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Product and process development of mango flakes using response surface methodology

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Abstract

Mango fruit (***Mangifera indica L***.) is one of the tropical fruits which are produced in large volumes in Kenya. Transformation of the perishable fruit into shelf-stable nutritious products is one of the interventions that can be used to reduce losses while accruing better returns for farmers. The objective of this study was to determine the optimum processing parameters in the production of consumer-acceptable mango flakes. Fifteen treatments were obtained using sugar variations of 0%, 2%, and 4%, and starch at 0%, 10%, and 20%. Process variables were determined by varying pressure of steam (0.8 BAR, and 1.6 BAR) and speed of drum drying (2.2 rpm and 7.6 rpm). Sensory analysis was done using a 7-pointer hedonic scale while physicochemical, and proximate lab analysis was done using predetermined AOAC procedures. Response Surface Methodology (RSM) of Design Expert 13 software, was used to optimize mango flakes production procedures by adjusting settings of factorial variables. Results indicated that formulations that were incorporated with 20% starch, 0% sugar, and dried at 7.57 rpm for 5 minutes and 2 seconds at a constant gauge pressure of 0.8 BAR were the most preferred with a mean overall score of 5.79. Homogeneity of variances was observed between different formulations for overall acceptability (*P=0.192*). The predictive model of the Central Composite Design stipulated that an increase in sugar concentration reduces the sensory quality of drum-dried mango flakes. Nutritional profile of the most acceptable mango flakes was a composite of 1.9g/100g, 2.8g/100g, 0.9g/100g, and 0.5g/100g for carbohydrates, vitamin C, crude protein, and crude fat, respectively. A significant difference was observed between values for protein and vitamin C (*P=0.002*). In conclusion, the organoleptic acceptability and nutritional profiles of drum-dried mango flakes were affected by the time: pressure exposure of the puree as well as the product ratios of ingredients.

Keywords: *drum-drying; mango flakes; Optimization; postharvest; processing; sensory; value addition*

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Introduction

Mango fruit (*Mangifera indica. L*) is a common fruit produced in the tropical regions. According to Mitra (2016) mango farming is estimated to be taking place in over 100 countries worldwide with an estimated production volume standing at 40 metric tons. Its production is characterized by both small scale and large-scale farming. In Kenya, mangoes are considered one of the high production potential fruits which can survive a wide range of ecological zones. Mangoes can grow in semi humid areas as well as in the semi- arid regions (Mitra, 2016). In mango production, there are two important factors to be considered; a dry period to facilitate flowering, and exposure to sufficient heat for ripening with the main growing seasons in

Kenya recorded between November to April, and between May to July. (Fresh Plaza, 2019). Mango production has not only improved farmers' livelihoods but has also positively impacted growth of food industries through production of mango products. Mango processing in Kenya is carried out by medium, small and micro enterprises which play an important role in boosting food security, as well as preventing reducing post-harvest losses (Owino and Ambuko, 2021). However, despite the potential of mangoes to enhance food security in developing countries, their utilization has not been fully exploited.

In Africa, it is estimated that postharvest losses account for over 50% of the produced mangoes especially during harvesting (Owino and Ambuko, 2021). Postharvest management is one of the interventions that aims at mitigating effects of these losses. Generally, postharvest management of perishable horticultural food products determine their nutritive value, sensory quality and visual standards (Nazah, 2015). All the above-mentioned factors contribute to the safety of the products. In the case of mango value chain, post-harvest losses which can be attributed to lack of enough modern processing technology has been a bottleneck in the maximization of the fruit's economic and nutritional potential. Another challenge is its seasonal availability and that is beside its high perishability. Waste products from mango processing, which are a composite of peels and seeds are among the leading agro-industrial wastes worldwide with about 123000 metric tonnes recorded every year. However, research has indicated that these wastes have the potential to industrial applications through value addition (Wall-Medrano *et al.,* 2020). Mango harvesting in Central and Eastern parts of the country is at its peak between the month of December and March while in the Coastal region, mangoes are in plenty between the month of November and December (Kehlenbeck *et al.,* 2010). Lack of knowledge on the appropriate mango varieties for the different ecological zones is another drawback in optimization of its production volume in Kenya. Currently, mango varieties available in Kenya include, Apple, *Ngowe*, *Keitt, Van Dyke*, *Sensation*, *Sabine*, *Haden*, and *Maya* (Muchiri *et al.,* 2012). The later can be attributed to inadequate dissemination of mango varieties that were introduced from foreign countries such as Australia, USA, and Israel. This is because the new commercial mango varieties were introduced in the 1980s from the above-mentioned countries but farmers were not sufficiently trained on the proper agro-ecological zones for the specific new varieties.

