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Use Sensory Analysis to Optimize Corn Seed Storage Methods in a Triple Bagging and Biopesticide System (Leaves of *Lippia multiflora Moldenke* and *Hyptis suaveolens Poit*) in Côte D'ivoire

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ABSTRACT

The effectiveness of dried leaves of *Lippia multiflora* and *Hyptis suaveolens* on maize grains stored in a triple bagging system was tested. A three-factor central composite design (CCD) affecting the storage of maize grains was used to monitor changes in sensory quality, namely moldy aroma and rancid odor, during storage. The first CCD factor comprised six observation periods: 0, 1, 4.5, 9.5, 14.5, and 18 months. The second factor was the type of treatment, which consisted of 1 control batch with polypropylene bags (WB) and 9 experimental batches, including 1 in a triple bag without biopesticides (TBS0) and eight (8) additional batches containing ratios and/or combinations of biopesticides (TB1 to TB8). Finally, the third factor concerned the combination of two biopesticides, with the percentage (%) of *Lippia multiflora* as the reference. The results indicate that the ideal conditions for maintaining the sensory quality of maize grains during storage, based on the intensity of the rancid odor and moldy aroma, are achieved under the following conditions: Storage period: 18 months. Ratio of biopesticides to maize: 2.5%- Combination of biopesticides: 100% Lippia multiflora or 100% Hyptis suaveolens

under the best-expected conditions, the experimental values were: rancid odor 4.10±0.25 and musty aroma 3.70±0.37.

Keywords: Biopesticides, descriptive sensory analysis, stored maize, triple bagging, optimization.

INTRODUCTION

Sustainable agriculture is a means of ensuring environmental stability, food security, and poverty eradication in sub-Saharan African countries [1]. Due to rapid population growth and low agricultural productivity, many African countries face recurring food emergencies and uncertainty in food aid. Thus, it is important to find solutions to protect foodstuffs such as cereals in the region. [2].

In Côte d'Ivoire, agriculture is crucial to food security (World Bank, 2007). This sector supports the subsistence of over 70% of the population and contributes around 28% to the national gross domestic product [3]. In addition to coffee and cocoa, cereals such as rice and maize are essential agricultural products [4].

Maize ranks seventh in agricultural production and second in cereal production after rice [5], with annual national production rising from 760,000 metric tons in 2016 to 1,006,000 metric tons in 2018, for a total sown area of 386,633 ha [6]. It is an important element in agricultural activities and in the diet of Ivorian populations, accounting for 68% of total national cereal production. Its primacy has continued to grow thanks to government policies, which have encouraged the selection and popularization of improved varieties in a bid to increase production with a view to food self-sufficiency [7] [8].

However, this cereal is often destroyed by insect pests during storage and requires further research to reduce losses. Indeed, *Sitophilus zeamais*, *Tribolium castaneum*, and *Plodiainter punctella* [9] [10] are the main insect pests that damage maize grain stocks in Côte d'Ivoire, leading to rapid crop degradation. The losses caused by these insects in large-scale post-harvest maize storage farming systems are considerable. They are estimated at between 20% and 80% after just a few months' storage using traditional methods [11] [12] [13].

Because of the threat posed by these insects, some farmers sell their maize early to avoid the previously mentioned losses. Others treat their crops with synthetic insecticides of unproven efficacy [14], whose widespread use leads to serious environmental pollution, affects human health, and causes the death of non-target organisms [15] [16]. Despite the extent of the damage caused by these chemicals, the application of biopesticides as an alternative solution has been promoted in recent decades [17] [18] [19]. The use of plants for protection is an ancient practice that makes food almost available in rural areas, where agricultural production is seasonal while consumer needs are spread throughout the year. These aromatic plants and their derivatives are an effective means of pest control. They are less expensive and guarantee biodiversity [20] [21] [22] [23]. *Lippia multiflora and Hyptis suaveolens*, local plants accessible in all regions of Côte d'Ivoire, have been the subject of several works on biofunctional properties [24][25]. In addition, recent studies of maize grain storage in Côte d'Ivoire have shown the effectiveness of triple bagging systems associated with or not with Lippia multiflora and Hyptis suaveolens leaves on market and sanitary quality.

However, this less costly method of preservation would be better valued if it integrated sensory testing, as the latter has the inevitable advantage of seeking to assess a food's character using the tool that will ultimately be the final judge when the product is consumed, namely man. In this sense, sensory analysis is reliable and inevitably yields the best results. Accordingly, the present work contributes to determining a minimum concentration of Lippia multiflora and Hyptis suaveolens leaves that will sustainably preserve the sensory quality of corn kernels. This approach is based on a composite central experimental design to optimize the post-harvest storage of maize kernels in triple bagging systems. This surface-response methodology makes it possible to optimize post-harvest storage by determining an ideal (minimal and effective) proportion and/or combination of Lippia multiflora and Hyptis suaveolens leaves to sustainably stabilize the parameters of grain sensory quality deterioration.

MATERIALS AND METHODS

Study Site

The experiment was carried out at the Laboratoire de Biochimie et Sciences des Aliments (LaBSA) of the UFR Biosciences at the Université Félix HOUPHOUET-BOIGNY. The bags were kept in a laboratory storage room at 27.78 ±0.19°C and 75.0 ±0.99% relative humidity. Wooden pallets were placed on the floor to support the bags.

Biological Materials

Collection of Maize Kernels Used in the Study:

Dry maize kernels were obtained from growers in the Hambol region of north-central Côte d'Ivoire, in the department of Katiola, between 8°10' North and 5°40' West just after harvest. It is an improved GMRP-18 variety with a yellow morphotype and a short production cycle of 90-95 days.

