

Research Article

Validation of a Methodology for Enriching Agbodjama Attiéké with Concentrate of Moringa Leaves, Turmeric Rhizomes and Cashew Almond Paste

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Abstract

The Attiéké (semolina from the root of the *Manihot esculenta* plant) is increasingly consumed in several African countries, particularly in Côte d'Ivoire. Unfortunately, from a nutritional point of view, attiéké is one of those dishes with a low micronutrient content. In Côte d'Ivoire, local edible plant sources, notably cashew kernels, turmeric rhizomes and moringa, are used to correct nutritional deficiencies in vulnerable populations. This study aims to validate a methodology for enriching agbodjama attiéké with concentrates of *Moringa oleifera* leaves, turmeric rhizomes and cashew almond paste, in order to obtain a quality agbodjama attiéké. In Côte d'Ivoire, cassava roots, moringa leaves, turmeric rhizomes and cashew nuts were collected in Bonoua (Sud-Comoé region) for cassava, Divo (L'ŋh-djiboua region) for turmeric rhizomes and moringa leaves, and Ségou (Ségou region) for cashew nuts. After sampling, the samples were sorted, processed and transformed into press cakes (for cassava roots), concentrates (for moringa leaves and turmeric rhizomes) and cashew kernel paste (for the kernels contained in cashew nuts). A three-factor composite central design was used to determine the appropriate proportions of each component of the enriched attiéké in order to maintain the intensities of aroma, color and sourness at an appreciable level. The independent variables taken into account for this study are the ratio of moringa leaf concentrate/press cake (X_1), the ratio of turmeric rhizome concentrate/press cake (X_2) and the ratio of cashew kernel paste/press cake (X_3). The analyses showed that ratios of 1.64% moringa concentrate/pressed cake, 1.46% turmeric concentrate/pressed cake and 0.52% cashew kernel paste/pressed cake are required to produce quality attiéké agbodjama. The attiéké agbodjama prepared under these conditions had a color intensity of 5.18 ± 0.75 , an aroma intensity of 5.39 ± 0.81 and a sourness of 2.82 ± 0.25 . The characteristics of this attiéké agbodjama are similar to those predicted by the central composite design, which are 5.19 ± 0.66 ; 5.41 ± 0.23 and 2.81 ± 0.37 for color intensity, aroma and sourness respectively. The enrichment of attiéké agbodjama was successfully optimized.

Keywords

Enrichment, Attiéké agbodjama, Moringa, Turmeric, Cashew Kernel, Composite Central Design

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1. Introduction

Atti éké (cassava semolina) is one of the main products of cassava processing. Atti éké is increasingly consumed in several African countries, particularly Côte d'Ivoire. This consumption frequency, which was 28-30 kg/year/inhabitant in the years 1995-2001, has risen to 110 kg/year/inhabitant since 2016 [1]. Indeed, the increase in the number of consumers is favored by rapid urbanization and economic difficulties [2]. However, from a nutritional point of view, atti éké is one of the dishes with a low micronutrient content and generally covers only a small proportion of daily requirements for most vitamins and minerals [3]. Given this low micronutrient intake, fortification of this met with other local edible plant sources, notably cashew kernels, turmeric rhizomes and moringa, are able to correct the nutritional deficit, with reference to a wealth of data accumulated over the years by IFPRI and its partners [4]. What's more, in recent years, this practice has received particular attention [5]. This is because the beneficial effect of combining other plant sources with roots and tubers at nutritional level has been proven by numerous studies [5, 6]. In Côte d'Ivoire other important plant sources rich in essential nutrients, such as moringa leaves, turmeric rhizomes (*Curcuma longa*) and cashew kernels (*Anacardium occidentale*) are increasingly used in this approach. Speaking of the nutritional richness of these plant materials, *Curcuma longa* rhizomes are an important source of nutrients and are also used as a food additive for their coloring and aromatic properties. These rhizomes do not alter taste and are virtually non-toxic [7, 8]. Cashew kernels are derived from the nuts of the *Western Anacardium* tree, of which Côte d'Ivoire is the leading producer and exporter [9]. The nutritional value of cashew kernels makes them one of the fruits rich in unsaturated fatty acids, vitamins and minerals [10, 11]. Thus, the local use of cashew kernels to enrich other micronutrient-poor dishes such as atti éké could be a nutritional and economic asset. As for the *Moringa oleifera* species, it is considered the most useful in the world, as all its parts (leaves, flowers, pods, seeds) are edible. In particular, several previous works have highlighted the exceptional nutritional qualities of *Moringa oleifera* leaves, which are used in food in Asia, Africa due to their richness in proteins, vitamins (A, B, C, E), mineral salts (Ca, K, Mg, P, Iron, Zn, Se, Cu, Mn, Na, Cl) and for water purification [5, 12]. Moringa leaves are also used for medicinal, industrial and pharmaceutical purposes. In some African countries, the use of Moringa leaves as a food fortifier is increasing. They are widely used to combat malnutrition in children, pregnant women and nursing mothers [13-15]. Given their dietary interest, the development of cassava-based composite dishes, notably atti éké agbodjama enriched with moringa leaves, cashew kernels and turmeric rhizomes, could be beneficial to populations. Thus, the present study investigates the optimization of the enrichment of atti éké agbodjama with moringa leaf concentrate, turmeric rhizome concentrate and cashew almond paste, in order to enhance their value.

