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NUTRITIVE COMPOUNDS EVOLUTION OF POST-HARVEST MAIZE (Zea mays L.) STORED IN GRANARIES WITH BIOPESTICIDES FROM RURAL CONDITIONS IN COTE D'IVOIRE

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Abstract

A Combination of leaves derived from *Lippia multiflora* Moldenke and *Hyptis suaveolens* Poit. Benth were tested for their protective effect on the chemical composition of stored maize cobs and grains in traditional and improved granaries. Thus, a 3x4 factorial design was considered to evaluate the nutritional qualities in both forms of maize. Factors were three types of granaries (control, traditional and improved) and four periods of observation (0, 2, 6 and 8 months). Results showed significant influence of the interaction between types and times of storage upon chemical compositions of maize. This interaction revealed significant changes in the contents of moisture (from 9.14% to 12.78%), ash (1.63% to 2.5%), proteins (8% to 5.70%), lipids (4.73% to 3%), starches (65.10% to 53.5%), fibers (5.76% to 3.5%), total sugars (2.56% to 1.5%), reducing sugars (0.50% to 0.20%) and energy (381% to 360.5%) of treated or untreated maize. For each stage, chemical composition of maize cobs and grains did not differ whether they are treated in traditional or improved granaries with both plant materials. The results of this study indicate that the maize storage for 6 months with the combination of both local plants would be more suitable.
With an equivalent daily intake of 28.4 g of maize in Côte d'Ivoire, that food resource covers proportions of 3.78% of proteins, 1.57% of lipids, 4.3 to 6.14% of fibers, 21.85% of carbohydrates and 4.73% of energy from the recommended daily intakes, when stored for 6 months.

Keywords: Stored maize, nutritive quality, biopesticides, traditional and improved granaries

Introduction

Maize (Zea mays L., Poaceae) is a substantial contribution in the diets of rural and urban populations. Its cultivation increased gradually over the years [1] thanks to adoption of best production technologies and improved varieties [2]. In Côte d'Ivoire, this crop is generally cultivated by small-scale farmers and widely grows across various ecological zones, from the northern savannah till the rain forest belt in the south [3], with a yield of 654,738 tons in 2012/2013 from 327,800 ha of total cultivated area [4]. Maize is a major source of food, feed and raw material for food industries [5]. In Côte d'Ivoire, the mean daily consumption of maize grains is estimated at 28.4 g [6]. It allows diverse dishes such as porridge, couscous or dense paste (tô) eaten with sauce [7].

However, after harvest, inadequate infrastructure and lack of economic means usually involve in storage of maize crops by farmers, either shelled or unshelled using traditional structures and processing, such as living rooms, cribs, baskets, polypropylene bags, earthen ware and granaries [8]. Unfortunately, crops kept in these conditions and structures are generally subject to deterioration. The primary factors affecting the grains during their storage are the moisture, the temperature and the relative humidity of the environment. Other maize deterioration agents are rodents, insect pests and microorganisms. Both primary and secondary factors lead to chemical changes, weight loss and finally to changes in the maize quality [9]. These are so important damages that the farmers often dispose of significant proportion of their stored grains due to deterioration. In general, infestations start at fields and continue throughout the storage period [10].

The full losses resulting with deterioration are about 25-30% of the stored food grains [11]. Thus, proper conditions of maize storage could allow significant improvement in the national farmer's economy by controlling the losses.

In fact, the storage technologies have major roles upon the final quality of the resulted grains. Ensuring optimal efficiency of the storage technologies is highly crucial for the safety of stored grain and for the consumer's health. Common pests controlling system of stored products is with the application of synthetic contact insecticides [12] despite many risks on the health of users and consumers and environmental pollution [13]. Nevertheless, other methods of storage and conservation could be improved in order to find alternative in uses of synthetic pesticides for the post-harvest losses reduction.

The objective of the current research is to establish the most efficient, economically feasible and safe storage structure that would benefit to farmers. The study assesses effects of two local plants *Lippia multiflora* and *Hyptis suaveolens*, deriving with the nutritional qualities of maize stored in traditional and improved clay granaries in rural conditions of Côte d'Ivoire.

Materiel and methods

1. Experimental site

Experiments were carried out in the rural farming community of Djedou village in the department of Botro, Gbèkê region, in the center of Côte d'Ivoire. The village is located at 40 km from Bouaké, with points of 7°50' N and 5°18' W. This region has a humid tropical climate with annual rainfall ranging between 1000 and 1100 mm, mean temperatures of 21.4°C to 30.6°C and 75% to 80% of relative humidity [14].

2. Collection of the maize used in the study

Maize grains and full maize cobs were bought in January 2014, approximately one month after harvest, from the young cooperative of the Djedou village. Prior to the storage, maize were sun-dried for 2 to 3 days before being used for the experiments.

3. Biopesticides collection and processing

Two plants species *Lippia multiflora* and *Hyptis suaveolens* have been selected for their biopesticides properties. Both plants are spontaneous perennial and fragrant shrubs growing from the central to the Northern parts of Côte d'Ivoire [15 and 16]. Leaves of *L. multiflora* and *H. suaveolens* were collected around Djedou village. After harvest, the leaves have been dried out of direct sunlight for 6-7 days.

4. Experiments implementation

4.1. Granaries main parameters

A cylindrical clay granary covered with a straw roof side was chosen for the experiment. Such convenience is commonly used by farmers to keep their cereal crops (maize, rice, millet, sorghum). The granaries are built by a specialist farmer after the main fieldwork. Such operation runs from 1 to 12 months. To relieve the difficulties encounted, traditional granaries (Photography 1.a) are modified by replacing their cylindrical roof with a simple device in similar design.
The straw roof has been substituted with a plastic for hermetical recovering of granaries (Photography 1.b). Besides, granaries are raised from the ground to prevent moisture and rodent attack. Such systems reveal general storage capacity of 9 m^3 to 12 m^3 (Figure 1).

4.2. Experimental design

The experiment was carried out using a completely randomned 3x4 factorial design with two forms of maize: cobs and grains. Factors were three types of granaries (control, traditional and improved) and four observation periods (0, 2, 6 and 8 months). The investigation runned from January to September 2014 and the young cooperative of Djedou village was associated. The maize grains storage granaries were built in Djedou village; and the maize cobs storage granaries were located at N'godrjenou camp, 4 km far from Djedou, to facilitate the surveillance and monitoring. Excepted for the control, granaries contained mixtures of chopped dried leaves of *L. multiflora* and *H. suaveolens* at 2.5% w/w of each plant. The required quantities of each plant material were intermittently sandwiched manually in granaries, after 120 kg of maize cobs or grains.

