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Perceptions of traders and characterization of insect pests during the conservation of maize grains (*Zea mays* L.) in southern Benin

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Abstract: Maize is one of the most important cereals which helps maintain food security. This study aims to characterize the insects during maize grain storage to ensure food security. Then, a questionnaire was administered to 100 traders randomly selected from 10 markets at Cotonou and Abomey-Calavi. Samples were collected and analyzed at the Laboratory of Plant Physiology and Environmental Stress Study to characterize insect species and assess their impact on grain quality and quantity. Survey results show all traders (100 %) experience huge losses due to insects during conservation. However, three methods of control have been recorded, namely the use of pesticides (28 %), good drying before storage (54 %), and the use of inert plants and materials such as neem, dry pepper, and ash (18 %). Two insects recognized by traders were identified in the laboratory, *Sitophilus zeamais* and *Tribolium confusum*. However, white maize is more contaminated with *Sitophilus zeamais* according to 56 % of respondents, while yellow maize is mainly contaminated with *Tribolium confusum* (20%). Despite this short shelf life, these beetle insects caused grain weight losses of up to 34.48 %. Further work would therefore be needed to broaden the study area for full characterization of these pests.

Keywords: Constraints, harvest losses, Storage, *Tribolium confusum*, *Sitophilus zeamais.*

1.INTRODUCTION

Maize (Zea mays L.), a major food, feed, and industrial crop in sub-Saharan Africa (SSA), has been the subject of extensive research for genetic improvement for more than half a century in the sub-region. One aspect that has received increased research attention over the past three or four decades is the genetic improvement of early and extra-early maturing genetic material for resistance or tolerance to drought, striga, and low soil nitrogen [1]. Due to pest attacks, maize is also subject to qualitative and quantitative post-harvest losses. For example, because of the high post-harvest and storage destruction of seeds, many producers have included insect resistance in their choice' criteria [2].

Cereal grains are the fruits of cultivated grasses that provide humanity with more food than any other food class and nearly half of the total caloric requirements. Although there are about a dozen cereal crops used for food, only wheat, maize and rice are important food sources, accounting for 94% of total cereal consumption [3,4]. The two largest producers, the United States and China, account for nearly 60% of the world's total production.

In Benin, maize is the most widely produced cereal and plays a very important role in the economy, in food and feed. It is the staple food of the Beninese population and plays an important role in contributing to food security. However, even though this cereal occupies a dominant place in national agricultural production, it is clear that there are significant risks of food insecurity in households [5]. According to the Global Analysis of Vulnerability, Food Security and Nutrition (AGVSAN) conducted by the Government of Benin and the World Food Program (WFP), it was estimated at the national level in (2020) that 972,000 people are food insecure, representing 12% of households (AGVSAN). There are several factors that jeopardize the storage of maize, with negative effects resulting in a depreciation of the quality of the grain.

Among the main constraints to improving food security in Africa, are losses resulting from poor post-harvest management of cereals, estimated at between 20 and 30 percent, amounting to more than $4 billion per year [6]. Some of these losses are caused by insects and fungi, and the rate at which they multiply is influenced by prevailing environmental conditions [7].

In western Kenya, for example, it is estimated that 10-88% of the total maize produced each season is lost to field and warehouse pests [6,8]. Incidentally, the presence of harmful insects may indeed deteriorate the health status of grains and seeds stored in the long term, but in the short term, the mere presence of insects in a lot constitutes a major obstacle to national and international trade [9].

The objective of this study is to identify and characterize the different storage insects of grain maize during storage. To achieve this objective, a survey was carried out among traders, and then, based on the corn samples taken, tests were carried out in the laboratory.

2. MATERIAL AND METHODS

2.1. Material:

2.1.1. Presentation of the study area and choice of markets: This study was conducted in southern Benin where several markets for the sale of maize exist even in whole and retail. Benin is located in West Africa between latitudes 6°10 N and 12°25 N and longitudes 0°45 E and 3°55 E. The surveys were carried out in the municipalities of Abomey-Calavi (Atlantic) and Cotonou (Coastal). The municipalities of Abomey-Calavi and Cotonou are respectively located in agroecological zones 6 and 8, which are characterized by a Sudano-Guinean climate with two rainy seasons. The average precipitation is between 1100 and 1400 mm for temperatures generally between 25° C and 35° C. The relative humidity of this zone is between 69 and 97% [10].

