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Post-harvest insect infestation and mycotoxin levels in maize markets in the Middle Belt of Ghana

J.K. Danso [a], E.A. Osekre [a], G.P. Opit [b], N. Manu [a], P. Armstrong [c], F.H. Arthur [c, *], J.F. Campbell [c], G. Mbata [d], S.G. McNeill [e]

[a] Dept. of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[b] Dept. of Entomology and Plant Pathology, Oklahoma State University, 127 Noble Research Center, Stillwater, OK 74078, USA
[c] USDA-Agricultural Research Service, Center for Grain and Animal Health Research, 1515, College Ave., Manhattan, KS 66502, USA
[d] Agricultural Research Station, Fort Valley State University, 1005 State University Drive, Fort Valley, GA, USA
[e] Biosystems and Agricultural Engineering, University of Kentucky, Research and Education Center, Princeton, KY 42445, USA

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ABSTRACT

This study focused on assessing maize post-harvest losses in three maize markets in the Middle Belt of Ghana during the storage periods after the harvest of major and minor cropping seasons, September to December and January to April, respectively. The major and minor cropping seasons in the Middle Belt occur during the periods April to August and September to December, respectively. Storage temperature of bagged maize, grain moisture content (MC), and relative humidity (r.h.) were monitored monthly, along with insect infestations, percentage weight loss of kernels (% WL), the percentage of insect damaged kernels (% IDK), and percentage of discolored grains (% DG). Aflatoxin and fumonisin levels were assessed at the beginning and end of the major and minor crop storage seasons. *Cryptolestes ferrugineus* (Stephens), *Cathartus quadricollis* (Guerin-Meneville), *Carpophilus dimidiatus* (F.), *Sitotroga cerealella* (Olivier), *Tribolium castaneum* (Herbst), and *Sitophilus zeamais* (Motschulsky) were found in all markets. Mean insect infestation levels varied throughout the sampling period and were generally similar in the three markets, but were not correlated with temperature, MC, or r.h. ($P \geq 0.05$). Mean % WL, % IDK, and % DG peaked in November and December and were usually correlated with total insect populations ($P < 0.05$). Aflatoxin levels of 2.9–3.4 ppb were found in all markets in the minor season maize samples, but levels ranging from 38.2 to 64.0 ppb were found in the major season samples. Fumonisin levels for all markets ranged between 0.7 and 2.3 ppm. Environmental conditions favor insect pest population development throughout the year in maize stored in markets in Ghana, thus the maize must be monitored regularly and appropriate interventions implemented to avoid product loss.

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1. Introduction

In Ghana, the maize market is dominated by small-scale traders, with women constituting the greater proportion of traders (Akowuah et al., 2015). Despite an increase in maize production in Ghana over the past few years, market demand is usually greater than supply (Angelucci, 2012). In most sub-Saharan African countries, post-harvest losses are estimated to be in the 20–30% range for staple foods such as maize (Yusuf and He, 2011; FAO, 2011). Major reasons for maize post-harvest losses are the informal marketing systems (open air market systems), biological agents (insect pests, fungi and rodents) and physical and environmental conditions in the market storage systems (Hell and Mutegi, 2011; Tefera et al., 2011).

Insect pests are the principal cause of post-harvest losses (Gwinner et al., 1996). *Sitophilus zeamais* (Motschulsky), *Prostephanus truncatus* (Horn), *Tribolium castaneum* (Herbst), *Rhyzopertha dominica* (F.) and *Sitotroga cerealella* (Olivier) are important post-harvest insect pests of maize in sub-Saharan Africa (Tefera et al., 2011). Insect pests cause damage that pre-disposes maize to mycotoxigenic fungi such as *Aspergillus flavus* (Link) and *Fusarium verticillioides* (Sacc Nirenberg) that produce aflatoxin and fumonisin, respectively (Pittet, 1998; Lamboni and Hell, 2009). Aflatoxin and fumonisin are natural carcinogenic substances that are

* Corresponding author.
E-mail address: frank.arthur@ars.usda.gov (F.H. Arthur).

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detrimental to animal and human health and constitute a factor in economic losses; including income loss due to early sale or costs incurred from purchasing replacement maize (Magrath et al., 1996). Losses can also result from contaminated grain or rejection of products due to mold. Mycotoxins can restrict maize trade and limit income of smallholder farmers because of food safety concerns (Suleiman et al., 2013; Suleiman, 2015).

Both qualitative and quantitative post-harvest losses are challenges in the development of new market opportunities at national and regional levels. Post-harvest losses can be minimized when insect infestation, fungal infection and physical conditions of the market storage environment are monitored and appropriate interventions implemented. The objectives of this study were to: 1) determine prevalence and abundance of insect pest species in maize stored in commercial markets in the Middle Belt production zone in Ghana, 2) assess product damage and loss caused by insects, 3) determine if environmental conditions were correlated with insect pest populations, and 4) evaluate fungal contaminant levels in the stored maize.