Collection and Processing of Biopesticides:

The Biochemistry and Food Science Laboratory has been working on the conservation of cereals, legumes and other agricultural products for many years. Biopesticides represent a very good alternative in the fight against pests and fungi. In this study, Lippia multiflora and Hyptis suaveolens were chosen for their phytosanitary properties. These are perennial, fragrant shrubs found spontaneously in the central and northern zones of Côte d'Ivoire [26] [27]. Leaves of L multiflora and H suaveolens were harvested and sun-dried for one week in the Gbéké region of Côte d'Ivoire. Dried leaves were chopped into fine particles before use.

Methods

Experimental Set-up:

The conservation tests carried out in this study were implemented on the basis of a composite central design (CCD) as proposed by the work of Konan et al [29] modified. This is a second-degree polynomial model experimental design that aims to highlight existing relationships between an explained variable and explanatory variables. It involved studying these relationships by varying all the factors or parameters and assessing the effect of variations on the response [30] in order to highlight the interactions between these factors.

Parameters Evaluated:

This method began by defining the experimental domain. To do this, the independent variables influencing conservation were selected and their low (-1) and high (+1) levels were defined. For this study, three (3) technological parameters were taken into account, namely storage time (expressed in months), the quantity of biopesticides used (expressed in %) and the combination of the two plants (with % Lippia as reference Table 1). Also, for this design, each factor presented 5 levels (-1.682, -1, 0, +1 and +1.682). Thus, 20 trials comprising 8 factorial trials, 6 star trials and 6 trials in the center of the experimental field (Table II) were carried out according to the principle of use described by [31] Feinberg (1996). These correspond to the different samples taken, according to the experimental matrix. For each test, the musty aroma (Y1) and rancid odour (Y2) of the different batches were determined by means of descriptive sensory analysis. The actual values of the different levels for each factor (Xk) were estimated according to the following relationship:

$$X_k = X_{cent} + Z_k \times (\frac{X_{max} - X_{min}}{Z_{max} - Z_{min}}$$

with: Xk: coded value of the factor; Xmin: minimum actual value of the factor; Xmax: maximum actual value, of the same factor; Xcent, actual value of the same factor at the center; Zk: coded value of the coded value of the variation limit; Zmin: minimum actual value of the variation limit; Zmax: maximum actual value of the variation limit. Based on the PCC, the main effects and interactions between the various factors were determined by fitting the data with the second-degree polynomial equation:

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

Where **Yn** is the experimental response, X1, X2 and X3 correspond respectively to the technological parameters shelf life, biopesticide/corn ratio and biopesticide combination. The values of bn represent the corresponding regression coefficients.

Table I: Parameters assessed, their coded and real variables used.

Technological parameters	**Level coding / Extended**				
	-1.682	**-1**	**0**	**1**	**1.682**
X_1 : Storage life (months)	1	4.45	9.5	14.5	18
X_2 Ratio of biopesticides to maize (%)	0	1.01	2.5	3.99	5
X_3 : Biopesticide combination (% *Lippia*)	0	20.27	50	79.73	100

Tableau II: Experimental matrix for composite central plane (CCP) tests

Test groups		**Coded and actual values of parameters assessed**		
	Test number	**X_1(months)**	**X_2 (%)**	**X_3 (% *lippia*)**
Factorial tests	1	-1 (4.5)	-1 (1.01)	-1 (20.27)
	2	1 (14.5)	-1 (1.01)	-1 (20.27)
	3	-1 (4.5)	1 (3.99)	-1 (20.27)
	4	1 (14.5)	1 (3.99)	-1 (20.27)
	5	-1 (4.5)	-1 (1.01)	1 (79.73)
	6	1 (14.5)	-1 (1.01)	1 (79.73)