Then, four markets were selected in the municipality of Cotonou (Dantokpa, Gbégamey, Sainte-Rita, and Fifadji) and six were selected in Abomey-Calavi (Akassato, Calavi-Kpota, Cocotomey, Godomey, Kindonou, and Djadjo) for a total of ten (10) markets.

2.1.2. Plant material: The plant material consists of maize grains stored by traders in the various localities of the markets surveyed. In this study, the selection is based on the maize grain color; the only criterion used by consumers.

2.2. Methods

2.2.1. Sampling and data collection: The first step was to carry out prospecting in the various markets in the study area where maize is sold. It was an opportunity to assess the density of these markets in the trading of food products and how maize is sold (retail or wholesale). Based on the data received, a total of 10 randomly selected maize traders of all categories were surveyed during the actual market-based collection phase.

The collection phase allowed us to observe the different structures and technologies used by traders to conserve maize; the framework in which the traders conserve maize; the methods of storage and to understand the problems that traders face when conserving maize.

In the case of stored grain corn pests, photos of insects were printed and presented to the respondents.

2.2.2. Study of the traders' perception of the constraints of maize storage: The questionnaire submitted to traders allows to determine the socio-economic characteristics of the respondents; the method of storage and the pests of stocks. One person responsible for each sales display of grain corn was surveyed for a total of ten (10) displays per market. One hundred (100) people were interviewed in all markets. It provided their views on the state of post-harvest losses in maize storage.

Following the interviews, samples of maize grains were systematically taken from each of the prospected displays to obtain a relatively large sample to assess the diversity and incidence of the stock pests. At each stall, samples were taken at three different levels; at the top, middle, and bottom of the stock to have an infestation level close to the storage conditions.

2.2.4. Evaluation of post-harvest losses in maize conservation: The grains taken from different depths on each display were mixed to form a composite sample per locality. A total of 500 grains were collected and evaluated in clear bottles to monitor the emergence of pests. These bottles were closed by muslin to allow ventilation on the one hand and to prevent any insects from coming out and/or entering. The samples were thus kept at room temperatures 25° C to 28° C.

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2.2.5. Identification of storage pests: A quantity of 300 g was taken from each sample of maize and stored in the laboratory for insect identification. Insects from the various samples previously stored were inventoried after six (06) months. The grains were sieved using a 2 mm mesh sieve [11] to isolate all live and dead adult insects as described by Compton and Sherington[12] and used by Fufa et al.[13] . The insects were separated and grouped according to the different species. They were stored in a 75% ethanol solution to facilitate their identification. The identification was then possible by combining insect characteristics, the available photos, and then the comparison using specimens of storage maize insects available in the laboratory.

2.2.6. Evaluation of insect-damaged maize grains: The damaged grains were counted and weighed using an SF-400 type balance. Knowing the initial weight, each sample was evaluated and used to collect data on the number and weight of grains damaged and undamaged by insects. The damage rate was calculated using the method used by CGC,[14] and Fufa et al.[13], as follows:

$$\textit{Damaged grain rate} = \frac{\textit{Number of grains damaged}}{\textit{Number of total grains}} \times 100$$

2.2.7. Evaluation of the rate of weight loss of the grains: Weight loss was determined by initially recording the initial weight of the container (preservation bottle) and the maize kernels initially preserved. Thus, the weight loss of the grains was calculated by subtracting from the initial weight the weight of the samples after six months of storage according to the method used by Wambugu *et al.* [15], and Fufa *et al.*[13], which is as follows:

$$\textit{Weight loss}\ (\%) = \frac{\textit{Initial weight} - \textit{Weight after storage}}{\textit{Initial weight}} \times 100$$

2.2.8. Data processing and analysis: A manual analysis of the survey sheets followed by the codification of the information collected in the field was carried out. Analyzes of traders' perceptions and laboratory data were carried out using the Excel 2016 spreadsheet.

