Session 2
Biology, Ecology and Behavior

Insect infestation sources in stored maize grain; what is more important resident versus incoming infestation?

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DOI 10.5073/jka.2018.463.021

Abstract

Most studies targeted pest control inside stores; incognisant of the population dynamics in the store vicinity; leading to product re-infestation. Distinction between storage insect pest source and sink grain patches is important for effective pest management strategies. We examined the role of resident versus incoming insect infestation in phosphine-fumigated closed or open and unfumigated closed or open maize farm stores. Grain quality measurements were recorded over 32 weeks for two storage seasons. Whether open or closed, fumigated grain had significantly lower ($p < 0.001$) grain damage and lower grain weight loss ($p < 0.05$) than unfumigated grain. Fumigated open stores had significantly higher ($p = 0.004$) grain damage and weight loss than closed ones. Grain damage was higher in unfumigated-closed than fumigated-open, evidence that resident infestation inflicted higher food loss than incoming infestation. *Prostephanus truncatus*, *Cryptolestes ferrugineus* and *Tribolium castaneum* had significantly higher populations ($p < 0.001$, $p = 0.018$ and $p = 0.001$; respectively) at bottom levels of unfumigated and fumigated grain (*T. castaneum*). *Sitotroga cerealella* and *Sitophilus zeamais* were significantly higher ($p < 0.001$) at the top of closed than open unfumigated compartments. Grain suffers less infestation and quality loss when it is a sink patch than when it is a source patch. Population build-up and 'settling' to inflict significant food loss takes longer for incoming compared to resident infestation. These results have ecological implications on postharvest IPM.

Key words: Grain sink-source patches, closed and open grain stores, fumigated and unfumigated grain, grain insect damage, grain weight loss, storage insect pests

1. Introduction

Stored product insect pests ecology has not been accorded the systematic scientific investigation it deserves, but effective stored product IPM from any perspective requires the understanding of insect pest behaviour and bionomics. Stored grain, compared to any other insect pest habitats resembles a unique and largely homogeneous habitat in which food availability for many storage pests is unlimited, making a perfect ecological system from which we can better understand the population dynamics, relationships and associations between storage pests (Athanassiou et al., 2005; Nansen et al., 2009). Studies on the ecology of most storage pests of maize have been done in laboratories giving results that are thus limited in scope of application to the farm situation. Farmer-managed stores have very diverse spectra of species, complex levels of inter-, and intra-specific competition, environmental conditions and the presence or absence of natural enemies that influence field ecological studies (Mvumi et al., 2003; Nansen et al., 2009). Therefore a study of the ecology of the maize pest complex on-station is meant to determine *in situ* activities of insect pests and associated trends in grain damage and weight loss. Many stored product pests are highly mobile and can freely move in and out of storage facilities (Campbell and Arbogast, 2004), however, it is often thought that grain insect pest infestation is largely facilitated by human activities during grain exchange, transportation and way of storage. Since insect pest status is often partly derived from their mobility to colonise unexploited grain patches, we set out to determine whether storage losses are higher when the grain patch acted as a sink (colonised only by incoming new infestation) or as a source (colonised only by resident infestation). In the process, we determine insect succession in grain infestation, the abundance and length of storage period. We relate this to the damage and weight loss to get an indepth understanding of the stored grain ecosystem to enable development of postharvest IPM (Athanassiou et al., 2005; Carvalho et al., 2013). It has been reported, that the key to controlling stored product pests is to explore the potential connection between resident infestation (inside stored grain) and outdoor populations (Campbell and Toews, 2005). This is important to reduce the cost and risk associated with chemical pesticides (Campbell and Arbogast, 2004) in stored grain. The main objectives of the current study were to (1) determine which source of insect pest infestation between the resident (field infestation) and incoming (re-infestation) caused more grain damage and weight lossthan the other, (2) determine the trends in populations of different insect pest species over a storage season both on pest-free (fumigated) and on field-infested (unfumigated) grain; and (3)to investigate population dynamics, grain damage and weight loss and associated pest species in bulk grain in relation to granary depth as in (Athanassiou et al., 2005).

2. Materials and Methods

2.1 Granary preparation

The experiment was carried out at the Institute of Agricultural Engineering (IAE, Harare, Zimbabwe) in the granaries. Three granaries were selected, repaired, thoroughly cleaned and re-plastered using clay and small amounts of cow-dung (to prevent the clay from cracking), as per typical farmer practice.

