ml. The bulk density could be affected by particle size and initial the 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.

Water absorption capacity (WAC) was observed to be 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 values of WAC are desirable in dough and baked goods such as cookies since it helps 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 had a significant difference ($p < 0.05$). Water absorption capacity (WAC) signifies the ability of a substance to interact with water in an environment of a small amount of water (Ishiwu et al., 2020).

The least gelation concentration (LGC) indicates the gelation ability of the flour. Lower gelation concentration suggests the gelling ability of the flour even when flour quantity is dispersed in water for reconstitution into the dough (Ishiwu et al., 2020). The flour samples formed gel at 6 g/ml except for run 11 and 14 having LGC of 4 g/ml, consequently, runs 11 and 14 would form gel quickly. However, Fadimu et al. (2018) reported the least gelation concentration values of between 6 – 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 are similar to those obtained by Oko et al. (2015). The high amylase content of plantain may be responsible for the high gelatinization temperature of the 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	$8.38^{a} \pm 0.60$	$3.59^{a} \pm 0.29$	$3.17^{a} \pm 0.47$	$1.37^{a} \pm 0.23$	$4.85^{a} \pm 0.37$	$78.66^{a} \pm 0.02$
9	3	4	75	$9.17^{a} \pm 0.74$	$3.62^{a} \pm 0.39$	$3.26^{a} \pm 0.53$	$1.58^{a} \pm 0.60$	$4.76^{a} \pm 0.47$	$77.62^{a} \pm 1.79$
12	1	6	120	$8.03^{a} \pm 0.21$	$3.55^{a} \pm 0.64$	$2.89^{a} \pm 0.04$	$1.59^{a} \pm 0.06$	$5.18^{a} \pm 0.83$	$78.77^{a} \pm 0.37$
15	3	2	75	$9.39^{a} \pm 0.59$	$3.92^{a} \pm 0.31$	$3.12^{a} \pm 0.26$	$1.97^{a} \pm 0.24$	$4.77^{a} \pm 0.43$	$77.97^{a} \pm 1.15$

Data are means ± standard deviation (n = 3). Mean in the same column having different superscript differed significantly ($p < 0.05$).

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	$0.82^{f} \pm 0.00$	$285.00^{cde} \pm 1.41$	6.00 ± 0.00	$72.50^{ab} \pm 0.71$	$31.28^{a} \pm 0.39$	$5.64^{cde} \pm 0.06$	$11.82^{bcd} \pm 0.08$	$4.69^{n} \pm 0.00$
2	1	4	75	$0.84^{h} \pm 0.00$	$299.50^{ef} \pm 2.12$	6.00 ± 0.00	$75.00^{de} \pm 0.00$	$39.40^{c} \pm 0.85$	$5.73^{def} \pm 0.35$	$11.08^{abc} \pm 0.53$	$4.20^{d} \pm 0.00$
3	5	2	120	$0.82^{f} \pm 0.00$	$290^{def} \pm 1.41$	6.00 ± 0.00	$71.50^{a} \pm 0.71$	$31.91^{ab} \pm 0.15$	$6.62^{f} \pm 0.13$	$12.17^{cd} \pm 0.61$	$3.59^{a} \pm 0.00$
4	3	4	75	0.77^{c}	249.50^{ab}	6.00	73.50^{b}	39.75^{cd}	5.28^{bcd}	11.29^{abc}	4.11^{e}

				±0.01	±4.95	±0.00	c ±0.71	±1.77	±0.69	d ±0.89	±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 means ± Standard deviation. Mean in the same column with different superscripts are significantly different ($p<0.0$).

Keys: 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.

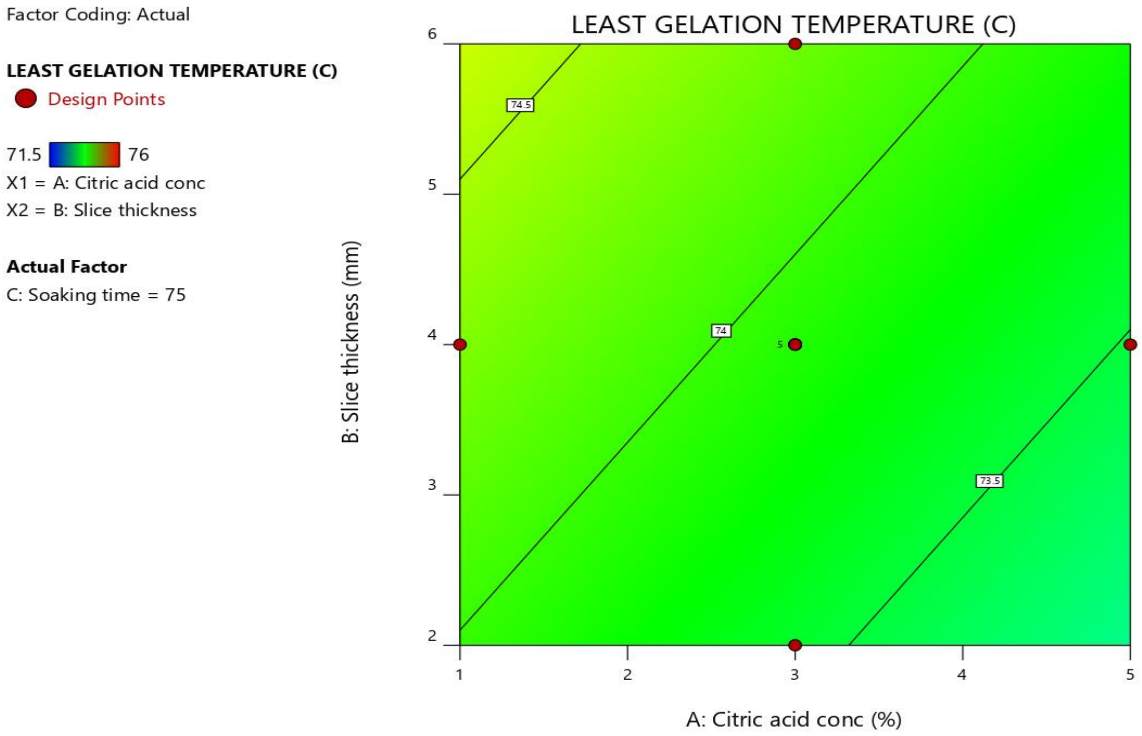


Figure 1. Contour plot for least gelation temperature of the plantain flour sample

The least gelation temperature was modeled as shown in Equations 1 and 2.