2. Materials and Methods

2.1. Biological Materials

Biological material consisted of cassava roots (*Manihot esculenta* Crantz), *Moringa oleifera* Lam leaves, *Curcuma longa* rhizomes and *Anacardium occidentale* L. nuts.

2.2. Methods

2.2.1. Sampling

The various samples were collected in Côte d'Ivoire in the localities of Bonoua (Sud-Comoé region) for manioc, Divo (L'oh-djiboua region) for turmeric rhizomes and Moringa leaves, and S'égou (worodougou region) for cashew nuts. These different regions are natural areas for the exploitation of these raw materials. Two hundred and seventy (270) kg of cassava were collected from three producers at a rate of 90 kg per producer at three local sites, and one hundred and twenty (120) kg of cashew nuts were collected from three (3) traders at a rate of 40 kg of cashew nuts per trader. Moringa leaves and turmeric rhizomes were also collected from three sites, totalling 120 and 80 kg respectively. Once collected, the samples were sent to the laboratory for analysis. At the laboratory, pools were made by mixing the collected samples. Thus, 250 kg of cassava and 75 kg of each of the other samples were pooled.

2.2.2. Production of Agbodjama Atti éké

The production of atti éké involves several unit operations. Cassava tubers are peeled with stainless steel knives and cut into small pieces to extract the fibers. The resulting cossettes were washed several times in plenty of water. The cossettes were ground using a motorized grinder, after the addition of palm kernel oil and the previously prepared ferment. The resulting crushed paste was rehydrated, then left to stand for hours in the basins, followed by fermentation at room temperature for 18 to 24 hours in hessian bags. The bags containing the fermented paste were then pressed using a screw press. The resulting press cake was crushed on a sieve to remove unfermented cassava pieces, and granulated by hand in a basin. The semolina obtained was dried in thin layers for at least an hour before being further sieved, winnowed and defibered. This homogeneous semolina was steam-cooked to produce atti éké agbodjama (AA) ready for consumption [16-18].

2.2.3. Production of Cashew Almond Paste

The cashew nuts were cleaned, then the shells were moistened, heated by boiling in water for 25 minutes [19] in order to weaken them for easier shelling [20]. The kernels were removed from the shells using Calao (home-made) tongs. Once shelled, the almonds were dried at 50 °C in an oven for 24 hours, then manually dehusked with knives or gentle

brushing followed by winnowing [20]. The almonds were then ground using a disc mill. The resulting paste was stored in jars and kept at 4 °C for the next stage.

2.2.4. Production of Moringa Leaf Concentrate

Fresh moringa leaflets were manually detached from their petioles and sorted to remove diseased or damaged leaves. They were then sanitized for 5 minutes in bleach (50 mL of 8% sodium hypochlorite in 30 L of distilled water). After rinsing with distilled water and draining for 30 minutes, they were sun-dried at 30 °C for 10-14 days before being ground with a hammer mill. The crushed material was macerated for 24 hours in hydroalcoholic solvent (water + 50% alcohol). The extract obtained was filtered and concentrated by rotary evaporation. The moringa concentrate obtained was then stored at 4 °C for the next step.

2.2.5. Production of Turmeric Rhizome Concentrate

The turmeric rhizomes were cleaned, sorted to remove black spots and breakage. This resulted in defect-free material. Next, the rhizomes were peeled and sliced to maximize surfaces for drying in the sun for two weeks. After drying, the rhizomes were ground using a hammer mill. The crushed material was macerated for 24 hours in an alcoholic solvent. The extract obtained was filtered and concentrated by rotary

evaporation. The resulting turmeric rhizome concentrate was then stored at 4 °C until further use.

2.2.6. Central Composite Design

The central composite design (CCD) was carried out to optimize the production method for attiké enriched with cashew almond paste, moringa leaf concentrate and turmeric rhizome concentrate. The experimental domain of this study takes into account the ratio of moringa concentrate/press cake (X1), the ratio of turmeric concentrate/press cake (X2) and the ratio of cashew kernel paste/press cake (X3) (Table 1). For this design, each factor presented 5 levels (- α , -1, 0, +1 and + α). Referring to Feinberg [21], and the combination of the levels of the 3 factors studied led to the implementation of $2^3 + 2 \times 3 + 6 = 20$ trials (3 represents the number of factors) comprising 8 factorial trials, 6 star trials and 6 trials in the center of the experimental field (Table 2).