2.2. Treatments

One tonne of shelled maize (SC 637 hybrid variety) was fumigated using phosphine tablets (Phostoxin®, Detia-Degesch GmbH, Aluminium phosphide 56% w/w + inert ingredients 44% w/w) at the recommended rate. Fumigation was done in a metal silo of volume 2.395 m3. The metal silo was placed on a strong iron bench and loaded with the grain. Ten tablets were applied to the grain at different levels (3 at the bottom, 4 at the middle and 3 at the top). This was achieved by driving a metal pipe to the desired level and then dropping the tablet through the metal pipe. The spouts of the metal silo were then immediately closed using custom-made tight fitting lids followed by extensively wrapped with packaging tape to make the silo air tight.

About 900 kg of the fumigated grain were weighed and separated into six portions of 150 kg each. These portions were loaded into granary compartments in three granaries (blocks). Each granary had two compartments loaded with the fumigated grain, immediately after loading one compartment was closed and sealed completely while the other was left open. The closed compartments (Fumigated Closed and Unfumigated Closed) were fitted with tightly closing doors whose surfaces were then plastered using clayey soil to make a continuous seal with the wall plastering. The same was repeated with un-fumigated grain. The grain treatments are shown in Table 1.

Tab. 1 Grain treatments.

Grain treatment	Entrance status	Treatment code
Fumigated	Open	FO
Fumigated	Closed	FC
Not fumigated (unfumigated)	Closed	UFC
Not fumigated (unfumigated)	Open	UFO

2.3 Grain sampling frequency

After every four weeks, grain samples were withdrawn collected using a multi-slotted double tube brass sampling spear (about 1.2 m long). The spear was dipped vertically inside the grain whilst it was closed, it was then opened when its tip touched the bottom, before being shaken to enable grain to enter, then it was closed. The sampling pattern in each granary compartment was as shown in Figure 6. The depth of the grain (60 cm) in each compartment enabled sampling to be conducted from the top (50-60 cm), middle (20-30 cm) and bottom (0-10 cm) positions in the granary. Grain sampled from each level was packed and labelled separately. This was meant to enable observation of the differences in grain damage and pest densities and distribution between the top, middle and bottom layers of stored grain. Samples from each point per level were bulked to make a composite sample of size approximately 1 kg.

2.4. Data collection and analysis

For each 1kg grain sample, all insect pest species, were identified, counted and recorded. Insect-damaged and undamaged grains were separated, counted and weighed. This was achieved by dividing each sample into four equal sub-samples using a riffle sample divider. A sample was first poured out from the sample bag into the riffle divider to produce two equal sub-samples. These were each further divided in the same manner to produce a total of four equal sub-samples. Grain from three sub-samples were each poured out into white plastic trays and examined for insect damage. The fourth sub-sample was not considered. Data from the three sub-samples were averaged to give a sample average for damage and weight loss. Trash weight and insect counts were done for the entire sample. Data on grain damage (%) was arcsine square root–transformed before being analysed. Data on grain weight loss (%) were analysed without any transformation. Data on insect numbers for each species were $\sqrt{(x+1)}$ -transformed (Fowler et al., 1998). All the data were then subjected to one way analysis of variance (ANOVA) in STATISTICA 13.3.Where the F-ratio was significant ($p < 0.05$), means were separated by Tukey-Kramer's HSD test.

3. Results

In season 1, grain damage started increase notably in the unfumigated grain (UFC and UFO) from week 12 - 32 (Fig 1A) and from week 8 – 32 in season 2 (Fig. 1B). Generally, unfumigated grain showed consistently significantly higher ($F_{(24, 288)} = 2.810$, $p = 0.0002$) grain damage than the fumigated grain regardless of being closed or open from week 12-28. In both seasons, at week 32, only the unfumigated open (UFO) had significantly higher grain damage ($p < 0.001$) than fumigated closed (FC). However, lack of significant differences between fumigated open (FO) (no resident infestation) and unfumigated closed (UFC) (with resident infestation) in both seasons signified that both sources of infestation were equally important over time (Fig 1 A and B). In both seasons, there was a significant interaction ($F_{(24, 288)} = 2.810$, $p = 0.0002$) (Season 1) and ($F_{(24, 288)} = 1.7711$, $p = 0.0161$) (Season 2), signifying that grain damage was significantly affected by the treatments over time (Fig 1A &B).