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

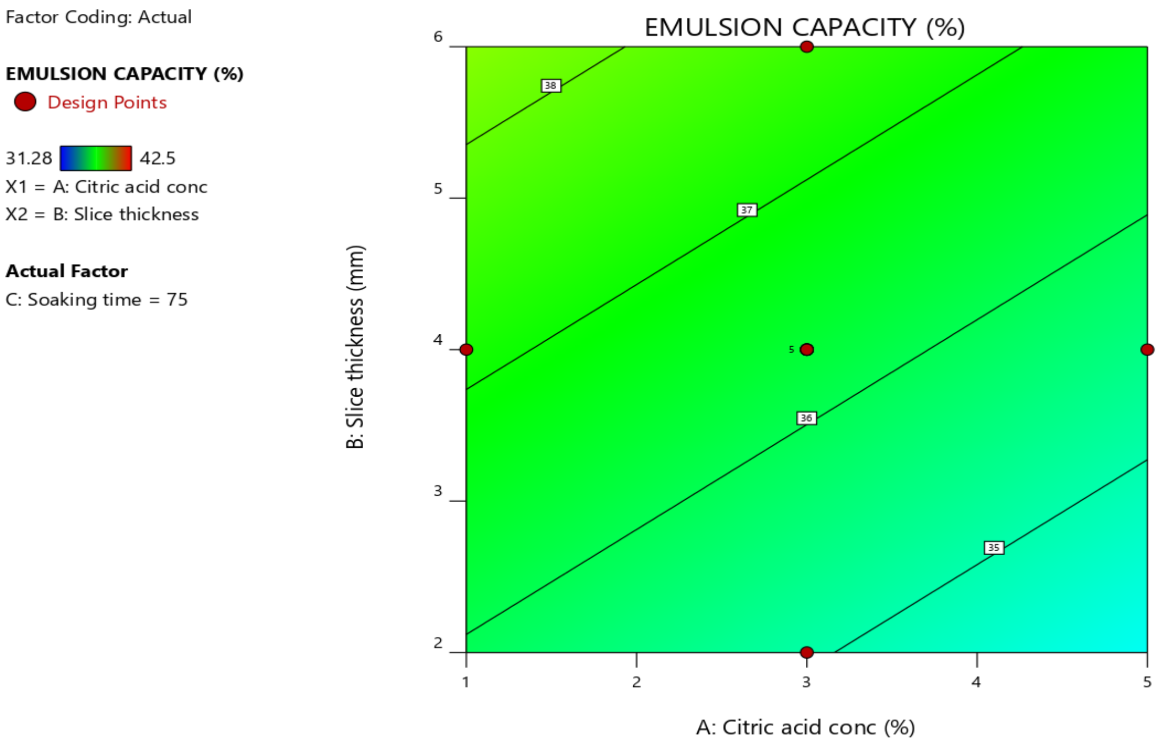
α is the intercept, A and C represent citric acid concentration and soaking time respectively. Figure 1 represents the contour plot for the least gelation temperature (LGT). Equations 1 and 2 explain the least gelation temperature as a function of the citric acid concentration (A) and the soaking time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

Both the citric acid concentration and soaking time influenced the least gelation temperature. From the model, 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 has a greater effect as compared with the 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 %) and this 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 is suggesting a high interpretation that the model is a true representation of the relationship between the least gelation temperature and the citric acid concentration and the 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 ^oC

The emulsion capacity of the treated plantain flour had a significant difference between the samples ($p<0.05$) and values ranged from 31.28 % as obtained from sample 1 to 42.50 % for sample 11. From the results, it can be deduced that lower steeping time resulted in higher emulsion capacity and vice versa.

From the analysis done by Oluwatonyin (2017) whose values ranged from 17.86 – 39.84 %, emulsion capacity and stability of the blanched samples were generally lower for the blanched samples than the un-blanched control sample, and hence decreasing with increasing heat. This could be a result of the heat of blanching.

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



The model equation for emulsion capacity is presented in equations 3 and 4. Eq.3 is the ideal model, while Eq. 4 shows the model with the coefficient of C substituted for β_3. The equations showed that only the steeping time (C) has a significant effect on the emulsion capacity. From equation 4, increasing the steeping time would decrease 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 – 4.3 %, and the slice thickness reduced from 5.3 – 3.8 mm, the emulsion capacity decreased from 37 to 38 %. The R^2 adjusted is moderately high (53.39 %) and is 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 ($p< 0.05$). Values for the solubility of the plantain flour ranged from 4.31 – 6.62 % with samples 14 and 3 having the least and maximum values respectively. The result obtained from this research is similar to that obtained by Arisa et al.

(2013) in their report with values ranging from 4.67 – 6.80 % and Oluwatonyin (2017) whose values ranged from 4.14 – 5.89 %. Equations 5 and 6 show the regressions for solubility. Figure 3 represents the contour plot for the solubility of the plantain flour samples.