3. RESULTS3.1. Socio-economic and demographic characteristics of the respondents: The majority of the population surveyed in the municipalities of Cotonou and Abomey-Calavi and engaged in maize conservation was women, i.e. 86% compared with 14% of men. Relatively young, these respondents range in age from 24 (all markets) to 50 (Dantokpa and Calavi-Kpota) with an overall average of 33.4 ± 10.59 years. Most of the respondents from the Cotonou markets are the most experienced in the maize trade with an average experience of 4 to 20 years, while those from the markets of the Commune of Abomey-Calavi have an average experience of 2 to 10 years. The ethnic groups represented during the surveys are six, namely the Fon; Dindi; Tori; Goun; Mahi; and Sahouè, with a predominance in the Fon.

3.2. Causes of loss of maize grains from conservation: Post-harvest losses during maize conservation are a real problem for traders in the study area. An on-the-spot survey confirmed that 100% of traders experience losses during maize conservation. These losses vary according to the surveyed, depending on the conservation technologies used (65%), the storage practices/methods used (25%), and the pre-and post-harvest measures taken by producers before delivery to traders (15%). In addition, once the maize has been purchased and stored, several causes create damage, leading to huge losses for traders. The highest proportion of these factors among traders is related to insects (45%), followed by temperature (coolness or heat) and especially humidity (air and water) (26%). The lowest proportions are reserved for causes such as lack of training on maize conservation measures and technologies (18%); and lack of access to information on conservation technologies (11%).

Table III: Characteristics of the population surveyed in the municipality of Cotonou

Municipalities	Market	Women	Men	Age	Ethnicity	Experience (years)
Cotonou	Dantokpa	6	4	[29 - 50]	Tori, Fon	[2 - 20]
	Fifadji	8	2	[24 - 44]	Fon	[2 - 20]
	Saint Rita	7	3	[24 - 42]	Fon, Goun	[2 - 20]
	Gbégamey	10	0	[26 - 30]	Fon	[2 - 20]
Abomey-Calavi	Djadjo	9	1	[24 - 47]	Mahi, Fon	[2 - 20]
	Calavi-kpota	7	3	[25 - 50]	Fon	[2 - 20]
	Akassato	8	2	[24 - 45]	Fon	[2 - 20]
	Cocotomey	10	0	[28 - 35]	Sahouè	[2 - 20]
	Godomey	9	1	[24 - 40]	Fon	[2 - 20]
	Kindonou	10	0	[25-47]	Fon	[2 - 20]
Total		84	16	33.4		10.56

3.3. Inventory of methods used to conserve maize: The main storage structures and conservation tools used by traders are, respectively, rooms and shops. For all respondents, maize is either packed in jute bags before being placed in rooms or shops or left on the ground if no conservation method is envisaged to prevent insect attacks.

Several methods are used by traders to preserve maize. A total of 54% of respondents indicated sun drying, followed by using chemicals such as Actellic super, and pesticides by 28%, and plant substances such as fresh or dried neem leaves, and dry pepper by 18%. The latter shall justify their choice based on the benefits of each method during the marketing period.

Chemicals are syntheses of chemicals used by humans to protect crops from pests and insects. Several chemicals such as acetic super and fumigants are used to preserve maize. According to the respondents, one (01) sachet of actellic super is added and mixed with 50 kg of well-dried maize. They justify its use because it has better control of the great corn beetle (*Prostephanus truncatus*) than the Sofagrain because of its toxicity, which eliminates eggs and then the odor that repels insects. Fumigants such as phostoxin, magtoxin, bextoxin, and thomaxin are used by some traders to store large quantities of corn over a period of 2 to 3 years. The high cost of its products thus limits their accessibility to the traders.

The plant substances used by the small proportion of traders in maize conservation are derived from plants. Two methods were recorded for the use of leaves (added in layers to maize in or out of spars) or neem (*Azadirachta indica*) seeds (dried, crushed, and mixed with ginned maize) for conservation over a period of 1 to 2 years. The local variety of the pepper called Agossakpedo in the Benin language "Fon" is also used in the conservation of maize. According to the respondents, the latter can be used directly after drying in a mixture with shriveled maize or crushed with a mortar and then spread in layers in a stock of spathe maize. In addition, 2% of respondents noted a decline in the use of chili because overdosing or failure to control the dose/amount to be applied during treatment made maize kernels unfit for food after cooking. The aroma of dry chili creates breathing problems and prevents some producers and traders from using it. Other techniques have been proposed by the traders to ensure proper conservation of the corn. The most common technique is sun drying, a physical method used to improve the ability of maize to be preserved. It is very important in order to reduce the moisture content of maize before it is put into storage. Some insects and larvae are destroyed by sunlight. Some respondents reported the use of cow dung mixed with neem leaf on the one hand and the use of stalk waste after ginning.