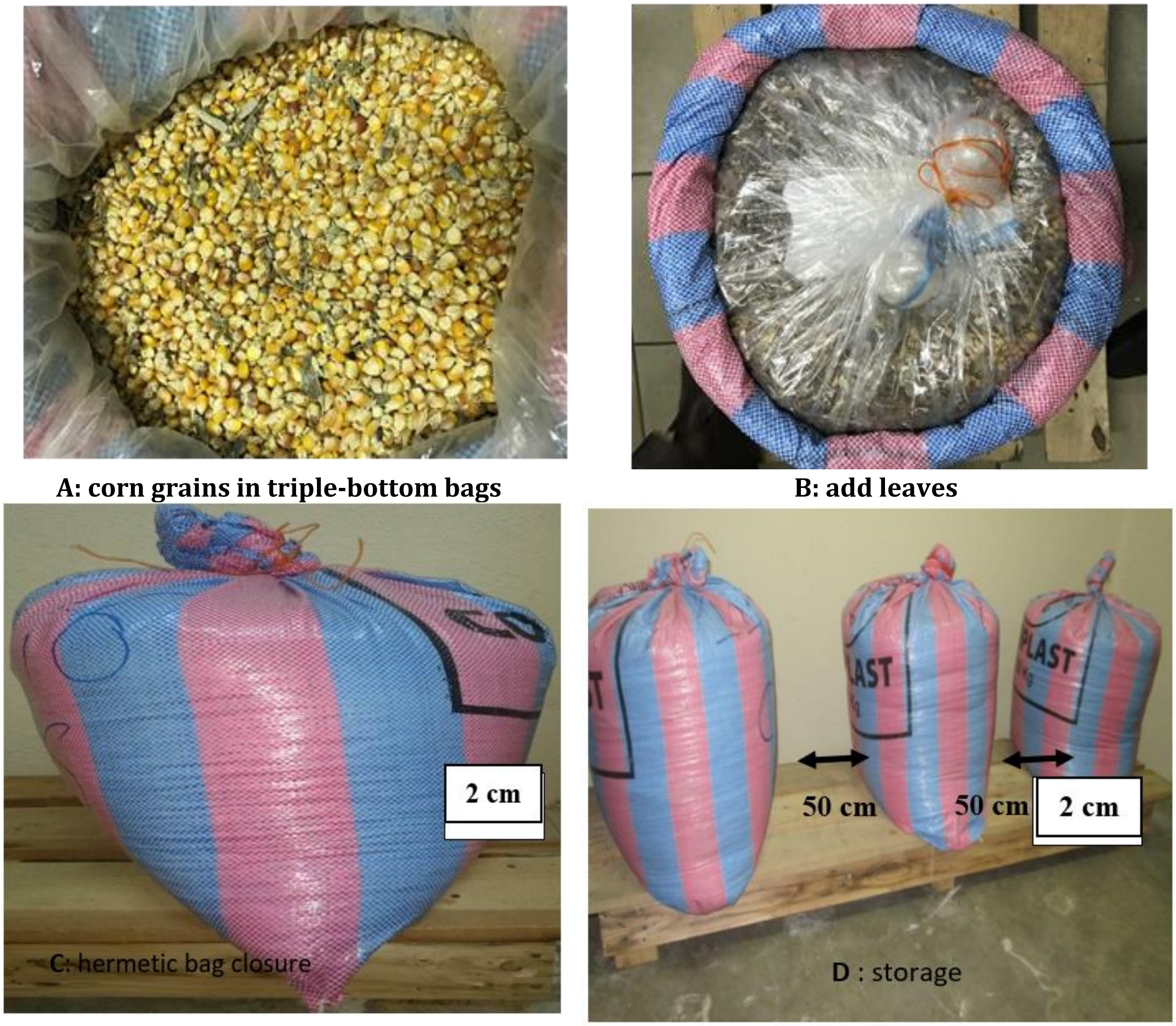
	7	-1 (4.5)	1 (3.99)	1 (79.73)
	8	1 (14.5)	1 (3.99)	1 (79.73)
Star testing	9	-1.682 (1)	0 (2.5)	0 (50)
	10	1.682 (18)	0 (2.5)	0 (50)
	11	0 (9.5)	-1.682 (0)	0 (50)
	12	0 (9.5)	1.682 (5)	0 (50)
	13	0 (9.5)	0 (2.5)	-1.682 (0)
	14	0 (9.5)	0 (2.5)	1.682 (100)
Tests in the centre	15	0 (9.5)	0 (2.5)	0 (50)
	16	0 (9.5)	0 (2.5)	0 (50)
	17	0 (9.5)	0 (2.5)	0 (50)
	18	0 (9.5)	0 (2.5)	0 (50)
	19	0 (9.5)	0 (2.5)	0 (50)
	20	0 (9.5)	0 (2.5)	0 (50)

Sample Preparation:

The storage method using triple bagging of maize involved mixing a proportion of dried leaves with a quantity of 50 kg of maize kernels according to the method described by [32]. The mixture was packaged either in triple-bottom bags or in a woven polypropylene bag, then placed on pallets (figure 1). The various experimental batches were distributed as follows:

- ✓ control batch: 50 kg of maize packed in a polypropylene bag without biopesticides (TB0SP);
- ✓ 1st experimental batch: 50 kg of corn packed in a biopesticide-free triple bagging system (TB0P);
- ✓ 2^e experimental batch: 50 kg corn conditioned in a triple bagging system with 2.5% biopesticides consisting of 0.625 kg L. multiflora and 0.625 kg H. suaveolens (TB1);
- ✓ 3^e experimental batch: 50 kg maize packed in a triple bagging system with; 3.99 % biopesticides composed of 0.40 kg L. multiflora and 1.60 kg H. suaveolens (TB2);
- ✓ 4^e experimental batch: 50 kg maize packed in a triple bagging system with 3.99 % biopesticides composed of 1.60 kg L. multiflora and 0.40 H. suaveolens (TB3);
- ✓ 5^e experimental batch: 50 kg maize conditioned in a triple bagging system with 1.01% biopesticides composed of 0.10 kg L. multiflora and 0.40 kg H. suaveolens (TB4).
- ✓ 6^e experimental batch: 50 kg maize packed in a triple bagging system with 1.01% biopesticides composed of 0.40 kg L. multiflora and 0.10 kg H. suaveolens (TB5);
- ✓ 7^e experimental batch: 50 kg maize packed in a triple bagging system with 5% biopesticides composed of 2.5 kg L. multiflora and 2.5 kg H. suaveolens (TB6);
- ✓ 8^e experimental batch: 50 kg maize conditioned in a triple bagging system with 2.5% biopesticides composed of 1.25 kg L. multiflora (TB7) and
- ✓ 9^e experimental batch: 50 kg maize conditioned in a triple bagging system with 2.5% compound biopesticides, 1.25 kg H. suaveolens (TB8).

A total of ten (10) batches were obtained, including a control batch and nine (9) experimental batches. Corn kernels and leaves were bagged in strata, alternating corn kernels with Lippia multiflora M. and Hyptis suaveolens P. leaves, so as to obtain leaves on the bottom and surface of the bags covering the kernels (figure 1).



A: corn grains in triple-bottom bags **B: add leaves**

C: hermetic bag closure **D: storage**

Figure 1: How grain maize is packaged

Sensory Evaluation of Different Samples:

Sensory properties are the most direct assessment of food product quality during prolonged storage in the environment to which the products would be exposed in their final application [33]. Thus, after an eighteen-month storage period following a three-factor composite central plan (CCP), corn kernels were subjected to technological transformations in order to assess the sensory stability of the kernels over a storage period.

Corn Flour Production:

The flours were produced using the traditional milling technique. The corn kernels were first sorted and then washed with tap water. They were then crushed by hand using a wooden mortar and pestle. The crushed grains were winnowed to remove the skins. The pulped grains were washed and soaked for ten (10) hours. Finally, the grains were drained, ground with a

Moulinex and sieved using a 200-micrometer-diameter sieve. The various flours obtained were used to make the different porridges.