4.3. Sampling

The sampling was performed at the beginning of the storage (0 month), then 2, 6 and 8 months later, in triplicate. Thus, 1 kg maize samples from each granary were gathered through the top, the centre and the bottom opening side. Maize samples were then conveyed to laboratory for the nutritive properties assessments.

4.4. Biochemical analysis

Proximate analyses were carried out using standard methods AOAC [17]. Thus, maize moisture was deduced after drying the samples in an oven (MEMMERT, Germany) at 105°C. Ash content resulted from incineration of 5 g of dried maize sample at 550 °C in an oven (PYROLABO, France) for 12 h. For crude fibers, 2 g of crushed maize samples were taken. Then, extraction mixture was prepared using 0.25 M sulfuric acid and 0.31 M sodium hydroxide with intermittent boiling. After suction filtration, the insoluble residue was washed with hot water, dried with an oven (MEMMERT, Germany) at 100 ºC for 2 h then incinerated. The final residue allowed estimation of the crude fibers content. The proteins contents were determined with use of the Kjeldhal method. The lipids contents resulted from a solvent (hexane) extraction using a Soxhlet device. Starches contents were determined using iodine method of Jarvis and Walker [18]. Total soluble sugars amounts were determined by the method of Dubois *et al* [19] with phenol and sulfuric acid, then reducing sugars were mesured out according to the method of Bernfeld *et al* [20] basing on the 3, 5- dinitrosallicyclic acid reagent. Prior to their quantification, sugars were extracting with ethanol, zinc acetate and oxalic acid [21]. Total carbohydrate and energy (caloric value) were estimated using formulas indicated by FAO [22] as follow:

Carbohydrates (%) = 100 – (% moisture + % proteins + % lipids + % ash) (1)

Energy (%) = (% proteins x 4) + (% carbohydrates x 4) + (% lipids x 9) (2)

The results of protein, lipid, ash, fiber, starch, total carbohydrate content, total soluble and reducing sugars were expressed on the dry weight basis.

4.5. Assessment of dietary intakes deriving from the maize storage for adults Ivorian

According to the National agricultural statistics of Côte d'Ivoire, maize is domestically consumed at the rate of 28.4 g per capita [6]. Thus, the main nutrients of maize stored as grains in the improved granaries at 6 month were estimated in order to determine its contribution in an adult Ivorian diet. The recommended intake of a nutrient is the mean amount of this nutrient that should be supplied daily per person to cover the needs and ensure good health. For each nutrient, the intake resulting from maize grain consumption is evaluated with the equation:

$$NI\ (g/kg/day) = (C \times A)/W \qquad (3)$$

With NI, the nutrient intake; C, the nutrient content (mg/g); A, the amount of food consumed per day (g) and P the means weight of an adult (70 kg).

4.6. Statistical analysis

All analyses were performed in triplicate and the full data were statistically treated using SPSS software (version 20.0). It consisted in Analysis of Variance according to two factors: duration and method of storage. Means derived from parameters were compared with the Tukey High Significant Difference test at 5% significance level. Correlations between parameters were also assessed according to the Pearson index. Then, Multivariate Statistical Analysis (MSA) namely Principal Components Analysis (PCA) and Ascending Hierarchical Classification analysis (AHC) were performed using STATISTICA software (version 7.1).

Experimental results

1. Evolution of the aerothermal parameters

Figure 2 shows the evolution of the temperature and relative humidity in the experimental area. The mean air temperature during the studies implementation (January to September 2014) was 30.58±1.97 °C. But, a higher temperature of 33.81±3.00 °C was noticed in March, while August provided the lowest temperature (27.50±1.10 °C). With the relative humidity of the area, general average of 80.38±4.08% was recorded during the study period. The months of January, February and March 2013 (68.71±3.52%, 56.21±5.52% and 70.95±6.00%, respectively), were less humid than the others months while August recorded the top value of 91.12±5.00%

2. Evolution of the nutritive parameters

Except for the carbohydrates, the statistical traits reveal significantly changes ($P<0.05$) in the contents of the biochemical parameters assessed according to the duration and the type of storage, whether the maize was treated or untreated with biopesticides (tables 1 and 2).

2.1. Moisture content

Tables 3 and 4 show the moisture of maize cobs and grains stored in the different granaries. With respective means of 9.23% and 9.05% at the beginning (0 month), the moisture contents increase significantly ($P<0.001$) during the storage period. The highest moisture values are recorded after 8 month of storage in the control granaries with means of 13.82% and 13.52% from maize cobs and grains.

These values are higher than the moisture deriving with traditional and improved granaries from both maize cobs (12.85% and 12.74%, respectively) and grains (11.85% and 11.87%, respectively). Besides, the interaction between type and time of storage does not involve any significant effect upon this parameter as show in previous tables 1 and 2.

2.2. Ash, fibers, Protein and lipid contents in the different maize storage types

From the various technologies, the ash content remains constant during 6 months of storage, with means remaining between 1.62% and 1.82% of the maize dry matter. But this trait rises significantly at the 8^{th} month of storage, highlighting higher values of 2.64% or 2.70% from maize grains or cobs in the control granaries than the traditional (2.31% or 2.39%) and improved (2.40% or 2.47%) granaries. On the other hand, the contents of fibers, proteins and lipids change steadily with duration and types of storage. The fibers contents recorded at the earlier storage (5.74% to 5.78%) dropped at 2.54% to 4.36% after 8 months of storage, with higher step means from the treated granaries than the untreated ones. Similarly, maize cobs or grains present proteins contents declining significantly and respectively from 8% or 7.88% to means fluctuating between 4.77% and 6.32% in the control, traditional and improved granaries. Concerning the lipids contents, the means of 4.70% or 4.76% recorded at the earlier storage decrease to 2.42% to 2.75% with the control and between 3.00% and 3.62% for the traditional and improved granaries. Moreover, proteins and lipids contents from the untreated granaries are lower than values provided by the biopesticides treatments (Tables 3 and 4).

2.3. Starches and total carbohydrates contents in the different maize storage types

The starches contents are significantly influenced ($P<0.05$) by the interaction between type and duration of storage (Tables 1 and 2).