3.4. Perception of shelf life and maize pests in storage: Depending on the conservation objective and sometimes recurring financial problems, traders may keep maize grains for between 1 month and 36 months. An in-depth analysis of the data from this study reveals that 55% of traders in all 10 markets keep maize for 12 to 24 months, while 33% and 12% of respondents keep their maize production for 24 to 36 months and 1 to 12 months, respectively.

During the survey phase, in order to categorize the various pests that destroy the quality of corn grains in storage, the traders identified two large groups on presentation of the specimens, one consisting of insects (78%) and the other of rodents (22%). Recognition of the different types of weevil during storage of maize and on maize grains was easy for the latter. For example, some traders particularly recognize two types of insects as black weevil more present in white corn (56%), and brown weevil dominant in yellow corn (20%). The rest of the proportion recognizing insects have no knowledge of the specificity of these insects in relation to the type of maize attacked (24%). Among the group of respondents who highlighted the rodent attack, two subdivisions were noted, one for mouse identification (80%) and the other for rat recognition (20%). The presence of these pests is due not only to poor structuring of the storage sites but also to the way of life of the populations.

3.5.Inventory of insects identified in the laboratory: All samples analyzed in this study were contaminated with storage pests, although for some, insect development at the time of analysis did not change significantly. Two species of storage insects have been identified. These are the species *Sitophilus zeamais* and the species *Tribolium confusum* (**Figure 1**) found in all samples collected in the various markets. The brown tribolium worm was also specifically observed in a sample from Gbegamey, which experienced a high rate of infestation (**Figure 2**). These two arthropods are therefore the dominant insects according to the characteristics of the grains. During the analysis, *S. zeamais* is most often noted in white maize kernels, while *T. confusum* is most noticeable in yellow kernel stocks. The mainly white maize grains collected in the Djadjo market are unique in that they contain both species of storage insects. This assessment did not identify an insect-specific to a maize marketing market.

Figure 1: *Sitophilus zeamais* on the left and *Tribolium confusum* on the right

Figure 2: Small Flour Worm (*Brown Tribolion*)

3.6. Impact of grain storage insects on maize quality and quantity: After the laboratory evaluation period, the presence of insect pests (*Sitophilus zeamais* and *Tribolium confusum*) caused huge losses in the amount of grain ranging from 1% (Kindonou) to 25.65% (Gbegamey) (**Figure 3**). This result also indicates that the quantity of damaged grain is greater in the Cotonou markets, with a proportion of losses varying between 4.2% and 25.65%. It should be noted that the majority of maize grains collected in the Cotonou markets are white, while in the Abomey-Calavi markets the dominance is yellow. In addition, the proliferation of these insects induces a loss in the market value of its corn grains resulting in a reduction in the weight of the grains compared with the initial storage weight (**Figure 4**). Thus, the increase in weight loss is related both to the type of insect identified (*beetle*) and to the length of time the corn is stored.