Preparation of Porridges:

Preliminary tests with tasters suggested cooking 10 g of flour in 100 mL of tap water. This quantity took into account the fluidity of the porridge. Cooking lasted eight minutes over low heat, without adding sugar at the end to avoid any interaction. The porridges were cooled to 50°C at room temperature in the preparation room before being served.

Descriptive Sensory Analysis:

Detailed sensory evaluation of the corn porridge samples was carried out using quantitative descriptive analysis (QDA) according to a procedure described by [34]. This method has been chosen as a widely used method for evaluating different food products providing information on the whole product profile, which can easily be analyzed as well as presented statistically and graphically [35] [36].

❖ **Selection of Panelists**

Twenty (20) healthy volunteers with experience of sensory analysis were recruited from among the students of the Biochemistry and Food Science Laboratory by means of flyers and e-mails. Potential panelists were selected according to the following criteria:

- people with natural dentition;
- people with no food allergies;
- non-smokers;
- people who consume corn and/or corn-based products at least once a month;
- People available for all sessions.

A written consent form explaining all detailed information about the study was presented and signed by all participants. Members were free to withdraw from the study at any time. Monetary incentives were offered to all participants to compensate for their time. The selection process was based on the methodology described by [37]. Panelists completed the basic taste recognition test. Chemically pure solutions of basic tastes were used for this phase: sweet (2% sucrose), sour (0.07% citric acid), salty (0.2% sodium chloride) and bitter (0.07% caffeine). Panelists received 25 ml of each solution in disposable plastic cups coded with random three-digit numbers. Eighteen (18) subjects who responded correctly to at least 70% of the test series were selected as panelists for descriptive analysis. Two panelists were eliminated from the study during the pre-selection period due to poor performance and lack of availability.

❖ **Training Session**

All selected panelists were introduced to quantitative descriptive analysis (QDA) to familiarize them with the methodology. The selected panelists were trained in 20 sessions (one session per day), which took place four (4) days a week for five (5) weeks. The average duration of a session per day was one hour. During these training sessions, the panelists developed the descriptors, during which they evaluated samples of maize cooked in slurry form. The sessions took place at the Biochemistry and Food Science Laboratory of the Université Félix Houphouët-Boigny in Cocody, Côte d'Ivoire, in an air-conditioned environment with artificial lighting.

Panelists were spaced at least 2 m apart to avoid any interaction. During the training sessions, panelists defined the lexicon of nine (09) sensory descriptors, as well as specific and unambiguous definitions. An unstructured continuous scale 10 cm long, with the left end corresponding to the lowest intensity (value 0) and the right end to the highest intensity (value 10). The definitions of all descriptors and their reference standards, determined by consensus among panel members, are listed in (Table III).

Table III: Attributes, definitions and references used for the descriptive quantitative analysis of slurries from maize kernels stored under different conditions.

Description	Definitions	References
Appearance -Uniform colour	Intensity of the yellow color of the corn	Strong: Yellow colour of cooked corn Weak: Brown colour
Aroma/Smell Characteristic (of maize)	Overall intensity of the aroma of cooked corn kernels	High: Newly cooked maize grains Low Corn grains stored for 6 months and cooked
-Herbaceous flavour	The intensity of the aroma has been associated with Lippia multiflora	Strong: Lippia green tea. Weak: Distilled water
(musty)	Characteristic smell of damp wood or something musty.	High: Mouldy corn kernels Low: Newly cooked maize grain
-Rance	The intensity of the smell is associated with old frying oil.	Strong: two drops of corn oil diluted in 50ml of distilled water and heated in the microwave for 15 minutes. None: distilled water
Flavour Sweet	Typical taste of sugar solution (Mild after cooking)	Strong: 0.3% sucrose solution Weak: Distilled water
Acid	Taste sensation typical of organic acids (citric acid)	Strong: 0.3% citric acid solution None: Distilled water
Astringent	Sensation that lingers, dries and numbs the mouth, palate and tongue when eating corn porridge.	Strong: 0.1% tannic acid solution None: distilled water
After-taste	Sensation of a taste after swallowing the food.	Strong: 3% (w/w) unripe banana solution Weak: Distilled water

❖ Calibration and Panelist Performance

Before running the main experiment, panelists' performance was checked by analyzing their test results. Additional training was given to panelists whose performance differed from that of the group as a whole. Training continued until all panelists were performing reliably and consistently. Analysis of variance (ANOVA) for each panelist and each attribute was used to control panelist performance. Finally, fifteen (15) panelists were selected as participants for the final session on the basis of their discrimination ability ($P = .05$) and repeatability ($P = .05$) using the data collected during the training session.

❖ Sample Preparation and Presentation

Porridges were cooked by adding 10 g of flour to 100 mL of tap water. Cooking lasted eight minutes over low heat. The porridges were cooled to around 50°C before serving. Individual samples of each type of corn porridge (weighing around 15 g) were placed in odorless transparent plastic cans (125 mL) with lids to contain the flavors evenly throughout the sample headspace. Samples were evaluated at the Biochemistry and Food Science Laboratory, Université Félix Houphouët-Boigny, Cocody, Côte d'Ivoire. Each panelist received 10 g samples in disposable plastic cups coded with three-digit random numbers, paper napkins and mineral water for palate cleansing between tastings were provided.

Statistical Analysis

Statistical analyses of the data were carried out using SPSS (version 22.0) and STATISTICA (version 7.1) software. All tests relating to the analysis of sensory characteristics were run in triplicate, and results are expressed as mean ± standard deviation. An analysis of variance (repeated measures ANOVA) with two classification criteria (type of treatment and shelf life) was first performed on all results for the first nine and a half (9.5) months of shelf life. It was then completed by a one-factor analysis of variance (treatment type) for the remainder of the storage period (14.5 and 18 months). Significant differences were highlighted using Tukey's test at the 5% threshold. Finally, a multiple linear regression analysis was performed using Statistica version 8 software (Stat Soft, Inc., USA). Experimental data were fitted according to the second-order polynomial equation model, and the regression coefficients were obtained.