A gradual decrease is observed with the duration of storage. The starches contents of the maize cobs and grains at the earlier storage (64.90% to 65.10%) drop to 40.25% or 47.80%, to 45.20% or 52.10% and to 46.20% or 51.20% for the control, the traditional and the improved granaries, respectively, after 8 month of storage. Higher step means are recorded from the treated granaries than the untreated ones (Tables 3 and 4).

Regarding with the amount of total carbohydrates, results do not show any significant variation ($P>0.05$) with the maize stored as cobs (75.25% to 76.67%) or grains (75.77% to 77.40%) during the full storage investigated from the three types of granaries (Tables 1 and 2).

2.4. Total and reducing sugars in the different maize storage types

The post harvest maize storage revealed a significant decrease in the total sugars contents ($P<0.05$) during storage, from the beginning till the 8^{th} month. Considering both maize cobs and grains, the means ranging between 2.55% and 2.57% before the storage drop to 1.38% or 1.31% for the control granaries, to 1.87% or 1.67% with the traditional granaries and to 1.94% or 1.65% in the improved granaries (tables 3 and 4).

The reducing sugars contents showed significant differences ($P<0.05$) between the beginning and the end of storage. The means were between 0.50% and 0.51% after the maize harvest and before the storage. Then the reducing sugars contents increased significantly at the 2thmonth of storage with means of 0.71% or 0.72% in control, 0.64% or 0.68% in traditional, 0.61% or 0.69% in improved granaries, before dropping till the 8thmonth of storage where values of 0.12% or 0.19%, 0.22% or 0.35% and 0.23% or 0.34% are recorded from the respective granaries (tables 3 and 4).

2.5. Energy content in the different maize storage types

The 8 months of storage show significant decreasing of the caloric values involving with the three technologies investigated. The caloric values, estimated around 381 kcal/100g before the storage, drop significantly ($P<0.05$) to 364.34 kcal/100g or 360.27 kcal/100g with the traditional granaries, to 364.50 kcal/100g or 360.76 kcal/100g for the improved granaries and to 352.24 kcal/100g or 350.39 kcal/100g from the control granaries considering the maize cobs or grains, respectively (tables 3 and 4). During the storage, the granaries managed with biopesticides allow higher caloric values to maize than those without any treatment.

3. Correlations between nutritive parameters

The Pearson indexes (r) indicate positive and negative significant correlations between the 10 parameters assessed for both maize forms (cobs and grains). Thus, fibers, proteins, lipids, starch, total carbohydrates, total and reducing sugars are closely correlated during the storage of the post harvest maize, r varying from 0.50 to 0.96 for maize cobs and from 0.61 to 0.96 for maize grains. Also, the lipids and the proteins contents change tightly ($r=0.88$ and 0.94 for maize cobs and grains respectively). The starches contents are directly correlated with the fibers contents ($r=0.93$ and 0.95 for maize cobs and grains respectively). Positive significant correlations are observed between total and reducing sugars ($r=0.60$ and 0.80 for maize cobs and grains respectively) and between proteins contents and caloric values ($r=0.94$ and 0.92 for maize cobs and grains respectively).

On the other hand, moisture and ash contents of both maize forms are reversely correlated with all different parameters, with r values ranging from -0.97 to -0.72 (moisture contents) and -0.78to -0.58 (ash contents) for maize cobs and from -0.98 to -0.52 (moisture contents) and -0.72 to -0.59 (ash contents) for maize grains (tables 5 and 6).

4. Variability between storage structures and nutritive parameters during storage

Principal Component Analysis (PCA) was achieved with the main factors F1 and F2 (table 7) delivering eigenvalue equal or superior to 1, according to statistical standard of Kaïser. Then, gatherings highlighted from the PCA were clarified by Ascending Hierarchical Classification (AHC) performed with the Unweighted Pair Group Method with Arithmetic means (UPGMA).

4.1. Principal Component Analysis (PCA)

Figure 3.a shows the correlation circle between the F1-F2 factorial drawing, which expresses 94.36% of the total variability (table 7), and the nutritive parameters of maize stored. The moisture and ash contents had significant positive contribution in the formation of F1. Oppositely, the contents of starch, proteins, fibers, lipids, energy and sugars recorded negative significant correlations with F1. The F2 is significantly engaged only with the total carbohydrates content with a positive correlation.

The projection of the samples studied highlighted 4 groups of individuals (Figure 3.b). The Group 1 consists mainly in individuals from control granaries at 8 months of storage which are linked to the characters correlated positively to F1. Thus, they are characterized by high levels of water and ash contents. The second group includes samples resulting from the treated granaries (traditional and improved) at the 8th month of storage and the untreated granaries at 6 months of storage which also overlap with characters correlated positively factor F1.

Moreover, these individuals exhibit also high water and ash contents. The third group contains samples from the treated granaries (traditional and improved) at 6 months of storage and the control granaries at 2 months of storage. They are distinguished by high level in lipid, protein fiber, starch, energy, total soluble and reducing sugars during maize conservation. The group 4 is with samples from treated granaries (traditional and improved) at 2 months of storage, providing higher contents of lipids, proteins, fibers, starch, energy, total soluble and reducing sugars than those of other individuals.

4.2. Ascending hierarchical classification (AHC)

The Ascending hierarchical classification (AHC) corroborates the variability observed in the PCA (Figure 4). Indeed, at the gene distance of 5, the UPGMA dendrogram shows four clusters of the maize samples during storage. The first cluster is the control granaries at 8 month of storage with higher water and ash contents. The second cluster encloses individuals resulting from the treated granaries at the 8th month of storage and the untreated granaries at 6 months of storage, which provide similar nutritive parameters. The maize samples deriving from treated granaries and the control at respective 6 months and 2 months of storage inner the third cluster, showing similar high levels of lipids, proteins, fibers, starch, energy, carbohydrates and total soluble and reducing sugars. The fourth cluster includes maize samples from the treated granaries at 2 months of storage, which have contents of lipids, proteins, fibers, starch, energy, total soluble and reducing sugars superior to values provided by the other individuals.

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5. Dietary intake of nutritive compounds from maize grains after storage

Table VIII shows the contribution of proteins, lipids, carbohydrates, fibers and energy deriving from the intake of maize grains stored for 6 months.

According to the Dietary Reference Intakes [23], the recommended daily intakes of macronutrients for adults (70 kg) are 46 g for protein, 70 g for lipid, 30 g for fiber, 130 g for carbohydrate and 2,200 kcal for energy.