The matrix of experiments was established by replacing the coded values with the actual values of the factor levels, presented in the table of the experimental area reduced to percentages (Table 2).

The production of the various enriched attikés was assessed in relation to measurable responses, in particular color intensity (Y1), aroma (Y2) and sourness (Y3).

Table 1. Experimental parameters of the composite central design and their coded and actual values used.

Independent variables	Symbols	Coded levels / Actual values				
		-1.682	-1	0	1	1.682
[MO]/GP ratio (mL/kg)	X ₁	5	8	12.5	17	20
[CU]/GP ratio (mL/kg)	X ₂	4	6.8	11	15.2	18
AC/GP ratio (g/kg)	X ₃	3	5.4	9	12.6	15

[MO]: Moringa concentrate; [CU]: Turmeric concentrate; AC: Cashew kernel; GP: Press cake

Table 2. Experimental matrix for composite central design.

Test group	N °Trials	Actual factor values			
		GPM (%)	X ₁ (%)	X ₂ (%)	X ₃ (%)
Factorial tests	1	98.00	-1 (0.79)	-1 (0.67)	-1 (0.54)
	2	97.16	1 (1.65)	-1 (0.66)	-1 (0.53)
	3	97.22	-1 (0.78)	1 (1.48)	-1 (0.52)
	4	96.38	1 (1.64)	1 (1.46)	-1 (0.52)
	5	97.33	-1 (0.78)	-1 (0.66)	1 (1.23)
	6	96.49	1 (1.64)	-1 (0.66)	1 (1.21)

Test group	N °Trials	Actual factor values			
		GPM (%)	X ₁ (%)	X ₂ (%)	X ₃ (%)
Star tests	7	96.54	-1 (0.77)	1 (1.47)	1 (1.22)
	8	95.71	1 (1.63)	1 (1.45)	1 (1.21)
	9	97.56	-1.682 (0.49)	0 (1.07)	0 (0.88)
	10	96.15	1.682 (1.92)	0 (1.06)	0 (0.87)
	11	97.51	0 (1.22)	-1.682 (0.39)	0 (0.88)
	12	96.2	0 (1.2)	1.682 (1.73)	0 (0.87)
	13	97.42	0 (1.22)	0 (1.07)	-1.682 (0.29)
	14	96.29	0 (1.2)	0 (1.06)	1.682 (1.45)
	15	96.85	0 (1.21)	0 (1.07)	0 (0.87)
	16	96.85	0 (1.21)	0 (1.07)	0 (0.87)
Center tests	17	96.85	0 (1.21)	0 (1.07)	0 (0.87)
	18	96.85	0 (1.21)	0 (1.07)	0 (0.87)
	19	96.85	0 (1.21)	0 (1.07)	0 (0.87)
	20	96.85	0 (1.21)	0 (1.07)	0 (0.87)

GPM: cassava press cake

2.2.7. Sensory Evaluation

For each enrichment trial, the Agbodjama atti é prepared from the different products was subjected to a sensory evaluation (descriptive test) to assess and quantify the intensity of color (Y1), aroma (Y2) and sourness (Y3).

(i). Panelist Selection and Training

A panel of 20 volunteers was selected on the basis of their availability and their ability to recognize and assess the level of perception of color, aroma and sourness characteristic of food products. Those recruited were trained in the methodology for analyzing and assessing selected qualitative characteristics in accordance with the requirements of sensory analysis [22]. These panelists were instructed in the gustatory areas of the tongue. They were then familiarized with atti é agbodjama during eight tasting sessions [23].

(ii). Preparation of Enriched Atti é Agbodjama

Four samples of atti é were cooked per tasting session, introducing distilled water up to 50% of the mass of dehy-

drated atti é. Steaming lasted 30 minutes. Enriched atti é were prepared under the same conditions and without the addition of any ingredients, for better characterization of each atti é. The atti é were cooled to room temperature in the preparation room before being served.

(iii). Presentation of Agbodjama Atti é to Be Analyzed and Evaluation Method

Samples of atti é for analysis were presented to a panel of 15 trained panelists. These atti é were served disposable rubber plates, coded (3 digits) and presented monadically to each panelist in randomized order. The sensation perceived by each panelist was marked on a category scale with ratings ranging from 1 (not at all) to 9 (very much).

2.2.8. Statistical Analysis

Linear multiple regression analysis was performed using *Statistica 8.0* software (Statut Soft, Inc., USA). The relationship between factors and responses was represented by a second-degree polynomial model of the form:

$$Y_n = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

With: Y_n : experimental response; b_n : values representing the corresponding regression coefficients; X_1 , X_2 , X_3 : independent variables which are respectively the ratio of moringa

concentrate/press cake, the ratio of turmeric concentrate/press cake and the ratio of cashew almond paste/press cake.

