Effect of Process Variables on Some Physical Properties and Hydrogen Cyanide Content of Dried Cassava Slices ("abacha")

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Abstract

A 3-factor, 2-level full factorial experiment was designed and used to study the effect of some process variables (slice thickness, boiling time and drying temperature) on some physical properties and hydrogen cyanide content of dried cassava slices ("Abacha"). Freshly harvested cassava roots were washed, peeled and divided into eight groups. Each group was sliced into a selected uniform thickness of 2.70 or 2.85 mm and soaked in water for 12 h at room temperature. After soaking, it was washed and rinsed twice with water before it was dried at the selected drying oven temperature of 50 or 70°C for 12 h to obtain the dried cassava slices. These slices were subjected to moisture content, breaking force, swelling capacity and hydrogen cyanide content determinations. Coefficients of the factors generated from the multiple linear regression analyses were used to fit into mathematical models that could predict the response variables under the same experimental conditions. Factorial plots including main and interaction effects of independent variables on the responses were further used to explain the results. The three input variables exhibited significant effects (p<0.05) on the product characteristics.

Keywords: Dried cassava slices; Process variables; Breaking force; Swelling capacity; Hydrogen cyanide

Introduction

Cassava (Manihot esculenta) is a major staple crop in Nigeria as cassava and its products are found in the daily meals of most Nigerians. According to Kajuna et al. [1], cassava is the third most important staple food in the tropics after rice and maize. Oyenuga [2] reported that in Africa about 70% of cassava production is used as human food while 30% is for animal feed and other industrial raw materials. Cassava is playing a major role in an effort to alleviate the African food crisis [3]. Nigeria is the world’s largest producer of cassava tuber with annual production of 49 million metric tonnes [4]. Cassava is consumed only in its processed form due to its hydrogen cyanide content also known as prussic acid [5]. The processed form include, cassava slices,gari, chips, flour and starch. There has been an increase in the demand for cassava production in Nigeria due to federal government’s policy to incorporate cassava flour into the baked food products consumed within Nigeria, and in compliance, cassava flour is now being complemented with the wheat flour to make composite bread and pastries [6].

In Nigeria, cassava production is majorly dominated by the southern and north central regions in terms of area cultivated and number of farmers growing the crop. The major states of Nigeria which produce cassava are Enugu, Ebonyi, Edo, Benue, Kogi, Nasarawa, Cross River, Imo, Oyo, Rivers, Kwara and Ondo [7]. The major factor limiting cassava consumption as human food is its high content of cyanogenic glucosides, mainly linamarin, and in a small proportion lotaustralin which during processing are hydrolysed by the endogenous enzyme linamarase to liberate hydrogen cyanide [8,9]. Cassava has been classified into three based on the level of HCN in its tuber and leave and the cyanide ranged between 5 to 10 mg/100 mg fresh cassava root.

Drying has been identified as the biggest challenge in industrial production for cassava - based products. Drying aims at reducing the water content of cassava to less than 15% [10,11]. Cassava drying is best done at temperatures between 40 and 60°C. At temperatures above 60°C, gelatinization of cassava starch sets in Wenlapatit [10].

The ability of the dried cassava slices to resist breakage or shatter during packaging and transportation is a desirable attribute for the finished product by both the retailers final consumers the product. Dried cassava slices are processed by different methods and in different sizes. It is a traditional convenience food consumed mainly by the Igbo's of eastern Nigeria. In order to prepare the dried slices as a meal, the dried slices are shortly hydrated by soaking them in potable water to a crunchy texture before the water is completely drained off and the wet slices mixed with spiced emulsion sauce and garnished with chopped leafy vegetables, eggplant, sliced-fermented oil bean seed and fish. The prepared meal is also served in local restaurants and hotels and hawked in the streets by the food vendors. The reason why this food has not been widely accepted is due to lack of standardization in the slice production and packaging.

The objective of this research is to standardize the processing of cassava roots into dried slices by varying the process variables such as boiling time, slice thickness and oven drying temperature and thereafter, evaluate the effect of these process variables on the selected physical properties and hydrogen cyanide content of the dried slice.