The mean macronutrients daily intakes from maize grains stored for 6 months are 1.74 g of proteins, 1.10 g of lipids, 21.85 g of carbohydrates, 1.30 g of fibers and 104 kcal of energy. These values still respectively represent 3.78%, 1.60%, 16.80%, 4.30% and 4.73% of the recommended intakes for an equivalent daily consumption of maize stated at 28.4 g per capita in Côte d'Ivoire [6].

Moreover, a consumption of 100 g of maize grains would bring 6.12 g of proteins, 3.81 g of lipids, 4.53 g of fibers, 76.94 g of carbohydrates and 366.41 kcal of energy; that would cover 13.30%, 5.44%, 15.10%, 59.20% and 16.65% of the daily intake recommended for these respective nutrients [23].

Photography1a: Traditional granary with straw roof for maize storage

Photography1b: Improved granary with plastic cover for maize storage

Figure 1: Experimental setup granaries deployed for maize storage

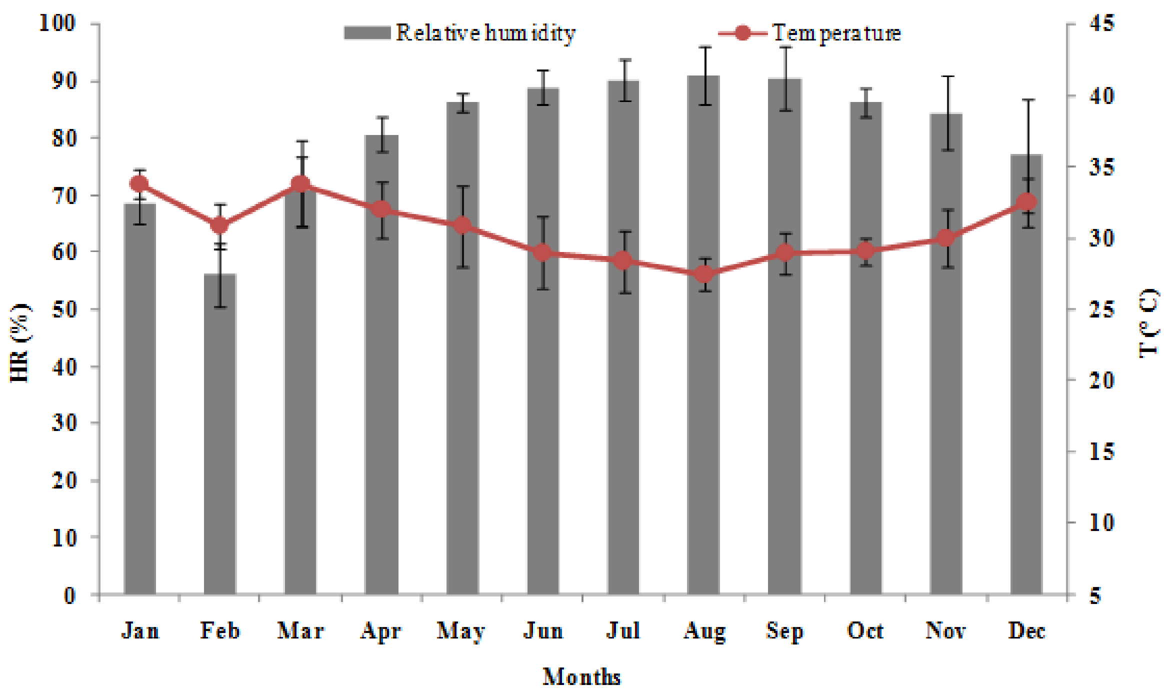

Figure 2: Ambient temperature and relative humidity changes of study site during storage

Table 1: Statistical data of proximate compositions of maize grains under different storage conditions

Source of Variation	df	statistical trait	Parameters									
			MC	ASC	PRC	LPC	STC	TCC	FBC	TSC	RSC	EC
Types	2	SS	5.86	0.86	3.31	2.16	81.22	0.43	2.96	0.39	0.009	318.47
		F-value	11.72	0.54	31.63	46.30	19.53	0.49	23.56	19.17	1.70	53.60
		P-value	<.001	0.59	<.001	<.001	<.001	0.62	<.001	<.001	0.20	<.001
Durations	3	SS	58.57	4.31	29.94	17.21	2302.49	5.20	35.30	5.55	1.255	2811.07
		F-value	78.13	18.13	190.50	245.40	369.20	3.93	187.51	181.15	152.23	315.32
		P-value	<.001	<.001	<.001	<.001	<.001	0.02	<.001	<.001	<.001	<.001
Types x Durations	6	SS	6.00	0.53	1.725	0.88	34.67	0.98	1.84	0.17	0.05	124.81
		F-value	1098	0.11	5.49	6.30	2.78	0.37	4.88	2.70	3.28	7.00
		P-value	0.11	0.99	0.001	<.001	0.03	0.89	0.002	0.04	0.02	<.001
Error	24	SS	6.00	1.90	1.26	0.56	49.90	10.58	1.51	0.25	0.07	71.32
Total	36	SS	4527.41	136.80	16.37	525.72	1097.67	2189.68	745.88	166.12	7.22	4852.34

SS, sum of squares; F-value, value of the statistical test; P-value, probability value of the statistical test; df, degree of freedom. MC, moisture content ; LPC, lipid content ; PRC, protein contents; STC, starch content ; ASC, ash content ; FBC, fiber content ; TCC, total carbohydrate content; TSC, total soluble sugar content; RSC, reducing sugar content;EC, energy content.

