Conservation of Mineral Elements in Maize Grains by a Triple Bagging System and Biopesticide (*Lippia multiflora* Moldenke and *Hyptis suaveolens* Poit Leaves).

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ABSTRACT— ***Maize (Zea mays) is a staple food in the traditional diet of rural populations in Côte d'Ivoire. It is a source of many minerals. However, inefficient and sometimes harmful storage methods hamper its large-scale production in Côte d'Ivoire. It is in this context that a triple bagging system associated or not with biopesticides of plant origin (Lippia multiflora and Hyptis suaveolens leaves) was proposed in this study to evaluate its efficacy on the conservation of mineral quality of grains over an 18-month period following a 3-factor central composite design (CCD). The first CCD factor consisted of 6 observation periods: 0; 1; 4.5; 9.5; 14.5 and 18 months. The second factor, the type of treatment, included 1 control lot with a polypropylene bag (TB0SP) and 9 experimental lots including 1 lot in triple bagging without biopesticides (TB0P) and the remaining 8 lots containing variable proportions and/or combinations of biopesticides (TB1 to TB8). And finally, the third factor was the combination of the two biopesticides with % Lippia multiflora as a reference. The results indicate that the shelf life, ratio and combination of biopesticides significantly (P < 0.05) influence the mineral quality of grain maize. Principal component analysis revealed that the addition of at least 1.01% biopesticides (leaves of Lippia multiflora and Hyptis suaveolens) in triple bagging systems improves preservation efficiency and preserves the mineral quality of the grain over a period of 15 months as opposed to triple bagging without biopesticides where the mineral elements are preserved during the first 10 months of storage. However, this preservation of mineral quality is more pronounced in these storage systems with combinations of biopesticides (of which the proportion is greater than or equal to 3.99%) or with 2.5 % of individual biopesticides.***

Keywords— *Maize conservation, mineral quality, triple bagging, biopesticides, Côte d'Ivoire.*

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1. INTRODUCTION

Among food crops in Côte d'Ivoire, maize (*Zea mays* L.) is the crop with the largest geographical expansion, thanks to its adaptability and high consumption **(Kouakou *et al*., 2010).** It is the second most cultivated and consumed cereal after rice (*Oryza sativa*). Its production in Côte d'Ivoire increased from 654.738 tonnes in 2013 to 760.000 tonnes in 2016, for a total area estimated at nearly 386.633 ha **(FAOSTAT, 2016).** Maize is the staple food of a large part of the Ivorian population and makes it possible to subsist during the agricultural off-season in rural areas. It is consumed in a variety of forms and is considered a good source of minerals for both food and feed **(Deffan, 2016).** Its nutritional assets (source of many minerals) make it a competitive product that contributes to lowering the price of certain basic food products such as milk **(Nuss and Tanumihardjo, 2011).** Despite the recognized nutritional value of this cereal, maize production remains below local consumption needs as is the case in most developing countries. In order to meet the ever-increasing industrial and consumer demand for maize, the grains must be stored throughout the year. Unfortunately, storage modules are major factors affecting the nutritional quality and thus the mineral composition of maize grains **(Deffan *et al*., 2015).** As a result, farmers resort to unconventional storage and/or conservation methods that are often harmful to human health **[5].** Yet simple, effective and less costly means seem to exist in rural areas for the protection of food. Indeed, the efficacy of plant-derived biopesticides has been an important research topic for the conservation of maize in the farming environment in Côte d'Ivoire. **Ezoua (2019)** studied the marketability and sanitary qualities of grain maize stored in polypropylene bags in the presence of biopesticides (*Lippia multiflora* and *Hyptis suaveolens*) for 8 months and indicated that these qualities (marketability and sanitary) remain in conformity with international standards during the first 6 months of storage. In a previous study also conducted over 8 months, **Niamketchi (2017)** showed very significant changes in the marketability and sanitary quality of maize after 6 months of storage in granaries in the presence of *Lippia multiflora* and *Hyptis suaveolens* leaves (biopesticides). In addition, the efficacy of triple bagging systems whether or not associated with *Lippia multiflora* leaves has been demonstrated by recent studies of cowpea seed storage in Côte d'Ivoire **(Konan, 2017; Fofana, 2019)**. However, similar studies on maize during a long storage period are not available. Given the great importance of maize preservation for the food industry and for consumers throughout the year, it is also important to study the nutritional quality of maize grains stored in triple-bottomed bags. Thus, the purpose of this study is to evaluate the effects of triple bagging systems with or without biopesticides on the mineral composition of maize grain during 18 months of storage.

2. MATERIAL AND METHODS

2-1- Study site

The experiments were carried out in the storage room of the Research Unit of Biochemistry and Food Sciences (URBSA) at the Félix Houphouët-Boigny University, where the average temperature and relative humidity were respectively 27.27ºC ± 1.41 and 81.58 ± 3.02%. Wooden pallets were placed on the floor as a support for the storage of the bags.

2.2 Biological material

2.2.1 Maize used in the study

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

2.2.2 Selected plants

The leaves of *Lippia multiflora* and *Hyptis suaveolens* were harvested in the Gbêkê region (70°50' North and 50°18' West).They were dried out of the sun for a week and then chopped into fine particles.

2.2.3 Storage equipment

Polypropylene and polyethylene bags with a capacity of 120 kg were purchased from the market of Adjamé (commune of Abidjan) for the storage of maize. The triple bagging system is a set of synthetic fabric bags (polypropylene), lined on the inside with two plastic bags (polyethylene).

