

Original Research Article

**Seasonal changes in field-to-storage insect
pests of maize in Southwestern Cameroon and
implications for their control**

ABSTRACT

Aims: The studies sought to identity and assess the seasonal population dynamics of field-to-store insect pests of maize in Southwestern Cameroon at various harvesting dates.

Methodology: Maize was planted once mid-monthly during the rainy seasons of 2014 and 2015 in 16 plots. At physiological maturity, 2 cobs per plot were harvested weekly for four and five consecutive weeks from March to May plantings and August to October plantings respectively. The different insects were assessed from maize cobs with intact husk at harvest, during de-husking after one month drying and subsequently during incubation at two and four weeks. Insect pests from intact and bird-induced damaged cobs at harvest were also compared.

Results: The results showed that at harvest, *Cryptolestes* spp., *Sitophilus zeamais*, *Ephestia* spp. and *Sitotroga cerealella* were the major field-to-store insect pests. *Cryptolestes* spp. was present during all the months of harvest, *S. zeamais* only in cobs harvested during the dry season months of November, December and January while *Ephestia* spp. and *S. cerealella* though present year round showed a slight increase during the months of the dry season. As concerns harvest dates, the longer maize stayed in the field post physiological maturity, the higher the population of *S. zeamais* and *Cryptolestes* spp. while *Ephestia* spp. and *S. cerealella* did not vary significantly. Cobs damaged by birds

had significantly higher numbers of *Cryptolestes* spp. and *S. zeamais* compared to intact maize cobs while *Ephestia* spp. and *S. cerealella* did not show any difference between the damaged and intact maize cobs.

Conclusion: Harvesting maize early and separating bird-induced damaged cobs from intact ones can therefore minimize stored insect pest numbers and grain losses in storage.

Key words: cobs, maize, bird-induced, harvest dates, intact.

1. INTRODUCTION

Maize (*Zea mays*) is a widely grown crop and one of the most affordable cereals in terms of market price and cost of seeds in Africa [1] [2]. In Cameroon, maize is produced countrywide and it contributes enormously to food security and employment since agriculture employs 73% of the workforce of the country [3]. It is the first most widely produced and consumed cereal in the country with over 700,000 families involved in its cultivation [4].

In Cameroon, maize may be consumed in the form of dry fermented dough, roasted or used as corn porridge or converted into a locally produced corn beer. Maize is also used in the agro and food industry for animal feed and beer production. It further serves as an economic safety net as much of it can be sold fresh as green maize or dried grain and hence it acts as an important contribution to the local economy in many rural areas [5].

The South West region of Cameroon has the highest potential for maize production in the country but the region's current average yields of 1.67 tons/ha are still low compared to the potential of 6 tons/ha [4]. Despite this low yield, post-harvest insect pests are also a major problem to the preservation of the harvested grain. Some of these stored product insects are acquired from the field to storage where their populations rapidly build up during storage period. Post-harvest maize insect pests which include the 'field-to-store' and the 'store' pests are a major constraint to food security and income generation in Sub-Saharan Africa in general; they cause significant post-harvest losses in quantity and grain quality degradation [6].

Most of these stored grain insects pests belong to the orders of Coleoptera and Lepidoptera. The most destructive tropical species for cereals that begin infestation in the field and continue in storage in most parts of African belong to genera *Sitophilus*, *Tribolium*, and *Sitotroga* [7][8][9]. Though most of these species can potentiate their entry into intact maize cobs, feeding on cobs in the field by other animals can cause an increase in the numbers of these field-to-store insect pests besides acting as pests themselves. Birds for example have been noted to be serious pests of maize in the field [10] [11] and they feed by opening the husk thus exposing the grains to varied group of insects, and microorganisms alike. It has been shown that a tight and long husk cover can reduce weevil entry and thus grain damage in maize cobs [12]. Also a good husk cover that is tight at the tip with many husk leaves that are extended above the ear contributes to reducing insect damage and attack by microorganisms in the field [13]. Consequently, the opening of cobs by birds poses a serious threat to preserving maize as this can increase the populations of pests of the harvested produce in storage.

To mitigate the damage inflicted by these varied post-harvest pests, farmers have resorted to using various methods. The most common methods employed by most farmers worldwide to control insect pests in the field and storage is through the use of synthetic residual insecticides. These chemicals although effective, pose many environmental threats such as pollution, human health hazards and the development of resistance in pests among others [14] [15]. Furthermore, most farmers in Africa are resource-poor, coupled with low education and therefore do not have the means or skills and knowledge to obtain and handle pesticides appropriately. For instance most farmers in most areas of Cameroon when using insecticides often do not use appropriate protective clothing, nose masks or goggles and do not respect pre-harvest interval stipulated by manufacturers [16] [17]. In view of the above, farmers need to resort to safe and more environmentally friendly methods of managing pre- and post-harvest pests. However, the vital first step in implementing any curative and sustainable pest management program are the proper identification of the pest involved and monitoring their population dynamics over time and/or seasons. Therefore the objectives of this study were to identity

the various field-to-storage insect pests of maize in Southwestern Cameroon, assess their population dynamics and the effect of bird-induced damaged cobs on their numbers in the target area.

2. MATERIALS AND METHODS

2.1. Study Site

This study was conducted at the Institute of Agricultural Research for Development (IRAD) Ekona, Cameroon located at 4.1327°N and 9.1923°E and 410m above sea level and at the University of Buea, Cameroon located at 4.1537°N and 9.2920°E and 530m above sea level,. The climate in these study sites is of the Equato-Guinean type with a long rainy season from March to October and a dry season from November to February. Ekona has a mean annual rainfall of 2,085mm, monthly temperature range of 19-30 °C and mean annual relative humidity of 86%. Buea has an annual rainfall of about 2,000mm and a temperature range of 18-23°C; most of the rain is received between June and September. The soil types are basically volcanic making them agriculturally productive [18].