Materials and Methods

Freshly harvested cassava roots used for this research were bought from UdiOrie market in Enugu state- Nigeria. The two manual slicers used were locally fabricated. The analytical equipment used were those ofPymotech Research. Centre and Laboratory, Abakpa –Nike Enugu-Nigeria and the major ones include: Drying oven (Seradon, DHG-9023A),Tensometer (Code Ref. AIO, Model 8889, made in England)

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and Vernire caliper. The reagents were purchased from Conraw Home of Science -Enugu.

Experimental design
The experiment was designed using MINITAB software (version 14.0). It is a 2- level full factorial design of the type \(2^{3}\) = 2. There were 3 independent variables or factors (boiling time, slice thickness and drying temperature) and 2 levels for each independent variable. The experimental run (samples) with process variable combinations is shown in Tables 1a and 1b for coded and uncoded designs respectively. In the coded experimental design, 2 and 1 represent high and low levels of the factors respectively.

Production of dried cassava slices
The processing of the dried cassava slices was carried out following the modification of the method described by FAO [12]. Cassava roots were washed, grouped into eight portions and each portion boiled for the appropriate times, cooled to ambient temperature, manually peeled and manually sliced to the selected thickness of 2.7 or 2.8 mm with locally made hand slicers. The slices were soaked in potable water for 12 hours at room temperature and thoroughly washed before drying in a pre-heated drying oven (Seradon, DHG-9023A) at the selected temperature of either 50 or 70°C to obtain the dried cassava slices. The flow chart for the production of the slices is shown in Figure 1.

Determination of the slice thickness
Slice thickness was determined using Vernire caliper before the boiling process. The individual thickness of 10 randomly selected slices was measured and the average thickness calculated.

| Sample | Boiling time (min) | Slice size (mm) | Drying temperature (°C) |
|--------|-------------------|----------------|------------------------|
| 1      | 1                 | 1              | 1                      |
| 2      | 1                 | 1              | 2                      |
| 3      | 1                 | 2              | 1                      |
| 4      | 2                 | 2              | 2                      |
| 5      | 1                 | 2              | 1                      |
| 6      | 2                 | 2              | 1                      |
| 7      | 1                 | 1              | 1                      |
| 8      | 2                 | 1              | 2                      |

Table 1a: Coded Experimental Design.

| Sample | Boiling time (min) | Slice size (mm) | Drying temperature (°C) |
|--------|-------------------|----------------|------------------------|
| A      | 3                 | 2.70           | 50                     |
| B      | 1                 | 2.70           | 70                     |
| C      | 1                 | 2.85           | 50                     |
| D      | 3                 | 2.85           | 70                     |
| E      | 1                 | 2.85           | 70                     |
| F      | 3                 | 2.85           | 50                     |
| G      | 1                 | 2.70           | 50                     |
| H      | 3                 | 2.70           | 70                     |

Table 1b: Uncoded Experimental Design.

[Flowchart Image]

Figure 1: Flow chart for the production of dried cassava slices.

Determination of moisture content
Moisture content was determined using the procedures described by Odo and Ishiwu [13].

Determination of breaking strength
Tensometer (Code Ref. AiO, Model 8889, made in England) was used to determine the breaking strength of the cassava slices. The sample (load) was applied at one end of the tensometer and the magnitude of force (N) that broke the sample measures at the other end.

Determination of swelling capacity
The modification of the method described by Odo and Ishiwu [13] was used. The thickness of 10 randomly selected dried cassava slices were measured with venire caliper and the average thickness taken, then after soaking in 100 ml of water for 30 min inside a beaker at room temperature, the soaking water was drained off and the slices thickness re-measured with venire caliper to obtain the average thickness.