2.3 Methods

2.3.1 Bagging

Maize grain preservation trials were carried out over a period of 18 months on the basis of a central composite design (CCD). This technology was based on mixing a proportion of crushed dried leaves with a defined amount of maize grains. It is an alternating stratification of maize grains and leaves of *Lippia multiflora* and/or *Hyptis suaveolens* so as to obtain leaves at the bottom and surface of the bags covering the grains. A total of nine (9) experimental lots and one control lot were constituted as follows: **TB0SP**: control lot; 50 kg of maize stored in a woven polypropylene bag without biopesticides. **TB0P**: 1st experimental batch; 50 kg of maize stored in a triple bagging system with 0% biopesticides. **TB1**: 2nd experimental lot; 50 kg of maize stored in a triple bagging system containing 2.5% biopesticides (i.e. 0.625 kg of *L. multiflora* leaves and 0.625 kg of *H. suaveolens* leaves). **TB2**: 3rd experimental lot; 50 kg of maize stored in a triple bagging system containing 3.99% biopesticides (i.e. 0.40 kg of *L. multiflora* leaves and 1.60 kg of *H. suaveolens* leaves). **TB3**: 4th experimental lot; 50 kg of maize stored in a triple bagging system containing 3.99% biopesticides (i.e. 1.60 kg of *L. multiflora* leaves and 0.40 kg of *H. suaveolens* leaves). **TB4**: 5th experimental lot; 50 kg of maize stored in a triple bagging system containing 1.01% biopesticides (i.e. 0.10 kg of *L. multiflora* leaves and 0.40 kg of *H. suaveolens* leaves). **TB5**: 6th experimental lot; 50 kg of maize stored in a triple bagging system containing 1.01% biopesticides (i.e. 0.40 kg of *L. multiflora* leaves and 0.10 kg of *H. suaveolens* leaves). **TB6**: 7th experimental lot; 50 kg of maize stored in a triple bagging system containing 5% biopesticides (i.e. 1.25 kg of *L. multiflora* leaves and 1.25 kg of *H. suaveolens* leaves). **TB7**: 8th experimental lot; 50 kg of maize stored in a triple bagging system containing 2.5% biopesticides (i.e. 1.25 kg of *L. multiflora* leaves) and **TB8**: 9th experimental batch; 50 kg of maize stored in a triple bagging system containing 2.5% biopesticides (i.e. 1.25 kg of *H. suaveolens* leaves).

2.3.2 Sample collection

Sampling for mineral quality analysis was carried out at different storage periods: In month T0, i.e. just after purchase and before storage; then in months T1; T4.5; T9.5; T14.5 and T18 as defined by the central composite design (CCD). These withdrawals were carried out in triplicate. Thus, samples of 5 Kg of maize were collected from each bag at different strata at random.

2.3.3. Determination of essential minerals

2.3.3.1 Sample Mineralization

Mineralization of the ash samples was carried out by incineration at 550ºC using an electric muffle furnace according to the method described by **AOAC (923.03.1990) .**Thus, a mass of 5 g of maize powder previously charred on a Bunsen burner was introduced into an incineration capsule. The capsule was placed in a muffle furnace of the brand PYROLABO (France). The powder was incinerated at 550°C for 24 hours. After calcination and cooling in desiccators, the white ash was collected for analysis.

2.3.3.2 Determination of Mineral Elements

The levels of macroelements (Mg, P, K, Na and Ca) and trace elements (Fe, Zn, Mn and Cu) were determined using a scanning electron microscope (SEM) coupled to an energy dispersive spectrophotometer (EDS).

❖ Operating conditions of the scanning electron microscope (SEM/SED)

The variable pressure SEM-SDE device (SEM FEG Supra 40Vp Zeiss) used for the dosing was equipped with an X-ray detector (Oxford instruments) connected to a platform of SDE microanalysers (Inca dry cool. without liquid nitrogen).The operating conditions of the MEB-SDE were as follows:

- Magnification: between 10 x and 1000000 x;
- Resolution: 2 nm;
- Variable voltage: 0.1 KeV to 30 KeV;
- Acquisition of elemental chemical composition: magnification. 50x; probe diameter, 30 nm and 120 nm; probe energy, 20 KeV and 25 KeV; working distance (WD), 8.5 mm.

2.3.3.3 Method Validation Testing

The validation was carried out according to the method of **AFNOR (1996).** This operation consists of studying linearity, repeatability, reproducibility, extraction yields, detection limits and quantification limits. The linearity of the 09 mineral elements was tested between 25% and 125% using 5 calibration points (25%, 50%, 75%, 100% and 125%). Repeatability and reproducibility tests were carried out with the standards of the various minerals at a concentration of 25%.Thirty (30) tests were performed for repeatability and reproducibility tests respectively. Additions of 5% of the standards were made for the determination of mineral extraction yields.

2.4 Statistical analysis

All analyses were performed in triplicate and all data were statistically processed using SPSS software (version 22.0).It consisted of an analysis of variance (repeated measures ANOVA) based on two factors: the shelf life and method of storage, i.e. the various treatments carried out during storage. The significant parameters were compared using the Tukey test with a level of significance less than or equal to 5%.Then, a Principal Component Analysis (PCA) was performed using the STATISTICA software (version 7.1) to classify the samples having a similar behaviour on all the mineral elements during conservation.

3. EXPERIMENTAL RESULTS

3.1 Validation Parameters for the Quantification of Mineral Elements Using SDE.

The analysis of the validation parameters for the quantification of mineral elements using the scanning electron microscope (SEM/SED) **(Table 1)** shows that the different minerals studied have their square of correlation coefficients (R2) between 0.99 and 1.The detection limits for minerals range from 104 µg/kg to 581 µg/kg and their minimum quantified values are between 146 µg/kg and 796 µg/kg. The coefficients of variation (CV) of the 10 repeatability tests ranged from 1.0% to 1.8%, while the results of the coefficients of variation of the 15 reproducibility tests ranged from 2.3% to 4.7%.These results reflect a satisfactory stability and precision of the micro-analysis techniques. Finally, extraction yields range between 97.3% and 99.5%, thus showing that extraction defects are between 0.5% and 2.7%. The method is reliable and accurate.

Table 1: Data from validation parameters for evaluation of minerals contents using the energy diffusion spectrometer (EDS).

Mineral	Linearity		CV Repeat. (%. n= 10)	CV Reprod. (%. n= 15)	Ext yield (%. n= 10)	LOD (µg/kg)	LOQ (µg/kg)
	Standard	CD (R^2)					
Mg	1452x + 237	0.99	1.1±0.21	3.1±1.44	97.9±0.68	426±0.11	635±0.19
P	2667x + 1742	0.99	1.4±0.11	3.7±1.22	99.4±0.66	334±0.21	467±0.88
K	3821x + 3838	1	1.3±0.04	4.7±0.32	98.4±1.51	581±0.04	796±0.09
Na	2083x + 147	0.99	1.2±0.05	3.4±0.48	98.8±0.33	261±0.74	365±0.07
Ca	6581x + 5287	1	1.5±0.43	2.3±0.93	97.3±0.84	514±0.15	704±0.47
Fe	Y= 2285x - 88	0.99	1.4±0.07	3.6±0.01	99.5±0.17	107±0.32	149±0.55
Zn	Y= 4365x - 523	0.99	1.3±0.51	3.2±0.96	98.3±0.03	281±0.58	396±0.29
Mn	3659x + 74454	1	1.2±1.01	2.9±0.77	99.0±0.78	337±0.81	488±0.60
Cu	1953x + 6951	0.99	1.8±0.95	2.5±0.03	98.8±0.43	104±0.05	146±0.63

***CD**, coefficient of determination; **CV** Repeat, coefficient of variation from repeatability test; **CV** Reprod, coefficient of variation from reproducibility test; **Ext** yield, extraction yield from added minerals; **LOD**, limit of detection; **LOQ**, limit of quantification; **Mg,** magnesium; **P**, phosphorous; **K,** potassium; **Na**, Sodium; **Ca**, Calcium; **Fe**, iron; **Zn**, Zinc; **Mn**, manganese; **Cu**, copper*

3.2 Changes in the mineral content of maize grains according to treatments carried out during storage

The data from the statistical tests used to evaluate all minerals during storage are shown in **table 2.** The tests carried out show very significant changes (P<0.001) in mineral contents depending on the duration and type of treatments (single bagging. triple bagging with or without biopesticides) carried out. The interaction between type of treatment and shelf life has a significant effect.