2.2. Planting of maize

The maize variety CMS 8704 was used and it reaches physiological maturity 90 days after planting. The maize was planted two seeds per hill mid-monthly from March to October in 2014 and 2015 in research plots of IRAD Ekona. The planting was done in sixteen plots of 5m x 4.5m each at spacing of 75cm and 50cm between and within rows respectively. Two weeks after planting, gaps were filled by replacing those that did not germinate and/or destroyed by pest. At four weeks post-planting NPK (20:10:10) fertilizer was applied at the rate of 5 grams per plant. Weed control by hoeing and manual weeding was done at 4 weeks after planting prior to the fertilizer application.

2.3 Assessment of field-to-store insect pests

To identify and quantify the various field-to-store insect pests, 2 cobs from each of the sixteen plots were randomly harvested weekly after physiological maturity. The harvesting was done for four weeks for the maize planted from March to May and for five weeks in the plots planted from August to October. The harvested cobs were placed in small fine mesh storage bags and taken to the Zoology Laboratory of the University of Buea where the cobs were observed and the insects therein collected, identified and counted. The identification was done with the aid of standard published pictorial guides and comparing with laboratory voucher specimens. After collecting the insects, the cobs were returned to their respective bags and those that were harvested in June, July and August (months of higher rainfall) were dried for one month using a rotatory electric drier. During the drying, the cobs were placed at a distance of 26 cm from the source of heat in the drier to have a temperature of 35°C. Cobs that were harvested in November, December and January (dry season) were sun-dried also for one month. After drying, the cobs were de-husked and observed to collect, identify and count any insect therein that emerged during the drying period. After which, the cobs were maintained inside their storage bags in the laboratory and checked after two and four weeks of incubation to collect, identify and count any more insects that emerged. To compute the seasonal abundance of the different insects collected, the numbers collected during the first four weeks of a month were summed up to give the monthly abundance.

2.4 insects from maize cobs with intact husk and those opened by birds

During each weekly harvest and depending on the presence of cobs whose husk were opened by birds in each plot, two of the cobs opened by birds were randomly harvested, put in fine mesh storage bags and taken to the laboratory. In the laboratory these cobs with opened husk were assessed for field-to-store insect pests. The mean numbers of insects observed in these damaged cobs harvested each week were identified and compared with those from maize cobs with intact husks harvested during the same week.

2.5 Statistical analysis

Data collected were analysed using MINITAB Package version 16. The number of insects collected was log-transformed ($\log_{10}(x + 1)$) in order to normalize the data before analysis; however, the original counts of insect pests are presented in tables. Analysis of variance (ANOVA) was performed at 95% confidence level to compare mean number of insects collected during the various weeks of harvest. When the differences were significant, the means were separated using Turkey multiple range test. Insects obtained after two and four weeks of the laboratory incubation of the harvested maize were represented graphically. Paired t-test was used to compare the insect pest counts from maize cobs with intact husks and those opened by birds (bird-induced damaged cobs).

3. RESULTS

3.1. Field-to-store insect pests at harvest

Maize planted in March, April and May matured in June, July and August while that planted in August, September and October matured in November, December and January respectively. Maize planted in June and July was stunted and did not grow to produce mature cobs and as such is not further discussed. The main insect pests acquired from the field into stores were *Cryptolestes* spp., *Sitophilus zeamais*, *Ephestia* spp and *Sitotroga cerealella*. During harvest, a total of 195 and 154 *Cryptolestes* spp. were identified in 2014 and 2015 respectively. For *S. zeamais*, a total of 188 and 200 were identified in 2014 and 2015 respectively while 8 and 15 *Ephestia* spp. were identified in 2014 and 2015 respectively and *S. cerealella* was 1 and 4 in 2014 and 2015 respectively.

Cryptolestes spp. was present during all months of harvest and the highest population density per two maize cobs recorded in July (2.2 ± 0.9) and June (2.7 ± 1.2) of 2014 and 2015 respectively. Only the different weeks of harvest in July and August 2014 and August of 2015 respectively had significant differences in the number of *Cryptolestes* spp. (Table 1).

Throughout the study period, *Sitophilus zeamais* was collected only from cobs harvested during the dry season months November, December and January. The highest population densities of *S. zeamais* were recorded in December 2014 (6.3 ± 3.7) and in January 2015

(5.0±2.5). There were no statistical differences among the different weeks of harvest for both 2014 and 2015; the population densities of *S. zeamais* increased in the maize cobs as harvest was delayed that is in the later weeks of harvest (Table 1).

Ephestia spp. was also more common during months of dry season though a few were also recorded during the rainy season. The population of *Ephestia* was lower than that of *S. zeamais* regardless of the month of harvest of the dry season. There were no significant differences in number of *Ephestia* spp. observed over the different weeks of harvest for the various months of 2014 and 2015 (Table 1).

Sitotroga cerealella was observed in very small numbers and only seen during week V of January in 2014 and in 2015 it was seen during weeks II of July, week III of August, week V of November and week I of December where it all had a mean number of 0.1±0.3 per two cobs. Generally it was observed both in maize cobs harvested during the rainy and dry seasons but in very low populations compared to the other insect pests.