3. Results

3.1. Experimental Responses Obtained with the Central Composite Design

The Table 3 shows the experimental responses obtained after running the 20 trials of the experimental matrix. The color intensity of the prepared atti & é agbodjama varies between 3.70/10 and 5.75/10. The lowest color intensity was observed with the moringa concentrate [MO]/press cake (GP) ratio at 1.22%, the turmeric concentrate [CU]/GP ratio at 0.39% and the cashew almond paste (AC) ratio at 0.88% cashew almond (MCA11). On the other hand, the highest color intensity was

observed with the [MO]/GP ratio at 1.2%, the [CU]/GP ratio at 1.73% and the AC/GP ratio at 0.87% (MCA12). As for the aroma and sourness of atti & é, intensities ranged respectively from 4.98/10 to 6.11/10 and from 1.05/10 to 3.63/10. The highest intensities of aroma (6.11) and sourness (3.63) are provided by the [MO]/GP ratio at 0.78%, the [CU]/GP ratio at 0.66% and the AC/GP ratio at 1.23% (MCA5), followed by the [MO]/GP ratio at 1.64%, the [CU]/GP ratio at 0.66% and the AC/GP ratio at 1.21% (MCA6) respectively (Table 3).

There is a relationship between the various parameters studied and the results of the different descriptors evaluated in a composite central design [24]. This relationship is of the form:

$$Y_1 = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

$$Y_2 = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

$$Y_3 = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

The various coefficients and their significance are determined using *Statistica 8.0* software, based on the experimental matrix and the results of the various measurements.

Statistical analysis of the results in Table 3 has enabled us to determine the different coefficients assigned to each parameter for each response, and the coefficient of determination (R^2) between the experimental and predicted values for each response (Table 4).

The coefficients of determination (R^2) for the color, aroma and sourness regression models are 0.98, 0.97 and 0.96 respectively. The adjusted coefficient of determination (adjusted R^2) for each response ranges from 0.93 to 0.97.

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Table 3. CCD experimental matrix and results.

N°Trials	Parameter levels in coded and real values				Experimental results		
	GPM (%)	X1 (%)	X2 (%)	X3 (%)	Y1	Y2	Y3
1	98.00	-1 (0.79)	-1 (0.67)	-1 (0.54)	3.89	5.98	2.57
2	97.16	1 (1.65)	-1 (0.66)	-1 (0.53)	3.98	5.00	3.05
3	97.22	-1 (0.78)	1 (1.48)	-1 (0.52)	5.09	5.34	2.09
4	96.38	1 (1.64)	1 (1.46)	-1 (0.52)	5.18	5.39	2.82
5	97.33	-1 (0.78)	-1 (0.66)	1 (1.23)	3.81	6.11	1.77
6	96.49	1 (1.64)	-1 (0.66)	1 (1.21)	4.07	5.36	3.63
7	96.54	-1 (0.77)	1 (1.47)	1 (1.22)	5.14	5.40	1.05
8	95.71	1 (1.63)	1 (1.45)	1 (1.21)	5.48	5.85	2.76
9	97.56	-1.682 (0.49)	0 (1.07)	0 (0.88)	4.15	6.01	1.41
10	96.15	1.682 (1.92)	0 (1.06)	0 (0.87)	5.02	5.57	3.06
11	97.51	0 (1.22)	-1.682 (0.39)	0 (0.88)	3.70	5.37	2.26
12	96.2	0 (1.2)	1.682 (1.73)	0 (0.87)	5.71	4.98	2.21

N °Trials	Parameter levels in coded and real values				Experimental results		
	GPM (%)	X1 (%)	X2 (%)	X3 (%)	Y1	Y2	Y3
13	97.42	0 (1.22)	0 (1.07)	-1.682 (0.29)	4.38	5.03	2.42
14	96.29	0 (1.2)	0 (1.06)	1.682 (1.45)	4.77	5.43	2.33
15	96.85	0 (1.21)	0 (1.07)	0 (0.87)	4.75	5.16	1.37
16	96.85	0 (1.21)	0 (1.07)	0 (0.87)	4.76	5.17	1.36
17	96.85	0 (1.21)	0 (1.07)	0 (0.87)	4.78	5.18	1.35
18	96.85	0 (1.21)	0 (1.07)	0 (0.87)	4.74	5.15	1.36
19	96.85	0 (1.21)	0 (1.07)	0 (0.87)	4.76	5.16	1.38
20	96.85	0 (1.21)	0 (1.07)	0 (0.87)	4.73	5.17	1.37

Table 4. Statistical estimation of CCD coefficients.