Table 2: Statistical data of the parameters according to the treatments during the storage time

SOV	Stat para	Parameters								
		Mg	**P**	**K**	**Na**	**Ca**	**Fe**	**Zn**	**Mn**	**Cu**
Time	**Df**	5	3.218	1.859	15237.673	3.16	2992	1.837	1.207	1.906
	SS	14873.431	183945.72	324553.366	2.599	10567.75	69.909	75.013	2.583	1.532
	F	8126.644	21245.657	11244.266	2725.684	4066.458	2227.469	1545.509	291.756	135.671
	P	***p<0.OO1***								
Error Time	**Df**	100	64.368	37.179	51.977	63.202	59.835	36.738	24.15	30.647
	SS	36.604	173.161	577.278	111.808	51.975	0.628	0.971	0.117	0.215
Methods	**Df**	**9**								
	SS	5104.241	22698.5	5532.386	1795.769	2248.611	69.909	17.564	0.448	0.241
	F	1446.11	1304.68	197.287	110.688	369.546	2227.469	180.452	29.584	6.303
	P	***p<0.OO1***								
Error Methods	**Df**	**20**								
	SS	7.844	38.662	62.316	36.053	13.522	0.082	0.216	0.034	0.085
Time x Methods	**Df**	30.698	28.965	16.731	23.29	28.441	26.926	16.532	10.867	13.791
	SS	32.197	14346.985	4037.748	1224.322	1380.849	10.271	11.799	0.223	0.215
	F	11.395	184.119	15.543	24.334	59.039	36.361	27.01	2.798	1.703
	P	***p<0.OO1***								

***SOV**, source of variation; **Stat Para,** statistical parameters; **Df,** degree of freedom; **SS**, sum of squares; **F.** value of the statistical test; **P**. probability value of the statistical test. **Mg,** magnesium; **P**, phosphorous; **K,** potassium; **Na**, Sodium; **Ca**, Calcium; **Fe**, Iron; **Zn**, Zinc; **Mn**, manganese; **Cu**, copper.*

3.3 Macronutrient content of maize grains

Magnesium (Mg), Phosphorus (P), Potassium (K), Sodium (Na) and Calcium (Ca) are the 5 preponderant macroelements that have been identified in maize grains **(Table 3).** Analysis of the results indicates that the levels of macroelements evolve differently (P<0.001) in maize grains during the storage period (18 months) in the polypropylene control bag (TB0SP), the triple single bagged (TB0P) and the different systems that have received treatment (biopesticides). At the end of the first 4 and a half months of storage, the contents for all the macroelements dropped significantly (P<0.001) in the polypropylene control batch. With mean values of 110.46±0.57 mg/100g (Mg); 300.73±1.10 mg/100g (P); 330.70±3.12 mg/100g (K); 61.36±1.63 mg/100g (Na); and 49.47±1.11 mg/100g (Ca) at the beginning of storage (month 0), the contents of Mg, P, K, Na and Ca fall to 86.70±0.90 mg/100g; 257.56±0.61 mg/100g; 319.99±1.54 mg/100g; 49.24±0.46 mg/100g and 34.71±1.06 mg/100g, respectively **(Table 3).**T his represents decreases of 21.51%, 14.35%, 3.24%, 19.75% and 29.83% respectively for Mg, P, K, Na and Ca. In simple triple bagging (without biopesticides), the rates of decline after 9.5 months of storage are respectively of the order of 11% (Mg), 6% (P), 4% (K), 18% (Na) and 23% (Ca). At the end of the 18th month of storage, the lowest levels for all the above macroelements were recorded respectively in the polypropylene control lot and in the triple bagging without biopesticides **(Table 3).** In triple bagging systems with different proportions of biopesticides after 14.5 months of storage, the mean macroelement contents decreased from 110.46±0.57 mg/100g to 100.46±0.48 mg/100g; 300.73±1.10 mg/100g to 272.87±0.58 mg/100g; 330.70±3.12 mg/100g to 293.53±0.82 mg/100g; 61.36±1.63 mg/100g to 50.01±0.48 mg/100g and from 49.47±1.11 mg/100g to 38.61±0.06 mg/100g for magnesium, phosphorus, Potassium, sodium and calcium respectively **(Table 3).** That is to say, rates of decline which vary respectively between 7% and 12% (Mg), 7% and 14% (P), 10% and 13% (K), 15% and 22% (Na) and between 16% and 29% (Ca) depending on the proportion and/or combination of biopesticides used. However, these decline rates evolve considerably to reach values that vary between 19% and 22% (Mg), 25% and 30% (P), 33% and 36% (K), 34% and 45% (Na) and between 30% and 46% (Ca) at the end of the 18th month of storage in these systems, depending on the proportions and/or combinations of associated biopesticides.

3.4 Oligoelements content of maize grains

During storage, iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) were identified as oligoelements in maize grains **(Table 4).** For initial values (month 0) of 4.99±0.11 mg/100g (Fe) and 5.07±0.11 mg/100g (Zn) the levels of iron and zinc drop significantly (P<0.001) in the control lot (TBOSP) to reach values of 3.47±0.05 mg/100g and 3.60±0.06 mg/100g respectively after the first 4.5 months of storage, then in the triple bagging without biopesticide (3.94±0.06 mg/100g and 4.01±0.01 mg/100g) after 9.5 months of storage. That is, loss rates of 30.46% (Fe) and 28.99% (Zn) in the control batch. In triple bagging without biopesticide, these reduction rates are of the order of 21.04% and 20.91% for iron and zinc. The iron and zinc contents remain lower in these 2 types of storage (polypropylene bag and triple single bag) at the end of the experiment **(Table 4).**

The average Fe and Zn contents of maize grains in triple bagging systems with biopesticides after 14.5 months of storage are of the order of 4.04±0.06 mg/100g (Fe) and 4.10±0.01 mg/100g (Zn) **(Table 4).** This corresponds to rates of decline ranging from 16% to 22% for iron and 17% to 21% for zinc depending on the proportion and/or combination of biopesticides. However, after 18 months of storage these loss rates reach values of the order of: 25 - 37% (Fe) and 24 - 43% (Zn) depending on the type of treatment.