167 **Table 1: Mean number ($\pm$ SEM) of various field-to-store insect pests per two maize cobs at**
 168 **various weeks of harvest**

Month of harvest	Week of harvest	Field-to-store insect pests					
		<i>Cryptolestes</i> spp.		<i>S. zeamais</i>		<i>Ephestia</i> spp.	
		2014	2015	2014	2015	2014	2015
June	I	0.1 $\pm$ 0.1a	0.8 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	II	0.4 $\pm$ 0.3a	0.8 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	III	0.4 $\pm$ 0.2a	0.5 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	IV	0.7 $\pm$ 0.3a	0.6 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	Total	1.6 $\pm$ 0.9	2.7 $\pm$ 1.2	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
July	I	0.1 $\pm$ 0.1a	0.7 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	II	0.2 $\pm$ 0.1a	0.4 $\pm$ 0.2a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	III	0.9 $\pm$ 0.3b	0.8 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	IV	1.3 $\pm$ 0.4b	0.6 $\pm$ 0.2a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	Total	2.2 $\pm$ 0.9	2.5 $\pm$ 1.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.2 $\pm$ 0.2
August	I	0.2 $\pm$ 0.1a	0.0 $\pm$ 0.0b	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	II	0.2 $\pm$ 0.1a	0.4 $\pm$ 0.2ab	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	III	0.4 $\pm$ 0.2ab	0.4 $\pm$ 0.2ab	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	IV	0.8 $\pm$ 0.3b	0.9 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a
	Total	1.6 $\pm$ 0.7	1.7 $\pm$ 0.7	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1	0.2 $\pm$ 0.2
November	I	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a
	II	0.0 $\pm$ 0.0a	0.3 $\pm$ 0.2a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	III	0.1 $\pm$ 0.1a	0.2 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	IV	0.1 $\pm$ 0.1a	0.5 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.4 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	V	NH	0.4 $\pm$ 0.3a	NH	0.2 $\pm$ 0.2a	NH	0.1 $\pm$ 0.1a
	Total	0.3 $\pm$ 0.3	1.1 $\pm$ 0.7	0.0 $\pm$ 0.0	0.6 $\pm$ 0.5	0.1 $\pm$ 0.1	0.2 $\pm$ 0.2
December	I	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.2 $\pm$ 0.2a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.2 $\pm$ 0.1a
	II	0.2 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.5 $\pm$ 0.4a	0.6 $\pm$ 0.4a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a
	III	0.3 $\pm$ 0.2a	0.1 $\pm$ 0.1a	1.0 $\pm$ 0.7a	0.4 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	IV	0.4 $\pm$ 0.3a	0.4 $\pm$ 0.2a	4.6 $\pm$ 2.4a	0.4 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	V	0.6 $\pm$ 0.3a	0.6 $\pm$ 0.3a	5.4 $\pm$ 2.3a	2.1 $\pm$ 1.4a	0.0 $\pm$ 0.0a	0.2 $\pm$ 0.1a
	Total	1.0 $\pm$ 0.7	2.2 $\pm$ 0.5	6.3 $\pm$ 3.7	1.5 $\pm$ 1.1	0.1 $\pm$ 0.1	0.4 $\pm$ 0.3
January	I	0.2 $\pm$ 0.1a	0.2 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.3 $\pm$ 0.2a	0.0 $\pm$ 0.0b	0.1 $\pm$ 0.1a
	II	0.5 $\pm$ 0.4a	0.3 $\pm$ 0.2a	0.1 $\pm$ 0.1a	1.2 $\pm$ 0.7a	0.0 $\pm$ 0.0b	0.0 $\pm$ 0.0a
	III	0.0 $\pm$ 0.0a	0.7 $\pm$ 0.3a	0.0 $\pm$ 0.0a	2.1 $\pm$ 0.9a	0.1 $\pm$ 0.1b	0.0 $\pm$ 0.0a
	IV	0.6 $\pm$ 0.3a	0.6 $\pm$ 0.3a	0.0 $\pm$ 0.0a	1.4 $\pm$ 0.7a	0.1 $\pm$ 0.1b	0.0 $\pm$ 0.0a
	V	0.8 $\pm$ 0.5a	1.0 $\pm$ 0.6a	0.0 $\pm$ 0.0a	3.2 $\pm$ 1.5a	0.2 $\pm$ 0.1a	0.0 $\pm$ 0.0a
	Total	1.3 $\pm$ 0.8	1.8 $\pm$ 0.9	0.2 $\pm$ 0.2	5.0 $\pm$ 2.5	0.2 $\pm$ 0.2	0.1 $\pm$ 0.1

169 Means that do not share a letter in a column are significantly different. NH = no harvest.
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3.2. Field-to-store insect pests observed during de-husking

During de-husking of maize cobs thirty days after harvest, the same insect pests observed during harvest were recorded, but in higher numbers. A total of 1,801 and 926 *Cryptolestes* spp., 241 and 525 *S. zeamais*, 72 and 99 *Ephestia* spp. and 16 and 11 *S. cerealella* were observed in 2014 and 2015 respectively.

The highest number of *Cryptolestes* spp. was collected from cobs harvested in July (27.1 ± 9.3) and January (6.1 ± 3.0) of 2014 and 2015 respectively. There were significant differences ($P < 0.05$) among the different weeks of harvest for all the months of 2014 except November where cobs harvested during weeks IV or V exhibited a higher number of *Cryptolestes* spp. Also in 2015, the difference in the numbers of *Cryptolestes* spp. among the weeks of harvest in July, August and January was significant as cobs harvested during weeks IV or V had a higher number of *Cryptolestes* spp (Table 2).