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

Where Yn is the experimental response, X1, X2 and X3 correspond respectively to the technological parameters, i.e. shelf life, biopesticide/corn ratio and biopesticide combination. The values of b_n represent the corresponding regression coefficients. According to the experimental data, the suitable model represented by the equation was constructed and the statistical significance of the model boundaries was examined by regression analysis and analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Results

Optimization of Corn Grain Storage Conditions:

The effects of storage time, the ratio of biopesticides and/or the combination of biopesticides likely to influence the organoleptic quality of maize kernels during storage were studied using the Central Composite Design (CCD). The tests carried out enabled us to determine the optimum conditions for grain deterioration, with the appearance of rancid odor (Y1) and musty aroma (Y2) as design responses linked to poor storage. Within the chosen experimental range, the scores for each sensory attribute varied from zero to 4.5 and from 0.65 to 3.3 for rancid odor and musty aroma respectively **(Table IV).**

Model Fitting:

There is a relationship between the different parameters studied and the different experimental results obtained. This relationship is of the form:

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

The various coefficients and their significance were determined using Statistical 7.1 software, based on the experimental matrix and the results of the descriptive sensory analysis. The different coefficients assigned to each parameter for the rancid odor and musty aroma, their quadratic effect and the interaction effects obtained are presented in **(Table V).**

The values of the coefficients of determination R2 and R2 adjusted for the rancid odor regression model are 0.93 and 0.88 respectively; for musty aroma, these values are 0.92 and 0.86 respectively (Table V). These respective values of R2 and adjusted R2 close to 1 confirm that the predicted second-degree polynomial model better defines the behavior of the system studied. The non-significant misfit also shows that this model was well fitted. This lack of fit was used to justify the model's ability to predict variations.

Table IV: Matrix of the composite central plane and experimental results

Tests	Parameter levels in real values			Experimental results	
	X_1 (months)	X_2 (%)	X_3 (% lippia)	Y_1	Y_2
1	4.45	1.01	20.27	0.55	1.1
2	14.5	1.01	20.27	3.8	3.3
3	4.45	3.99	20.27	0.35	1.03
4	14.5	3.99	20.27	2.7	2.13
5	4.45	1.01	79.73	0.6	1.13
6	14,5	1,01	79,73	3.9	3.25
7	4.45	3.99	79.73	0.4	1.09
8	14.5	3.99	79.73	1.8	2.17
9	1	2.5	50	0.00	0.11
10	18	2.5	50	4.5	3.3
11	9.5	0	50	3.8	2.9
12	9.5	5	50	1	0.65
13	9.5	2.5	0	2	1.75
14	9.5	2.5	100	2	1.79
15	9.5	2.5	50	1.5	1.74
16	9.5	2.5	50	1.2	1.65
17	9.5	2.5	50	1.7	0.91
18	9.5	2.5	50	1.8	1.03
19	9.5	2.5	50	1	1.37
20	9.5	2.5	50	1.05	1.51

The experimental results were determined in triplicate X1= actual values for the shelf life of the maize; X2= actual values for the proportion of biopesticides; X3 = actual values for the combination of biopesticides; Y1 = Rancid odour Y2: Musty aroma;

Table V: Statistical estimation of the regression coefficients of the polynomial model predicted for the rancid odour and mouldy aroma of grains

	Factors	Estimation of coefficients	
		Rancid smell	Musty flavor
	b_0	1.40**	1.36**
Linear			
	b_1	1.31**	0.87**
	b_2	-0.61**	-0.45**
	b_3	-0.05ns	0.010ns

Quadratic			
	b_{11}	0.20^{ns}	0.14^{ns}
	B_{22}	0.26^{ns}	0.17^{ns}
	B_{33}	0.11^{ns}	0.16^{ns}
Interaction			
	b_{12}	-0.35^{ns}	-0.26**
	B_{13}	-0.11^{ns}	-0.01^{ns}
	B_{23}	-0.13^{ns}	0.015^{ns}
R^2		0.94	0.93
R^2 **adjusted**		0.88	0.86
***p*- fault adjustment**		0.17^{ns}	0.49^{ns}

*Significant at P = .05; ** Significant at P = .01; ns: not significant; R^2: coefficient of regression; p-fit failure: Probability of misfit; b1, b2 and b3 = linear regression coefficients corresponding to X1, X2 and X3 respectively; b12 = regression coefficients for the interaction between X1 and X2; b13= regression coefficients for the interaction between X1 and X2; b23= regression coefficients for the interaction between X2 and X3; b11= quadratic regression coefficients for X1; b22= quadratic regression coefficients for X2; b33= quadratic regression coefficients for X3.

Effects of Factors on The Rancid Odor of Porridge from Preserved Grain:

The results of the statistical analysis of the effects of the variable's storage time, biopesticides/maize ratio, and combination of biopesticides on the perception of rancid odor by the panelists in the grains obtained, based on the composite central design, are presented in (Table IV). A multivariate regression analysis is conducted on the experimental data, and the significance of the model coefficients is assessed. Therefore, the duration of storage and the proportion of biopesticides to maize had significant effects (P =.05). The final predictive equation for the rate of increase in rancid odor (Y1), which disregards non-significant factors, was provided by the following equation:

$$Y = 1.40 + 1.31X_1 - 0.61X_2$$

The linear coefficients of the variables (X1, X2) are statistically significant (P 0.05). The significant terms have an impact on the rancid odor perceived in the slurries prepared from the stored grains, while the non-significant terms (all the interactions as well as the quadratic terms) have a negligible influence. **Figure 2,** constructed from the above equation, shows the effects of significant terms (storage time and biopesticides/corn ratio) on the perception of rancid odor in maize grains during storage. This figure shows the effects of time and the ratio of biopesticides to biopesticides in maize on the intensity of the rancid odor perceived by the panelists. When the X1 variable is at its highest level and the X2 variable is at its lowest level, the intensity of the rancid odor increases rapidly. However, at a threshold biopesticides concentration, the rancid odor is inhibited until the eighteenth month of storage. Similarly, rancid odor is still progressively inhibited up to 18 months. The results of the experimental analysis show that grain storage to maintain sensory quality is favored when the 'X1 storage time' variable is at its highest level at 18 months (coded + 1.682), the 'biopesticides/corn ratio' variable is at level 2.5 (coded 0) and the coded value of the biopesticides combination is 100% (coded +1.68). Thus, the ideal process for preserving the quality of maize grains based on the intensity of the rancid odor is achieved under the following conditions: - Storage period: 18 months - Ratio of biopesticides to maize: 2.5 - Combination of biopesticides: 100% Lippia multiflora or 100% Hyptis suaveolens

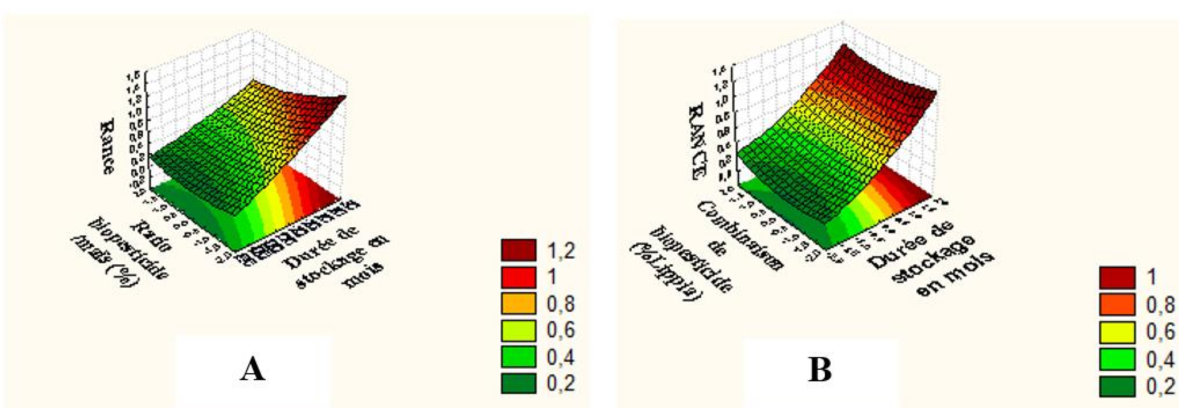
Effects of Factors on The Moldy Aroma of Porridge Obtained from Preserved Grains:
The results show that the intensity of the moldy aroma of maize grains obtained from the different preservation combinations after 9.5 months is 2.90±0.36 for triple bagging without biopesticide and 0.66±0.23 in triple bagging systems with 5% biopesticide. A multiple regression analysis performed on the experimental data was used to evaluate the coefficients of the model. These coefficients are evaluated for significant effects according to the equation below.

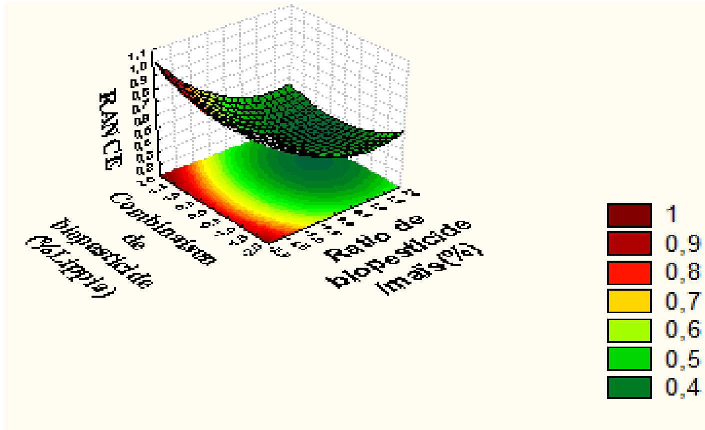
$$\mathbf{Y = 1.36 + 0.87X_1 - 0.45X_2 - 0.27X_1X_2}$$

The linear coefficients (X1 and X2) are significant. There is therefore an interaction effect between X1 and X2. These significant terms have a remarkable impact on the moldy aroma of maize grains during storage. The effect of storage time and biopesticide concentration are significant (P = .05 and P = .001). However, the quadratic term (X21) and the combination of biopesticides (X3) were not significant and had a negligible influence on the intensity of moldy aroma. The outer area of the plot in **Figure 3** shows the effect of time and biopesticide concentration on moldy aroma intensity. The musty aroma increased significantly over time during storage (P = .05). However, the negative effect of the X2 variable, above a certain threshold concentration, significantly inhibited the increase in this undesirable aroma (P = .001).

The results of the experimental analysis show that the sensory quality of maize grains deteriorates most when the storage time variable is at its highest level (+1.68) and when the coded value of the biopesticide quantity variable is -1.68, i.e. at its lowest level. Above this biopesticide concentration, maize grain quality is maintained. The process of deterioration in the sensory quality of the kernels is maximum under the following conditions:

- Shelf life: 9.5 months
- Quantity of biopesticides in the triple bagging system: 0.00 %.