Table 2: Statistical data of proximate compositions of maize cobs under different storage conditions

Source of Variation	df	Statistical trait	Parameters									
			MC	ASC	PRC	LPC	STC	TCC	FBC	TSC	RSC	EC
Types	2	SS	4.23	0.10	3.70	1.52	73.05	0.63	4.88	0.24	0.041	254.25
		F-value	6.90	0.84	63.78	10.52	52.62	0.68	57.17	2.50	4.69	21.25
		P-value	0.004	0.44	<.001	0.001	<.001	0.52	<.001	0.10	0.02	<.001
Durations	3	SS	83.52	4.30	19.96	10.03	1045.61	11.77	17.10	3.36	0.57	3325.86
		F-value	90.70	28.21	229.76	46.35	502.15	8.46	133.44	23.70	43.31	185.31
		P-value	<.001	<.001	<.001	<.001	<.001	0.001	<.001	<.001	<.001	<.001
Types x Durations	6	SS	1.54	0.19	1.03	1.34	26.68	2.07	1.60	0.15	0.20	103.08
		F-value	0.84	0.64	5.90	3.10	6.41	0.75	6.24	0.51	7.41	2.87
		P-value	0.56	0.70	0.001	0.02	<.001	0.62	<.001	0.79	<.001	0.03
Error	24	SS	7.37	1.22	0.70	1.73	16.66	11.13	1.03	1.14	0.105	143.58
Total	36	SS	4876.10	132.06	1802.85	580.05	123205.10	205896.52	908.47	181.46	8.80	4429962.06

SS, sum of squares; F-value, value of the statistical test; P-value, probability value of the statistical test; df, degree of freedom. MC, moisture content ; LPC, lipid content ; PRC, protein contents; STC, starch content ; ASC, ash content ; FBC, fiber content ; TCC, total carbohydrate content; TSC, total soluble sugar content; RSC, reducing sugar content;EC, energy content.

Table 3: Evolution in proximate compositions of maize cobs according to the storage conditions (on dry weight basis)

Parameters	Storage time	Control	Traditional granary	Improved granary
Moisture (%)	0	9.23 ± 0.06^{Aa}	9.23 ± 0.06^{aA}	9.23 ± 0.06^{aA}
	2	11.82 ± 0.98^{aB}	10.75 ± 0.38^{aB}	10.67 ± 0.08^{aB}
	6	13.15 ± 0.62^{aBC}	12.45 ± 0.57^{aC}	12.32 ± 0.49^{aC}
	8	13.82 ± 0.82^{aC}	12.85 ± 0.72^{aC}	12.74 ± 0.65^{aC}
Ash (%)	0	1.62 ± 0.02^{aA}	1.62 ± 0.02^{aA}	1.62 ± 0.02^{aA}
	2	1.71 ± 0.20^{aA}	1.67 ± 0.02^{aA}	1.63 ± 0.06^{aA}
	6	1.74 ± 0.15^{aA}	1.76 ± 0.19^{aAB}	1.72 ± 0.18^{aA}
	8	2.70 ± 0.30^{aB}	2.31 ± 0.39^{aB}	2.40 ± 0.48^{aB}
Fiber (%)	0	5.74 ± 0.5^{aD}	5.74 ± 0.5^{aC}	5.74 ± 0.5^{aC}
	2	4.75 ± 0.20^{aC}	5.72 ± 0.11^{bC}	5.68 ± 0.11^{bC}
	6	4.01 ± 0.15^{aB}	5.03 ± 0.06^{bB}	5.10 ± 0.06^{bB}
	8	3.24 ± 0.20^{aA}	4.25 ± 0.10^{bA}	4.36 ± 0.31^{bA}
Protein (%)	0	8.00 ± 0.26^{aD}	8.00 ± 0.26^{aD}	8.00 ± 0.26^{aC}
	2	7.00 ± 0.15^{aC}	7.55 ± 0.21^{bC}	7.60 ± 0.10^{bBC}
	6	6.24 ± 0.24^{aB}	7.10 ± 0.10^{bB}	7.22 ± 0.03^{bB}
	8	5.21 ± 0.18^{aA}	6.24 ± 0.01^{bA}	6.32 ± 0.31^{bA}
Lipid (%)	0	4.70 ± 0.25^{aC}	4.70 ± 0.25^{aC}	4.70 ± 0.25^{aB}
	2	3.87 ± 0.32^{aBC}	4.12 ± 0.13^{aB}	4.05 ± 0.05^{aA}
	6	3.21 ± 0.68^{aAB}	4.00 ± 0.16^{aAB}	3.97 ± 0.23^{aA}
	8	2.75 ± 0.25^{aA}	3.62 ± 0.18^{bA}	3.62 ± 0.15^{bA}
Starch (%)	0	64.90 ± 0.55^{aD}	64.90 ± 0.55^{aD}	64.90 ± 0.55^{aD}
	2	58.78 ± 0.92^{aC}	62.10 ± 0.40^{bC}	61.90 ± 1.10^{bC}
	6	53.50 ± 0.76^{aB}	58.70 ± 1.80^{bB}	57.90 ± 0.25^{bB}
	8	47.80 ± 0.10^{aA}	52.10 ± 1.28^{bA}	51.20 ± 0.14^{bA}
Total carbohydrate (%)	0	76.67 ± 0.63^{aA}	76.67 ± 0.62^{aA}	76.67 ± 0.45^{aA}
	2	75.90 ± 0.87^{aA}	75.25 ± 0.05^{aA}	76.05 ± 0.25^{aA}
	6	76.06 ± 0.05^{aA}	76.14 ± 0.55^{aA}	76.07 ± 0.29^{aA}
	8	75.92 ± 0.42^{aA}	76.27 ± 0.47^{aA}	76.12 ± 1.19^{aA}
Total soluble sugar (%)	0	2.55 ± 0.30^{aC}	2.55 ± 0.30^{aA}	2.55 ± 0.30^{aC}
	2	2.32 ± 0.09^{aBC}	2.51 ± 0.50^{aA}	2.52 ± 0.08^{aBC}
	6	1.98 ± 0.02^{aAB}	2.10 ± 0.10^{aA}	2.12 ± 0.08^{aAB}
	8	1.38 ± 0.16^{aA}	1.87 ± 0.03^{bA}	1.94 ± 0.04^{bA}
Reducing sugar (%)	0	0.50 ± 0.01^{aC}	0.50 ± 0.01^{aC}	0.50 ± 0.01^{aC}
	2	0.72 ± 0.03^{aD}	0.65 ± 0.02^{aD}	0.66 ± 0.02^{aD}
	6	0.26 ± 0.01^{aB}	0.39 ± 0.02^{bB}	0.40 ± 0.01^{bB}
	8	0.19 ± 0.01^{aA}	0.35 ± 0.01^{bA}	0.34 ± 0.04^{bA}
Energy (kcal/100g)	0	381 ± 0.75^{aC}	381 ± 0.75^{aC}	381 ± 0.75^{aC}
	2	366.47 ± 1.26^{aB}	370.27 ± 1.21^{aB}	371.10 ± 0.28^{aB}
	6	358.12 ± 4.96^{aB}	368.96 ± 1.14^{aB}	368.91 ± 0.98^{aAB}
	8	352.24 ± 2.10^{aA}	364.34 ± 1.95^{aA}	364.50 ± 1.10^{aA}

Means (±SD) with different lower-case/upper-case letters in the same line/column are different at 5% probability test.