As during harvest, *S. zeamais* was only seen in cobs that were harvested during the dry season (November, December and January). The highest densities 5.9 ± 4.3 and 21.9 ± 6.6 for 2014 and 2015 were respectively obtained in December and January. There were significant differences ($P < 0.05$) in the numbers of this pest among the different weeks of harvest of December 2014 and November, December and January of 2015 with the lowest recorded during week I and the highest in week VI (Table 2).

Ephestia spp. in 2014 and 2015 was highest in cobs harvested in January and December. There were no statistical differences in the number of this pest among the different weeks of harvest (Table 2)

Sitotroga cerealella was also observed in very low numbers with the highest in cobs harvested in January in 2014 (0.6 ± 0.4) and December in 2015 (0.5 ± 0.3). There was no difference among the different weeks of harvest. *S. cerealella* during de-husking in 2014 and 2015 was seen in very low numbers and during few weeks of harvest with the highest week having a mean of 0.2 ± 0.1 .

Table 2: Mean number ($\pm$ SEM) of various field-to-store insect pests per two maize cobs observed during de-husking

Month of harvest	Week of harvest	Field-to-store insect pests					
		<i>Cryptolestes spp.</i>		<i>S. zeamais</i>		<i>Ephestia spp.</i>	
		2014	2015	2014	2015	2014	2015
June	I	0.3 $\pm$ 0.1a	0.5 $\pm$ 0.2a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	II	0.6 $\pm$ 0.4a	0.4 $\pm$ 0.2a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a
	III	3.3 $\pm$ 1.1a	0.9 $\pm$ 0.4a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	IV	14.4 $\pm$ 3.5b	1.6 $\pm$ 0.5a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	Total	18.6 $\pm$ 5.1	3.4 $\pm$ 1.3	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1	0.2 $\pm$ 0.2
July	I	1.8 $\pm$ 0.6a	0.1 $\pm$ 0.1b	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	II	4.8 $\pm$ 1.2ab	0.8 $\pm$ 0.3ab	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a
	III	6.5 $\pm$ 2.1b	1.0 $\pm$ 0.5ab	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	IV	14.0 $\pm$ 5.4b	1.6 $\pm$ 0.5a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	Total	27.1 $\pm$ 9.3	3.5 $\pm$ 1.4	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1
August	I	1.3 $\pm$ 0.7a	0.8 $\pm$ 0.2b	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	II	4.5 $\pm$ 1.5ab	0.8 $\pm$ 0.2b	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	III	6.8 $\pm$ 2.8ab	0.9 $\pm$ 0.3ab	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.2 $\pm$ 0.1a	0.2 $\pm$ 0.1a
	IV	10.4 $\pm$ 3.2b	1.9 $\pm$ 0.4a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.2 $\pm$ 0.1a
	Total	23.0 $\pm$ 8.2	4.4 $\pm$ 1.1	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.2 $\pm$ 0.1	0.6 $\pm$ 0.4
November	I	0.5 $\pm$ 0.3a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a
	II	0.5 $\pm$ 0.3a	0.6 $\pm$ 0.6a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.2 $\pm$ 0.1a	0.2 $\pm$ 0.1a
	III	0.8 $\pm$ 0.4a	0.8 $\pm$ 0.8a	0.0 $\pm$ 0.0a	2.1 $\pm$ 1.3ab	0.1 $\pm$ 0.1a	0.3 $\pm$ 0.2a
	IV	1.0 $\pm$ 0.5a	0.7 $\pm$ 0.7a	0.0 $\pm$ 0.0a	1.2 $\pm$ 1.1ab	0.1 $\pm$ 0.1a	0.4 $\pm$ 0.2a
	V	NH	1.1 $\pm$ 1.1a	NH	2.6 $\pm$ 1.3ab	NH	0.5 $\pm$ 0.2a
December	Total	2.8 $\pm$ 1.5	2.2 $\pm$ 2.2	0.0 $\pm$ 0.0	3.2 $\pm$ 2.5	0.5 $\pm$ 0.4	1.0 $\pm$ 0.6
	I	0.2 $\pm$ 0.1d	1.1 $\pm$ 0.8a	0.1 $\pm$ 0.1a	0.6 $\pm$ 0.6a	0.1 $\pm$ 0.1a	0.3 $\pm$ 0.1a
	II	1.8 $\pm$ 0.6cd	0.8 $\pm$ 0.6a	0.5 $\pm$ 0.4a	2.3 $\pm$ 1.6a	0.3 $\pm$ 0.1a	0.3 $\pm$ 0.1a
	III	4.9 $\pm$ 1.5b	2.7 $\pm$ 1.4a	0.9 $\pm$ 0.5a	2.0 $\pm$ 1.9a	0.2 $\pm$ 0.1a	0.7 $\pm$ 0.4a
	IV	2.3 $\pm$ 1.1cd	2.6 $\pm$ 1.0a	4.4 $\pm$ 3.3b	5.4 $\pm$ 2.2b	0.1 $\pm$ 0.1a	0.4 $\pm$ 0.2a
January	V	9.5 $\pm$ 2.2a	3.6 $\pm$ 1.6a	6.8 $\pm$ 3.4b	4.8 $\pm$ 2.5b	0.1 $\pm$ 0.1a	0.6 $\pm$ 0.3a
	Total	9.2 $\pm$ 3.3	7.2 $\pm$ 3.8	5.9 $\pm$ 4.3	10.3 $\pm$ 6.3	0.7 $\pm$ 0.4	1.7 $\pm$ 0.8
	I	0.8 $\pm$ 0.3c	1.4 $\pm$ 0.6a	0.0 $\pm$ 0.0a	4.6 $\pm$ 1.7a	0.4 $\pm$ 0.1a	0.3 $\pm$ 0.2a
	II	1.9 $\pm$ 1.0bc	0.9 $\pm$ 0.6a	0.0 $\pm$ 0.0a	4.8 $\pm$ 0.2a	0.1 $\pm$ 0.1a	0.3 $\pm$ 0.1a
	III	5.7 $\pm$ 1.9ab	1.2 $\pm$ 0.8a	0.1 $\pm$ 0.1a	4.6 $\pm$ 1.4a	0.9 $\pm$ 0.4a	0.3 $\pm$ 0.1a
January	IV	5.4 $\pm$ 2.8ab	2.6 $\pm$ 1.0a	0.1 $\pm$ 0.1a	7.9 $\pm$ 3.3ab	0.8 $\pm$ 0.2a	0.4 $\pm$ 0.2a
	V	8.8 $\pm$ 5.1a	5.8 $\pm$ 2.5b	2.1 $\pm$ 1.9a	10.8 $\pm$ 1.8b	0.7 $\pm$ 0.3a	0.4 $\pm$ 0.2a
	Total	13.8 $\pm$ 6.0	6.1 $\pm$ 3.0	0.2 $\pm$ 0.2	21.9 $\pm$ 6.6	2.2 $\pm$ 0.8	1.3 $\pm$ 0.6