Coefficients	Estimation of coefficients		
	Color	Aroma	Sourness
b ₀	2.06**	10.59***	9.31***
Linear			
b ₁	0.08 ^{ns}	-0.55***	-0.46***
b ₂	0.15*	-0.25***	-0.41**
b ₃	0.05 ^{ns}	-0.10 ^{ns}	-0.72***
Quadratic			
b ₁₁	-0.00 ^{ns}	0.01***	0.02***
b ₂₂	-0.00 ^{ns}	0.00 ^{ns}	0.02***
b ₃₃	-0.01*	0.004**	0.03***
Interaction			
b ₁₂	-0.00 ^{ns}	0.02***	0.00 ^{ns}
b ₁₃	0.00 ^{ns}	0.01**	0.02**
b ₂₃	-0.00 ^{ns}	0.00 ^{ns}	-0.01 ^{ns}
R ²	0.98	0.97	0.96
R ² adjusted	0.97	0.94	0.93

*: significant at 5%; **: significant at 1%; ***: significant at 0.1%; R²: regression coefficient; ns: not significant

To better see the influence of different operating conditions on the responses, we have made a 3D representation in space

(response surface representation) by fixing one of the parameters at its zero level (at the center of the experimental domain)

to examine the response surfaces as a function of the other selected parameters.

3.2. Influence of Various Factors on the Color of Atti & és

The color of atti & és is only influenced by the ratio [CU]/GP (X_2). There is also a quadratic effect with the AC/GP ratio. The model obtained for atti & és color (Y_1), is given by the following mathematical equation with a satisfactory value of R^2 ($R^2 = 0.98$) and adjusted R^2 ($= 0.97$):

$$Y_1 = 2,06 + 1,05X_2 - 0,01X_3^2$$

The Y_1 equation obtained shows that the linear term of the [CU]/GP ratio (X_2) is significant ($p < 0.05$). The individual effect of the [CU]/GP ratio is positive on the color of atti & és, as the corresponding coefficient is positive (+1.05). The negative quadratic effect of the AC/GP ratio (X_3^2) on color is shown in figure 1A.

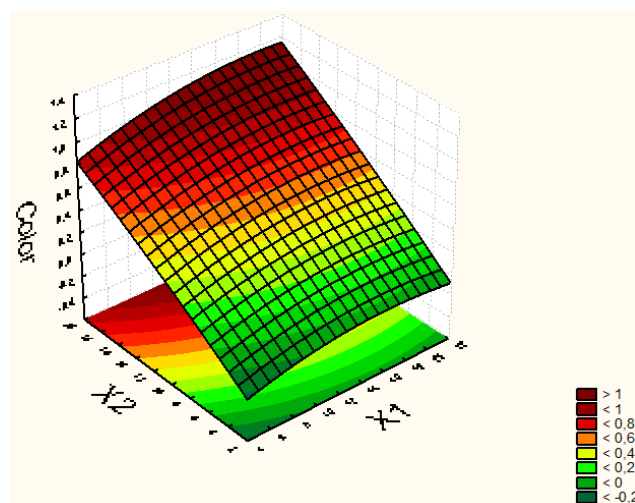
Figure 1A shows the positive individual effect of the [CU]/GP ratio on atti & és color by keeping the amount of turmeric constant at its zero level. Figure 1B, on the other hand, shows a negligible effect of the [MO]/GP ratio and the AC/GP ratio on coloration by keeping their quantities constant at their zero levels. Figure 1C shows a similar effect of the positive individual effect of the [CU]/GP ratio with the AC/GP ratio on atti & és color.

3.3. Influence of Various Factors on Atti & és Aroma

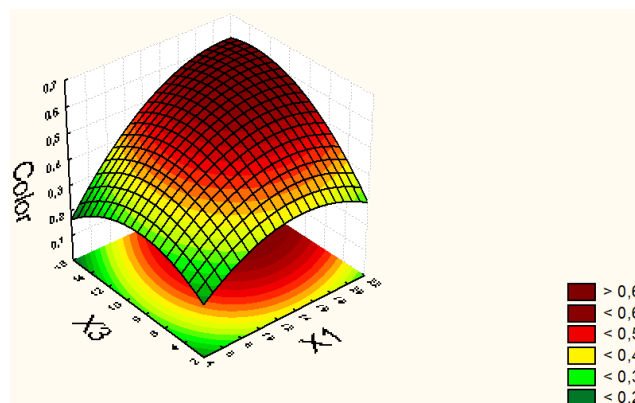
Statistical analysis of the results of the central composite design experiments was used to determine the variation in aroma in the different atti & és (Table 3). The results obtained show significant ($p < 0.001$) and negative individual effects with regard to the [CU]/GP ratio on the aroma of atti & és enriched by maintaining all quantities at their zero levels. Quadratic effects are also observed with the [MO]/GP ratio with the AC/GP ratio on the aroma of atti & és. In addition, positive interactions were recorded between the [MO]/GP ratio and the [CU]/GP ratio, and similarly between the [MO]/GP ratio and the AC/GP cashew nut paste ratio on atti & és aroma. The different coefficients assigned to each factor are shown in Table 4. The mathematical model has a satisfactory value of R^2 ($R^2 = 0.97$) and adjusted R^2 ($= 0.94$):