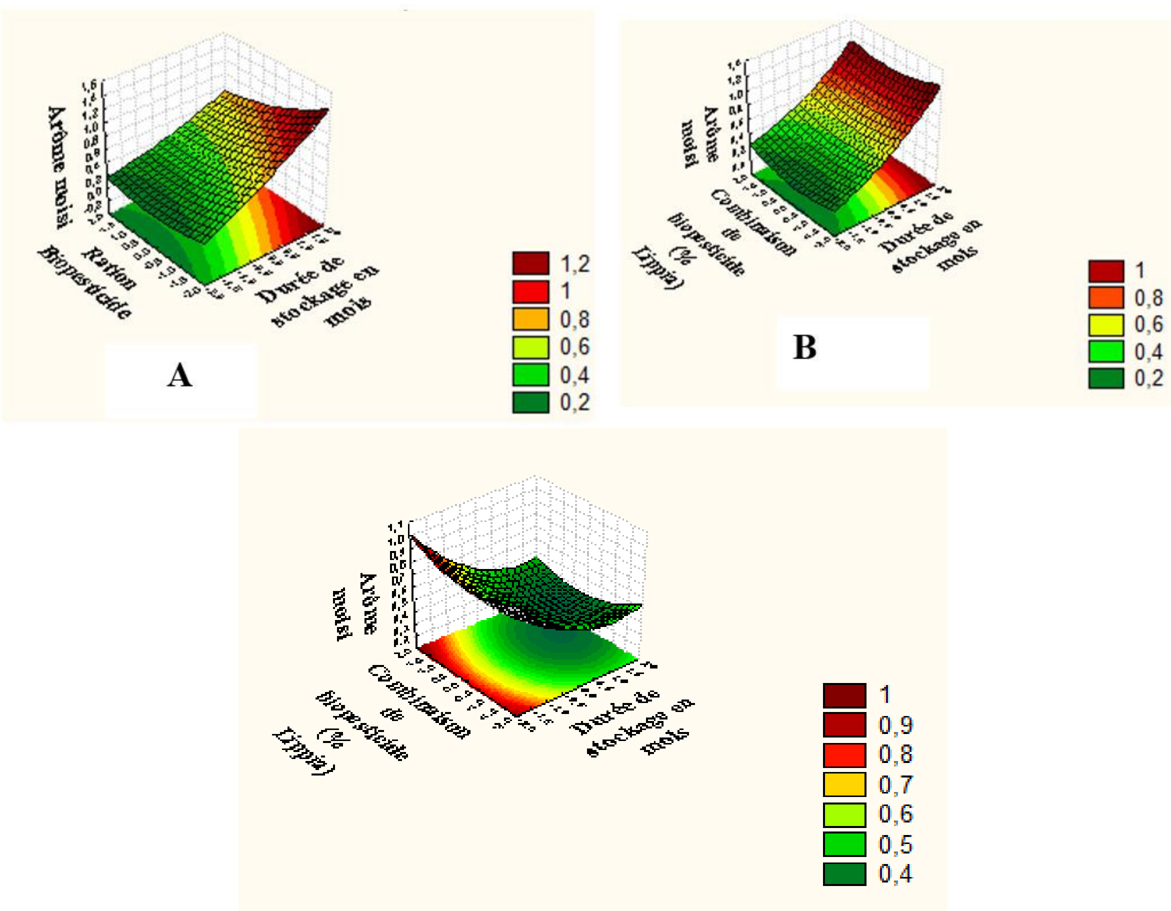




Very satisfactory flavour | Very satisfactory flavour | Satisfying flavour

Satisfying flavour | Flavour control

Figure 02: Effects of the different factors X1 (storage time) and X2 (biopesticide ratio) A; X1 (biopesticide ratio) and X3 (biopesticide of biopesticides) B and X2 (storage storage time) and X3 (combination of biopesticides) C on the rancid odor of the grains



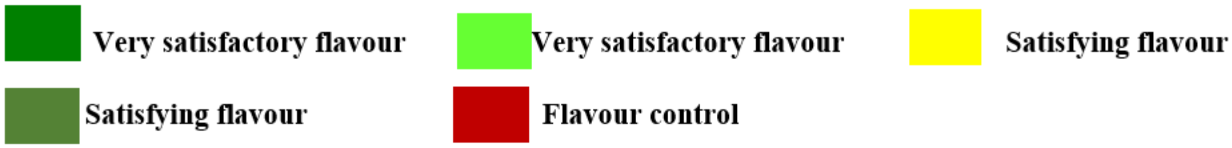


Figure 03: Effects of the different factors X1 (storage time) and X2 (biopesticide ratio) A; X1 (biopesticide ratio) and X3 (biopesticide of biopesticides) B and X2 (storage storage time) and X3 (combination of biopesticides) C on the moldy aroma of the grains

Determining the Best Storage Conditions:

Using the desirability function of the surface response methodology of the Statistica 7.1 software, the ideal storage conditions for maize grains were predicted, with 2.5% biopesticides, including 100% Lippia multiflora or 100% Hyptis suaveolens, for 18 months in triple bagged bags. The highest possible values for rancid odour and moldy aroma (sensory quality parameters) were determined.

Under the above conditions, the experimental results are very close to those predicted in Table VI. This expresses a perfect convergence between the values observed in the experiment and those predicted by the regression model. For these sensory parameters, the experimental values obtained under identical conditions remain significantly lower than those obtained in the polypropylene control batch (TB0SP) after 9.5 months of storage. Furthermore, they remained significantly distinct (P .05) from those obtained with the triple bagging system without biopesticides (TB0P) after a duration of 18 months. In addition, for the two (2) types of bags used without biopesticides (polypropylene and triple-bottom bags) for a period of 9.5 months, the values obtained for rancid odor and moldy aroma in the triple-bagging system batch (TB0) remained significantly lower than those in the control batch (TB0SP). Table (VII)

Table VI: Experimental value of the rancid odour and mouldy aroma of slurry from grains under ideal storage conditions and in the triple single bagging system (at 18 months).

