Insect Pests and Fungal Pathogens in Maize Stored in Ghana

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Abstract

Insect infestations and mycotoxin contamination contribute to postharvest degradation and crop loss in sub-Saharan Africa, including maize stored in Ghana. Surveys were conducted to assess the prevalence of insect pests and fungal pathogens in stored maize from the major and minor cropping seasons (September to December and January to April, respectively) that was stored on-farm and in retail markets in Ghana. Results show differences between the major and minor storage seasons for on-farm sites and retail markets. The presence of internal feeders such as *Sitophilus zeamais* (Motschulsky) was positivly correlated with insect-damaged kernels and percentage weight loss. Levels of aflatoxin were generally greater than the established threshold of 15 ppb early in the major crop storage season, while fumonisins were generally lower than threshold levels of 4.0 ppm in on-farm sites and in the retail markets.

Keywords: maize, storage, management, insects, mycotoxins

Introduction

Stored-product insects are a major threat to food security in sub-Saharan Africa, with loss estimates due to insects and associated mycotoxins ranging as high as 70%, depending on the specific commodity, storage site, and management strategies (Hell and Mutegi, 2011; Affognon et al., 2015; Kumar and Kalita, 2017). Major insect pests include the larger grain borer, *Prostephanus truncatus* (Horn), maize weevil, *Sitophilus zeamais* (Motschulsky), lesser grain borer, *Rhyzopertha dominica* (Fauvel), and Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Darfour and Resentrater, 2016). Interactions between insect infestations and subsequent prevalence of mycotoxins are known to occur (Lamboni and Hell, 2009). Many African countries have set tolerances for mycotoxins; for example, the allowable limits for aflatoxin and fumonisin in Ghana are 15 ppb and 4.0 ppm, respectively (Ghana Standards Authority, 2013). In 2015 to 2016, surveys were conducted by the Department of Crop and Soil Sciences of Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, to assess insect pest populations and mycotoxin content of maize stored on-farm and in commercial markets. The United States Agency for International Development (USAID), through the U.S. Government's Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss (PHLIL) funded this work conducted in Ghana.

On-farm sites

The survey of on-farm sites was conducted in the Middle Belt crop production region of Ghana, which is the primary grain-producing region of the country. Complete details of this survey are described in Danso et al. (2017). In this study, a total of 51 farm sites were sampled from three separate geographic areas within the Middle Belt of Ghana: Ejura, Sekyedumase, and Amantin. Sampling was conducted on maize on stalks just before harvest, maize piled on the ground as unshelled cobs pending threshing (shelling), or maize shelled and then stored for distribution to grain markets. For the field sampling and sampling from ground piles, maize cobs were collected from different areas within the piles, then dehusked and mixed into 500-g replicate lots, and the kernels stored for subsequent analysis and processing. Sampling for the third category, dried maize, was done by collecting 2-kg samples, then sub-dividing and mixing into 500-g lots as described for the first two categories. For each sample, temperature, moisture content, and relative humidity (r.h.)

were assessed using a John Deere moisture meter (Armstrong et al., 2017). Samples were sieved to collect live insects. Separate subsamples were taken to analyze for aflatoxin and fumonisin, using a standard Romer Labs test kit (romerlabs.com). Complete data analyses are given in Danso et al. (2017) and Armstrong et al. (2017), and will be summarized here in general terms.

Data for each species were summed over the entire year and analyzed first by Chi-Square analysis (SAS Institute) to determine differences between the three sites at each geographic area, and then summed by the months associated with major season storage (September to December) and with minor season storage (January to April) to determine differences between storage season. The predominant species collected were *S. zeamais* and *S. cerealella*, with ground piles as the site where most were found (Table 1) in the respective geographic areas. The other species in order of abundance were *Carpophilus dimidiatus*, *Cathartus quadricollis*, *Cryptolestes ferrugineus*, and *Tribolium castaneum*, with ground piles again being the site where most *C. dimidiatus* and *C. quadricollis* were found (Table 1). *Cryptolestes ferrugineus* and *T. castaneum* were the least prevalent species (Table 1).

Table 1. Total numbers of *S. zeamais* (SZ), *S. cerealella* (SC), *C. dimidiatus* (CD). *C. quadricollis* (CQ), *C. ferrugineus* (CF), and *T. castaneum* (TC) collected from three types of on-farm areas where maize was stored after harvest (Field, Ground Piles, and Post-drying) in Ejura, Sekyedumase, and Amantin during September to April. Sum totals within columns followed by different lower-case letters are significantly different (Chi Square, $P< 0.05$).