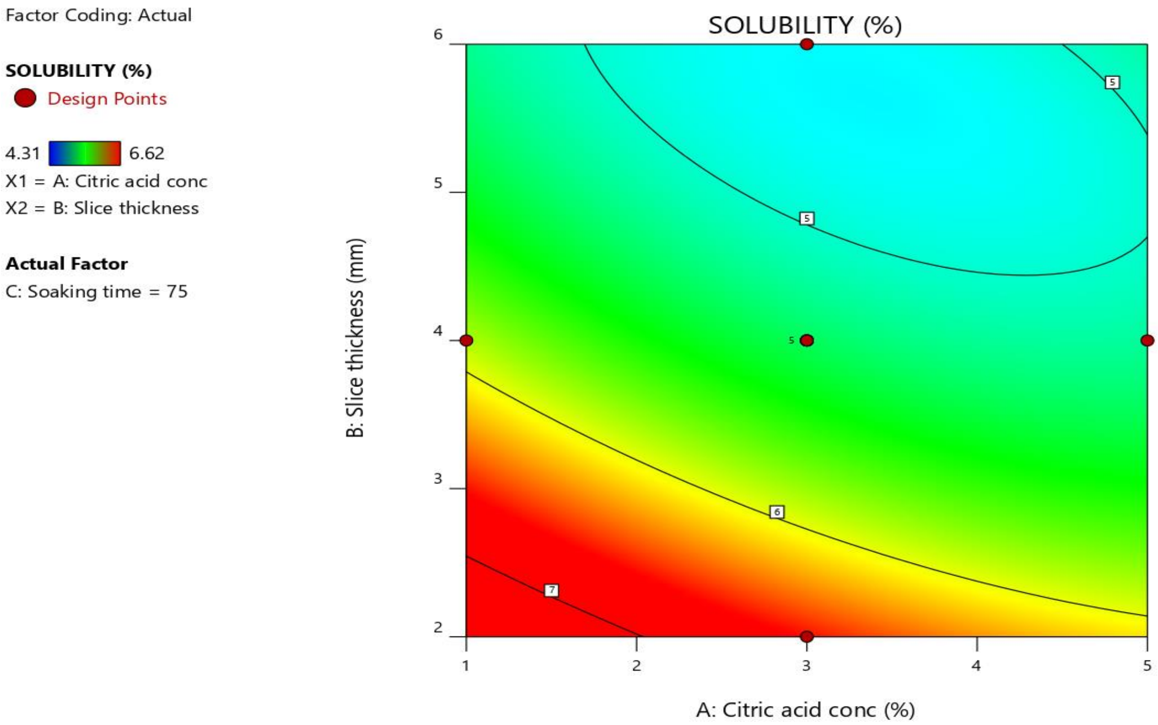


Figure 3. Contour plot for solubility for the plantain flour samples

An increase in both the slice thickness and steeping time had 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 is very high (89.72 %). This implies that the model is adequate and hence explains the true relationship between the solubility and the slice thickness and steeping time. From the equation, increasing the slice thickness would reduce the solubility; however, increasing the square of the slice thickness as well as the steeping time will 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 result of this analysis shows that the different process variables caused slight aggregation of the starch granules to different levels and hence affected the level of its exposure and its 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 from this research were quite higher than that obtained by Ijeoma et al. (2014) whose values ranged from 2.07 – 5.20 %. On the contrary, Arisa et al. (2013) and Fadimu et al. (2018) obtained very much higher values ((38.18 – 48.89 %) and (31.85 – 39.54 %)) in their research.

The pH values as indicated by the results ranged from 3.59 – 4.69. There were significant differences ($p<0.05$) in the pH 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 and this is a result of the citric acid pretreatment. However, the pH results obtained in this research are lower than that seen in the analysis done by Ijeoma et al. (2014) with values ranging from 6.24 to 6.88. The regressions for pH are shown in Equations 7 and 8.

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

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

R^2 adjusted = 99.65 %

Figure 4 represents the contour plot of pH for the plantain flour samples. The citric acid concentration, slice thickness and steeping time affected on the pH. The pH was also influenced by the interaction between the citric acid concentration and slice thickness, citric acid concentration and steeping time and the 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 the citric acid concentration and slice thickness and the slice thickness and steeping time and the squares of the slice thickness and steeping time would increase the pH of the plantain flour samples with the steeping time having a greater effect.

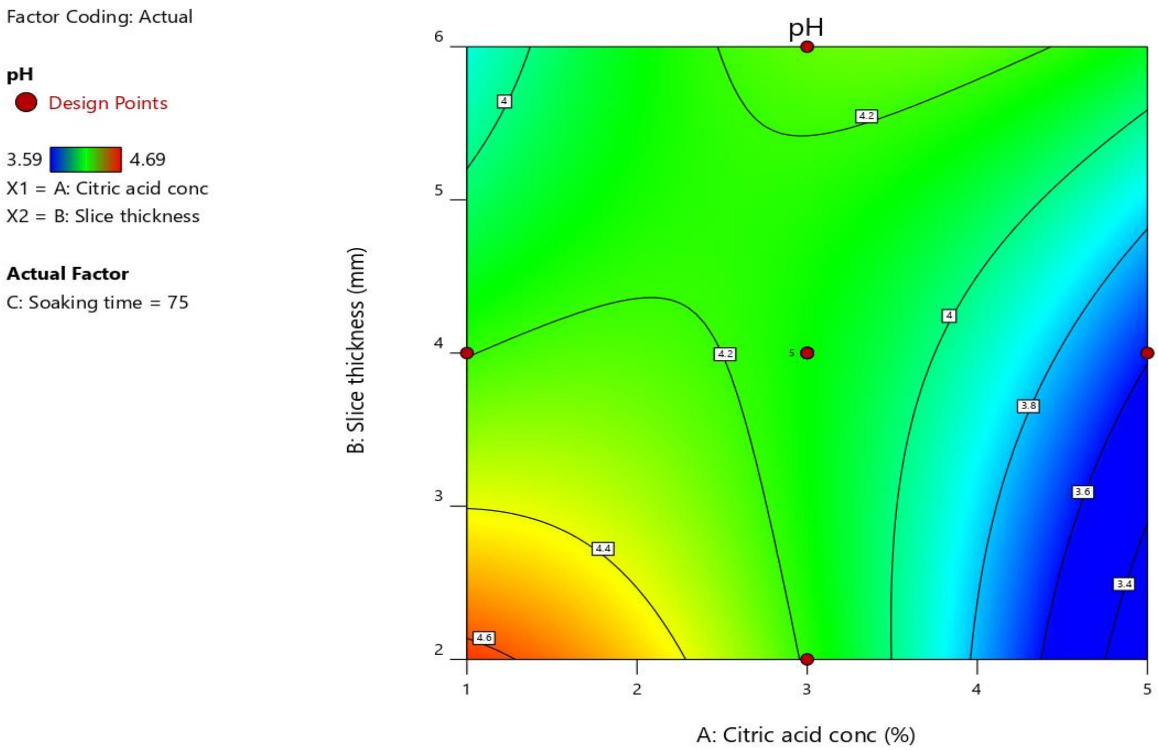


Figure 4. Contour plot of pH for the plantain flour samples

From the contour plot, in case 1, when the citric acid treatment increased from 1.3 - 2.3 % and slice thickness increased from 2.1 – 2.95 mm, the pH decreased from 4.6 – 4.4. While in case 2, when the citric acid is increased from 3.9 – 4.4 %, and the slice thickness is decreased from 4.8 – 3.9 mm, the pH decreased from 3.8 – 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 so explains the relationship between the citric acid concentrations, 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 the pH and the interaction effect.