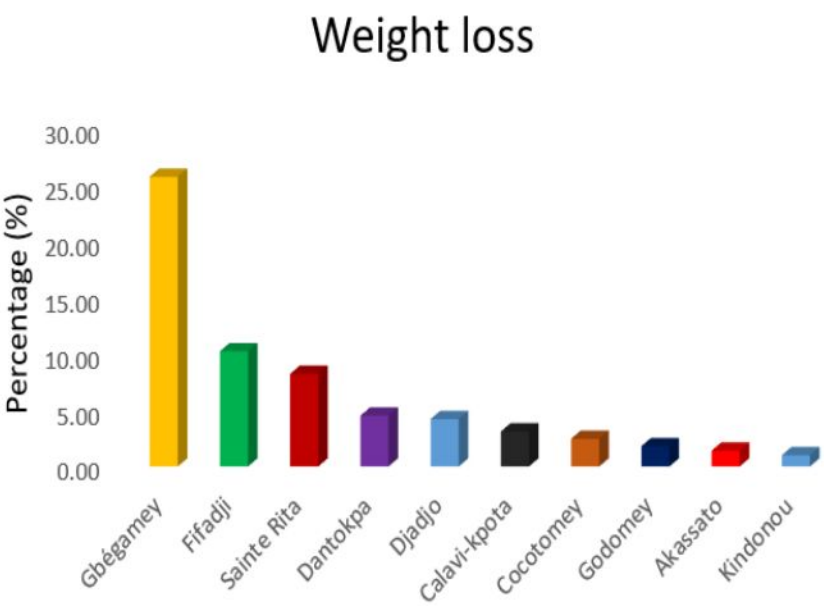

Figure 3: Rate of grain loss due to the presence of storage insects

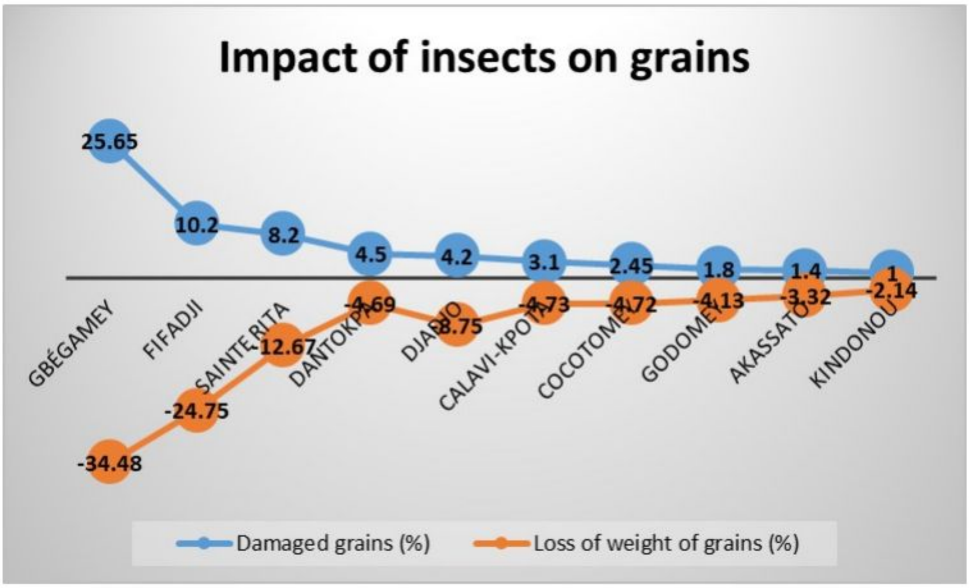

Figure 4: Relationship between insect presence and grain weight loss

4.DISCUSSION

Maize is a staple food crop in several sub-Saharan African countries [16] including Benin. Crop conservation plays a key role in maintaining food security. Storage and conservation structures not only offer the possibility of alleviating hunger between basic crop harvests, but farmers can also improve income by storing crops and selling them at higher prices when demand exceeds supply later in the post-harvest period [17]. However, significant crop losses can occur during post-harvest activities and maize conservation [18,19]. These losses are mainly caused by the growth of pest populations (in particular insects, rodents, etc.) and the presence of mycotoxins [16,20,21]. In order to assess the sources of contamination of maize by these insects during storage in Benin, this study was carried out in the communes of Cotonou and Abomey-Calavi. Analysis of the perception of traders shows that maize suffers huge losses during the storage period, as reported by Guèye *et al.* [22]. During this period, according to Sankara *et al.* [23] , maize is subject to constant depredation by storage insects. Storage technology is believed to be one of the causes of maize loss during storage for the majority of respondents. In line with this perception of traders, the teams in Guèye[22] and Sankara[23] reported that the storage of corn either in loose cobs or bags after husking results in the loss of quantity and quality of dry corn [22,23]. Thus, the factors that can cause huge losses of stored grains are storage insects [13] reported by 45% of respondents; the inadaptability of storage methods or technologies also reported by Abass et al.[24] . Furthermore, the purpose of conservation technologies is to preserve the quality of grains and seeds during storage by all appropriate means. Some authors stated that, for long-term storage, a number of rules concerning the temperature of the grain and storage room had to be complied with. Multiple examples show that losses are lower in traditional systems than in modern structures [25].