Mangoes possess good nutritional contents such as carotenoids, minerals and antioxidants (Yamato *et al.,* 2020). Even though value addition is important in realizing its nutritional and economic potential, some of the processing methods used for production of various mango products lead to nutritional losses (Mishra *et al.,* 2021). Effective preservation of mango pulp can be achieved using chemical preservatives such as sodium benzoate, and potassium metabisulfite at suitable concentrations. These preservatives have antimicrobial effect that can prolong the shelf life of mango puree. However, these preservatives have some negative effects on the sensory characteristics of fresh mango products as observed in mango juices (Siddiq *et al.,* 2017). Nutritive deterioration of mango products can be as a result of many factors. One of these factors is exposure to high temperatures. Optimization of heat treatment plays a major role in determination of the quality of different mango products (Lofti *et al.,* 1996).

There are diversified products that can be processed from the different varieties that are found in Kenya. These include but not limited to juices, puree, chutney, jam, dried and canned mangoes. However, in the recent past, dried mango products have continuously gained popularity among consumers. This may be associated with their shelf stability, as well as sensory appeal, making them consumable as healthy snacks. Mango flakes are one of the products that can be produced from mango fruits. When compared to other mango products such as juice, puree, and concentrates, mango flakes can stay for long without spoilage due to the reduced water activity (Kim *et al.,* 2009). Flakes production through drum drying has shown to be effective in that it has a high nutrient retention as well as its benefits in terms of cost effectiveness (Yamato *et al.,* 2020).

Optimization refers to the variation of certain production conditions and raw materials' parameters in order to minimize or maximize pre-defined criteria such as product quality or profitability (Banga *et al.,* 2003). In the production of mango flakes, the process is constrained to certain conditions to enable maximization of desirable outcomes such as their nutritional value and microbiological safety. Additionally, the optimization process has to be systematic and efficient to reduce errors that may lead to wastage. There are many states of the art methods of optimizing product processes. Response Surface Methodology is a mathematical and statistical tool that has been widely used for analyzing and modelling processes in which responses of interest are affected by independent and dependent variables (Aydar, 2018).

Materials and methods

Mangoes acquisition and preparation

Ngowe and apple mango varieties, 14.5 kgs and 17.5 kgs respectively, were bought from local markets and processed in the food processing hub at the department of Food Science, Nutrition and Technology-University of Nairobi. The mangoes were stored in open carton boxes for 24 hours at a room temperature (25°C), prior to product development. The processing involved cleaning, peeling, slicing, pulping, product formulation and drum drying. Upon pulping of the obtained mangoes and pasteurization of the pulp, formulations were made from varied ratios of starch, sugar, and mango pulp. Mango flakes were developed from two mango varieties; *Ngowe*, and Apple through drum drying.

Yield

Calculation of the total percentage yield from the pulping process was done using an adopted formula which was initially used by Aydar et al. (2018) in the extraction of olive oil from olive fruits. Table 1 summarizes the total yield from the process. The extraction formula is as follows:

Yield= $\frac{Extracted\ pulp\ (g)}{Weight\ of\ fruits\ (g)} \times 100\%$

Table 1. Yield percentage in mango processing

	Ngowe	Apple
Fruits weight (kg)	14.5	17.5
Pulp weight (kg)	7.0	10.0
Weight of waste(kg)	6.0	6.5
Yield (%)	43	57

Pasteurization and storage

Upon storage, the pulp was pasteurized in a pasteurizer at 850C for 5 minutes. It was then cooled to 65^{0}C and packaged aseptically in 5-litre sterilized bottles. The bottles were then stored in a cold room. To prevent microbial growth and retain the color of pulp, sodium metabisulfite and potassium sorbate were both added at 250 ppm.

Product formulation

The optimization process involved varying a number of parameters against the two mango varieties. During the formulation phase, sugar and corn starch concentrations were varied. Three samples were obtained from starch concentration variation. The subsequent concentrations were 0%, 10%, and 20% starch. Samples from sugar content variation were formulated with 0%, 2%, and 4% sugar. Formulation with corn starch was achieved by pasteurizing the mixture of pulp and starch to a gelatinization temperature of 60°C.

Drum drying

Pureed formulations were dried over a steam heated drum dryer (model number BK.2406.C) of an area of 0.2847 m^2 to produce sheets of drum dried mango flakes. The samples generated from sugar and corn starch alterations were processed at constant conditions of speed, pressure, and time (31.2781 rpm, 4 BAR, and 5 minutes 2 seconds respectively). Speed of drum dryer was calculated by the formula: rpm= Surface feet per minute (sfm) ÷ diameter ×3.82 ((Piyarach *et al.,* 2021).