Response	Ideal storage conditions (triple bagging with biopesticides)		Triple bagging without biopesticides
	Predicted value	Resulting value	TB0P (18 months)
Rancid odour	4.10 ± 0.25[a]	4.18 ± 1.1[a]	7.33 ± 0.35[b]
Musty flavour	3.70±0.37[a]	3.54 ± 0.43[a]	6 ± 1.67[b]

TB0: triple bagging without biopesticides. Values on the same line with the same letters are statistically in the same homogeneous group at P = .05.

Table VII: Experimental value of the rancid odour and mouldy aroma of slurry from grains after 9.5 months' storage in the polypropylene control batch and in the triple single bagging system.

Response	Without biopesticides (9.5 months)	
	Polypropylene bag	Triple single bagging
Rancid odour	5.03± 0.16[a]	3.80 ± 0.27[b]
Musty flavour	4.07± 0.56[a]	2.90 ± 0.36[b]

Values on the same line with the same letters are statistically in the same homogeneous group at P = .05.

DISCUSSION

The utilization of triple bagging technology, as defined by a composite central plane, demonstrates that the presence of Lippia multiflora and Hyptis suaveolens leaves in these storage systems proves to be efficacious in preserving the sensory attributes of maize grains. Indeed, it has been observed that slurries derived from grains that have been stored in the presence of biopesticides exhibit minimal levels of odor, rancidity, and moldy aroma. After the first nine and a half months of storage, the average results for moldy aroma and rancid odor obtained from triple-bottom bags with or without biopesticides changed very little. However, after 14 and a half months of storage, the values of 6 ± 1.67 and 7.33 ± 0.35, respectively, for moldy aroma and rancid smell obtained for the batch stored in the single triple-bottom bag are very high, compared with those obtained with different proportions and/or combinations of biopesticides. These values indicate the effectiveness of the leaves of Lippia multiflora and Hyptis suaveolens for storing maize grains. This effectiveness may be reflected in the dual insecticidal and insect repellent properties of the leaves treated with various biopesticides [38, 39, 40]. Our results confirm the work carried out by Niamketchi et al [41] in the central region of Côte d'Ivoire. These authors showed the effectiveness of dried leaves of Lippia multiflora and Hyptis suaveolens against the development of pests responsible for grain spoilage in traditional and improved granaries. Our results are also in agreement with those of the work of [42] in Benin, who showed that the essential oils of *Pimenta racemosa* and *Syzygium aromaticum* considerably reduced the fungal flora responsible for altering the organoleptic properties of cowper seeds during storage over a period of three months. During storage, analysis of the results indicated that the progressive increase in the rancid odor of the grains was relatively low in triple bagging systems with biopesticides during the 18 months of storage compared with the triple bagging batch without biopesticides and the polypropylene batch without. This increase in the intensity of the rancid odor of maize grains could be attributed to an increasing concentration of hexanal, resulting from lipid oxidation. According to the work of [43], this aldehyde is responsible for rancidity and unpleasant odors in cereals. Rancidity is caused by the oxidation of lipids, which can be accelerated by light, heat, or the presence of moisture, but above all by the presence of oxygen [44] [45]. This implies that the low intensity of rancid odor in samples stored in triple bagging systems with biopesticides was due to the low oxygen permeability of the packaging materials.

However, samples stored in triple single bagging systems showed a steady increase in rancid odor after 9.5 of storage due to the higher oxygen permeability of these bags due to insect perforation [46]. This suggests that the incorporation of biopesticides, such as leaves of Lippia multiflora and H. suaveolens, aids in limiting the oxidation of maize kernels. The results of the sensory analysis conducted on the various slurries produced from maize grains indicate a gradual increase in the moldy aroma in maize grains stored in polypropylene bags and triple bagging systems, whether combined with *Lippia multiflora and H. suaveolens* leaves (biopesticides). This increase in the intensity of the moldy aroma recorded during storage could be explained, on the one hand, by the recovery of moisture due to the partial impermeability of these storage systems [47] and, on the other hand, by the increased activity of insects and microorganisms responsible for the production of mycotoxins [48] [49]. Indeed, Gnandé et al. (2019) [50] demonstrated that the moisture content of grains recorded during the monitoring of nutrient parameters in polypropylene bags (control batch) after the first 9.5 months of storage was 16.67 0.27%. In contrast, the rate is less than 13% in the diverse triple bagging batches that have been treated or not with biopesticides plants up to a period of 18 months of storage. The ideal storage conditions for maize grains were predicted using the desirability function of the Statistica 7.1 software, with 2.5% biopesticides in triple-bottom bags for 18 months. In fact, the mathematical model with regression coefficients greater than 0.70 is effective at predicting the variation in responses [51]. This highlights the proven validity and accuracy of the results obtained. According to the experimental analysis, the intensities of the rancid odor and moldy aroma of the grains remain insignificant when the variable'storage time' is at its highest level, 18 months, and when the value of the variable 'amount of biopesticides' is 2.5% or 1.25 kg of leaves based on 50 kg of maize. Under these conditions, the experimental results are very close to those predicted. Thus, according to the results of the work of Koffi et al. (2015) [52], the composite central design is successfully applied.

CONCLUSION

The results of our study confirm the importance of triple bagging for preserving maize grains. This container makes it possible to extend the shelf life of the kernels while guaranteeing their sensory qualities. This study also shows that the addition of *Lippia multiflora* and H. *suaveolens* leaves, as a biopesticide, further extends the shelf life of maize grains in Côte d'Ivoire. These biopesticides provide effective control of the insects and microorganisms responsible for altering the sensory characteristics of stored grain. This study enabled us to determine the ideal conditions for effective conservation of sensory characteristics based on a composite central plane. The ideal conditions for storing maize grains obtained in our study are 2.5% biopesticides with 100% Lippia multiflora or 100% Hyptis suaveolens for 18 months in triple-bottomed bags. The method developed in our study using leaves of *Lippia multiflora* and H. *suaveolens* (biopesticides) in triple-bottom bags is inexpensive and promising for low-income Ivorian producers.

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