Thus, the store is the most used conservation structure for the long-term conservation of corn. In fact, the preservation of cereal grains in stores generally ensures their good preservation, all the more so since they are located in a low-humidity environment. Whatever, good conservation practice consists of controlling three main factors: the temperature, the water content of the grain, and the storage time. In Senegal, for example, six different storage methods were recorded [22], including bags, trays, attics, trays and bags, drums, and shops. This difference in the application of certain methods could be explained by the search for an ideal to limit or prevent the development of insect pests. The temperature is controlled

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by the use of ventilation systems. The ideal would be to store a grain of 12 to 13% moisture. According to Crépon and Cabacos[26], insect sensitivity to relative humidity is dependent on each species [26]. Long before the latter, Khan established in 1983 that the relative humidity range allowing the longest survival of insects from grains stored at 25°C ranged from 0 to 97% for the capuchin (Rhyzopertha dominica), 50 to 97% for the brown tribolium (Tribolium confusum), 50 to 95% for the silvain (*Oryzaephilus surinamensis*), 60 to 98% for the red tribolium (*Tribolium castaneum* 95-100% for grain weevil (*Sitophilus granarius*) and corn weevil (*Sitophilus zeamais*), which are the most hygrophilic species. Thus, below 50% humidity, at 25°C, the survival time of most grain insects decreases significantly without becoming impossible (Kumar et al., 2017). To prevent or protect corn stocks from insect pests, the Guèye team reported in 2012 the use of various methods including drying, use of chemicals, and plant extracts [22]. Several other authors have also made use of plants during storage which include plants for use alone such as *Azadirachta indica* A. Juss and *Hyptis spicigera* Lam [23]; or in combination such as *Azadirachta indica - Khaya senegalensis*. Apart from plants, sand [23]and salt [22,23] are the inert materials also used during this period. According to Zongo et al.[26] , insects that attack stored maize grains often require the use of synthetic insecticides to protect stocks, which poses risks to consumer health [26]. This could be justified by an overdose of these chemicals resulting in reduced germination capacity of the grains and food poisoning in households as pointed out by some respondents.

The assessment of the samples collected in the different markets reveals the presence of two species such as *Sitophillus zeamais* and *Tribolium confusum*. These species have also been found in maize stocks by several other researchers [11,16,24]. These two insects belong to the Coleoptera order, one of which represents a primary pest (*S. zeamais*) and the other a secondary pest (*T. confusum*). According to Abass et al.[24], the population of *S. zeamais* increased rapidly at the beginning of storage, which would justify the abundance of these insects in most of the samples collected in the different markets after the evaluation period. It has been observed that each species is specific to a given type of grain. Thus, based on insect damage to grains, the physical analysis of the seed coat of white grains has a harder structure than that of yellow grains [27]. This could justify this specificity comparable to the perception of merchants. The other argument is therefore related to the oral morphological structures of the two identified species, which allows them to be classified into the primary and secondary pest groups. Preserving the quality and quantity of corn grains in storage will therefore have to comply with certain factors to prevent the development of insects that hinder the maintenance of food security. The presence of these insect species in our stocks caused weight losses ranging from 3.32% to 34.48%. According to the work of several researchers, *Sitophilus zeamais* is responsible for 12-36% of grain weight loss worldwide [27-29]. This rate can also reach 67% in western Kenya, according to Midega et al.[6] . In general, this scenario of insect proliferation significantly undermines food security and leads to poverty in vulnerable regions [19].

CONCLUSION

The overall objective of this study is to contribute to improving the conservation of maize and to the sustainable management of insects harmful to stored maize grains. This study has allowed to learn more about the different structures and methods of conservation; and then to find initiatives to combat the depredators of the stocks to offer traders effective methods of conservation of maize. The results on the types of conservation structures show a structural preference as a function of the study sites. Through laboratory analyses of corn samples, two types of insects were identified, *Sitophilus zeamais* and *Tribolium confusum*. These grain-damaging insects multiply rapidly if the conditions of the storage structures are favorable to their development. The next step in this study would be to evaluate the resistance of available maize varieties to establish an improvement program against attack by these storage insects.