Means that do not share a letter in a column are significantly different. NH = no harvest.

3.3. Field-to-store insect pests during incubation

During the laboratory incubation of the maize cobs, *S. cerealella* was not seen. *Cryptolestes* spp. was present in cobs harvested during all the different weeks of the various months of June, July, August, November December and January of 2014 and 2015. In contrast, *S. zeamais* and *Ephestia* spp. were present only from maize cobs harvested during dry season months of November, December and January of both years. *Cryptolestes* spp. and *S. zeamais* numbers increased in cobs that were harvested late post physiological maturity; that is maize cobs harvested after one week post physiological maturity had significantly lower numbers than those harvested during the fourth and fifth weeks. The insect population also increased as the numbers of weeks of laboratory incubation increased (Figure 1).

The population of *Cryptolestes* spp. was always double that of *Ephestia* spp. irrespective of the month or week of harvest each year. The larvae of *Ephestia* produced a lot of silk and hence caused webbing the maize grains. These larvae also produced silken cocoons inside which they pupated. *Cryptolestes* often fed starting from broken areas of the grains created by *Ephestia* larvae. Hence *Cryptolestes* appears to be a secondary pest after the grains had been damaged by *Ephestia* larvae and/or *S. cerealella* larvae.

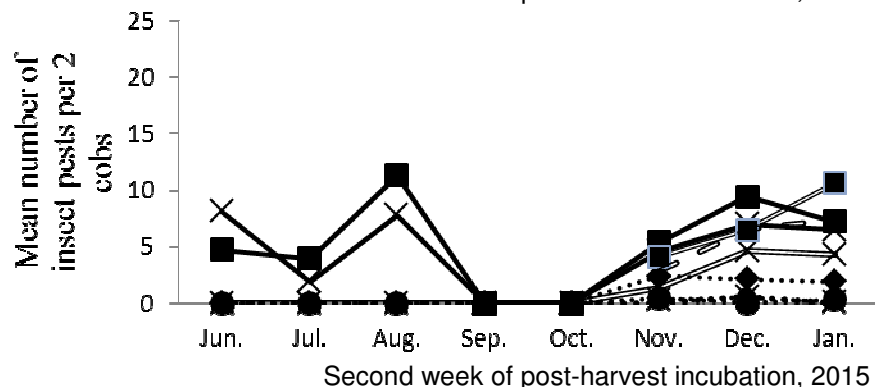
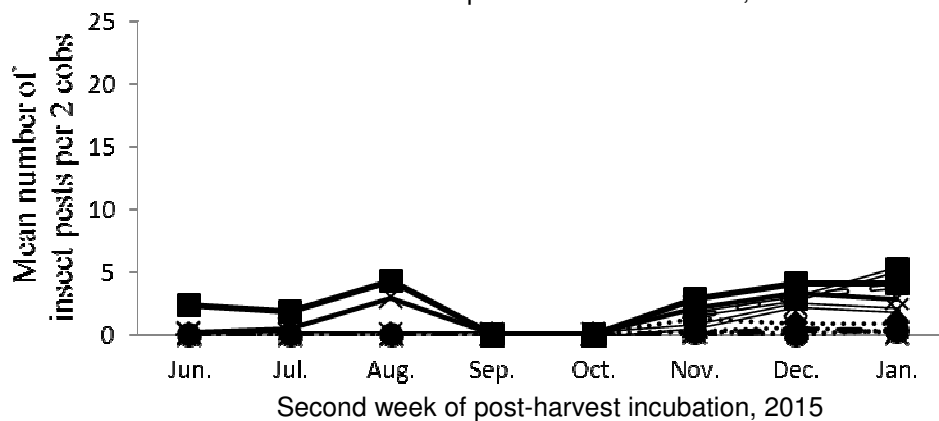
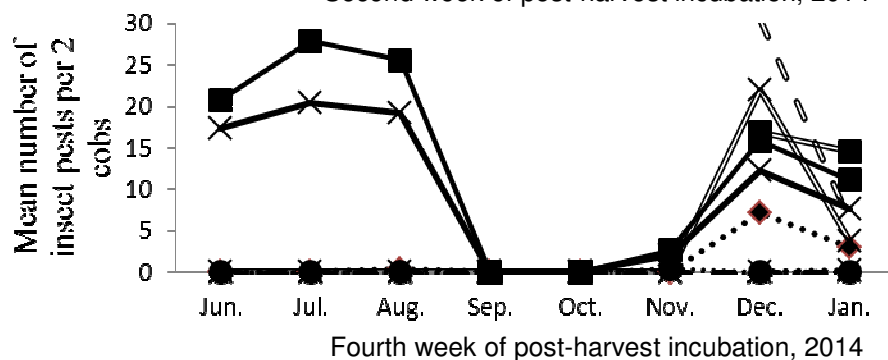
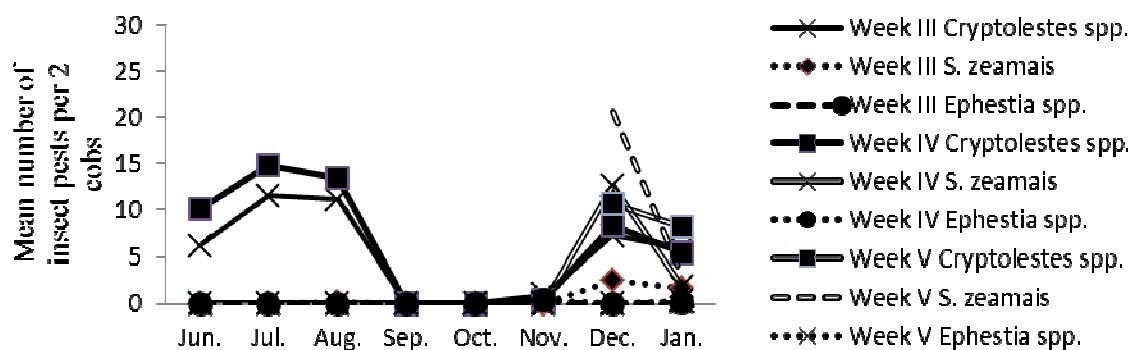