Location	Site	SZ	SC	CD	CQ	CF	TC
Ejura	Field	85b	71b	37b	48c	7a	0a
	Ground pile	200a	128a	76a	126a	9a	8a
	Post-Drying	181a	35c	26b	70b	15a	8a
Sekyedumase	Field	69b	48b	52a	40b	2a	0a
	Ground pile	149a	76a	70a	75a	6a	2a
	Post-Drying	141a	25c	63a	41b	10a	4a
Amantin	Field	112c	86b	17b	59a	6a	7a
	Ground pile	236a	125a	46a	76a	9a	13a
	Post-Drying	189b	58c	49a	65a	9a	6a

More *S. zeamais* were collected in the minor season compared to the major season in all three locations, but the only difference for *S. cerealella* occurred in Amantin (Table 2). More *C. dimidiatus* were collected from the major season compared to the minor season, while differences were mixed or not significant for the other four species (Table 2). Temperatures in all locations and sampling sites ranged from about 27.0 to 34.5°C during the period of the experiment. Moisture content was more variable, but in general ranged between 15 and 27% during the major season, and declined from September to December, with the low moisture content levels predominantly in the post-drying samples (as expected) (Danso et al., 2017). MC in the minor season ranged from about 9 to 17%, with less variation between sites, but MC was usually lowest in the post-dried samples. Neither temperature nor moisture content were correlated with the insect populations ($P < 0.05$). Numbers of *S. zeamais* were positively correlated with percentage of IDK and with kernel weight loss ($P < 0.05$). This was the primary species contributing to IDK and weight loss, as it is an internal feeder.

Average aflatoxin levels at all three locations were well above the tolerance level of 15 ppb during the major season, but ranged between 0.6 and 3.6 ppb during the minor season (Table 3). Fumonisin levels were below the tolerance level of 4 ppm.

Market Sites

The survey of market retail sites was also done in the Middle Belt of Ghana, in the geographic regions of Ejura, Techiman, and Amantin. The maize that was sampled was bagged mixed-variety white maize. Samples were taken monthly from September to April by randomly selecting 100-kg polypropylene or jute bags, inserting a 1.2-m grain probe into the bag (Seedboro, Chicago, IL, USA), and withdrawing a sample of approximately 350 g. Three samples were taken from the bag, mixed, and 500 g weighed out for sampling for insects. In selected months, a second 500-g sample was collected for mycotoxin analysis, as described above. The maize was sampled from the same market location, but not from the same bags each time as this was an active retail market. Maize was also sampled for temperature, moisture content, and r. h. Collection procedures, sample preparation, and methodology for collecting insects, is the same as described above. More detailed descriptions of methodology are found in Danso et al. (2018), along with complete depictions of the results. Data from this study are re-analyzed and summarized here to present important findings from the market survey.

Table 2. Total numbers of *S. zeamais* (SZ), *S. cerealella* (SC), *C. dimidiatus* (CD). *C. quadricollis* (CQ), *C. ferrugineus* (CF), and *T. castaneum* (TC) collected in Ejura, Sekyedumase, and Amantin during the Major and Minor seasons (data for the three sites combined). Sum totals within columns followed by different lower-case letters are significantly different (Chi Square, $P< 0.05$).

Location	Season	SZ	SC	CD	CQ	CF	TC
Ejura	Major	117b	111a	97a	95b	10a	1b
	Minor	349a	123a	42b	148a	21a	15a
Sekyedumase	Major	109b	73a	106a	72a	13a	2a
	Minor	250a	76a	79b	84a	5a	4a
Amantin	Major	121b	54b	94a	85b	7a	2b
	Minor	416a	215a	18b	115a	17a	24a

Table 3. Average aflatoxin values (ppb, means ± SE) during the major and minor seasons in Ejura, Techiman, and Amantin. Data from Danso et al. 2017. All comparisons by season were significant ($P < 0.05$, SAS, Tukey's Honestly Significant Difference Test).

	Major Season	Minor Season
Ejura	39.2 ± 9.1a	3.2 ± 0.1b
Sekyedumase	24.8 ± 0.8a	3.6 ± 3.6b
Amantin	23.4 ± 4.0a	3.6 ± 0.2b

There were six predominant stored-product insect species collected from the market samples: *S. zeamais*, *C. ferrugineus*, *C. quadricollis*, *S. cerealella*, *T. castaneum*, and *C. dimidiatus*. Data for each species were summed over the entire year and analyzed first by Chi-Square analysis (SAS Institute) to determine differences between markets, and then summed by the months associated with major season storage (September to December) and with minor season storage (January to April) to determine differences between storage season. The order of species abundance, in terms of total numbers, is arranged from left to right in Table 4, with *S. zeamais* as the predominant species. Varying levels of these six species were found in all markets, with no consistent differences between markets (Table 4).