$$Y_2 = 10,59 - 0,55X_1 - 0,25X_2 + 0,01X_1^2 + 0,004X_3^2 + 0,02X_1X_2 + 0,01X_1X_3$$

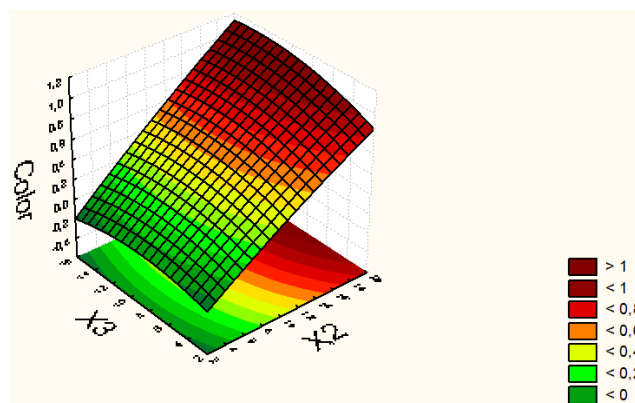
The effects between the different parameters influencing the aroma of atti & és are shown in figure 2A, 2B and 2C. An increase in aroma intensity is observed when the various proportions added are low.



A

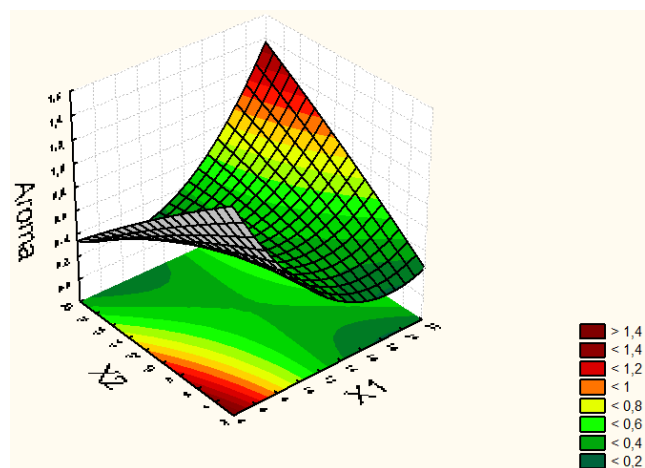


B

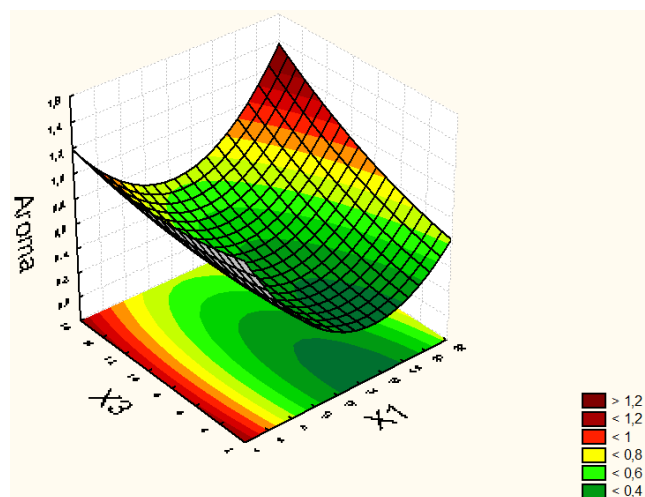


C

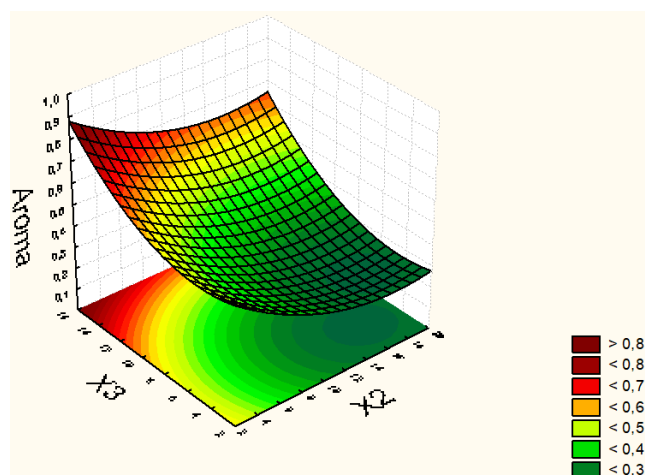
Figure 1. A: Influence of turmeric (X_2) and moringa (X_1) concentrates on atti & és color; B: Influence of moringa concentrate (X_1) and cashew almond paste (X_3) on atti & és color; C: Influence of turmeric concentrate (X_2) and cashew almond paste (X_3) on atti & és color.