For Mn, the content of samples from the control lot (TBOSP) decreased from 0.99±0.02 mg/100g to 0.76±0.00 mg/100g after the first 4.5 months of storage, which corresponds to a rate of decrease of 23.23%. A similar variation was made in the triple bagging system without biopesticide (TBOP), which after 9.5 months of storage went from 0.99±0.02 mg/100g to 0.78±0.01 mg/100g (Table 4). That is to say, a drop of around 21% compared to the initial value.

In the different triple bagging systems with biopesticides, after 14.5 months of storage, the levels recorded for manganese vary from 0.77±0.02 mg/100g to 0.86±0.00 mg/100g depending on the proportions and/or combinations of biopesticides used. That is to say, loss rates between 13 and 20%. However, after 18 months of storage, these loss rates evolve significantly to reach values that vary between 28 and 33% depending on the type of treatment. Prior to storage, the determined Cu content in the grains was 1.37±0.06 mg/100g. This content decreased significantly (P<0.001) after the first 9.5 months of storage in the polypropylene control (1.20±0.00 mg/100g) to a value of 0.87±0.02 mg/100g in 18 months and then in the triple bagging without biopesticides after 14.5 months (1.19±0.00 mg/100g) to a value of 0.97±0.04 mg/100g in the 18th month of storage. The respective rates of decline were 36.50% and 29.20%. Whereas in triple bagging systems associated with different proportions of biopesticides, the values for Cu levels after 18 months of storage range from 1.00±0.00 mg/100g to 1.20±0.00 mg/100g **(Table 4).** This corresponds to loss rates ranging from 12 to 27% depending on the type of treatment.

3.5 Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) carried out made it possible to screen the different maize samples studied on the basis of their mineral quality **(Figure 1).** The axes F1 and F2 characterized the different treatments evaluated during conservation. These axes accounted for 98.18% of the total variability observed. The set of mineral elements is strongly and negatively correlated to the F1 axis **(Figure 1a).** This axis made it possible to divide the maize samples into 4 groups **(Figure 1b)**.

Indeed, group 1 consists of all maize samples stored in triple bagging systems with or without biopesticides at one (1) month shelf life, the initial sample (just before the start of the experiment) and the sample from the polypropylene bag after 1 month of storage. This group is characterized by high levels of mineral elements. Maize samples from triple bagging systems with different proportions of biopesticides from 4.5 months to 14.5 months storage (C2-J2; C3-J3 and C4-J4) and those of the biopesticide-free triple bagging at 4.5 and 9.5 months storage (B2 and B3) form group 2. These samples have average grades for all mineral elements and are close to those of the first group. The third group contains all samples stored in triple bagging systems with biopesticides at 18 months (C5-J5), those of the triple bagging without biopesticide at 14.5 and 18 months of storage (B4 and B5) and that of the control lot at 4.5 months of storage (A2). The values for all mineral elements are lower than those of the mineral elements in the first two groups but higher than the values in the other samples. Finally, group 4 consisting of maize samples from the polypropylene bag (control lot) at 9.5, 14.5 and 18 months storage (A3, A4 and A5) differs very clearly from the other samples by very low values for all the mineral elements.

Table 3: Evolution of macronutrient (Mg, P, K, Na and Ca) content of maize grains during storage time according to treatment