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Table 4: Evolution in proximate compositions of maize grains according to the storage conditions (on dry weight basis)

Parameters	Storage time	Control	Traditional granary	Improved granary
Moisture (%)	0	9.05±0.21aA	9.05±0.21aA	9.05±0.21aA
	2	11.65±0.30bB	10.85±0.57aB	11.05±0.26aB
	6	12.56±0.68aBC	11.56±0.97aB	11.42±0.43aAB
	8	13.52±0.68bC	11.85±0.35aB	11.87±0.48aC
Ash (%)	0	1.65±0.3aA	1.65±0.3aA	1.65±0.3aA
	2	1.78±0.06aA	1.68±0.10aA	1.65±0.24aA
	6	1.82±0.10aA	1.73±0.02aA	1.72±0.01aAB
	8	2.64±0.37bB	2.39±0.50aA	2.47±0.53aB
Fiber (%)	0	5.78±0.20aD	5.78±0.20aC	5.78±0.20aC
	2	4.5±0.22aC	4.89±0.34aB	4.86±0.04aB
	6	3.25±0.2aB	4.54±0.26bB	4.53±0.31bB
	8	2.54±0.4aA	3.37±0.31bA	3.25±0.22abA
Protein (%)	0	7.88±0.18aD	7.88±0.18aB	7.88±0.18aB
	2	6.85±0.20aC	7.38±0.32bB	7.29±0.40abB
	6	5.5±0.26bB	6.59±0.28aA	6.12±0.23abA
	8	4.77±0.03aA	6±0.01bA	5.89±0.19bA
Lipid (%)	0	4.76±0.11aC	4.76±0.11aC	4.76±0.11aD
	2	3.54±0.36aB	4±0.01abB	4.11±0.11bC
	6	2.87±0.14aA	3.79±0.17bB	3.81±0.05bB
	8	2.42±0.24aA	3±0.01bA	3.12±0.03bA
Starch (%)	0	65.10±1.96aD	65.10±1.96aD	65.10±1.96aD
	2	58.80±2.30aC	60.10±2.00aC	59.80±0.95aC
	6	48.70±1.12aB	51.20±0.96bB	52.30±0.30bB
	8	40.25±0.05aA	45.20±1.00bA	46.20±0.20bA
Total carbohydrate (%)	0	76.70±0.22aA	76.70±0.22aA	76.70±0.22aA
	2	75.98±0.55aA	75.75±0.42aA	75.91±0.49aA
	6	77.26±0.97aA	76.34±1.40aA	76.94±0.25aA
	8	77.40±1.06aA	76.75±0.66aA	76.64±0.80aA
Total soluble sugar (%)	0	2.57±0.03aD	2.57±0.03aB	2.57±0.03aD
	2	2.12±0.14aC	2.49±0.30aB	2.50±0.03aC
	6	1.80±0.10aB	1.99±0.02bA	2.00±0.02bB
	8	1.35±0.01aA	1.67±0.01bA	1.65±0.02bA
Reducing sugar (%)	0	0.51±0.10aC	0.51±0.10aB	0.51±0.10aD
	2	0.71±0.01cB	0.64±0.01bB	0.61±0.01aC
	6	0.18±0.03aAB	0.28±0.02bA	0.31±0.01bB
	8	0.12±0.03aA	0.22±0.03bA	0.23±0.01bA
Energy (kcal/100g)	0	381.13±0.66aD	381.13±0.66aC	381.13±0.66aC
	2	363.18±2.22aC	368.57±0.45bB	369.80±0.64bB
	6	357.05±1.65aB	365.71±2.95bB	366.41±1.43bB
	8	350.39±2.03aA	360.27±2.65bA	360.76±2.07bA

Means (±SD) with different lower-case/upper-case letters in the same line/column are different at 5% probability test.

Table 5: Matrix of correlations between nutritive compounds of maize cobs

	MC	LPC	PRC	STC	ASC	FBC	TSC	RSC	TCC	EC
MC	1									
LPC	-0,84	1								
PRC	-0,88	0,88	1							
STC	-0,90	0,88	0,96	1						
ASC	0,57	-0,62	-0,74	-0,78	1					
FBC	-0.84	0,87	0,96	0,93	-0,71	1				
TSC	-0,78	0,80	0,87	0,84	-0,65	0,82	1			
RSC	-0,48	0,56	0,67	0,67	-0,58	0,68	0,60	1		
TCC	-0,72	0,29	0,41	0,50	-0,39	0,38	0,31	0,39	1	
EC	-0,97	0,92	0,94	0,95	-0,70	0,91	0,84	0,92	0,59	1

The parameters values are significant at P=0.05; MC, moisture content ; LPC, lipid content ; PRC, protein content; STC, starch content ; ASC, ash content ; FBC, fiber content ; TSC, total sugar content; RSC, reducing sugar content; TCC, total carbohydrate content; EC, energy content.

Table 6: Matrix of correlations between nutritive compounds of maize grains

	MC	LPC	PRC	STC	ASC	FBC	TSC	RSC	TCC	EC
MC	1									
LPC	-0,89	1								
PRC	-0,85	0,94	1							
STC	-0,87	0,94	0,93	1						
ASC	0,49	-0,66	-0,66	-0,66	1					
FBC	-0,90	0,95	0,93	0,95	-0,65	1				
TSC	-0,83	0,92	0,92	0,96	-0,72	0,90	1			
RSC	-0,52	0,66	0,80	0,76	-0,63	0,70	0,80	1		
TCC	-0,16	-0,22	-0,32	-0,18	0,05	-0,15	-0,20	-0,19	1	
EC	-0,98	0,96	0,92	0,92	-0,59	0,94	0,89	0,92	0,01	1

The parameters values are significant at P=0.05; MC, moisture content ; LPC, lipid content ; PRC, protein content; STC, starch content ; ASC, ash content ; FBC, fiber content ; TSC, total sugar content; RSC, reducing sugar content; TCC, total carbohydrate content; EC, energy content.