Modification was done on the speed of the drum dryer, and pressure of steam. Two samples of each of the above-mentioned parameters were derived with gauge pressure variation set at 0.8, and 1.6 (BAR). Speed was adjusted to 7.57 rpm and 4.2 rpm. The samples were given random numbers of ZBY and NFX for speed variation and FYB and BYA for gauge pressure variation.

Sensory analysis

Sensory evaluation was conducted mid-morning in a sensory room. A total of 28 panelists were recruited to participate in the evaluation using a 7-pointer hedonic scale with a lower expected limit set at 4.0. Clean water was provided to each panelist to rinse their mouth between each subsequent product evaluation. Data from the evaluation was analyzed using SPSS (version 20) software and output interpreted in terms of descriptive experiments, affective testing, and difference experiments.

Statistical analysis

Sensory evaluation was done using SPSS statistical software version 21. Optimization of the processing parameters of mango flakes was done using the Response Surface Methodology (RSM) of the Central Composite Design (CCD) in the Design Expert 13 Software. Responses were assessed using the maximum and minimum sensory acceptability values that were achieved. The independent variables included ratio of ingredients, speed of drier, and gauge pressure whereas the response variables were the sensory scores. The minimum (-α) and the maximum (+α) was generated from the similar studies on other products. The CCD of the Design Expert was used to compute the Centre points and the number of runs.

Results

Age and gender of panelists

Twenty-five panelists aged between 20 and 52 years participated in the consumer sensory evaluation. The panelists' mean age was 31.3 years. Female panelists accounted for the highest percentage (80%) compared to their male counterparts (20%). Results from panelist's scores were presented in terms of standard error of means, coefficients of variations, and the least standard deviation for the sensory parameters.

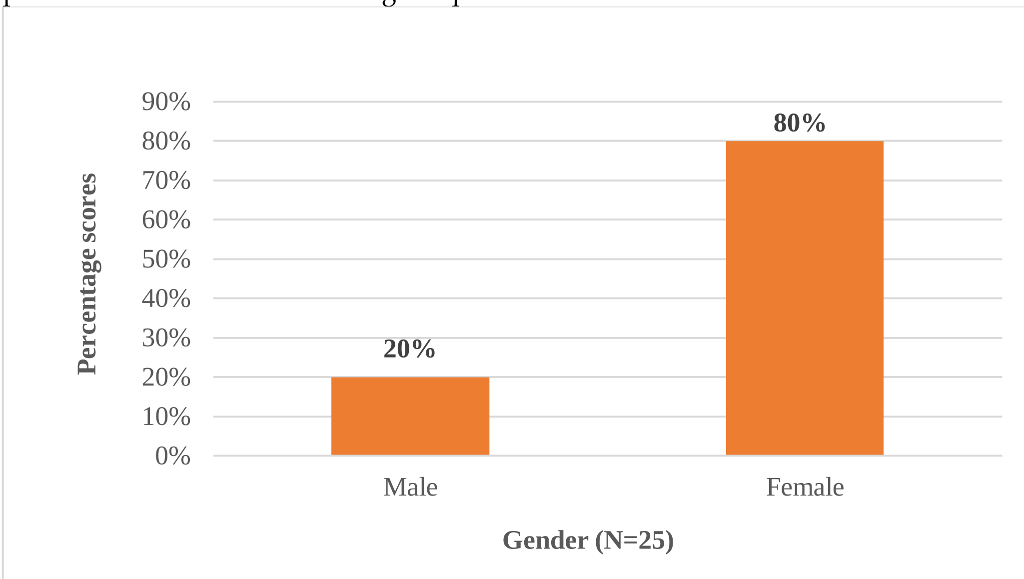

Figure 1. Level of acceptability

Products preference for overall acceptability

Results in table 2 and figure 2 below give the grand mean, standard deviation, and standard error values for the overall acceptability were 4.88, 1.652, and 0.081 respectively. The most acceptable product was KNM with a mean score of 5.79. This product was incorporated with 500g of pulp, 20% starch with 0% sugar, and processed at gauge pressure of 0.8 BAR. Products FZB and FYB had equal preference with a mean score of 5.04. The same case was observed for product ZBY, and MFX which had a mean score of 4.96. Product YFX, which was the placebo of the group, was the least preferred of all.