Parameters	Storage time	TB0SP	TBOP	TB1	TB2	TB3	TB4	TB5	TB6	TB7	TB8
Mg (mg/100g)	0	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}	110.46±0.57^{Aa}
	1	108.19±0.1^{Bb}	110.36±0.11^{Aab}	110.4±0.36^{Aab}	110.52±1.5^{Aa}	110.44±0.48^{Aab}	110.38±0.45^{Aab}	110.43±0.38^{Aab}	110.41±0.36^{Aab}	110.41±0.5^{Aab}	110.39±1.32^{Aab}
	4.5	86.7±0.90^{Cc}	102.47±0.61^{Bb}	104.51±0.46^{Bab}	106.47±0.63^{Ba}	105.77±0.99^{Ba}	105.06±0.60^{Ba}	104.98±0.56^{Ba}	106.12±1.5^{Ba}	106.44±0.49^{Ba}	105.55±0.59^{Ba}
	9.5	80.2±0.30^{Dg}	98.45±0.1^{Bf}	103.9±0.06^{Bd}	104.69±0.06^{Bab}	104.85±0.05^{Bab}	103.36±0.16^{Be}	103.71±0.05^{Bd}	104.9±0.06^{Ba}	104.23±0.17^{Cc}	104.61±0.07^{Bb}
	14.5	75.45±0.7^{Ed}	90.43±0.57^{Cc}	98±0.78^{Cb}	102.01±0.05^{Ca}	102.72±0.06^{Ca}	96.87±0.22^{Cb}	97.3±0.5^{Cb}	102.87±0.2^{Ca}	101.64±0.48^{Da}	101.93±0.06^{Ca}
	18	54.07±0.27^{Fd}	76.93±1^{Dc}	86.5±0.56^{Dc}	89.53±0.14^{Da}	89.69±0.05^{Da}	85.64±1.52^{Dc}	86.50±0.59^{Dc}	89.84±0.12^{Da}	89.31±0.59^{Ea}	89±0.3^{Da}
P (mg/100g)	0	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}	300.73±1.1^{Aa}
	1	298.86±4.5^{Aa}	300.62±0.65^{Aa}	300.83±1.66^{Aa}	300.92±1.96^{Aa}	300.95±0.17^{Aa}	300.72±0.48^{Aa}	300.89±0.89^{Aa}	300.92±0.81^{Aa}	300.74±0.65^{Aa}	300.97±0.86^{Aa}
	4.5	257.56±0.61^{Bb}	290.78±0.86^{Ba}	294.22±0.51^{Ba}	294.35±1.08^{Ba}	295.15±1.37^{Ba}	294.57±1.03^{Ba}	294.37±0.53^{Ba}	296.32±0.62^{Ba}	295.43±0.62^{Ba}	295.2±0.84^{Ba}
	9.5	244.5±0.68^{Be}	283.91±0.32^{Cd}	290.98±0.10^{Ba}	291.92±0.98^{Ba}	291.97±0.07^{Ba}	289.65±0.6^{Bb}	290.6±0.55^{Bab}	292±0.01^{Ca}	290.89±0.12^{Ca}	291.720.19^{Ca}
	14.5	201.24±1.01^{Cf}	246.28±5.54^{De}	263.34±1.09^{Cc}	278.32±0.58^{Ca}	278.69±0.25^{Ca}	259.62±2.04^{Cd}	262.05±1^{Cc}	278.66±0.57^{Da}	276.91±1.1^{Db}	277.40±0.45^{Da}
	18	156.64±1.57^{De}	196.131.19^{Ed}	209.23±0.46^{Dc}	223.28±1.14^{Da}	224.5±0.44^{Da}	208.62±2.22^{Dc}	208.97±0.79^{Dc}	224.98±0.11^{Ea}	220.92±1.05^{Ebc}	222.31±1.25^{Eb}
K (mg/100g)	0	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}	330.7±3.12^{Aa}
	1	326.12±13.63^{Aa}	330.52±0.44^{Aa}	330.66±0.1^{Aa}	330.7±0.61^{Aa}	330.63±0.16^{Aa}	330.63±0.41^{Aa}	330.69±0.1^{Aa}	330.68±0.19^{Aa}	330.640.49^{Aa}	330.66±0.38^{Aa}
	4.5	319.99±1.54^{Ac}	324±0.32^{Bb}	328.57±1.54^{Aa}	328.29±1.57^{ABa}	328.77±0.94^{ABa}	328.58±0.62^{Aa}	328.32±1.53^{Aa}	328.21±1.45^{ABa}	328.38±0.46^{ABa}	328.33±0.57^{ABa}
	9.5	302.31±0.51^{Be}	318.63±0.56^{Cd}	323.27±1.11^{Bbc}	325.51±0.73^{Ba}	325.91±0.08^{Ba}	321.65±0.56^{Bc}	322.66±0.57^{Bbc}	325.96±0.08^{Ba}	325.2±0.38^{Bab}	325.08±0.06^{Bab}
	14.5	255.7±2.16^{Cd}	277.24±1.53^{Dc}	288.61±0.56^{Cb}	296.8±0.82^{Ca}	296.82±0.13^{Ca}	288.61±1.46^{Cb}	288.65±0.58^{Cb}	297.16±0.45^{Ca}	295.53±0.59^{Ca}	296.5±0.5^{Ca}
	18	186.9±0.95^{Dd}	202.24±0.54^{Ec}	211.9±0.13^{Dc}	221.01±0.12^{Dab}	221.65±1.6^{Dab}	210.53±0.57^{Dc}	211.85±0.07^{Dc}	222.99±0.9^{Da}	216.98±0.99^{Db}	219.95±1^{Dab}
Na (mg/100g)	0	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}	61.36±1.63^{Aa}
	1	61±0.62^{Aa}	61.37±0.47^{Aa}	61.36±0.44^{Aa}	61.36±0.79^{Aa}	61.36±0.04^{Aa}	61.37±0.54^{Aa}	61.36±0.02^{Aa}	61.36±0.16^{Aa}	61.38±0.14^{Aa}	61.36±0.03^{Aa}
	4.5	49.24±0.46^{Be}	55.89±0.92^{Bd}	57.6±0.53^{Bb}	57.25±0.35^{Bbc}	57.96±0.90^{Ba}	57.58±0.54^{Bb}	57.28±0.52^{Bbc}	57.75±0.54^{Ba}	57.79±0.84^{Ba}	57.53±0.84^{Bb}
	9.5	40.44±0.46^{Cf}	50.08±0.07^{Ce}	54.47±0.44^{Cc}	55.76±0.55^{Bb}	55.8±.70^{Bb}	54.78±0.90^{Cc}	53.62±0.42^{Cd}	56.17±0.12^{Ba}	55.5±0.66^{Bb}	55.7±0.44^{Bb}
	14.5	32.25±5.53^{De}	43.77±0.75^{Dd}	48.18±1.04^{Dc}	51.42±0.48^{Ca}	51.9±0.06^{Cb}	47.6±0.55^{Dc}	47.45±0.5^{Dc}	52.36±0.53^{Ca}	50.25±0.59^{Cbc}	50.93±0.08^{Cb}
	18	19.98±0.99^{Ef}	27.93±0.94^{Ee}	34.29±0.5^{Ecd}	40.07±0.05^{Da}	40.35±1.10^{Da}	33.31±0.57^{Ec}	33.58±0.52^{Ec}	41.610.53^{Da}	38.64±0.57^{Db}	39.11±0.15^{Da}
Ca (mg/100g)	0	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}	49.47±1.11^{Aa}
	1	48.98±2.63^{Aa}	49.47±0.20^{Aa}	49.46±0.06^{Aa}	49.45±0.28^{Aa}	49.45±0.38^{Aa}	49.46±0.09^{Aa}	49.47±0.18^{Aa}	49.45±0.27^{Aa}	49.46±0.03^{Aa}	49.43±0.09^{Aa}
	4.5	34.71±1.06^{Bd}	43.24±0.64^{Bc}	47.38±0.56^{Ba}	47.19±0.55^{Ba}	47.42±0.74^{Ba}	47.23±0.55^{Ba}	47.18±0.62^{Ba}	47.35±0.43^{Ba}	47.26±0.53^{Ba}	46.61±0.66^{Bb}
	9.5	30.61±0.54^{Ce}	37.99±0.10^{Cd}	41.92±0.99^{Cc}	45.68±0.27^{Bab}	45.95±0.08^{Ba}	41.21±0.67^{Bc}	41.61±0.65^{Cc}	46.04±0.08^{Ca}	44.28±0.52^{Cb}	45.04±0 ;07^{Bab}
	14.5	20.4±0.59^{De}	30.06±0.04^{Dd}	35.51±0.63^{Dc}	40.93±0.06^{Ca}	41.07±0.04^{Ca}	34.05±0.94^{Cc}	35.05±0.06^{Dc}	41.59±0.09^{Da}	40.11±0.02^{Db}	40.6±0.11^{Cab}
	18	12.29±0.53^{Ef}	21.25±0.64^{Ee}	26.96±0.08^{Ed}	33.59±0.61^{Da}	34.28±0.51^{Da}	26.27±0.61^{Dc}	26.86±1.13^{Ec}	34.62±0.54^{Ea}	31.94±1.00^{Eb}	33.2±0.58^{Dab}