Table 7: Eigenvalues and correlation matrices factors of principal components analysis with nutritive compounds of maize stored studied

Factors	F1	F2	F3	F4	F5	F6	F7	F8
Eigenvalues	8.40	1.04	0.30	0.23	0.02	0.016	0.013	0.0011
Variances (%)	84.01	10.35	3.01	2025	0.20	0.16	0.013	0.011
Cumulative variance (%)	84.01	94.36	97.37	99.62	99.82	99.97	99.98	100
MC	0,97	0,03	0,17	0,16	0,023	-0,032	0,027	-0,0008
LPC	-0,97	-0,15	0,12	-0,11	-0,045	-0,047	0,0032	-0,015
PRC	-0,99	-0,03	-0,028	-0,041	-0,023	0,057	0,014	0,018
STC	-0,98	0,17	-0,027	0,04	0,08	-0,007	-0,0061	-0,003
ASC	0,81	-0,40	-0,39	-0,17	0,02	-0,027	0,0078	0,0003
FBC	-0,99	-0,04	0,07	-0,07	0,05	-0,072	-0,0003	0,017
TCC	0,43	0,88	-0,14	-0,10	-0,03	-0,028	0,0022	0,0026
EC	-0,98	-0,02	0,006	-0,13	-0,05	-0,009	0,010	-0,0022
TSC	-0,97	0,19	-0,12	-0,025	0,05	0,04	0,013	-0,014
RSC	-0,90	-0,02	-0,26	0,35	-0,04	-0,03	-0,0003	0,0002

Values of significant correlations in bold at P = 0.05; MC, moisture content ; LPC, lipid content ; PRC, protein content; STC, starch content ; ASC, ash content ; FBC, fiber content ; TSC, total sugar content; RSC, reducing sugar content; TCC, total carbohydrate content; EC, energy content

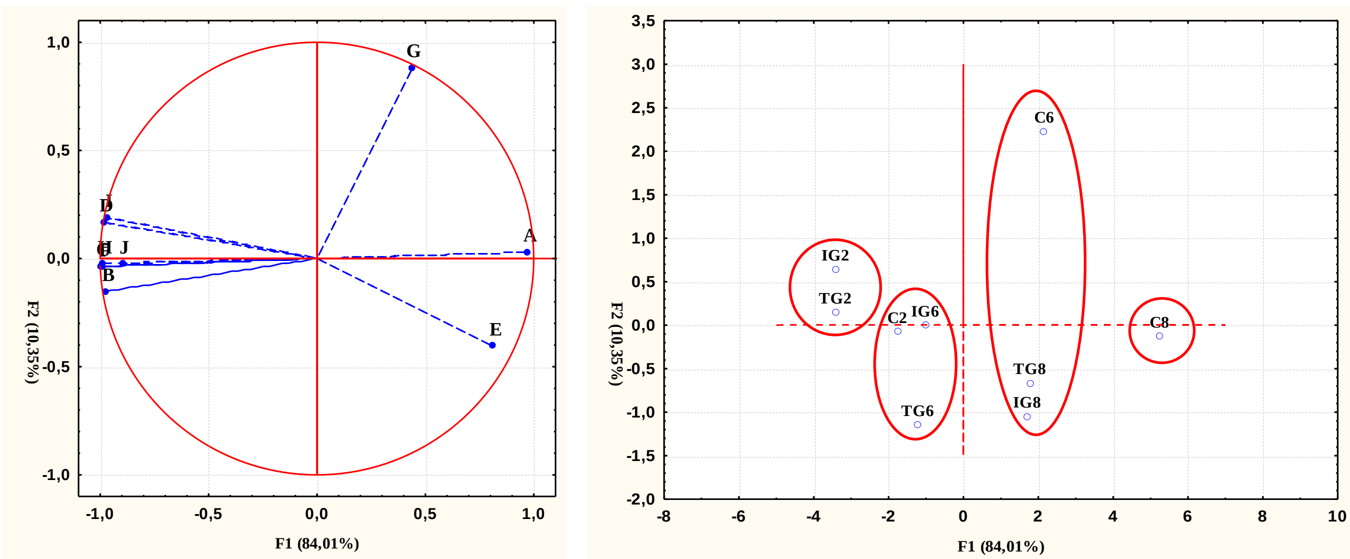
Table 8: Estimated nutritive compounds intake in maize grains stored at 6 month according to the consumption level

Nutritive compounds	RDI*	Current Ivorian consumption: 28.4 g		Projection for a consumption of 100 g of maize gains	
		EAI (g)	EAI (%)	EI (g)	EI (%)
Protein	46g	1.74	3.80	6.12	13.30
Lipid	70 g	1.10	1.60	3.81	5.44
Fiber	30 g	1.30	4.30	4.53	15.10
Carbohydrate	130 g	21.77	16.74	76.94	59.18
Energy	2200 kcal	104	4.73	366.41	16.65

RDI*: recommended daily intake (DRIs, 2005)

EAI: estimated mean intake level per day from the 28.4 g of maize grains consumed

EI: estimated intake for 100 g of maize consumed



(a) (b)

Figure 3 : Correlation drawn between the F1-F2 principal components (a) and the nutritional parameters and the types of individuals (b) deriving from the maize samples studied

A, moisture content ; **B**, lipid content ; **C**, protein content; **D**, starch content ; **E**, ash content ; **F**, fiber content ; **G**, total carbohydrate content; **H**, energy content ; **I**, total soluble sugar content; **J**, reducing sugar content

C_2, TG_2, IG_2, control, traditional and improved granaries at 2 month of storage;**C_6, TG_6, IG_6**control, traditional and improved granaries at 6 month of storage;**C_8, TG_8, IG_8**control, traditional and improved granaries at 8 month of storage;