AUTHORS CONTRIBUTION

Faton Manhognon Oscar Euloge, Bonou-Gbo Zaki, Montcho Hambada koffi David, NASSOUR Ibrahim, Djedatin Gustave, and Gnancadja-Andre Léopold Simplice contributed to the study conceptualization and designed the experiments. Faton Manhognon Oscar Euloge, Bonou-Gbo Zaki, and NASSOUR Ibrahim contributed to the statistical analysis. Faton Manhognon Oscar Euloge wrote the manuscript. Cynthia Atindehou, Lucie Fanou, Theophane Ayi, Gandonou Gbossegnon Bernard Christophe, Gnancadja-Andre Léopold Simplice, and Edorh Patrick Aléodjrodo supervised the entire study. Bonou-Gbo Zaki, Montcho Hambada Koffi David, Gnancadja-Andre Léopold Simplice, and Gandonou Gbossegnon Bernard Christophe reviewed and edited the manuscript. All authors contributed to the manuscript.

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REFERENCES

1. B. Badu-Apraku, M.A.B. Fakorede, Maize in Sub-Saharan Africa: Importance and Production Constraints. In: Advances in Genetic Enhancement of Early and Extra-Early Maize for Sub-Saharan Africa Springer, Cham.2017, https://doi.org/10.1007/978-3-319-64852-1_1.
2. Z. Bonou-gbo, G. Djedatin, A. Dansi, I. Dossou-Aminon, C.T. Odjo, W. Djengue and K. Kombate, Ethnobotanical Investigation and Collection of the Local Maize (*Zea mays* L.) Varieties Produced in Benin. Int. J. Curr. Res. Biosci. Plant Biol.2017, **4**(5), 9-29. https://doi.org/10.20546/ijcrbp.2017.405.002.
3. FAO. 2012. FAOSTAT, Food Supply. http://faostat.fao.org/site/345/default.aspx.
4. P. Ranum, P.J. Pena-Rosas, N.M. Garcia-Casal, Global maize production, utilization, and consumption. Ann. N.Y. Acad. Sci.2014, 1312, 105-112. doi: 10.1111/nyas.12396
5. A. Saïdou, I. Balogoun, E.L. Ahoton, A.M. Igué, S. Youl, G. Ezui, A. Mando, Fertilizer recommendations for maize production in the South Sudan and Sudano-Guinean zones of Benin. Nutr Cycl Agroecosyst, 2018, 110:361–373. https://doi.org/10.1007/s10705-017-9902-6
6. C.A.O. Midega, A.W. Murage, J.O. Pittchar, Z.R. Khan, Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. Crop Protection, 2016, 90: 142-149. https://doi.org/10.1016/j.cropro.2016.08.033.
7. E.N. Nukenine, C. Adler, C. Reichmuth, Bioactivity of fenchone and Plectranthus glandulosus oil against *Prostephanus truncatus* and two strains of *Sitophilus zeamais*. J. Appl. Entomol.,2010, 134: 132-141