A



B



C

Figure 2. A: Influence of moringa (X1) and turmeric (X2) concentrates on attiéké aroma; B: Influence of moringa concentrate (X1) and cashew almond paste (X3) on attiéké aroma; C: Influence of turmeric concentrate (X2) and cashew almond paste (X3) on attiéké aroma.

3.4. Influence of Various Factors on Sourness

Attiéké sourness was also influenced by the [MO]/GP ratio (X1), the [CU]/GP ratio (X2) and the AC/GP ratio. The results also show negative individual effects and positive quadratic effects on attiéké sourness with the [MO]/GP ratio, the [CU]/GP ratio and the AC/GP ratio. In addition, these effects are negative at the individual level and positive at the quadratic level for each (X1, X2, X3). A positive interaction effect (X1X3) is noted between the [MO]/GP ratio and the AC/GP ratio. The mathematical model (Y3) has a satisfactory value of R^2 ($R^2 = 0.96$) and adjusted R^2 ($= 0.93$):

$$Y_3 = 9,31 - 0,46X_1 - 0,41X_2 - 0,72X_3 + 0,02X_1^2 + 0,02X_2^2 + 0,03X_3^2 + 0,02X_1X_3$$

The figure 3 shows the effects of different parameters on attiéké sourness. Increasing the amount of moringa concentrate also leads to an increase in sourness. Curved shapes due to positive quadratic effects of all ratios on attiéké sourness are observed in figure 3A, 3B and 3C.

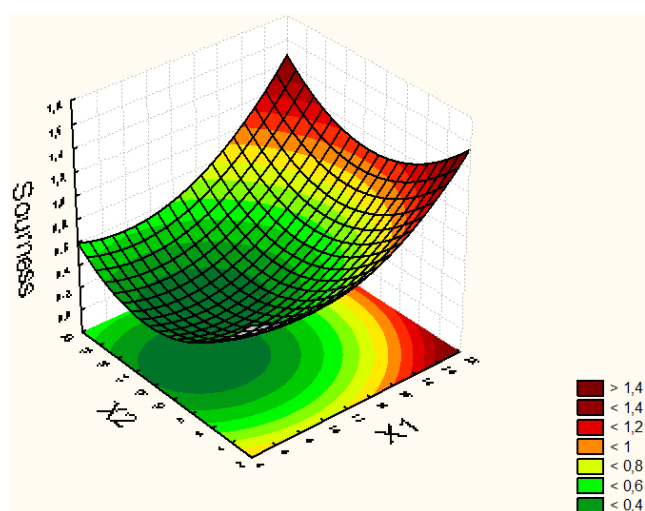
3.5. Experimental Optimization of Attiéké Enrichment Methodology

The mathematical models of the Central Composite Design (CCD) were used to determine the optimum conditions for attiéké enrichment. All models were established with a satisfactory R^2 coefficient ranging from 0.96 to 0.98. This shows a close relationship between experimental values and those predicted by the models. The predictive data for each model were performed at the recommended optimum condition. The results are shown in Table 5. The experimental values were $5.18 \pm 0.75/10$; $5.39 \pm 0.81/10$ and $2.82 \pm 0.25/10$ respectively for attiéké color, aroma and sourness. These experimental values obtained remain roughly equal to those predicted by the mathematical models. Furthermore, the ANOVA shows that there is no significant difference at 5% risk between the various experimental results and those predicted for each of the parameters analyzed (Table 5), indicating that the optimization carried out in the present study is reliable.

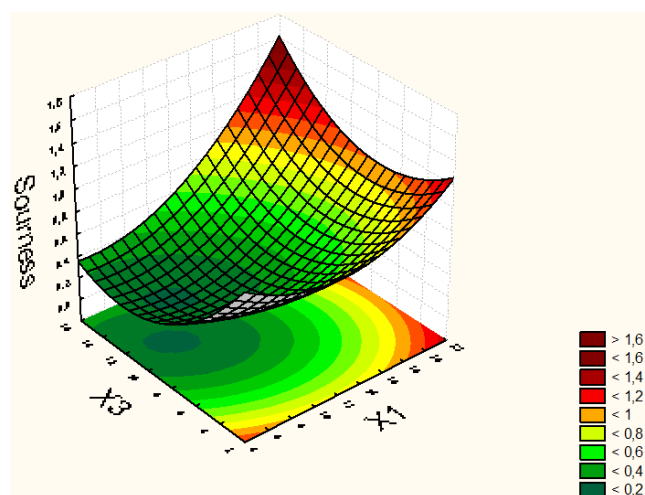
Table 5. Experimental validation of the CCD.