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	3.96	1.953	0.369	3.21	4.72
BZN	28	4.86	1.508	0.285	4.27	5.44
NXN	28	4.11	1.833	0.346	3.40	4.82
FZB	28	5.04	1.774	0.335	4.35	5.72
ZBY	28	4.86	1.627	0.307	4.23	5.49
NFX	28	4.07	1.804	0.341	3.37	4.77
FYB	28	5.04	1.201	0.227	4.57	5.50
BYA	28	4.96	1.374	0.260	4.43	5.50
KZM	28	5.43	1.665	0.315	4.78	6.07
NDB	28	5.00	1.700	0.321	4.34	5.66
FAN	28	5.18	1.492	0.282	4.60	5.76
MFX	28	4.86	1.433	0.271	4.30	5.41
DYY	28	4.50	1.795	0.339	3.80	5.20
KNM	28	5.79	1.397	0.264	5.24	6.33
GBK	28	5.61	1.100	0.208	5.18	6.03
Total	**420**	**4.88**	**1.652**	**0.081**	**4.72**	**5.04**

Table 2. Overall acceptability

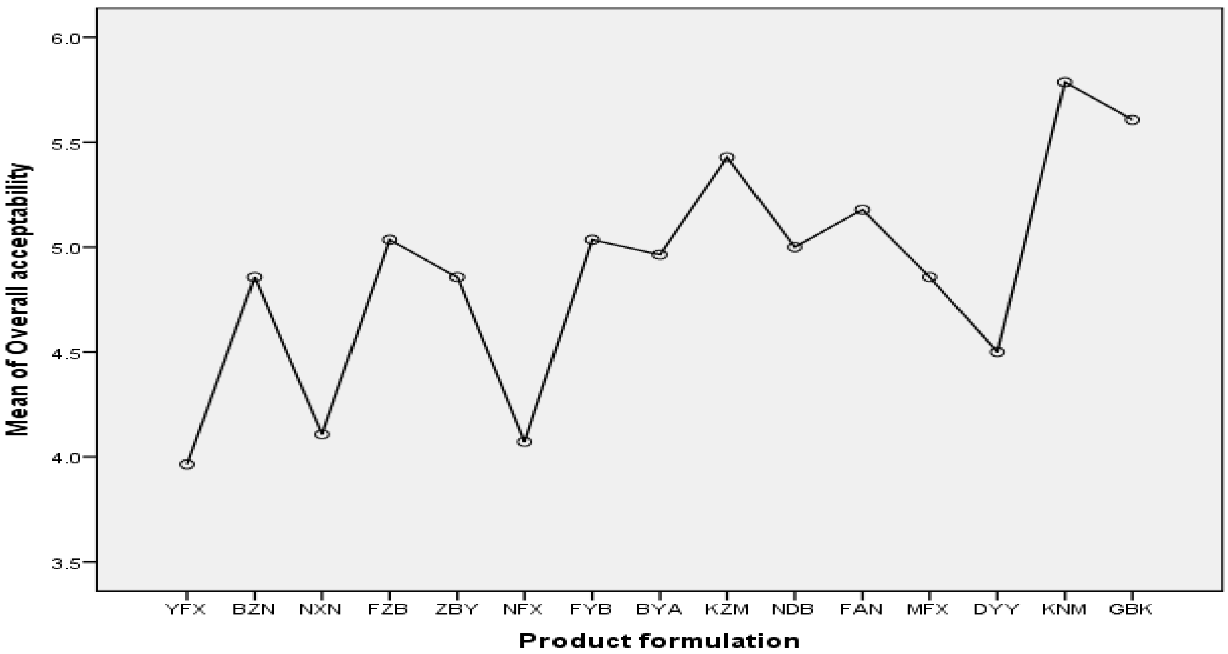

Figure 2. Sensory acceptability of mango flakes

Product preference for crunchiness

Results in Table 3 below indicate that the grand mean for crunchiness was 4.82 with a standard deviation of 1.65. The crunchiness of product GBK was the most acceptable with a mean score of 5.71. Product YFX scored the least with a score lower than the minimum expected score of 4.0 (3.64). Levene statistical test indicated that there was homogeneity of variances between the different formulations (P=0.192). Generally, GBK was formulated with 500g of pulp from apple mango variety, 20% corn starch with 0% sugar. Drum drying of the product was done at 1.6-gauge pressure at constant conditions of time and temperature.