Table 4. Total numbers of *S. zeamais* (SZ), *C. ferrugineus* (CF), *C. quadricollis* (CQ), *S. cerealella* (SC), *T. castaneum* (TC), and *C. dimidiatus* (CD) collected from three different maize markets in Ghana during September to April. Sum totals within columns followed by different lower-case letters are significantly different (Chi Square, $P< 0.05$).

Market	SZ	CQ	SC	TC	CF	CD
Ejura	816b	192a	112c	121a	100b	80a
Techiman	960a	139b	180a	125a	67c	37b
Amantin	930a	116b	207a	85b	144a	62a

Data were then summarized to compare total numbers during the major versus the minor season. For 14 out of the 18 comparisons (6 species x 3 markets), there were more insects collected during the major versus the minor season, and only one instance where there were more collected during the minor versus major season (*C. quadricollis* in the Amantin market) (Table 5).

Table 5. Total numbers of *S. zeamais* (SZ), *C. ferrugineus* (CF), *C. quadricollis* (CQ), *S. cerealella* (SC), *T. castaneum* (TC), and *C. dimidiatus* (CD) collected from each market during the major season vs the minor season. Sum totals within columns for each market followed by different lower-case letters are significantly different (Chi Square, $P < 0.05$).

Market	Season	CF	SZ	CQ	SC	TC	CD
Ejura	Major	91a	702a	113a	90a	77a	77a
	Minor	8b	116b	73b	22b	43b	3b
Techiman	Major	60a	786a	82a	80a	58a	31a
	Minor	8b	174b	57b	100a	67a	6b
Amantin	Major	136a	811a	28b	140a	49a	58a
	Minor	7b	119b	88a	67b	36a	5b

Again, temperature combined for all markets during the storage months was about 27 to 32°C, well within favorable limits for insect population development. Moisture content combined for all markets ranged from a high of approximately 15% in September to a low of about 9% in December, then began to increase until April. However, most of the *S. zeamais* collected during the major season storage were collected in November and December (see Danso et al., 2018), the months with the lowest MC. There was no correlation between temperature or MC and insect pest populations ($P < 0.05$). Average aflatoxin levels at all three market sites were far above the tolerance level of 15 ppb during the major season, but less than 4 ppb during the minor season (Table 6). Fumonisin levels were below the tolerance level of 4 ppm.

Table 6. Average aflatoxin values (ppb, means ± SE) during the major and minor seasons in markets in Ejura, Techiman, and Amantin. Data from Danso et al. 2018. All comparisons by season were significant ($P < 0.05$, SAS, Tukey's Honestly Significant Difference Test).

	Major Season	Minor Season
Ejura	66.2 ± 14.6a	3.4 ± 0.4b
Techiman	58.9 ± 14.2a	2.9 ± 0.2b
Amantin	28.0 ± 8.7a	3.1 ± 0.2b

Conclusions

Temperature was generally within 27 to 32°C during these studies, which is within the optimum range for development of the collected species (Howe, 1965; Fields, 1992), and hence was not correlated with the insect populations. The predominant stored-product insect collected in the on-farm and market sites was *S. zeamais*, but it was surprising that no *P. truncatus* were collected given the extensive presence of this species in stored maize, particularly cob-stored maize, in western Africa. Few *R. dominica* were collected as well, and this species is also listed as one of the main storage pests in Africa. More *S. zeamais* were collected during the minor season compared to the major season in the on-farm sites, but the reverse was true for the market sites. During the minor season, the maize is left on stalks for long periods to dry, in contrast to the major season, which is a possible explanation for the greater incidence of S. zeamais during the minor season. The greater infestation in the market sites during the major season versus the minor season may be because the maize in the market sites could have already been infested when the maize was brought to those sites. In addition to the seemingly greater insect populations in maize with high MC, drying of newly-harvested maize is also essential to reduce fungal contamination. Results show improved storage management, which includes integrated pest management strategies for drying and storing maize, may be necessary to limit economic losses and ensure food security.

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Low-Cost Instrument to Measure Equilibrium Moisture Content of Bagged and Bulked Grain

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Introduction

Storage of grain in bags is common in Africa, Asia, and many other less developed countries. Because of this an *in situ* grain bag probing method is well-suited for moisture content (MC) measurement. A low- cost meter was developed under a USAID project to reduce post-harvest loss (PHL)(Fig 1). The meter, referred to as the PHL meter, measures the MC of maize and other grains based on relative humidity (RH) and temperature (T) measurements obtained by a small digital sensor located in the tip of a tubular probe that can be inserted into bags of grain or other grain bulks (Armstrong et al., 2017). Measurements are used in equilibrium moisture content (EMC) equations programmed into the meter to predict MC. A handheld reader connected to the probe provides a user interface.

Keywords. Equilibrium moisture content, Grain storage, Maize, Moisture content, Moisture meter, Post-harvest