4.3 Sensory properties

The results of the mean scores obtained for the different parameters are shown in Table 4. The results showed that there were significant differences (p<0.05) in the mean score for all sensory attitudes as scored by the panelists. It was observed that the majority of the panelist 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 the product 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 means ± 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) on the aroma of the flour samples. The result for aroma ranged from 2.80 – 4.90. Figures 5 and 6 are the contour plots of aroma. The regression models are represented in 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 aroma. Increasing the stepping time would reduce the aroma of the plantain flour sample. The R^2 adjusted is moderately high and hence shows a true representation of the relationship between the aroma and steeping time in the model. From Figure 5, when the citric acid concentration increased from 1.8 – 4.0 % and the slice thickness increased from 3.1 - 5.6 mm, the aroma decreased from 4.4 – 4.0.

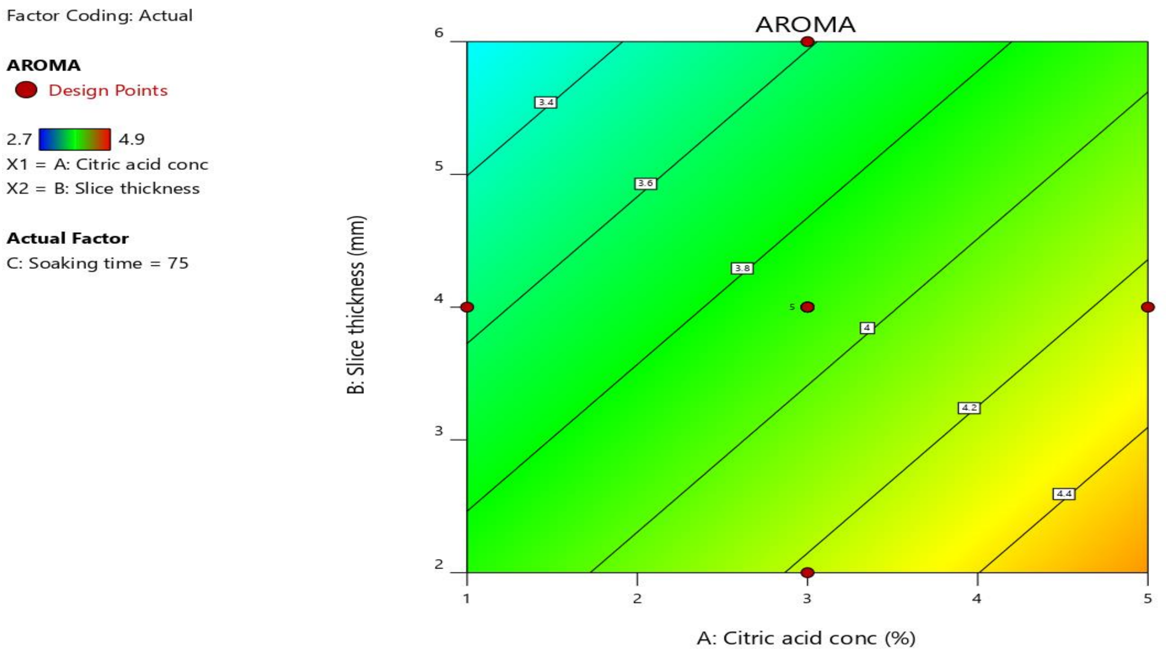


Figure 5. Contour plot for the aroma of the plantain flour samples; case 1

But from the contour plot (Figure 6), when steeping time is increased from 78 – 112 min and the citric acid concentration is reduced from 4.7 – 1.8%, the aroma decreased from 3.5 – 3.0. This suggests that increasing the citric acid concentration would increase the aroma and vice versa.