Table 3. Results for sample crunchiness sensory evaluation mean values

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	3.64	1.682	0.318	2.99	4.30
BZN	28	4.89	1.474	0.279	4.32	5.46
NXN	28	4.29	1.652	0.312	3.65	4.93
FZB	28	5.07	1.741	0.329	4.40	5.75
ZBY	28	4.68	1.701	0.321	4.02	5.34
NFX	28	3.68	1.827	0.345	2.97	4.39
FYB	28	5.07	1.215	0.230	4.60	5.54
BYA	28	4.89	1.423	0.269	4.34	5.44
KZM	28	5.07	1.720	0.325	4.40	5.74
NDB	28	5.14	1.508	0.285	4.56	5.73
FAN	28	5.18	1.786	0.337	4.49	5.87
MFX	28	5.04	1.319	0.249	4.52	5.55
DYY	28	4.39	1.685	0.318	3.74	5.05
KNM	28	5.50	1.427	0.270	4.95	6.05
GBK	28	5.71	1.243	0.235	5.23	6.20
Total	**420**	**4.82**	**1.649**	**0.080**	**4.66**	**4.97**

Product preference for flavor

Results in table 4 below show the mean of different formulation varied significantly (P=0.00). The panelists rated sample KNM significantly high with a mean score of 5.89 compared to the lowest rated product NFX which had a mean of 3.61 ($P<0.05$). The grand mean score for the group in terms of flavor was 5.02 with a standard deviation of 1.6. The general composition for product KNM was 500g of pulp from *Ngowe* variety, 20% starch with 0% sugar, and processed at gauge pressure of 0.8 BAR. On the other hand, product NFX was a composite of 500g of pulp from apple mango variety, 20% corn starch with 0% sugar. Drum drying was done at a speed of 4.2 rpm.

Table 4. Results for products flavor sensory evaluation as means

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	4.86	1.693	0.320	4.20	5.51
BZN	28	5.25	1.430	0.270	4.70	5.80
NXN	28	4.54	1.688	0.319	3.88	5.19
FZB	28	5.18	1.307	0.247	4.67	5.69
ZBY	28	5.46	1.319	0.249	4.95	5.98
NFX	28	3.61	2.114	0.400	2.79	4.43
FYB	28	5.25	1.430	0.270	4.70	5.80
BYA	28	5.07	1.359	0.257	4.54	5.60
KZM	28	5.29	1.675	0.316	4.64	5.94
NDB	28	5.14	1.458	0.276	4.58	5.71
FAN	28	5.21	1.371	0.259	4.68	5.75
MFX	28	4.54	1.575	0.298	3.93	5.15
DYY	28	4.32	1.847	0.349	3.61	5.04
KNM	28	5.89	0.994	0.188	5.51	6.28
GBK	28	5.75	1.236	0.234	5.27	6.23
Total	**420**	**5.02**	**1.599**	**0.078**	**4.87**	**5.18**

Products preference for Texture

The results presented in the table below indicated that the grand mean score for the texture parameter was 5.13 with a standard deviation of 1.64. Product KNM was the most preferred in terms of texture with an average score of 6.00. The least acceptable sample was NFX which was rated at 3.29. A significant difference was observed by the panelists between the highest ranked KNM and the lowest ranked NFX (P= 0.002).

Table 5. Results for texture sensory evaluation

Sample ID	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
YFX	28	5.07	1.698	0.321	4.41	5.73
BZN	28	5.39	1.548	0.292	4.79	5.99
NXN	28	4.79	1.833	0.346	4.07	5.50
FZB	28	5.32	1.416	0.268	4.77	5.87
ZBY	28	5.29	1.536	0.290	4.69	5.88
NFX	28	3.29	2.034	0.384	2.50	4.07
FYB	28	5.21	1.315	0.249	4.70	5.72
BYA	28	5.50	1.072	0.202	5.08	5.92
KZM	28	5.46	1.503	0.284	4.88	6.05
NDB	28	5.25	1.430	0.270	4.70	5.80
FAN	28	5.04	1.551	0.293	4.43	5.64
MFX	28	5.00	1.866	0.353	4.28	5.72
DYY	28	4.46	1.666	0.315	3.82	5.11
KNM	28	6.00	1.247	0.236	5.52	6.48
GBK	28	5.89	1.166	0.220	5.44	6.34
Total	**420**	**5.13**	**1.642**	**0.080**	**4.97**	**5.29**

Process optimization using response surface methodology

The Central Composite Design (CCD) of the Response Surface Methodology (RSM) was utilized in simulation of the optimization process. This was achieved through design of models and experiments, evaluating the effects of factors, and identifying the optimum conditions for the flakes production. The numeric factors which were put under analysis were starch concentration, sugar concentration, speed of drum drying, and pressure of steam. The mean sensory scores for the different samples were used as the response variables. The design was taken through 30 experimental runs.