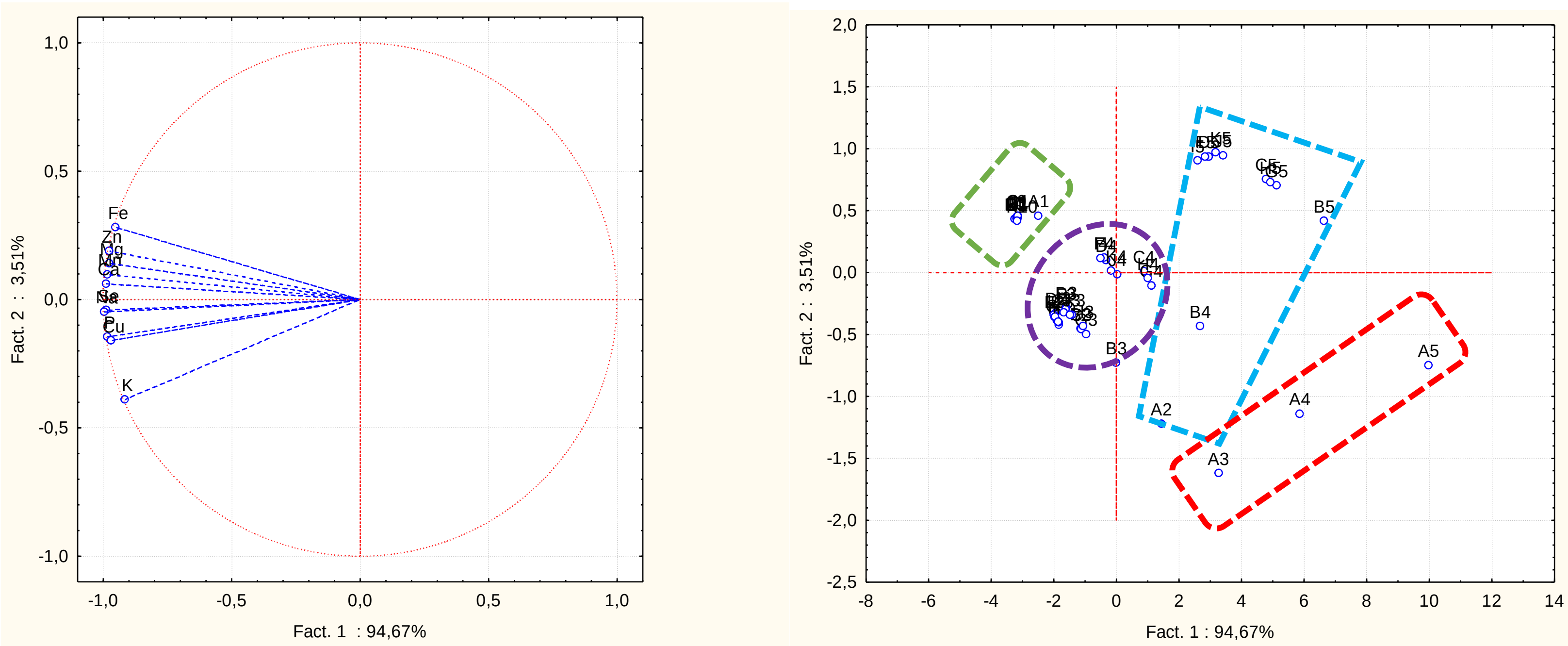
*The means (± standard deviation) with different lowercase / upper case letters on the same row/in the same column are different in the 5% probability test. **TB0SP**: control without biopesticides in the polypropylene bag, **TB0P**: triple bagging with 0% biopesticides, **TB1**: triple bagging with 2.5% biopesticides (p / p), **TB2**: triple bagging with 3.99% biopesticides (p / p), **TB3**: triple bagging with 3.99% biopesticides (p / p), **TB4**: triple bagging with 1.01% biopesticides (p / p), **TB5**: triple bagging with 1.01% biopesticides (p / p)), **TB6**: triple bagging with 5% biopesticides (p / p), **TB7**: triple bagging with 2.5% biopesticides (p / p) and **TB8**: triple bagging with 2.5% biopesticides (p / p)*

Tableau 4: Evolution of oligoelements (Fe, Zn, Mn and Cu) content of maize grains during storage time according to treatment