Figure 1: Cumulative number of field-to-store insects pests during incubation (weeks in legend represent when maize was harvested after physiological maturity)

3.4. Number of field-to-store insects in maize cobs opened by birds and intact cobs

Maize cobs with the husk opened by birds (bird-induced damaged) generally had higher numbers of the different insect compared to intact ones. In 2014, 59 and 218 *Cryptolestes* spp. as well as 100 and 569 in 2015 were obtained from intact and bird-induced damaged cobs respectively. There were 29 and 104 *S. zeamais* from intact and bird-induced damaged cobs in 2014 respectively but 77 and 465 in 2015. *Ephestia* spp. had 3 and 8 from intact and bird-induced damaged cobs respectively in 2014 while in 2015 there were 10 and 14 respectively. *S. cerealella* in 2014 was absent in intact cobs but 1 was observed in damaged ones while in 2015 both intact and bird-induced damaged cobs had 3 of this pest each.

With respect to the different weeks of harvest, the numbers of *Cryptolestes* spp. and *S. zeamais* were significantly higher in bird-induced damaged maize cobs compared to the intact maize cobs in 2014 and 2015. In contrast, the numbers of *Ephestia* spp. and *S. cerealella* did not show any significant difference regardless of the week of harvest (Tables 3 and 4).

253 **Table 3: Mean number ($\pm$ SEM) of field-to-store insect pests per two each of bird-induced damaged and intact maize cobs at**
 254 **various weeks after physiological maturity in 2014**

Month of harvest	State	I	II	III	I	II	III	I	II	III
		<i>Cryptolestes spp</i>			<i>S. zeamais</i>			<i>Ephastia spp</i>		
June	Intact	0.1 $\pm$ 0.1a	0.4 $\pm$ 0.3a	0.4 $\pm$ 0.2a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
	Damaged	2.6 $\pm$ 0.9b	3.4 $\pm$ 1.1b	0.4 $\pm$ 0.3a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
	t-value	3.17	4.17	0.18						
	P-value	0.006	0.001	0.86						
July	Intact	0.1 $\pm$ 0.1a	0.2 $\pm$ 0.1a	0.9 $\pm$ 0.3a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
	Damaged	1.3 $\pm$ 0.8a	3.0 $\pm$ 0.9b	0.7 $\pm$ 0.4a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
	t-value	1.75	4.57	0.30						
	P-value	0.13	0.01	0.78						
August	Intact	0.2 $\pm$ 0.1a			0.0 $\pm$ 0.0			0.0 $\pm$ 0.0		
	Damaged	6.0 $\pm$ 1.9b	NH	NH	0.0 $\pm$ 0.0	NH	NH	0.0 $\pm$ 0.0	NH	NH
	t-value	5.78								
	P-value	0.01								
November	Intact	0.1 $\pm$ 0.1a			0.0 $\pm$ 0.0			0.1 $\pm$ 0.1a		
	Damaged	0.0 $\pm$ 0.0a	NH	NH	0.0 $\pm$ 0.0	NH	NH	0.0 $\pm$ 0.0a	NH	NH
	t-value	1.00						0.99		
	P-value	0.33						0.34		
December	Intact	0.1 $\pm$ 0.1a	0.2 $\pm$ 0.1a	0.3 $\pm$ 0.2a	0.2 $\pm$ 0.2a	0.5 $\pm$ 0.4a	1.0 $\pm$ 0.7a	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a
	Damaged	1.5 $\pm$ 0.4b	2.2 $\pm$ 0.8b	3.4 $\pm$ 0.7b	0.6 $\pm$ 0.3a	10.3 $\pm$ 4.0b	26.0 $\pm$ 6.6b	0.0 $\pm$ 0.0	0.2 $\pm$ 0.2a	0.2 $\pm$ 0.2a
	t-value	3.60	2.85	2.70	1.09	3.80	7.24		0.52	1.00
	P-value	0.006	0.04	0.05	0.29	0.002	0.04		0.61	0.37
January	Intact	0.2 $\pm$ 0.1a	0.5 $\pm$ 0.4a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	Damaged	1.1 $\pm$ 0.5b	1.1 $\pm$ 0.4a	0.3 $\pm$ 0.3a	0.3 $\pm$ 0.2a	1.4 $\pm$ 0.6b	2.0 $\pm$ 1.2a	0.1 $\pm$ 0.1a	0.3 $\pm$ 0.2a	0.0 $\pm$ 0.0a
	t-value	2.11	1.54	1.00	1.53	3.11	1.73	1.00	1.45	1.00
	P-value	0.05	0.14	0.39	0.14	0.01	0.18	0.33	0.18	0.33