Answers	Experimental value	Predicted value
Color	$5,18 \pm 0,75^b$	5.19 ± 0.66^b
Aroma	$5,39 \pm 0,81^a$	5.41 ± 0.23^a
Sourness	$2,82 \pm 0,25^c$	2.81 ± 0.37^c

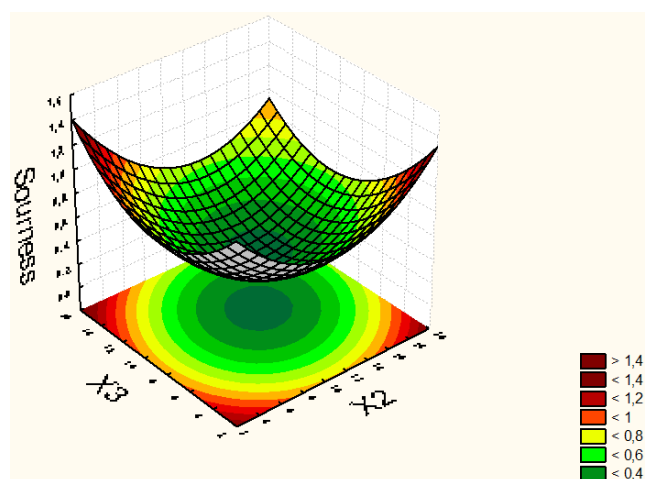
^{a, b, c}Values on the same line with the same signs are statistically in the same homogeneous group at $P = 0.05$.



A



B



C

Figure 3. A: Influence of moringa (X1) and turmeric (X2) concentrates on attiéké sourness; B: Influence of moringa concentrate (X1) and cashew kernel paste (X3) on attiéké sourness; C: Influence of turmeric concentrate (X2) and cashew almond paste (X3) on attiéké sourness.

4. Discussion

The coefficients of determination (R^2) obtained for each regression model are close to 1. Consequently, the 2nd-order mathematical models determined are valid for predicting the different responses [25]. The fitted coefficient of determination values are also satisfactory, suggesting a high significance of the mathematical models and a good fit of the latter to the experimental data [26], meaning that the experimental values of each response agree with those predicted. There is a relationship between the various parameters studied and the results of the different descriptors evaluated in a composite central design [24].

The results indicate that the different constituents (moringa and turmeric concentrates as well as cashew kernel paste) of enriched attiéké have a significant effect on the intensity of color, aroma and sourness. This implies that these three variables play a major role in the enrichment process.

The positive individual effect of turmeric concentrate is clear: the higher the proportion of turmeric concentrate, the stronger the color. In addition, increasing the proportion of turmeric concentrate does not affect the sourness of attiéké. However, it does have a negative effect on the characteristic aroma of fresh attiéké. This could be due to turmeric's bitter aftertaste.

In addition, the higher the moringa concentrate content, the more the aroma of fresh attiéké decreases, as moringa concentrate has a negative individual effect on aroma. In addition, moringa concentrate also has a negative influence on sourness, because as its proportion increases, so does the sourness of the attiéké. Cashew almond paste has a non-significant individual effect on aroma, because once cooked, the fresh attiéké aroma predominates. In addition, the non-significant individual effect of cashew kernels on color could be justified by the white color of the kernels and its unroasted state.

The results of optimization and experimental validation indicate good agreement between observed and predicted values. Under these conditions, according to Koffi *et al.* [24], the composite central design is successfully applied to optimize the enrichment of agbodjama attiéké with concentrates of *Moringa oleifera* Lam leaves, *Curcuma longa* rhizomes and *Anacardium occidentale* L. almond paste.

5. Conclusion

In this study, the optimization of the enrichment of agbodjama attiéké (cassava semolina) with moringa leaf and turmeric rhizome concentrates and cashew kernel paste was carried out, taking into account the intensity of color, aroma and sourness of the enriched attiéké. A central composite design was applied to the enrichment process. Enriched attiéké agbodjama should contain 1.64% moringa concentrate/GP ratio, 1.46% turmeric concentrate/GP ratio and 0.52% cashew kernel paste/GP ratio. The attiéké agbodjama prepared under these conditions has a color intensity of 5.18 ± 0.75 ; an aroma inten-

sity of 5.39 ± 0.81 and a sourness of 2.82 ± 0.25 . These intensities are similar to those predicted by *Statistica 8.0* software. Thus, the enrichment of attiéké agbodjama was successfully optimized using the composite central plane to simultaneously achieve good color, aroma and sourness intensity of attiéké agbodjama. This attiéké agbodjama could be used to combat malnutrition in vulnerable populations and contribute to the revalorization of the raw materials used. However, this study merits further investigation through a general acceptability test.

Abbreviations

AA	Agbodjama Attiéké
CCD	Central Composite Design
MO	Moringa Concentrate
CU	Turmeric Concentrate
AC	Cashew Kernel
GP	Press Cake
GPM	Cassava Press Cake

Conflicts of Interest

The authors declare no conflicts of interest.

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