Parameters	Storage time	TB0SP	TBOP	TB1	TB2	TB3	TB4	TB5	TB6	TB7	TB8
Fe (mg/100g)	0	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}	4.99±0.11^{Aa}
	1	4.92±0.06^{Aa}	4.99±0.10^{Aa}	5.02±0.06^{Aa}	4.99±0.10^{Aa}	4.99±0.01^{Aa}	5.04±0.06^{Aa}	4.99±0.10^{Aa}	4.99±0.20^{Aa}	5.03±0.06^{Aa}	5±0.11^{Aa}
	4.5	3.47±0.05^{Bb}	4.23±0 10^{Ba}	4.23±0.07^{Ba}	4.33±0.04^{Ba}	4.290.02^{Ba}	4.26±0.11^{Ba}	4.25±0.06^{Ba}	4.3±0.01^{Ba}	4.27±0.07^{Ba}	4.270.05^{Ba}
	9.5	2.99±0.01^{Cd}	3.94±0.06^{Cc}	4.02±0.02^{Cc}	4.29±0.09^{Ba}	4.29±0.07^{Ba}	4.01±0.01^{Bc}	4.09±0.13^{BCbc}	4.27±0.04^{Bab}	4.27±0.05^{Bab}	4.23±0.02^{Bab}
	14.5	2.54±0.07^{Dd}	3.45±0.08^{Dc}	3.94±0.07^{bCc}	4.19±0.02^{Ba}	4.18±0.03^{Ba}	3.82±0.06^{Cc}	3.86±0.04^{Cbc}	4.21±0.00^{Ba}	4.04±0.06^{Cab}	4.1±00^{Bb}
	18	1.53±0.05^{Ee}	2.83±0.06^{Ed}	3.21±00^{Dc}	3.7±00^{Cab}	3.74±0.03^{Cab}	3.13±0.04^{Dc}	3.19±0.01^{Dc}	3.76±0.02^{Ca}	3.64±0.01^{Db}	3.7±0.05^{Cab}
Zn (mg/100g)	0	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}	5.07±0.11^{Aa}
	1	4.89±0.21^{Aa}	4.98±0.21^{Aa}	5±0.28^{Aa}	5.01±0.21^{Aa}	5±0.21^{Ba}	4.99±0.10^{Aa}	5±0.28^{Aa}	5±0.00^{Aa}	5±0.10^{Aa}	4.98±0.23^{Aa}
	4.5	3.6±0.06^{Bc}	4.24±0.05^{Bb}	4.46±0.01^{Ba}	4.46±0.01^{Ba}	4.47±0.00^{Ba}	4.47±0.07^{Ba}	4.46±0.01^{Ba}	4.47±0.01^{Ba}	4.47±0.03^{Ba}	4.46±0.00^{Ba}
	9.5	2.82±0.04^{Cc}	4.01±0.01^{Bb}	4.39±0.12^{Ba}	4.42±0.00^{BCa}	4.44±0.01^{Ba}	4.31±0.03^{Ba}	4.36±0.05^{Ba}	4.45±0.02^{BCa}	4.4±0.04^{Ba}	4.42±0.00^{Ba}
	14.5	2.4±0.09^{De}	3.62±0.06^{Cd}	4.01±0.01^{Cbc}	4.16±0.05^{Ca}	4.19±0.01^{Ca}	3.98±0.03^{Cc}	4.01±0.01^{Cbc}	4.2±0.07^{Ca}	4.09±0.01^{Cab}	4.12±0.01^{Cab}
	18	1.7±0.06^{E}	2.72±0.06^{De}	2.98±0.02^{Dc}	3.77±0.01^{Db}	3.78±0.01^{Db}	2.91±0.07^{Dd}	2.91±0.13^{Dd}	3.86±0.00^{Db}	3.55±0.09^{Dbc}	3.67±0.02^{Db}
Mn (mg/100g)	0	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}	0.99±0.02^{Aa}
	1	0.94±0.04^{Aa}	1±0.00^{Aa}	0.99±0.00^{Aa}	1±0.18^{Aa}	1±0.18^{Aa}	0.99±0.00^{Aa}	0.99±0.00^{Aa}	1±0.10^{Aa}	0.99±0.00^{Aa}	0.99±0.13^{Aa}
	4.5	0.76±0.00^{Bc}	0.86±0.01^{Bb}	0.9±0.01^{Ba}	0.91±0.05^{Aa}	0.91±0.00^{Aa}	0.91±0.02^{Ba}	0.9±0.01^{Ba}	0.91±0.02^{Ba}	0.91±0.01^{Ba}	0.9±0.01^{Ba}
	9.5	0.66±0.01^{Cd}	0.78±0.01^{Cc}	0.88±0.00^{Ba}	0.89±0.01^{ABa}	0.89±0.00^{ABa}	0.87±0.01^{Bab}	0.87±0.01^{Bab}	0.9±0.01^{ABa}	0.88±0.00^{ABa}	0.88±0.01^{ABa}
	14.5	0.59±0.01^{De}	0.64±0.01^{Dd}	0.79±0.00^{Cc}	0.85±0.00^{ABa}	0.86±0.01^{ABa}	0.77±0.02^{Cc}	0.78±0.01^{Cc}	0.86±0.00^{ABa}	0.83±0.00^{Bb}	0.84±0.00^{Bb}
	18	0.45±0.02^{Ed}	0.54±0.01^{Ec}	0.68±0.00^{Dab}	0.7±0.00^{Ba}	0.7±0.00^{Ba}	0.66±0.00^{Db}	0.67±0.00^{Db}	0.71±0.00^{Ca}	0.69±0.00^{Cab}	0.7±0.00^{Ca}
Cu (mg/100g)	0	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}	1.37±0.06^{Aa}
	1	1.31±0.02^{ABa}	1.36±0.08^{Aa}	1.37±0.08^{Aa}	1.37±0.04^{Aa}	1.36±0.20^{Aa}	1.37±0.08^{Aa}	1.36±0.17^{Aa}	1.36±0.06^{Aa}	1.37±0.17^{Aa}	1.37±0±0.10^{Aa}
	4.5	1.25±0.00^{Bc}	1.31±0.00^{Ab}	1.36±0.00^{Aa}	1.36±0.00^{ABa}	1.36±0.00^{Aa}	1.36±0.00^{Aa}	1.36±0.00^{Aa}	1.36±0.00^{Aa}	1.36±0.00^{Aa}	1.36±0.00^{Aa}
	9.5	1.2±0.00^{Ce}	1.29±0.00^{ABd}	1.31±0.01^{ABbc}	1.33±0.00^{ABa}	1.33±0.00^{Aa}	1.31±0.00^{ABbc}	1.31±0.00^{Abc}	1.34±0.00^{Aa}	1.33±0.00^{Aab}	1.33±0.00^{Aab}

	14.5	**1.15**±0.00**CDd**	**1.19**±0.00**Bc**	**1.23**±0.01**Bb**	**1.27**±0.00**Ba**	**1.27**±0.00**ABa**	**1.23**±0.00**Bb**	**1.22**±0.00**ABb**	**1.28**±0.00**ABa**	**1.26**±0.00**ABa**	**1.27**±0.00**ABa**
	18	**0.87**±0.02**Dd**	**0.97**±0.04**Cc**	**1.02**±0.01**Cc**	**1.17**±0.00**Ca**	**1.18**±0.01**Ba**	**1**±0.00**Cc**	**1.08**±0.01**Bc**	**1.2**±0.00**Ba**	**1.14**±0.03**Bb**	**1.15**±0.02**Bab**

The means (± standard deviation) with different lowercase / upper case letters on the same row/in the same column are different in the 5% probability test. ***TB0SP****: control without biopesticides in the polypropylene bag,* ***TB0P****: triple bagging with 0% biopesticides,* ***TB1****: triple bagging with 2.5% biopesticides (p / p),* ***TB2****: triple bagging with 3.99% biopesticides (p / p),* ***TB3****: triple bagging with 3.99% biopesticides (p / p),* ***TB4****: triple bagging with 1.01% biopesticides (p / p),* ***TB5****: triple bagging with 1.01% biopesticides (p / p)),* ***TB6****: triple bagging with 5% biopesticides (p / p),* ***TB7****: triple bagging with 2.5% biopesticides (p / p) and* ***TB8****: triple bagging with 2.5% biopesticides (p / p)*



a- Projection of variables **b- Projection of individuals**

Figure 1: Projection of biochemical parameters (a) and individuals (b) in the factorial plan 1-2 of the main component analysis.