The difference in the average thickness after and before soaking was divided by the average thickness before soaking and then multiplied by 100 to obtain the % swelling capacity as shown in the expression below:

\[
\% SC = \left( \frac{ATAS - ATBS}{ATBS} \right) \times 100
\]

Where: ATAS= Average thickness before soaking
ATAS = Average thickness after soaking
SC= swelling capacity

Determination of hydrogen cyanide content
The hydrogen cyanide content was determined using the method described by AOAC [14]. The slices were ground into flour and 4 gram of the sample flour soaked in a mixture of distilled water and orthophosphoric acid. The mixture was stored at room temperature for 12 h to set free all bound hydrocyanic acid. The soaked mixture was then transferred into distillation flask and a drop of paraffin (anti foaming agent) was added. The flask was fitted to other distillation units to complete the set up and the mixture distilled to recover about 45 ml of the distillate inside a 50 ml receiving flask containing a mixture of 0.1 g of sodium hydroxide and 4 ml of distilled water. The flask was made up to the mark with distilled water. Then 1.6 ml of 5% potassium iodide was added and titrated against 0.01 M Ag(NO3)2. The end point was indicated by faint but permanent turbidity. The total HCN content in mg/kg was calculated thus:

\[
HCN = 1.35 \times TV 
\]

Where: TV = titre value
M = wt. of sample

Statistical analysis
Data obtained from all the analyses of the samples were statistically analyzed using a statistical package for social science (SPSS version 17.0). Significant differences between the sample means using LSD was detected at \(p \leq 0.05\). MINITAB version 14.0 was used to run the regression analysis that generated the coefficients of the process variables used to fit the model equations. All graphs (main and interaction) were plotted with MINITAB 14.0.
Results and Discussion

Table 2 shows the effect of processing variables on the physical properties and hydrogen cyanide content of dried cassava slices, while Tables 3a-3d show the ANOVA obtained from the Statistical analysis of the samples. Varying the boiling time, slice thickness and drying temperature significantly (p<0.05) affected the moisture content, breaking strength, swelling capacity and hydrogen cyanide content of the dried cassava slice. Moisture content ranged between 3.17-5.21%, breaking force (1.40-3.95N), swelling capacity (1.07-3.70%) and hydrogen cyanide (7.10-9.15 mg/kg). Moisture removal was achieved most efficiently at drying temperature of 70°C on slice size of 2.70 mm.

Table 2: Physical properties and hydrogen cyanide content of the samples.

| Sample | Moisture (%) | Breaking force (N) | Swelling capacity (%) | Hydrogen cyanide (mg/kg) |
|--------|--------------|--------------------|-----------------------|--------------------------|
| A      | 3.25a        | 1.403a             | 1.10a                 | 9.15a                    |
| B      | 3.98a        | 2.338b             | 3.70a                 | 7.32b                    |
| C      | 4.20b        | 3.438e             | 3.50b                 | 8.13b                    |
| D      | 4.82b        | 3.005d             | 1.07a                 | 6.38a                    |
| E      | 4.38b        | 3.95d              | 3.50b                 | 8.52a                    |
| F      | 5.21b        | 2.063c             | 1.07a                 | 8.20a                    |
| G      | 4.21b        | 1.729c             | 3.70b                 | 7.10a                    |
| H      | 3.17a        | 1.788e             | 1.10a                 | 7.75a                    |

Data are means of triplicate determinations. Data in the same column bearing different superscript differed significantly (p < 0.05)

Table 3a: ANOVA for moisture content (%) of samples.

| Source    | Type III Sum of Squares | df | Mean Square | F     | Sig. |
|-----------|-------------------------|----|-------------|-------|------|
| Corrected Model | 10.212a                | 7  | 1.459       | 534.528 | .000 |
| Intercept | 413.506                 | 1  | 413.506     | 151513.655 | .000 |
| Sample    | 10.212                  | 7  | 1.459       | 534.528 | .000 |
| Error     | .044                    | 16 | .003        |       |      |
| Total     | 423.761                 | 24 |             |       |      |
| Corrected Total | 10.255                | 23 |             |       |      |

a. R Squared = .999 (Adjusted R Squared = .999)
Dependent Variable: Moisture

Table 3b: ANOVA for breaking force (N) of samples.