255 Means that do not share a letter in a column are significantly different. NH = no harvest

256 **Table 4: Mean number ($\pm$ SEM) of field-to-store insect pests per two each of bird-induced damaged and intact maize cobs at**
 257 **various weeks after physiological maturity in 2015**

Month of harvest	State	I	II	III	I	II	III	I	II	III
		<i>Cryptolestes</i> spp			<i>S. zeamais</i>			<i>Ephastia</i> spp		
June	Intact	0.8 $\pm$ 0.3a	0.8 $\pm$ 0.3a	0.5 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	Damaged	5.0 $\pm$ 0.9b	3.4 $\pm$ 0.9b	2.0 $\pm$ 0.7a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	t-value	6.32	2.63	4.87						
	P-value	0.00	0.01	0.00						
July	Intact	0.7 $\pm$ 0.3a	0.4 $\pm$ 0.2a	0.8 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	Damaged	2.3 $\pm$ 0.8b	1.5 $\pm$ 0.8a	8.8 $\pm$ 2.2b	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	t-value	2.60	1.28	3.63				0.32		1.00
	P-value	0.02	0.25	0.02				0.76		0.33
August	Intact	0.0 $\pm$ 0.0a	0.4 $\pm$ 0.2a		0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a		0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	-
	Damaged	12.0 $\pm$ 5.2a	2.7 $\pm$ 1.2a	NH	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	NH	1.3 $\pm$ 0.9a	0.0 $\pm$ 0.0a	
	t-value	6.15	2.93					1.61		
	P-value	0.03	0.10					0.25		
November	Intact	0.1 $\pm$ 0.1a	0.3 $\pm$ 0.2a	0.2 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a
	Damaged	2.4 $\pm$ 1.0b	3.9 $\pm$ 1.7b	4.4 $\pm$ 1.1b	0.8 $\pm$ 0.5a	2.8 $\pm$ 1.0b	4.9 $\pm$ 5.0b	0.3 $\pm$ 0.3a	0.0 $\pm$ 0.0a	0.1 $\pm$ 0.1a
	t-value	2.38	2.84	6.51	1.49	3.31	3.11	0.65	1.00	1.00
	P-value	0.05	0.03	0.00	0.18	0.02	0.02	0.53	0.33	0.36
December	Intact	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.6 $\pm$ 0.5a	0.4 $\pm$ 0.3a	0.2 $\pm$ 0.1a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a
	Damaged	3.2 $\pm$ 1.1b	5.5 $\pm$ 2.0b	6.2 $\pm$ 1.8b	4.9 $\pm$ 2.1b	8.2 $\pm$ 3.0b	15.0 $\pm$ 3.9b	0.3 $\pm$ 0.2a	0.2 $\pm$ 0.2a	0.4 $\pm$ 0.3a
	t-value	3.18	3.96	6.86	2.75	3.66	9.95	0.76	0.59	1.63
	P-value	0.01	0.01	0.002	0.03	0.01	0.00	0.46	0.58	0.18
January	Intact	0.2 $\pm$ 0.1a	0.3 $\pm$ 0.2a	0.7 $\pm$ 0.3a	0.3 $\pm$ 0.2a	1.2 $\pm$ 0.7a	2.1 $\pm$ 0.9a	0.1 $\pm$ 0.1a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	Damaged	7.4 $\pm$ 1.3b	8.3 $\pm$ 1.1b	10.0 $\pm$ 2.1b	9.6 $\pm$ 3.1b	10.0 $\pm$ 3.5b	17.3 $\pm$ 4.2b	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a	0.0 $\pm$ 0.0a
	t-value	10.90	13.0	7.94	3.76	3.65	6.37	1.00		
	P-value	0.00	0.00	0.00	0.005	0.007	0.00	0.33		

258 Means that do not share a letter in a column are significantly different. NH = no harvest

4. Discussion

The results showed that the major insect pests of maize gotten from the field into storage in Southwestern Cameroon were *Cryptolestes* spp., *Sitophilus zeamais*, *Ephestia* spp. and *Sitotroga cerealella*. All these are typical insects found in most tropical stores thus suggesting that most of these pests can be carried from the field to stores.

Cryptolestes spp. was present in maize that was harvested during both the rainy and dry season months right from harvest, to de-husking through various weeks after post-harvest incubation. It is probable that during the rainy months, heavy rains hinder proper drying of the harvested crop, thus promoting decay of maize cobs thus providing a good trophic niche for *Cryptolestes*. They have been reported to occur under bark of hardwood logs and are apparently fungivorous [9]. It has also been reported that *Cryptolestes ferrugineus* feeds on detritus [19] which is often abundant during the rainy season. The presence of *Cryptolestes* spp. during the dry months might be attributed to the presence of *S. zeamais*, *S. cerealella* and *Ephestia* spp. which are primary feeders that fed on maize first thus producing powder that favoured the growth and reproduction of *Cryptolestes* usually known to be a secondary pest [20] that feeds on damaged grains, dried fruits, nuts and other stored plant materials. The larvae and adults of *C. pusillus* feed on damaged grains and also burrow into the softer grain to feed and even softer undamaged stored plant materials [20].