Grain weight loss was more pronounced in season 2 than in season 1 (Fig 2A & B). As observed in grain damage, significant increase was observed from week 12. Generally, unfumigated grain (UFC and UFO) specifically showed persistently significantly higher grain weight loss ($F_{(24, 288)} = 2.7946$, $p = 0.0003$ than fumigated grain (FC and FO) between 12-28 weeks in season 1. Again, in season 1, UFC showed consistently high grain weigh loss ($p < 0.001$) than FC between 12-28 weeks but was not significantly different from UFO. At week 32, although UFO had significantly higher grain weight loss than both FO and FC ($p < 0.001$), there were no significant differences between FO and UFC, again signifying that the visiting infestation (FO) and resident infestation (UFC) had equal similar impact on grain weight loss (Fig 2A). In season 2 however, there were no notable increases in grain weight loss from 0 – 24 weeks. Nevertheless, from week 28 – 32, unfumigated (UFC and UFO) grain started showing higher grain weight loss ($F_{(8, 297)} = 16.556$, $p = 0.0001$ than the fumigated grain (FC and FO). This showed that resident infestation had more negative impact than incoming infestation.

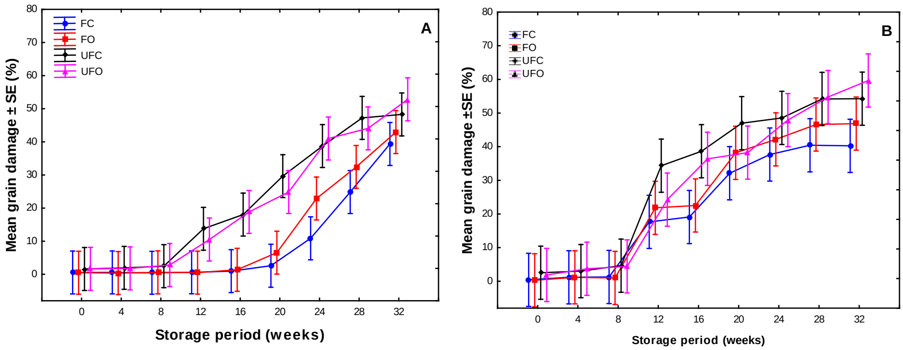


Fig. 1 Grain damage in (A) season 1 and (B) season 2 for different treatments: FC = Fumigated closed; FO = Fumigated open, UFC = Unfumigated closed and UFO = Unfumigated open

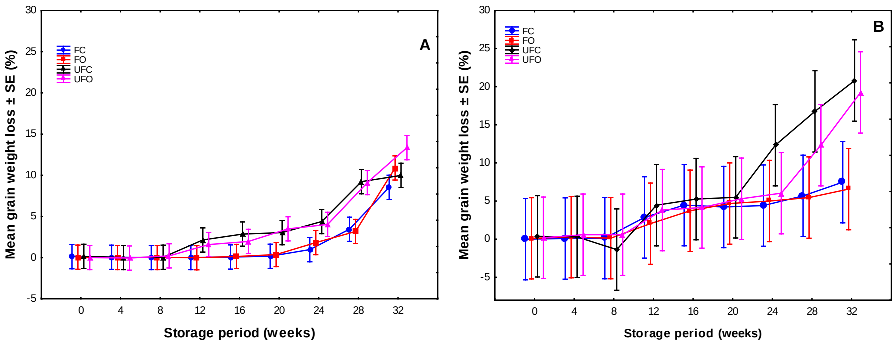


Fig. 2 Grain weight loss in (A) season 1 and (B) season 2 for different in different treatments: FC = Fumigated closed; FO = Fumigated open, UFC = Unfumigated closed and UFO = Unfumigated open.

In both seasons the opening or closing of the granary entrance did not show significant effect on grain weight loss compared to fumigation and non-fumigation. There was a significant interaction ($F_{24, 288} = 2.7946$, $p = 0.0003$) between the length of storage period and treatments on grain weight loss for season 1, showing that the length of storage period affected grain weight loss for each treatment. However, this was not the case for some treatments in season 2 ($F_{(16, 297)} = 1.2473$, $p = 0.231$).

We assessed the evolution of grain damage along the depth of the grain. In the granary in both seasons, grain damage was consistently low and constant for the first 8 weeks; significant increase changes at was observed from 12 weeks (Fig. 3A and B). Generally, the TOP layers of the grain had consistently higher grain damage in both season 1 ($F_{(16, 297)} = 2.3306$, $p = 0.00295$) and season 2 ($F_{(16, 297)} = 2.8282$, $p = 0.00027$) than the middle (MID) and the bottom (BOT) levels. The latter were not significantly different from each other in both seasons (Fig. 3A and B).