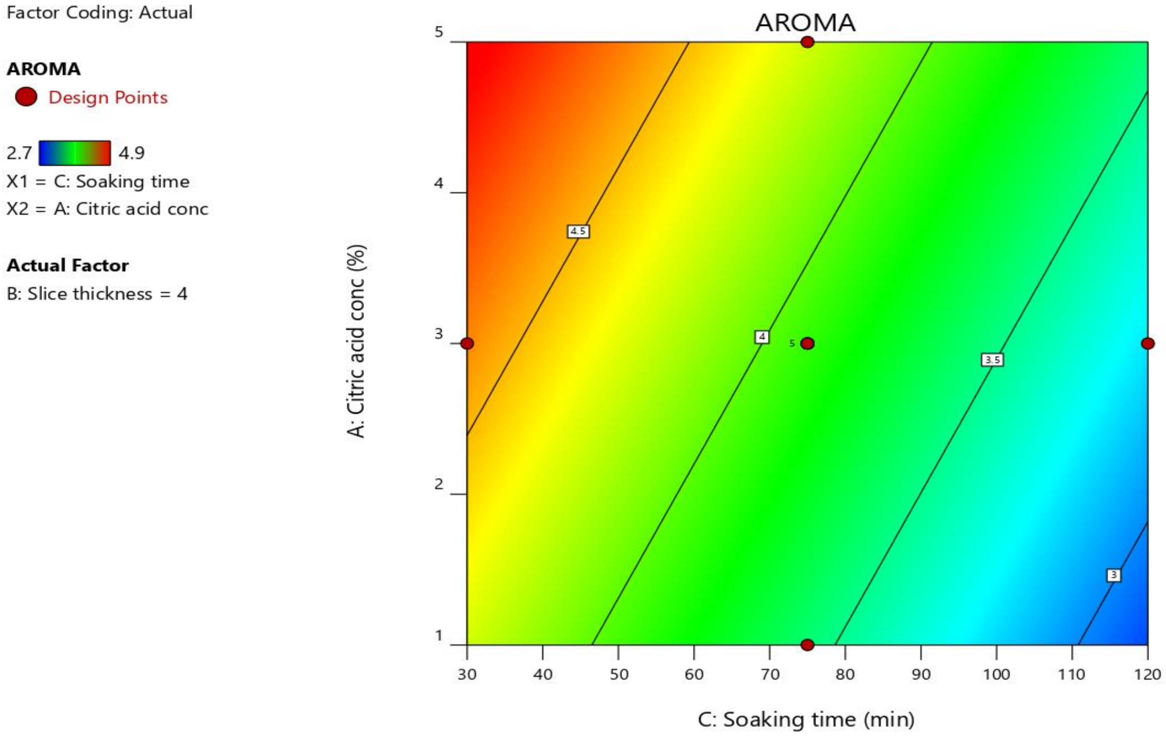


Figure 6. Contour plot for the aroma of the plantain flour samples; case 2

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

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

From the regression equation, both the slice thickness and interaction between the citric acid concentration and steeping time had a significant effect on the moldability of the plantain flour. Increasing both factors would increase moldability. However, the interaction between the citric acid concentration and steeping time would have a greater effect on moldability as compared to the slice thickness. From Figure 7, when the citric acid concentration is increased from 1.7 – 2.4 %, and the steeping time increased from 44 – 70 min, the moldability is reduced from 7 – 5.

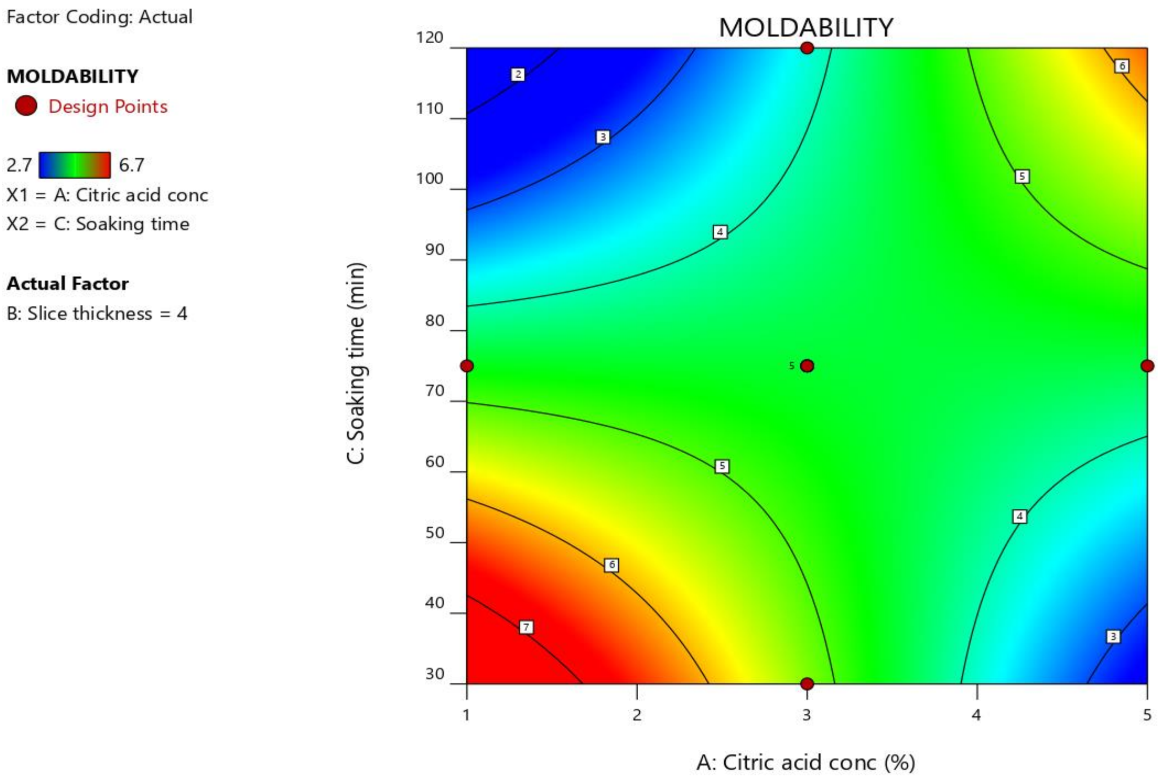


Figure 5. Contour plot for the aroma of the plantain flour samples; case 1

When the citric acid concentration is increased from 1.5 – 3.2 %, and the steeping time increased from 84 - 112 min, the moldability increases from 2 – 4. When the citric acid concentration is increased from 3.9 – 4.6 % and the steeping time is reduced from 64 – 42 min, the moldability is reduced from 4 – 3. The results of the analysis on texture showed that there was a significant difference ($p<0.05$) in the texture of the plantain flour samples. Variation in texture could be a result of the difference in the particle size. Scores for texture ranged from 2.60 – 5.70. Sample 12 had the best score for texture which indicates a smaller particle size as compared to 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 for texture is shown in Figure 8. The regression equations for texture are represented by 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 %.