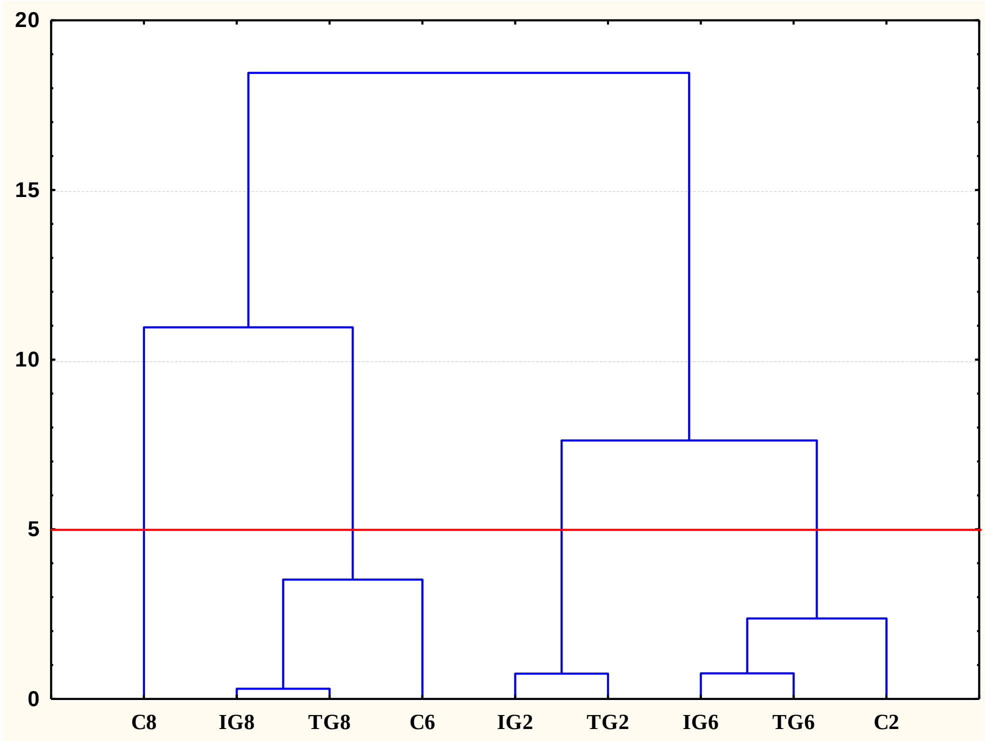


Figure 4 : Ascending hierarchical notation (dendrogram) with the nutritional parameters of maize storage

C_2, TG_2, IG_2, control, traditional and improved granaries at 2 month of storage;**C_6, TG_6, IG_6**control, traditional and improved granaries at 6 month of storage;**C_8, TG_8, IG_8**control, traditional and improved granaries at 8 month of storage;

Discussion

This study was carried out to strengthen ability of poor rural small-holder farmers in improving their crops productivity and incomes with low-cost, sustainable and environmental suitability.

The resumption and increase of moisture in granaries for both maize cobs and grains could be related to the air relative humidity, mean of which is around 80%. In fact, few increasing in the relative air humidity above 70% involve with great rising of the moisture content of the stored grains [24]. The increase in moisture content could also be linked to the respiration of fungi and insects during storage. Environmental moisture is produced by the respiration processes and could affect the moisture content of the stored grain. Previous researches also associated main increases in grain moisture content during storage to the bioactivities from insects and fungi [25].

The combination of the two plants materials at 2.5% w/w each is effective in comparison with the untreated control maize. Indeed, significant divergence is found with parameters assessed from the biopesticides treatments than the untreated granaries. The data from various maize parameters state on a better nutritive preservation of the maize stored after adding combination of *L. multiflora* and *H. suaveolens* than the storage without any treatment. Granaries treated with biopesticides at 6 and 8 months are similar to those obtained respectively at 2 and 6 months in the untreated granaries. In addition, this attempt shows that the protective property of the combination of the two local plants used is more effective at 6 months of maize storage than at 8 months of storage.

Results obtained from the contents of ash, fibers, lipids, proteins and carbohydrates from the current experiments agree with the investigations of Stefanello *et al* [26] in seeds of landraces maize stored under different conditions. These authors reported the increasing of ash content, as well as the dropping in the amounts of lipids, proteins and fibers when any variation was highlighted for the carbohydrates contents during the storage. Similar changes were also mentioned by Di Domenico *et al* [24] concerning the evaluation of the maize quality traits in different types of storage. According to them, the consumption of organic compounds through metabolisms of grains and associated microorganisms could increase the ash content during storage.

The reduction in lipids contents could derive from the degradations occurring during storage and is related with biochemical processes such as respiration, oxidation and enzyme activity [27]. The decrease of lipids contents may also be due to the insect and fungal attacks in grains during storage [25]. The loss of proteins contents involves in the rising of the moisture during storage regarding with the reverse correlation between both parameters. The changes of proteins contents could result from the grains intrinsic chemical degradation and/or its needs [25 and 27]. Moreover, Schuh *et al* [28] linked the reduction in the maize proteins contents during storage to the part of grains consumed by the associated insects and microorganisms. The starches contents decreased significantly during the storage because of deterioration induced by the increasing of insect and fungal growth in the stored maize cobs and grains. Such risks are originated with the fast moisturing of maize. The reduced starches contents found in our study corroborate the report of Simic *et al* [29] where starches are reduced when exposed to temperature of 25 °c for 6 month of storage. Elsewhere, Chattha *et al* [25] showed a decreasing in the starch content from wheat grains at mean of 12% of moisture during storage in straw clay bin for 12 months. According to Marshall and Chrastil [30], degradation of proteins and starch may also result from Maillard oxidation reactions.

Regarding with the carbohydrates contents, the duration and types of storage did not affect values. The same observation was reported from pumpkin seeds [31] and two cassava flour cultivars [32].The decrease of total and reducing sugars may be due to the microorganisms for their growth. According to olive [33], after hydrolysis of sucrose, the microbes, specifically yeasts, would prefer glucose which is directly metabolized. With such degradation in the main nutritive traits, the caloric values are logically affected and decrease during the storage, as well as shown by the close correlations between energy provided by maize and the proteins and lipids contents.

The recommended daily intakes of nutritive compounds for adult according to DRIs [23] are 46 g for protein, 70g for lipid, 30g for fiber, 130 g for carbohydrate and 2,200 kcal for energy. Consequently, the estimated intakes of macronutrients encountered with 28.4 g for daily consumption of maize grains in Côte d’Ivoire are below the references required. In that instance, the consumption of only maize grain shouldn’t meet the nutritive needs for the adult Ivorian. The hypothesis is all the likely as maize is accompanying of many household dishes foods in tropical lands.

Conclusion

The assessment of the maize storage showed a continuous degradation of the main biochemical parameters. Excepted for the unvarious carbohydrates contents, the post-harvest maize shows significant losses of fiber, protein, lipid, starch, soluble and reducing sugars and caloric value during the storage, whereas the contents of moisture and ash have raised. Hence, leaves of *Lippia multiflora* and *Hyptis suaveolens* could be potentially applied in food preservation, as alternatives to chemical pesticides in order to improve the self-life of staple foods, especially cereals. The technique is inexpensive, easily implemented and fits into the millennium guidelines of environment suitability. However, the study needs further investigation to preserve the quality, and ensure healthy and nutritive value of the maize after storage.

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