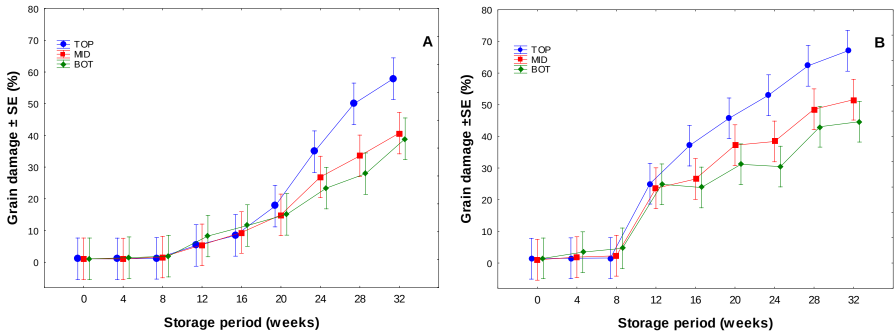


Fig. 3 Grain damage along the depth of grain at top (TOP), middle (MID) and bottom (BOT) in (A) season 1 and (B) season 2.

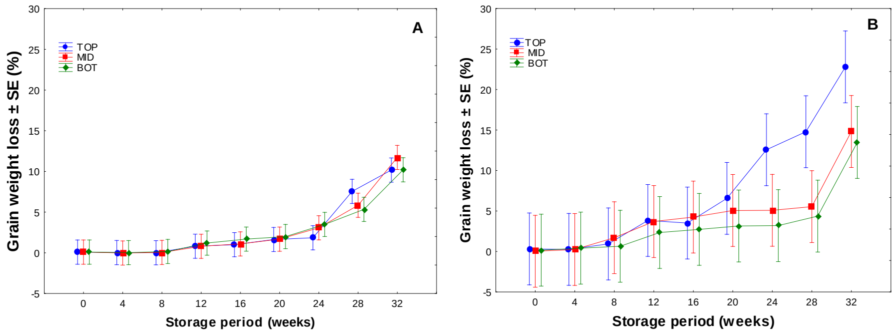
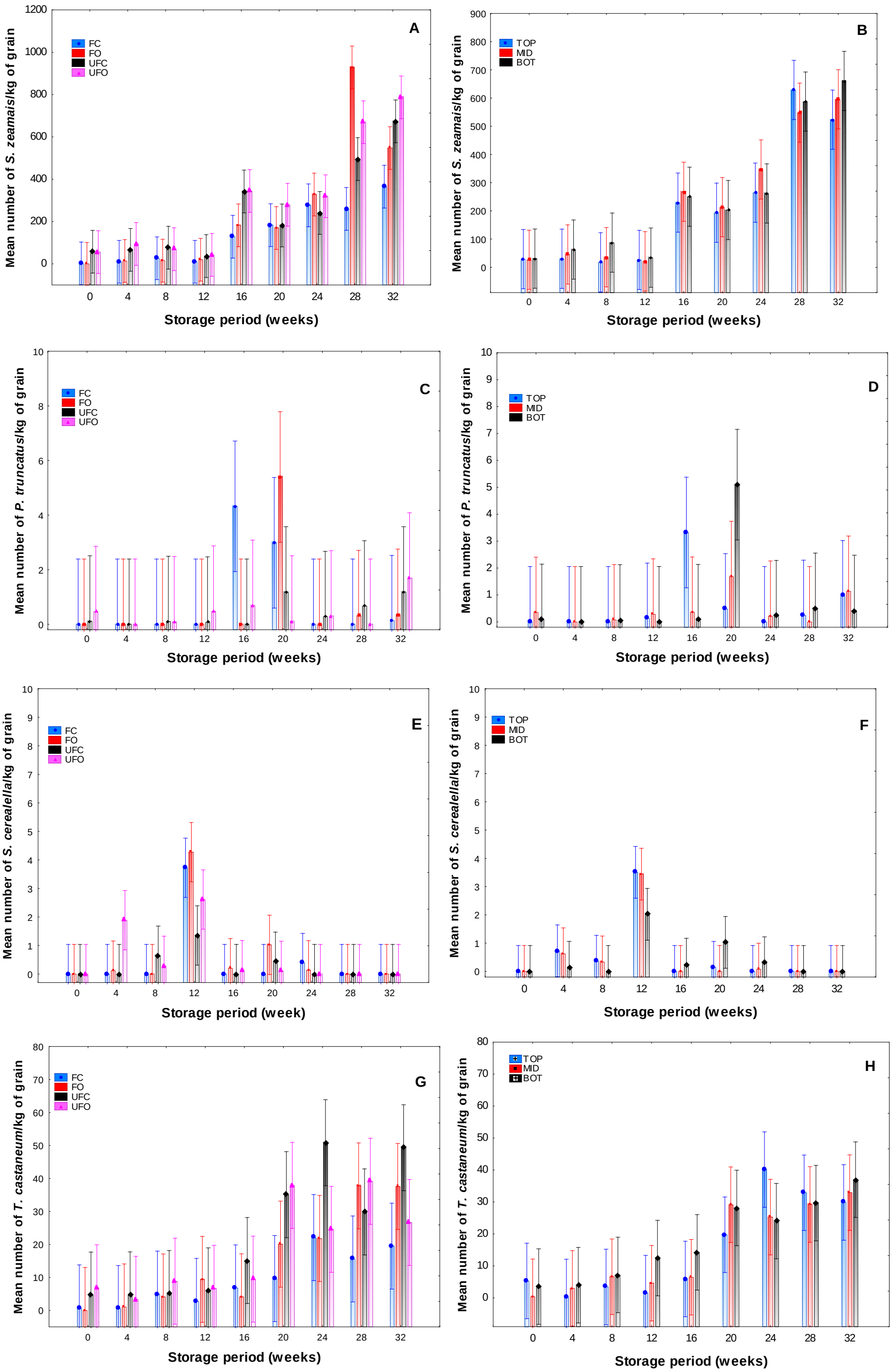