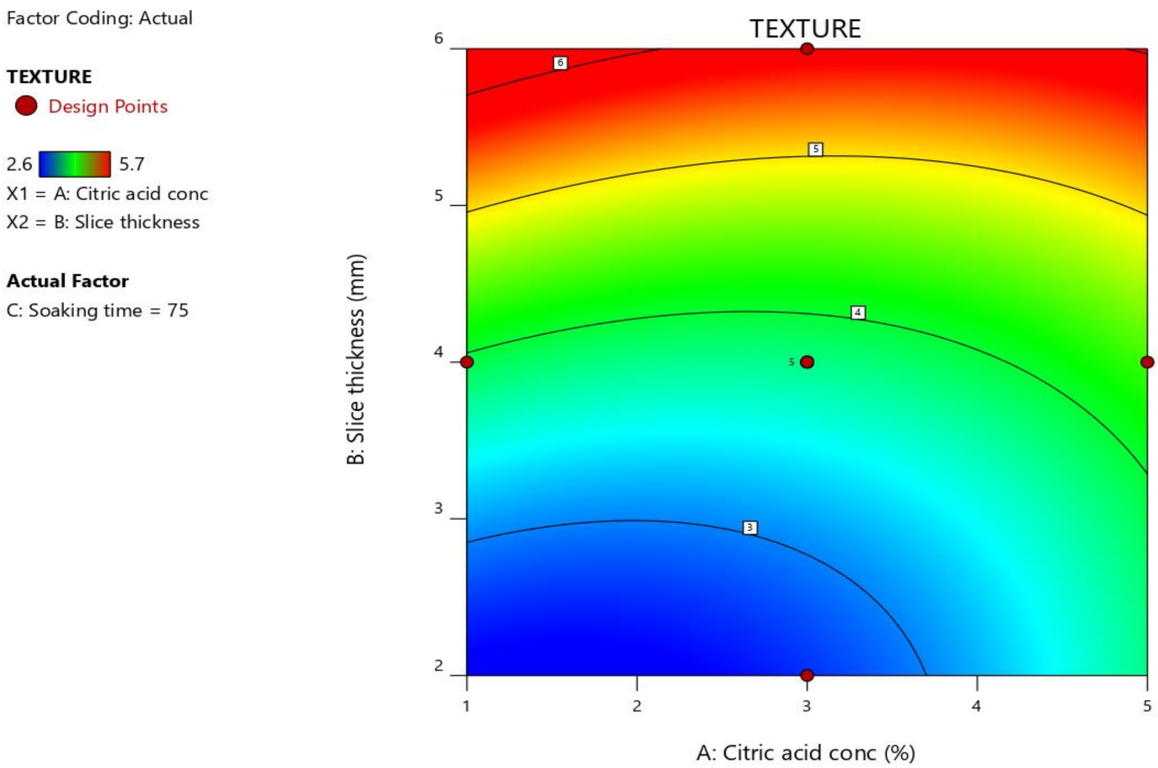


Figure 8. Contour plot for the texture of the plantain flour samples

The texture was influenced by the slice thickness and the interaction between the citric acid concentration and the steeping time, with the interaction between the citric acid concentration and the steeping time having a greater effect. Increasing both parameters would increase the texture of the plantain flour sample. The R^2 adjusted is very high and this 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 – 3.7 % and reducing the slice thickness from 5.7 – 2.8 mm, the texture decreased from 6 – 3.

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

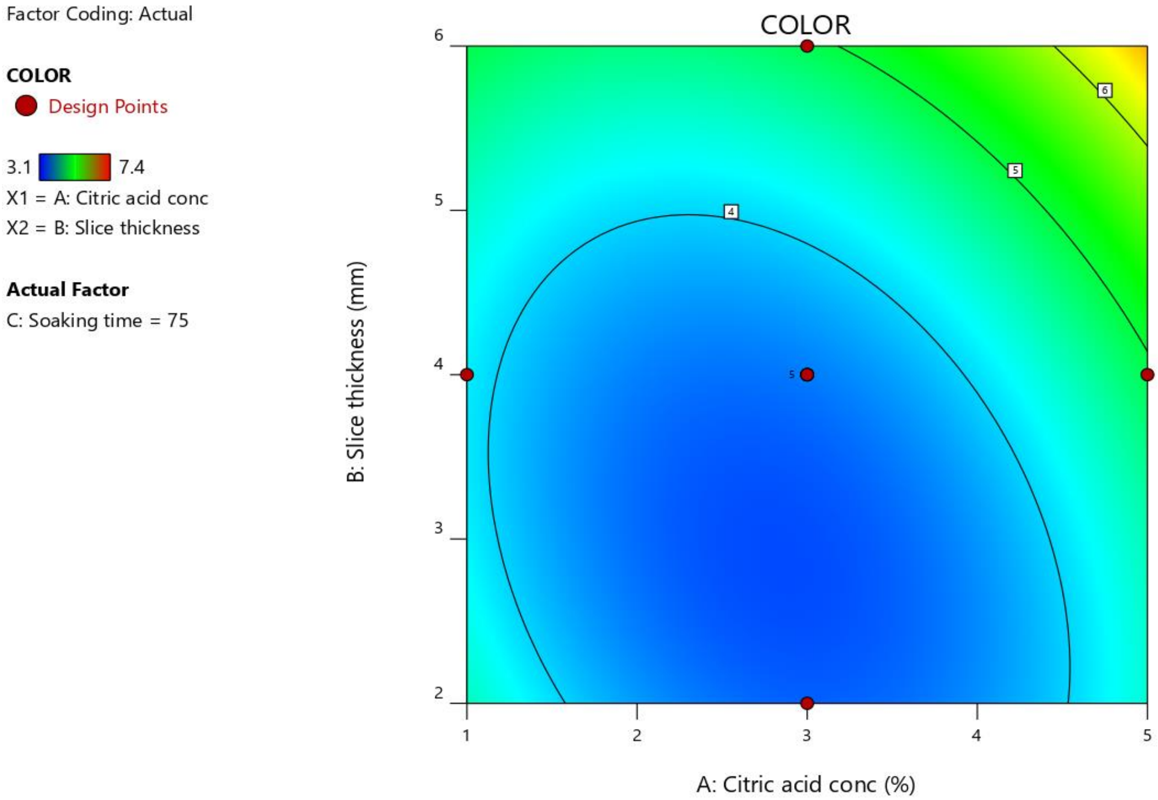


Figure 9. Contour plot for the color of the plantain flour samples

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

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

The results obtained from the analysis show that there was a significant difference ($p<0.05$) in the overall acceptability. The values ranged from 2.80 – 6.50. Sample 15 (3 % citric acid, 2 mm slice thickness, and 75 min steeping time) had the best overall acceptability while sample 7 (1 % citric acid, 2 mm slice thickness and 30 minutes 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 overall moldability are represented by Equations 16 and 17. The contour plot for overall acceptability is represented in Figure 10.