E0*: initial sample,* ***A1****: polypropylene bag at 1 month,* ***B1****: triple bagging without biopesticides at 1 month,* ***C1, D1, E1, F1, G1, H1, I1, J1****: triple bagging with 2.5%, 3.99%, 1.01% and 5% of biopesticides(depending on the combinations) at 1 month conservation,* ***A2****: polypropylene bag at 4.5 months,* ***B2****: triple bagging without biopesticides at 4.5 months,* ***C2, D2, E2, E2, F2, G2, H2, I2, J2****: triple bagging with 2.5%, 3.99%, 1.01% and 5% of biopesticides(depending on the combinations) at 4.5 months storage,* ***A3****: polypropylene bag at 9.5 months,* ***B3****: triple bagging without biopesticides at 9.5 months,* ***C3, D3, E3, F3, G3, H3, I3, J3****: triple bagging with 2.5%, 3.99%, 1.01% and*

*5% of biopesticides(depending on the combinations) at 9.5 months storage, **A4**: polypropylene bag at 14.5 months, **B4**: triple bagging without biopesticides at 14.5 months, **C4, D4, E4, F4, G4, H4, I4, J4**: triple bagging with 2.5%, 3.99%, 1.01% and 5% of biopesticides(depending on the combinations) at 14.5 months storage, **A5**: polypropylene bag at 18 months, **B5**: triple bagging without biopesticides at 18 months, **C5, D5, E5, F5, G5, H5, I5, J5**: triple bagging with 2.5%, 3.99%, 1.01% and 5% of biopesticides (depending on the combinations) at 18 months storage.*

4. DISCUSSION

The correlation coefficients (R^2) obtained were all close to 1, which would reflect a quasi-linear estimate of the different mineral elements studied. Also, the low coefficients of variation (<5%) in reproducibility and repeatability fully reflect the stability of the method used. In addition, these characteristics enhance the credibility and accuracy of the results in the determination of mineral element contents by the Energy Dispersive Spectrophotometry (EDS) method since the total amount of each mineral element is reported, as shown by the low extraction defects below 2.7% of the additional minerals (dosed additions).A total of nine mineral elements namely: magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), calcium (Ca), iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) have been detected and analysed during conservation. These mineral elements, considered essential nutrients for life, ensure the maintenance of tissue homeostasis and form the main structural component of bones and teeth. These nutrients must be provided in very small amounts in the diet to stimulate cell growth and metabolism **(Oyewole and Asagbra, 2003).** Thus, the study of these micronutrients during the storage of maize grains is of paramount importance because of their involvement in the physiological and metabolic functions of the body. However, under unsuitable storage and/or conservation conditions (traditional storage) these mineral elements undergo modifications **(Deffan *et al*., 2015).** The results of this study clearly show that, overall, mineral grades decrease over time depending on the type of treatment. **Deffan *et al.* (2015)** had also observed a significant decrease in the mineral content of corn kernels stored in different structures. For these authors, the decrease in mineral element contents during the storage of maize grains would depend on storage conditions. In Nigeria, **Danjumma *et al.* (2009)** also found that the mineral content of maize grains decreased with storage time. Indeed, these authors had shown that the loss of mineral elements during storage was related to the level of grain infestation.

Low rates of decline for all mineral elements were recorded for corn grains contained in triple bagging systems without biopesticides at the end of the first 9.5 months of storage compared to the polypropylene control batch, which recorded very significant loss rates at the end of the first 4.5 months of storage. After 9.5 months of storage, the levels of all the mineral elements in the triple-bagged batch without biopesticides dropped significantly, also reaching low values in the 14th month and a half of storage and then in the 18^{th} month. The combined effect of triple bagging and biopesticides made it possible to maintain mineral contents at high levels until the 14^{th} month and a half of storage in the other experimental batches (triple bagging systems associated with different proportions of biopesticides). Then at the 18^{th} month of storage the loss rates are more marked in these experimental batches. The preservation of the mineral quality of the grains marked by low rates of decline observed in triple bagged batches during the first 9.5 months of storage could be explained by a decrease in oxygen content during storage. These observations may be similar to data on controlled atmospheres in the control of stock pests in airtight storage bags **(De Groote *et al*., 2013).** Indeed, the low levels of oxygen resulting in high levels of carbon dioxide hinder the growth of insects during storage, leading to a reduction in their feeding activities. This would promote damage reduction **(Niamketchi *et al*., 2016).** The significant decrease in mineral content of corn kernels at 14.5 and 18 months in the triple bagging without biopesticides and the polypropylene bag (control lot) after the first 4.5 months of storage would be due to the increased metabolic activities of the insect populations. Indeed, according to **Mofunanya and Namgbe (2016),** parasitic insects during their various stages of development would use a large amount of minerals as nutrients needed to sustain life and to complete larval development and metamorphosis. However, the low rates of decrease in mineral content recorded after the first 14 and a half months of storage in the other experimental batches could also be attributed to the insecticidal and/or insect repellent effect of the leaves of *Lippia multiflora* and *Hyptys suaveolens* due to the release of bioactive molecules. Our investigations are similar to those of **Fofana *et al.* (2018)** on cowpea seeds in Côte d'Ivoire. These authors showed the efficacy of dried leaves of *Lippia multiflora* in preserving the mineral quality of cowpea seeds for 8 months in triple bagging systems. The results obtained are also in agreement with those of **Niamketchi *et al.* (2016),** who showed that the leaves of *Lippia multiflora* and *Hyptys suaveolens* would significantly reduce the development of the pests responsible for much of the deterioration of the nutritional quality of maize grains during storage.

Indeed, these bioactive molecules cause morphological and behavioural disturbances on stock pests. The prolonged effect of the bioactive molecules in the leaves of *Lippia multiflora* and *Hyptys suaveolens* on corn kernels at 14.5 months is due to the triple bagging system that works in a confined atmosphere, preventing any volatility of these odorous substances. The high rates of mineral decline observed in triple bagging systems associated with different proportions of biopesticides at the end of storage would be due to a decrease in the odour effect of the dried leaves after 14.5 months of storage, followed by perforation of these storage systems, resulting in a resumption of feeding activity by insect pests. However, the variability observed in mineral element contents in these storage systems with biopesticides would be explained by the synergistic or antagonistic effect of the different leaves used as a biopesticide. Indeed, the more the quantity of biopesticides increases, i.e. more than 2.5%, the combination of the two types of leaves is more effective (synergistic effect) as taken individually at 2.5%. But when the proportion of biopesticides is less than or equal to 2.5% an antagonistic effect is observed (combination of leaves is less effective compared to their individual use). This would make it possible to classify the efficacy of biopesticides according to the proportions and/or combinations of the leaves of *Lippia multiflora* and *Hyptys suaveolens*.

5. CONCLUSION

The work carried out in this study aims at preserving the mineral quality of grain maize through the use of a triple bagging system and biopesticides (leaves of *Lippia multiflora* and *Hyptys suaveolens*). The results obtained indicated that stored maize evolves differently depending on the type of treatment. The storage life, proportion and combination of biopesticides significantly influence the mineral quality during storage. Triple bagging systems helped maintain the mineral quality of the grain maize during the first 10 months of storage. However, the addition of *Lippia multiflora* and *Hyptys suaveolens* leaves as biopesticides in different proportions and/or combinations makes the conservation of the mineral elements more effective over a period of 15 months.

This study deserves to be deepened in order to estimate the inputs and the contribution in mineral elements of the maize grains being stored in these storage systems.

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