Fig. 4 Grain weight loss along the depth of grain at top (TOP), middle (MID) and bottom (BOT) in (A) season 1 and (B) season 2.

For grain weight loss however, notable increase was observed in week 28 through to week 32; with MID and BOT showing significant differences ($F_{(8, 297)} = 68.086$, $p < 0.0001$) between week 28 and 32. Nevertheless, the three levels did not show any significant differences ($F_{(16, 297)} = 0.66814$, $p = 0.82477$) among each other in season 1 (Fig 4A). This was inconsistent with season 2 which showed significantly higher ($F_{(2, 297)} = 16.555$, $p < 0.0001$) grain weight loss at the TOP level than the MID and BOT (28 weeks) and on the BOT only in week 32 (Fig 4B).

There was no significant interaction ($p = 0.82477$) (season 1) and ($p = 0.23100$) (season 2) between the level of grain and the length of the storage period on grain weight loss. This implies that in our results, length of storage period did not significantly influence grain weight loss for each grain level sampled.

For the sake of brevity, results reported for insect pest populations are for the second storage season only (2013/14). General increase in *S. zeamais* populations in grain was observed from 16 weeks of storage through to 32. Significantly higher ($p < 0.001$) was recorded in FO (922.3 insects/kg of grain) at 28 weeks.


A
FC
FO
UFC
UFO
Mean number of S. zeamais/kg of grain
Storage period (weeks)
B
TOP
MID
BOT
Mean number of S. zeamais/kg of grain
Storage period (weeks)
C
FC
FO
UFC
UFO
Mean number of P. truncatus/kg of grain
Storage period (weeks)
D
TOP
MID
BOT
Mean number of P. truncatus/kg of grain
Storage period (weeks)
E
FC
FO
UFC
UFO
Mean number of S. cerealella/kg of grain
Storage period (week)
F
TOP
MID
BOT
Mean number of S. cerealella/kg of grain
Storage period (weeks)
G
FC
FO
UFC
UFO
Mean number of T. castaneum/kg of grain
Storage period (weeks)
H
TOP
MID
BOT
Mean number of T. castaneum/kg of grain
Storage period (weeks)