| Source    | Type III Sum of Squares | df | Mean Square | F     | Sig. |
|-----------|-------------------------|----|-------------|-------|------|
| Corrected Model | 17.205a               | 7  | 2.458       | 7447.300 | .000 |
| Intercept | 146.277                 | 1  | 146.277     | 151513.655 | .000 |
| Sample    | 17.205                  | 7  | 2.458       | 7447.300 | .000 |
| Error     | .005                    | 16 | .000        |       |      |
| Total     | 163.488                 | 24 |             |       |      |
| Corrected Total | 17.210                | 23 |             |       |      |

a. R Squared = 1.000 (Adjusted R Squared = 1.000)
Dependent Variable: Breaking force

Table 3c: ANOVA for swelling capacity (%) of samples.

| Source    | Type III Sum of Squares | df | Mean Square | F     | Sig. |
|-----------|-------------------------|----|-------------|-------|------|
| Corrected Model | 38.994a               | 7  | 5.571       | 6651.172 | .000 |
| Intercept | 134.100                 | 1  | 134.100     | 160111.754 | .000 |
| Sample    | 38.994                  | 7  | 5.571       | 6651.172 | .000 |
| Error     | .013                    | 16 | .001        |       |      |
| Total     | 173.108                 | 24 |             |       |      |
| Corrected Total | 39.008              | 23 |             |       |      |

a. R Squared = 1.000 (Adjusted R Squared = 1.000)
Dependent Variable: Swelling capacity

Table 3d: ANOVA for Hydrogen cyanide content (mg/kg) of samples.

The breaking strength of the dried cassava slices varied due to variation in the level of the process factors. Figures 2a and 2b showed the main and interaction effects of process variables on the breaking strength of the dried cassava slices respectively. A main effect is an outcome that is a consistent difference between levels of a particular factor. The three process variables exhibited significant main effect on the breaking strength. The factor that showed the longest line in the plot is the one that exhibited the greatest effect [15]. From Figure 2a, the slice thickness had the greatest effect on the breaking strength of the dried cassava slices compared with boiling time and drying temperature.

The breaking strength is a measure of the force (N) that could break the slice or the ability of the slice to withstand destructive loads or forces during packaging, transportation and preparation as meal. The ability to resist breakage is a desirable physical property of cassava slices [16]. Brittle slices and broken pieces are generally downgraded and are prized low by both the marketers and consumers of “abacha".
Interaction effect is measured between factors and not on levels of one factor and factorial interaction plot better explains it than contour or surface plots. Whenever there are lines that are not parallel it implies that there is no significant interaction effect between those two factors. Figure 2b showed that there was no significant interaction effect caused by the three process factors on the breaking strength of the dried slices. The regression model that could predict the linear and interaction effects of the process variables on the breaking strength of the dried cassava slices is shown in equation 1.

\[ y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_12x_1x_2 + b_13x_1x_3 + b_23x_2x_3 \]  

Substituting the coefficients of the regression terms into equation 1 would give equation 2.

\[ y = 2.592 - 0.777x_1 + 0.522x_2 - 0.434x_3 - 0.303x_1x_2 + 0.185x_1x_3 - 0.097x_2x_3 \]  

Where \( y \) is the response (breaking force), \( a \) is the constant term, \( b_1, b_2 \) and \( b_3 \) are the coefficients of the independent variables \( x_1, x_2 \) and \( x_3 \), boiling time \( (x_1) \), slice thickness \( (x_2) \) and drying temperature \( (x_3) \).

The \( R^2_{adj} = 99.03\% \). This indicated that 99.03\% of the observed values in the breaking strength of the slices were caused by the three process variables. From equation 1, slice thickness had the highest coefficient (+ 0.522) suggesting that it exhibited the greatest positive effect on the breaking strength of the dried slices.