Table 6. Summary of fit for acceptability of mango flakes

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.2718	0.5391	0.1269	-0.3854	
2FI	0.2465	0.7308	0.4742		Suggested
Quadratic	0.7308		0.2314		Aliased

Analysis of variance was carried out to determine the effect of the independent variables on the dependent variables. The model F-value obtained was 1.35 which implied that the model was not significant relative to noise. There was a 50.23% chance that this large F-value was due to noise. The F-value in Table 3.7 below was less than 0.05 indicating that there were no significant model terms. The second order regression equation for the model that defines acceptability is given below:

Y= 5.28 – 0.6917A - 1.03B + 0.0767C + 0.5100D + 1.11AB - 0.2642AC - 0.2367AD + 0.1383BC- 0.3225BD + 0.0408CD + 0.2667A² + 0.0000B ² + 0.0000C² - 0.0367D²

$$Y = 5.28 - 0.6917A - 1.03B + 0.0767C + 0.5100D + 1.11AB - 0.2642AC - 0.2367AD + 0.1383BC - 0.3225BD + 0.0408CD + 0.2667A^2 + 0.0000B^2 + 0.0000C^2 - 0.0367D^2$$

Table 7. ANOVA results for the quadratic model

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.4600	10	0.3455	2.260	0.2241	**Not significant**
A-Starch concentration	0.2037	1	0.2037	1.330	0.3124	
B-Sugar concentration	0.7396	1	0.7396	4.840	0.0926	
C-Speed of drum dryer	0.0533	1	0.0533	0.349	0.5864	
D-Pressure of steam	1.9000	1	1.9000	12.43	0.0243	
AB	1.2200	1	1.2200	07.99	0.0475	
AC	0.1229	1	0.1229	0.804	0.4205	
AD	0.0896	1	0.0896	0.586	0.4865	
BC	0.0270	1	0.0270	0.176	0.6958	
BD	0.3788	1	0.3788	2.480	0.1904	
CD	0.0008	1	0.0008	0.005	0.9464	
Residual	0.6109	4	0.1527			
Lack of Fit	0.1644	2	0.0822	0.3683	0.7308	**Not significant**
Pure Error	0.4465	2	0.2232			
Cor Total	4.07	14				

Optimization process

The interaction of factors in this RSM model gave the region of overlaybility where the ideal conditions and parameters were applied to obtain the optimization process. In this scenario, the flexibility lies in between the yellow region for the sugar concentration formulations and the starch concentration. The minima and maxima of the plots are as shown in Figure 3.