8. J.A.Ojo, A.A. Omoloye, Rearing the maize weevil, *Sitophilus zeamais*, on an artificial maize-cassava diet. J. Insect Sci.,2012, 12 : 1-9
9. B.Barrier-Guillot, S. Dauguet, P. Ducom, M.P.Leblanc, K. Crepon, E.Frerot, E. Losser, .Bonnery, Y.Ciesla,F. Fleurat-Lessard, Economics and innovation in reasoned protection of cereals against insect infestation during storage. Agronomic Innovations, INRA, 2014, 34, pp.67-82.
10. I.B. Baoua, L. Amadou, B. Ousmane, D. Baributsa, L.L. Burdock, PICS bags for post-harvest storage of maize grain in West Africa. J. Stored Prod. Res. 2014, 58, 20-28. [CrossRef]
11. S. Waktole, A. Amsalu, Storage pests of maize and their status in Jimma Zone, Ethiopia. African Journal of Agricultural Research. 2012, **7**(28), 4056-4060, https://doi.org/ 10.5897/ AJAR11.1123.
12. J.A.F. Compton, J. Sherington Rapid assessment methods for stored maize cobs: weight losses due to insect pests. Journal of Stored Products Research. 1999, 35: 77-87. Link: https://bit.ly/3dF7XYD
13. N. Fufa, T. Zeleke, D. Melese, T. Daba, Assessing storage insect pests and post-harvest loss of maize in major producing areas of Ethiopia. J Agric Sc Food Technol, 2021, **7**(1): 193-198. DOI: 10.17352/2455-815X.000106
14. CGC (Canadian Grain Commission) 2014. Insect Identification and Biology 25.
15. P.W. Wambugu, P.W. Mathenge, E.O. Auma, H.A. Rheenen, Efficacy of traditional maize (*Zea mays* L.) seed storage methods in Western Kenya. African Journal of Food Agriculture Nutrition and Development, 2009, 9: 1110- 1128. Link: https://bit.ly/2QNbKtG.
16. D. Baributsa, O.N. Bakoye, B. Ibrahim, L.L. Murdock, Performance of Five Postharvest Storage Methods for Maize Preservation in Northern Benin. Insects, 2020, 11, 541. https://doi.org /10.3390/I nsects11080541
17. J.M.Thamaga -Chitija, S.L .Hendriks, G.F. Omana and M. Green, Impact of Maize Storage on rural house hold food security in northern Kwazulu –Natal Tydskrif vir Gesinsekologie en verb ruikerswetenskappe, 2004, 32 : 8-15.
18. S.J. Costa Reducing food losses in sub-Saharan Africa (Improving postharvest management and storage technologies of smallholder farmers). UN World Food Programme, Kampala. 2014 Link: https://bit.ly/32BpzhF
19. A.B.Abass, G. Ndunguru, P. Mamiro, B. Alenkhe, N. Mlingi, M. Bekunda, Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania. J. Stored Prod. Res. 2014, 57, 49-57.
20. I.B.L. Baoua,; L. Amadou, B. Ousmane, D. Baributsa, L.L. Murdock, PICS bags for post-harvest storage of maize grain in West Africa. J. Stored Prod. Res. 2014, 58, 20–28.
21. T. Tubbs, D. Baributsa, C. Woloshuk, Impact of opening hermetic storage bags on grain quality, fungal growth, and aflatoxin accumulation. J. Stored Prod. Res. 2016, 69, 276-281.
22. M.T. Gueye, D. Seck, J.P. Wathel, G. Lognay, Control of pests in cereal and legume stocks in Senegal and West Africa: bibliographic summary. Biotechnology. Agron. Soc. Approx., 2012, 15(1): 183-194.

23. F. Sankara, G.S. Abdoul, A.Waongo, M. Somda, P. Toé,I. Somda, Post-harvest farming practice of maize in the High Basins region of Burkina Faso. Journal of Animal & Plant Sciences, 2017. 33(1): 5274-5288
24. A.B. Abass, M. Fischler, K. Schneider, S. Daudi, A. Gaspar, et al. On-farm comparison of different postharvest storage technologies in a maize farming system of Tanzania Central Corridor. J. Stored Prod. Res, 2018, 77: 55–65.
25. D. Kumar, P. Kalita, Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. Foods. 2017, 6(1): 8. https://doi.org/ 10.3390 /foods 6010008
26. S. Zongo, Z. Ilboudo, A. Waongo, O. Gnankiné, A. Doumma, M. Sembène, A. Sanon, Risks associated with the use of insecticides during storage of cowpea (*Vigna Unguiculata* L. Walp.) in central Burkina Faso, Rev. CAMES, 2015, 3(1) : 24-31.
27. T. Tefera, S. Mugo, Y. Beyene, Y. Developing and deploying insect-resistant maize varieties to reduce pre-and post-harvest food losses in Africa. Food Secur. 2016, 8, 211e220. https://doi.org/10.1007/s12571-015-0537-7
28. S. García-Lara, D.J. Bergvinson, Phytochemical and nutraceutical changes during recurrent selection for storage pest resistance in tropical maize. Crop Sci. 2014, 54: 2423. https://doi.org/10.2135/cropsci2014.03.0223.
29. Z.M. Gitonga, H. De Groote, M. Kassie, T. Tefera, Impact of metal silos on households' maize storage, storage losses, and food security: an application of a propensity score matching. Food Pol. 2013, 43: 44e55. https://doi.org/10.1016/ j.foodpol.2013.08.005

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