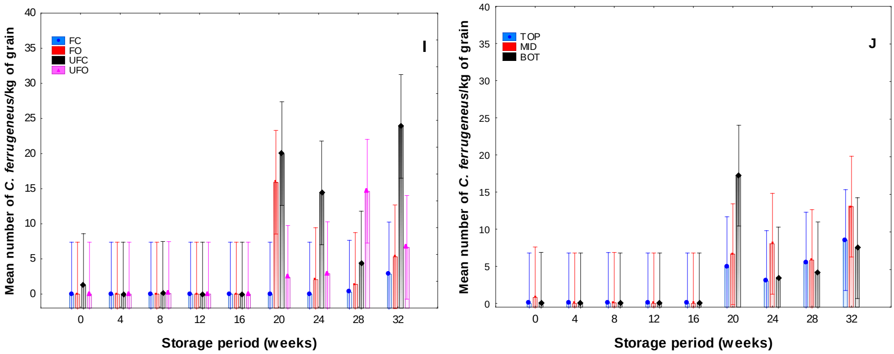


Fig. 5 Number of adult insects recorded over a 32 week storage period for each treatment and at different levels of grain depth (A &B) *S. zeamais*, (C & D) *P. truncatus*, (E & F) *S. cerealella*, (G & H) *T. castaneum*, and (I & J) *C. ferrugeneus*. (FC = fumigated closed, FO = fumigated open, UFC = unfumigated closed, UFO = unfumigated open; TOP, MID and BOT represent the top, middle and bottom level of grain depth in granary).

Unfumigated grain showed consistently high populations of *S. zeamais* up to 783.04 and 676.7 insects/kg of grain respectively at 32 weeks which did not significantly differ from each other. At termination, UFO (774.9 insects/kg) had significantly higher ($F_{(24, 288)}$ = 4.4915, $p < 0.001$) *S. zeamais* populations than FC (357.9 insects/kg) (Fig 5A). Along the depth of the grain, although there was a general increase in populations from week 16-32, *S. zeamais* did not show significant ($F_{(16, 297)}$ = 0.40373, $p = 0.9814$) preference for any specific level (Fig 5B). On the other hand, *P. truncatus* (Fig 5C and D) was detected in much lower (<10 insects/kg of grain) compared to *S. zeamais* and did not generally show significant differences between treatments ($F_{(24, 288)}$ = 0.84815, $p = 0.67324$) and grain depth levels ($F_{(16, 297)}$ = 1.0419, $p = 0.41205$ (Fig 5D). At peak populations (20 weeks) however, the bottom (BOT) level had significantly higher ($p < 0.001$) *P. truncatus* than the top (TOP) (Fig 5D), signifying *P. truncatus* tendency to concentrate at the bottom. *Sitotroga cerealella* increased quite earlier in storage (12 weeks)(Fig 5E) compared to other insect species. FO and FC had significantly higher ($F_{(8, 288)}$ = 13.175, $p < 0.001$) populations than UFC, signifying that resident infestation had less impact in population build up compared to incoming infestation for this species. At peak populations, *S. cerealella* was significantly ($p < 0.001$) concentrated at the TOP and MID levels than the BOT (Fig 5F).

Tribolium castaneum and *Cryptolestes ferrugenius* were the major secondary pests recorded in this study. Significant increases in *T. castaneum* were observed from week 20 – 32, where it fluctuated in abundance between different treatments (Fig 5G and H). At week 20, *T castaneum* was more dominant in unfumigated grain (UFC and UFO), whereas at week 28, it was more dominant in both fumigated (FO) and unfumigated (UFO) open granaries (Fig 5G). This indicated that incoming infestation played a major role in population built up. On the contrary, at week 28 and 32, high *T. castaneum* populations were recorded in unfumigated closed (UFC) (Fig 5G) grain signifying the important role of resident infestation in population buildup. Although each of TOP, MID and BOT showed a significant increase in *T. castaneum* population over the storage period ($F_{(8, 297)}$ = 14.578, $p < 0.001$), there were no significant differences between the different grain depths ($F_{(2, 297)}$ = 0.49571, $p = 0.60964$) (Fig 5H). *Cryptolestes ferrugenius* was dominant in unfumigated closed (UFC) grain at weeks 20, 24 and 32 where it was significantly higher ($F_{(24, 288)}$=1.8132, $p = 0.001276$) than FC and UFO signifying the dominance of resident infestation(Fig 5I) There were no significant differences ($F_{(2, 297)}$=.41696, p =.65943) in the number of *C. ferrugenius* between different grain depths (Fig 5J).