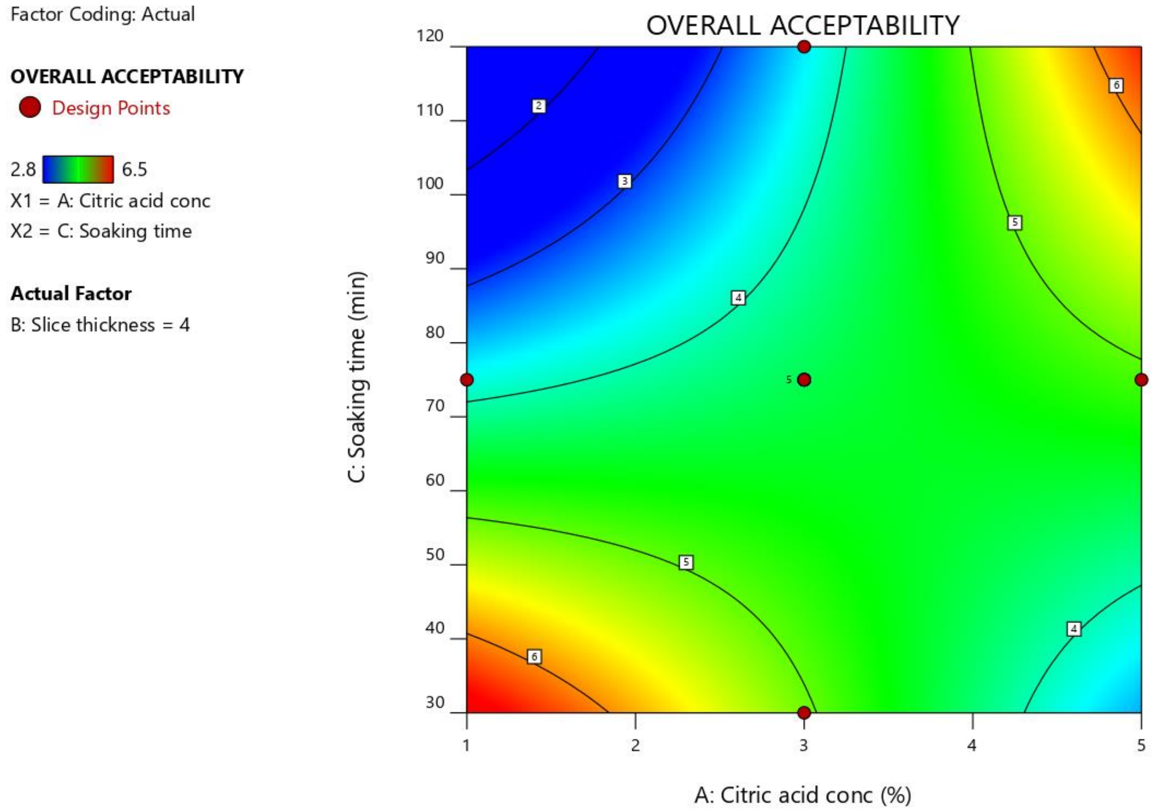


Figure 10. Contour plot for overall acceptability for the plantain flour sample

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

The overall acceptability was influenced by the interaction between the citric acid concentration and the steeping time. As this interaction increases, the overall acceptability increases. The model is adequate because R^2 adjusted is high.

From Figure 10, when the citric acid is increased from 1.8 – 3.1 % and the steeping time is increased from 41 – 56 min, the overall acceptability decreased from 6 – 5. When the citric acid is increased from 1.8 – 3.3 % and the steeping time is reduced from 104 – 73 min, the overall acceptability is increased from 2 – 4. When the citric acid concentration is increased from 4.0 – 4.7 % and the steeping time from 78 – 107 minutes, the overall acceptability increased from 5 – 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.