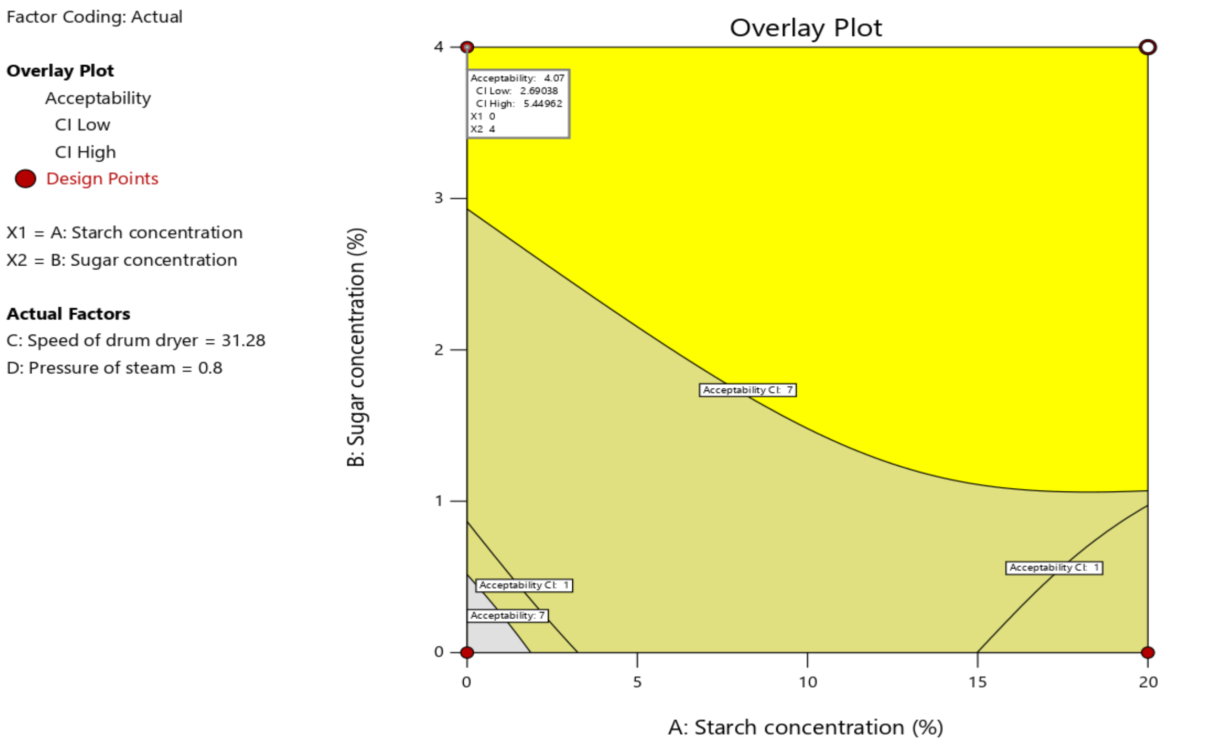

Figure 3. Optimization results for mango flakes production

Effects of changes in process factors on products acceptability

Contour graphs were used to illustrate the relationship between the factors under study. The plots in figures 3.3 and 3.4 below show how variable starch concentration and variable sugar concentration affected the overall quality of the produced mango flakes. The minima regions showed lower concentrations of starch and sugar in the products formulations. The contour levels revealed a peak percentage of 2 in B and 10 in A. The same findings were observed for the 3D contour plots. The quality scores for the above-mentioned regions were above 4.00, which was the minimum expected sensory scores in the sensory analysis. The same design experiment was done for the variable speed of drum drying and variable gauge pressure. However, although the graphs were useful in identifying the direction to increase or reduce the specific parameters, it proved to be difficult to determine the exact level of variables adjustments.