4. Discussion

Regardless of being closed or open, the unfumigated grain recorded more damage and weight loss in both seasons, suggesting that resident infestation is very critical in food loss. However, open granaries generally recorded higher damage than closed ones especially at the top surfaces signifying the importance of visiting infestation (re-infestation). Nevertheless, the significant differences observed in grain damage between the fumigated and unfumigated treatments attests to the fact that resident infestations play the major role in both grain damage and grain weight loss. This coupled with the low insect numbers in all fumigated closed and open compartments meant that incoming insects, although it should be carefully considered, does not play a key role in building up enough populations to ellicit significant grain damage and weight loss in initially pest-free grain especially in the short term.

The trend of *S. zeamais* populations remained fairly stable for the first 8 weeks, and began to show rapid increases from week 12, where higher numbers were observed at the middle and the bottom than the top layers of the granaries. In the unfumigated open environments, there were consistently higher *S. zeamais* populations at the top from around week 16. This agrees with reports by Mvumi et al. (2003) that *S. oryzae* (closely related to *S. zeamais*) in sorghum is consistently concentrated at the top levels. It is also interesting to note that there were very low populations in fumigated grain whether it was kept closed or open especially in the first 16 weeks. This shows that incoming infestations take time to build up as compared to resident ones. In open granaries, *S. zeamais* populations started to increase significantly at 16 weeks and were mainly concentrated at the top grain layers. In the closed granaries, the populations were higher at the bottom and middle layers. Campbell et al. (2006) explained that inside and outside grain storage structures, *S. zeamais* has patchy spatial and temporal distributions around the food source without a specifically apparent pattern (see also Throne and Cline, 1989). This is because of their high mobility on stored grain. Another possible explanation is that when the granary is open, insects are attracted to light and concentrate at the top layers, in addition, this within-store spatial distribution is also affected by temperature (seasons) (Athanassiou et al., 2005). Open granaries enabled insects to communicate with the outside environment by voluntary in and out movements.

Prostephanus truncatus did not occur in large numbers, but where it occurred, it was mainly found at the bottom layers, confirming reports by Vowotor et al. (2005) that the bostrychid favours bottom layers. It is postulated that bottom levels provides pressure from the grain above and *P. truncatus* manipulates this pressure to anchor its hind legs and bore into compacted maize kernels in straight lines (Vowotor et al., 2005). *Prostephanus truncatus* population trends showed that it began to appear at 16-20 weeks in fumigated open granaries at the bottom layers albeit at relatively lower populations compared to other species. This suggested that the population developed from incoming rather than resident infestation, from this standpoint, the low *P. truncatus* populations can also be explained by the fact that maize grain may not have as strong volatiles that attract *P. truncatus* compared to other comodities, e.g Cassava (Pike et al., 1994). Like *P. truncatus*, although there were fluctuations in the numbers, *S. cerealella*, was mainly detected in UFO and FO mainly at top and middle levels. This again resonates with Mvumi et al. (2002) who reported the same vertical gradient of *S. cerealella* along the depth of the grain. The invasion of fumigated grain by *S. cerealella* shows its ability to invade new territories as a primary moth and almost always appearing as the first pest on clean undamaged grain. The low numbers of *S. cerealella* observed in this study are attributable to the rapid movement and invasive nature of the moths as also reported for a similar moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) (Campbell and Arbogast, 2004) which could not be captured in significant populations due to the limitations of the sampling methods employed.

The source of infestation for all the fumigated closed compartments is not clear. Possibilities are that grain was infested in transit from the fumigation site to the granaries, or the re-plastering in granaries was not thorough enough to block resident insects in cracks and crevices inside the granary compartments. It is also possible that grain was infested during the short periods when these compartments were opened for sampling. Resistance of these species to the fumigant aluminium phosphide cannot also be ruled out (Daglish et al., 2004). Benhalima et al. (2004) reported detecting phosphine resistance by *S. oryzae* in Morocco and acknowledged receiving similar reports from many other countries due to the overuse of the fumigant.

We conclude that grain suffers more damage when it acts as the source patch than the sink patch. Resident infestation elicits more grain damage and weight loss than visiting infestation in the short term; but both elicit equal losses in the long term. *P. truncatus* and *C. ferrugenius* prefer the bottom levels of grain, whereas *S. cerealella* prefers top levels. *T castaneum* and *S. zeamais* did not show any specific grain depth preferences.

Acknowledgements

The authors are grateful to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) (Grant No:

RU2011GRG01) for funding this work.

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Climate change and its implications on stored food grains

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DOI 10.5073/jka.2018.463.022