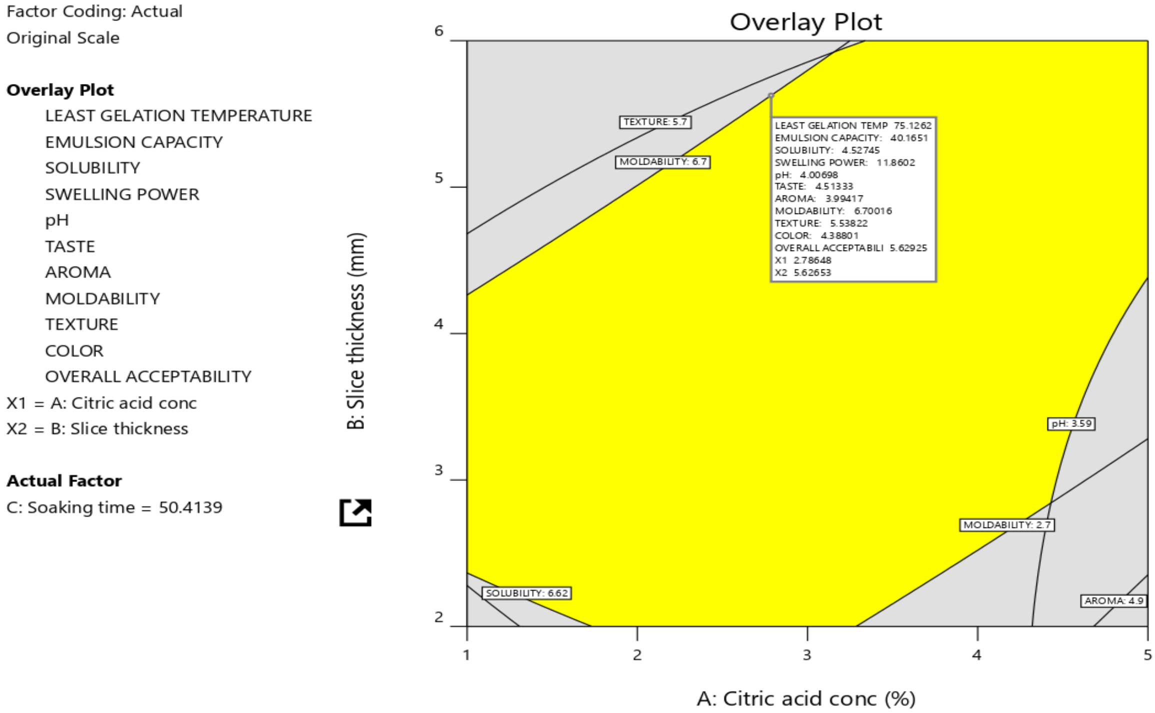


Figure 11. Optimization plot at the soaking time of 50.41 min

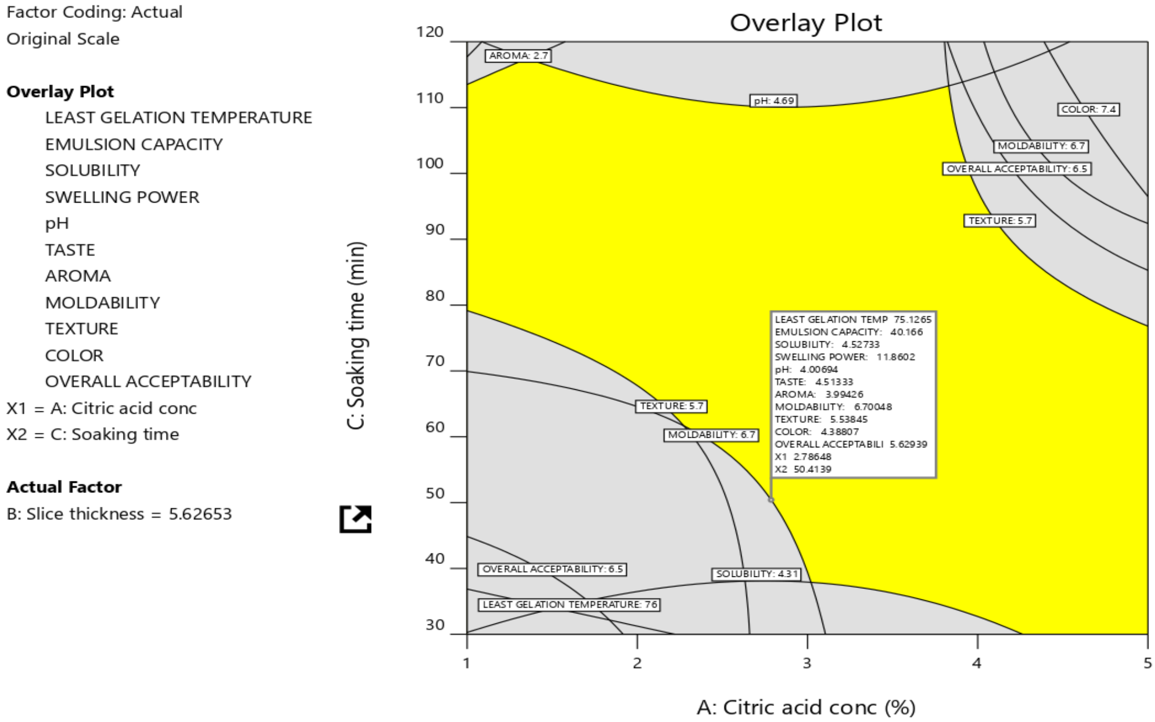


Figure 12. Optimization plot for slice thickness of 5.63 mm

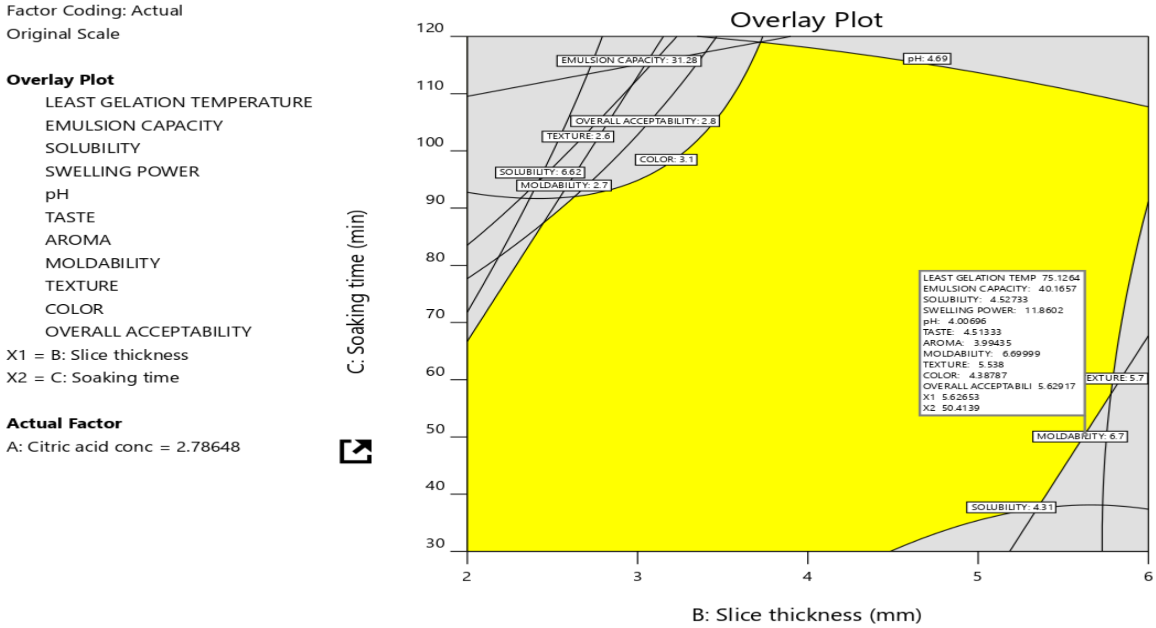


Figure 13. Optimization plot for the citric acid concentration of 2.79 %

It shows that if the selected optimum critical values of citric acid concentration of 2.77 % and slice thickness of 5.63 mm and soaking time of 50.41 minutes 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 carry out the optimization of 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 the responses that exhibited significant models and have been expressed in 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 value selected then gave the process variable combinations that would result in the optimized properties of plantain flour. The result obtained showed the following properties: Least gelation temperature = 75. 12 ºC, 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, colour = 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 at the fixed soaking time, slice thickness and citric acid concentration respectively.

5. Conclusion

This study showed that pretreatments given to the plantain slices had significant effects on the flours produced ($p<0.05$). The functional properties for all the plantain flour samples were significantly different ($p<0.05$). The results of the functional properties showed that high values for water absorption capacity, bulk density and swelling power were observed in samples 1, 2, 15 and 3 and this makes 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. It was observed that as the steeping time increased, the gelation temperature reduced. 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 store better than others because of its low moisture content as compared to the other samples. Sample1 is low in fat content and relatively high in ash content, making it a desirable alternative for people who seek low-caloric foods. The low protein content of sample 12 makes it suitable for people with a renal condition that do not easily metabolize proteins

It is therefore recommended that optimum critical values of citric acid concentration of 2.77 %, slice thickness of 5.63 mm and soaking time of 50.41 min could be employed in the production of plantain flour so that the flour should exhibit optimal functional and sensory properties. Future researchers should study the effect of packaging materials on the stability of plantain flour processed with citric acid. 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 algorithm and particle swarm optimization in estimating the optimum points. Future studies could focus on these areas.

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