Slices that exhibit high swelling capacity have high market price over those with low swelling capacity. Boiling time had significant influence on the swelling capacity. However, both slice thickness and drying temperature did not show significant effect on the swelling capacity. From Figure 3b, there was a slight interaction effect between slice thickness and boiling time on swelling capacity whereas the combined effect of either slice thickness and drying time or boiling time and drying temperature showed no significant effect on the swelling capacity. Cassava slice that could gain moisture and swell after hydrating in water during preparation as a meal is preferred to the counterparts that do not possess such attribute especially by the “Abacha” vendors.

The regression model that showed the effect of the process variables on swelling capacity is shown in equations 3 and 4 having the coefficients substituted

\[ y = a + b_1x_1 + b_2x_2 + b_12x_1x_2 \]  

Bringing in the coefficients into the model would generate equation 4.

\[ y = 2.343 + 1.258x_1 + 0.058x_2 + 0.042x_1x_2 \]  

The \( R^2_{adj}=98.05\% \). This is a high value, suggesting that the model is adequate to predict the response under the same experimental conditions [17].

Where: \( y=\)response (swelling capacity), boiling time \( (x_1) \), slice thickness \( (x_2) \) and drying temperature \( (x_3) \).

From the regression output, the coefficients of drying temperature, \( (x_3) \), interaction of boiling time and drying temperature \( (x_1x_3) \) and interaction of slice thickness and drying temperature \( (x_2x_3) \) were all zero, therefore, they were not supposed to be included in the regression model.

Effect of the processing variables on the hydrogen cyanide content of the cassava slice is shown in Figures 4a and 4b for main and interaction effects respectively. From the main effect plot, each of the three independent factors had significant effect on the hydrogen cyanide content of the dried cassava slice. Boiling time and slice thickness showed more significant effect on HCN content than the drying temperature.

Processing the slices at boiling time of 3 min and drying temperature of 70°C had a significant decrease on the hydrogen cyanide content of the dried slices. This can be attributed to the volatile nature of hydrogen cyanide when subjected to heat treatment. This observed decrease in HCN corroborates the earlier report by Famurewa and Emeluckele [18], that as the temperature of drying cassava chips increased the HCN content decreased progressively in the same fashion, but when the cassava chips were dried at temperatures above 60°C that any change in air velocity did not have significant effect on HCN content of the cassava chips. Possibly, this could be the reason the main effect of drying temperature on the HCN showed the least effect when the three process variables were compared as shown in Figure 4a. The hydrogen cyanide content of the samples fall within the safe level of 10 mg/kg dry wt. of processed cassava product [19].

The regression model showing the effect of combination of the process variables on the hydrogen cyanide content of the dried cassava slices is shown in equations 5 and 6 with the inclusion of the coefficients of the terms. Increasing the slice thickness increased the hydrogen cyanide content since the regression coefficient had a positive sign (+1.199), whereas increasing other variable would decrease the hydrogen cyanide content since their regression coefficients have

\[ y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_12x_1x_2 + b_13x_1x_3 + b_23x_2x_3 \]  

Figure 3a: Main Effects of Process variables on swelling capacity.

Figure 3b: Interaction Effect of Process variables on swelling capacity.
negative sign

\[ y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \]  

\[ y = 13.5688 - 4.739 x_1 + 1.199 x_2 - 2.826 x_3 - 0.319 x_1 x_2 - 0.531 x_1 x_3 - 0.479 x_2 x_3 \]  

The R^2 adj= 97.82%. This high value made the model adequate in this study.

**Conclusion**

The effects of the processing variables on the cassava slices were successfully studied. The processing variables (boiling time, slice thickness and drying temperature) were found to have significant effects on the dried cassava slices. The boiling time was affected positively by increase in the interaction effect of the boiling time and dry temperature. Swelling capacity was observed to have been significantly affected by boiling time. The process combination employed reduced the hydrogen cyanide of the cassava slices to less than 10 mg/kg which is the maximum allowable level of hydrogen cyanide in cassava based products. It is recommended to produce dried cassava slices by boiling the fresh cassava tuber in potable water for 3 minutes then slicing to a uniform thickness of 2.70 mm and drying at temperature of 70°C. Further work could be carried on the sensory properties of the product.

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