Sitophilus zeamais was present in maize cobs harvested during the dry season months. This insect pest was associated with these cobs during harvest, de-husking and at various weeks after post-harvest incubation. This might be due to an increase in temperature during the dry season which differs from that during the rainy season. Increased temperature has been reported to speed up the life cycle of insects leading to a faster increase in pest populations and it has been estimated that a 2°C increase in temperature has the potential to increase the number of insect life cycles during the crop season by one to five times [21] [22]. This obviously increased the population of *S. zeamais* during dry season months which are subsequently carried in to storage as maize is often allowed to get dry in the field during this period. Consequently farmers need to either harvest their maize early or apply control measures to suppress this pest as it is these cobs harvested during the dry season that

are often allowed to get dry in the field and later harvested for storage in Buea and its environ. This maize weevil is the most important post-harvest insect pest of maize in Cameroon and is largely responsible for most post-harvest losses [23] [24] with losses of up to 90% registered after 5 months of storage, [25].

For *Ephestia* spp. and *S. cerealella*, though they could be found during some months of the rainy season, they were more frequent during the dry season months which may be due to an increase in temperature during dry season months to dry up the grains and render them more suitable for these xerophilic stored insect pests.

Regarding the various harvest dates, the longer maize remained in the field post-physiological maturity, the higher the numbers of the various field-to-store insects in the grains. This is in line with [26] [27] who reported that delay harvesting in a humid sub-tropical environment to allow grain to get dry in the field increased risks of pest infestation. Therefore delayed field drying of maize could result in serious grain losses during storage [28]. This is because the longer maize remains in the field, a greater opportunity exists for stored grain insects to infest the grain in the field and then be introduced into the bin at harvest. The results showed that these insects multiply very fast once in storage as the numbers obtained during the fourth week of laboratory incubation was statistically higher than what was obtained during the second week. *Ephestia* spp. population did not increase in storage and *S. cerealella* was completely absent during incubation. This might be due to the fact that these insects were unable to move in the storage bags and look for mating partners and this is in line with [29] who reported that infestation by *S. cerealella* was observed to start in the field, but during storage they were never detected beyond 30 cm depth within bulk deposited grains after threshing. Harvesting maize immediately after physiological maturity will thus lead to decreased insect pests populations carried from the field-to-storage which will also advert the use of synthetic insecticides which are mostly used to control insect pests. These insecticides have caused problems such as increasing cost of application, insect pest resurgence and resistance to insecticides and lethal effect on non-target organisms in addition to direct toxicity to applicators [30]. The main purpose of storage by small scale farmers in Africa is to ensure household food supplies and seed for planting [31]; consequently this

objective can be attained without endangering humans and the environment with potentially hazardous synthetic insecticides.

The results showed that maize cobs opened by birds had higher numbers of *Cryptolestes* spp. and *S. zeamais* than intact maize cobs; this may contribute to increase the population of these pests from the field into stores. The husks of maize cobs act as physical barriers which prevent easy access of maize grains inside the cobs by insects and other pests. Therefore cobs whose husks have been opened by birds attract more insect pests and this in line with [12][32] who reported that the degree of field infestation largely depends on the completeness of husk cover of maize cobs where it was proven that a tight and long husk can reduce weevil entry and thus grain damage. Also a good husk cover that is tight at the tip with many husk leaves that are extended above the ear contributes to reducing insect damage and attack by microorganisms in the field which might subsequently be carried into storage [13]. The presence of maize cobs opened by birds is detrimental to maize storage as some farmers do not often separate these bird-induced damaged cobs from intact ones during drying and storage and this end up increasing the population of these pests in storage since some of these pests end up migrating from the damaged cobs to feed on the intact ones. There was no difference in the numbers of *Ephestia* spp. and *S. cerealella* between bird-induced damaged cobs and intact ones. This might be due to the fact that these insects especially *S. cerealella* was seen in very low numbers and also the larvae of both species can easily chew-up the husk of intact maize, making their way into an intact husk as compared to other insect pests. Harvesting maize early and separating bird-induced damaged cobs from intact ones during storage will reduce insect pest population carried from the field in to storage and may also reduce post-harvest rot/decay of maize. This is plausible because infestation of maize by insects does not only cause significant losses due to consumption of grains it also result in elevated temperature and moisture conditions that lead to accelerated growth of moulds including mycotoxins [33]. An example is aflatoxin which is invisible and tasteless but its presence may be correlated with other attributes that facilitate or result from fungal growth, including physical damage to the protective outer layer of the kernel, discoloration, and compromised taste quality [34].

5. Conclusion

The results showed that *Cryptolestes* spp., *S. zeamias*, *Ephestia* spp. and *S. cerealella* were carried from the field-to-storage especially in maize harvested during dry season months. Maize harvested early after physiological maturity had fewer or no insect pests. Therefore if farmers harvest their maize immediately after physiological maturity, the stored pest problems will be reduced. Also since *S. zeamais* was absent in maize harvested during the rainy season months, it implies that harvesting during this period can minimise the pest problem provided that farmers have appropriately and adequately drying facilities and also clean their stores before storing maize. Bird-induced damaged cobs had higher numbers of *Cryptolestes* spp. and *S. zeamais* and should therefore be separated from healthy ones during drying and storage in order to reduce introduction of more insect pests from the field into storage.

COMPETING INTERESTS

Authors declare that no competing interest exists.

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