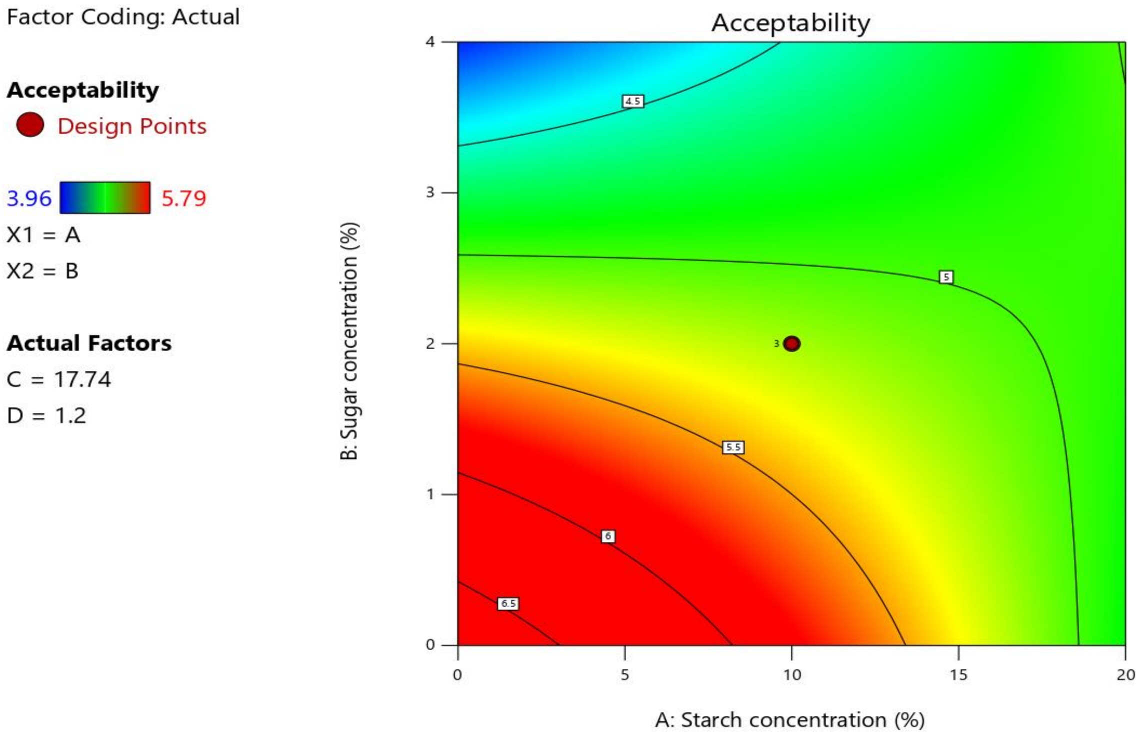

Figure 4. Model graph showing the acceptability regions for process conditions

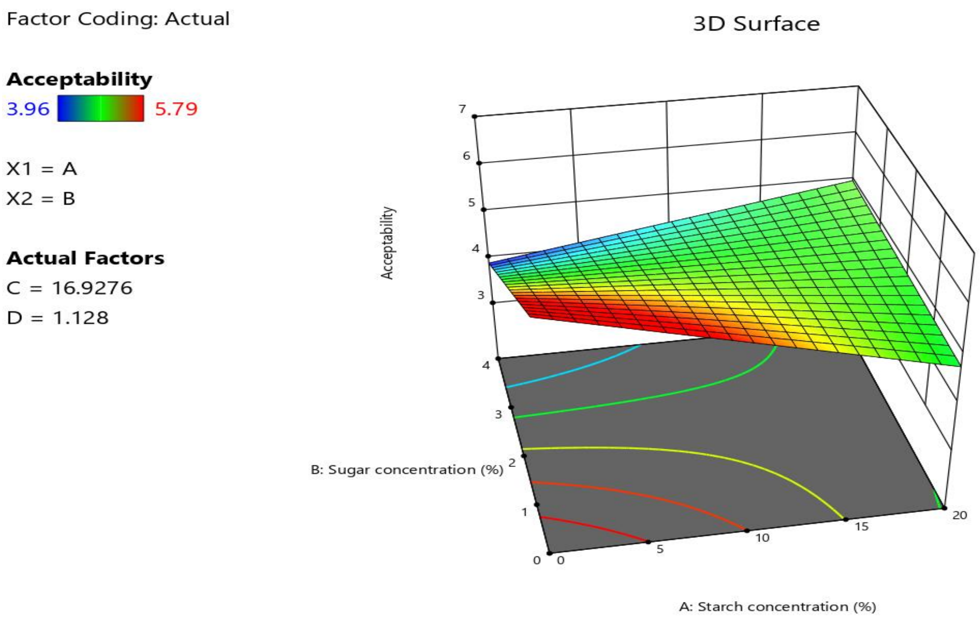

Figure 5. A 3D response surface plot simulating the changes in mango flakes acceptability with adjustment in process factor

Discussion

The response surface model is a representation of an industrial food production system that sets production parameters (Banga *et al.,* 2003). The findings from this study revealed that concentration of sugar and starch influence the consumer acceptability of drum dried mango flakes. This finding is consistent with the outcome of a research by Mwaurah *et al.,* (2020), which associated the physicochemical characteristics of starch with its effect in dissolution with mango pulp, which ultimately affects the quality of processed mango flakes. Similarly, the current study established that an increase in sugar concentration inversely affected the quality of mango flakes due to the constitution of reducing sugars, 16-18 *w/v* (fructose, glucose and sucrose) in ripe mangoes (Lebaka *et al.,* 2021). Moreover, it has been proven that addition of sugar has an effect on the quality of fruits and vegetable products (Owade *et al.,* 2021; Torres *et al.,* 2007; Yen *et al.,* 2018).

According to this study, increasing the speed of drum dryer reduces the contact time between the pureed formulation and the drum-drying plate. As a result, heat treatment is constrained leading to low quality flakes. Despite the negative effects of heat exposure on the volatile components of mangoes, heat treatment enhances dried products quality by increasing their crunchiness (Gates, 2007; Mwaurah *et al.,* 2020). Generally, the contoured model revealed that the four production parameters (sugar, starch, drum drying speed, and pressure of steam) had significance influence on the sensory quality of drum dried mango flakes. The variation recorded by the model for the overall acceptability of the drum-dried mango flakes was 50.23%. This high variation is as a result of the close relationship between the predicted and actual values as earlier described by (Banga *et al.,* 2003). The physicochemical composition of the most acceptable mango flakes was determined and the results summarized in Table 8 above. The results showed congruence with other studies (Yamato *et al.,* 2020) that reported a decrease in vitamin C, proteins while other value of some components such as minerals were retained (Maldonado-Celis *et al.,* 2019). These attributes can be associated with the heat treatment processes that lead to losses in volatile compounds. Additionally, a significant difference was observed between values for protein and vitamin C (*P=0.002*).

Conclusion

The acceptability of the mango flakes was dependent on the concentration of corn starch, speed of drum drying, gauge pressure, and the sugar content of the formulations. Generally, results from the sensory evaluation indicated that mango flakes produced from formulations of 20% starch, 0% sugar, and drum dried at speed of 7.57 rpm for 5 minutes 2 seconds at a constant pressure of 0.8 BAR were the most consumer acceptable. Additionally, the acceptability of the mango was not dependent on the mango variety. The gelatinization aspect of corn starch was used to achieve the dissolution of starch into the mango pulp. Changes in the above-mentioned factors significantly affected the sensory quality of the mango flakes. In general, the Response Surface Methodology can be useful in optimizing industrial production processes. Aside from enhancing products quality, the model can be utilized to predict the influence one production variable can have on another.

Acknowledgement

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