2. Materials and methods

2.1. Experimental locations and experimental design

The experiment was conducted in three markets located in maize growing areas in the Middle Belt of Ghana, namely, the Ejura market in the Ashanti-region, the Techiman market and the Amantin market, both in Brong-Ahafo region of Ghana. Market structure, storage management and practices in all the study sites were similar, with some variations in storage structures. The Ejura market had small warehouses and wooden stalls, the Amantin market was predominantly characterized by traders' resident storerooms and wooden stalls, and the Techiman market had sheds and open platforms with bagged maize stacked on either wooden pallets, old tires or bare concrete floors.

The study spanned September 2015 to April 2016. The experimental design was a two-factor factorial completely randomized design (CRD). Factors were month (cropping seasons) and market — two cropping seasons (major and minor) and three markets (Ejura, Techiman and Amantin). White maize varieties are cultivated and sold in markets in the Middle Belt of Ghana. Therefore, this study involved sampling white maize varieties from selected traders. The major and minor maize cropping seasons in the Middle Belt of Ghana occur during the periods April to August and September to December, respectively. The storage periods for the major and minor season maize crops are September to December and January to April, respectively. The sampling months for major season maize harvest comprised September to December while minor season harvest sampling months comprised January to April. In each maize market, ten maize sellers were randomly selected. For each maize seller, three bags containing 100 kg of maize in polypropylene or jute bags were randomly selected and sampled each month. This sampling protocol was repeated for all months. Sampling was done from the same traders; however, traders' stores may have been re-stocked when the quantity of the old stock diminished. Therefore, samples may not necessarily have come from the same batch but were mostly from the same source. Sources of maize in Techiman market were from both Northern and Southern Ghana while that of Ejura and Amantin were from Southern Ghana. All samples were generally processed within two weeks.

2.2. Temperature, moisture content, and relative humidity

The USAID Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss (PHL-IL) moisture meter (hereafter referred to as the PHL meter) (USDA-ARS) was used to measure temperature of bagged maize, moisture content (MC), and relative humidity (r.h.). A full description of the PHL meter, and how it was calibrated in comparison to a commercial meter, can be found in Armstrong et al. (2017). The meter was inserted in a bag of maize, left to stabilize over a 3-min period, and temperature, and MC, and r.h. from the monitor display were recorded. For each selected bag, three lots of maize were taken with the probe; from the center and two sides of the bag. This was done to ensure that a representative sample was taken from the bag. Means were calculated from these three readings.

2.3. Sampling for insects and determination of mycotoxin levels

A 1.2-m open-ended grain probe (Seedburo Equipment, Chicago, IL, USA) was used to take maize samples from bags; each time a ~350 g sample was obtained using the grain probe. Samples were taken from the center and two sides of each bag. The three lots sampled from each bag were mixed thoroughly in a 5-L plastic container to ensure homogeneity. A sample of 500 g was weighed out using a dial spring weighing balance (SP, CAMRY, Yongkang, PRC) and placed in a labeled Ziploc plastic bag (39 cm × 25 cm). After 500 g were weighed out from maize collected from each bag, the leftover maize from all three bags sampled from each seller was combined, thoroughly mixed, and a second 500-g sample obtained. The second 500-g sample was used for mycotoxin analysis. Therefore, four 500-g samples were altogether obtained from each seller, each month; three 500-g samples for insect infestation level estimation and kernel damage assessment, and one for mycotoxin analyses. Maize samples for the mycotoxin analyses were kept in a portable 17-L Koolatron ® 12-V Compact Portable Electric Cooler (P75, Koolatron® Canada, Brantford, CA) to reduce further growth and development of fungi. Temperature inside the cooler was not monitored but the approximate temperature was about 4 °C. The samples were taken to the Insect Laboratory of the Department of Crop and Soil Sciences of Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana for processing.

2.4. Other variables assessed

Other variables determined were percentage weight loss, number of insect damaged kernels (IDK), and percentage IDK and percentage of discolored grains. Aflatoxin and fumonisin titers of maize samples were also assessed. Maize samples were sifted using U.S. Standard #10 (2-mm openings) and #25 sieves (0.71-mm openings) (Dual Manufacturing Co., Franklin Park, IL) to recover insects. Insect species were identified using the Grain Research and Development Corporation Stored Grain Pests Identification Guide (2011) and their numbers recorded. Each 500-g sample was poured on a tray and all kernels were examined using a hand lens (10× magnification) to identify kernels with holes created by insects. These damaged kernels were separated from undamaged kernels and numbers of kernels in each category recorded. Insect damaged kernels were weighed using an electronic balance (Mettler Toledo, No. PB302, Columbus OH, USA). Percentage IDK was estimated based on total number of kernels. From each 500-g maize sample previously collected from each bag, 100 kernels were randomly selected and examined using a hand lens (10× magnification). Discolored grains were counted and rated using the method of Neergaard (1977). All maize samples were processed at the Insect Laboratory, KNUST.

2.5. Weight loss (%)

Weight loss due to insect damage was determined using the count and weigh method (Harris and Lindbald, 1978; Boxall, 1986) and the equation:

$$\%\ Wt\ Loss = \frac{[(Wu*Nd) - (Wd*Nu)]}{Wu*(Nd + Nu)}*100$$

where W_u is the weight of undamaged grain (kernels), N_u is the number of undamaged grain, W_d is the weight of damaged grain, and N_d is the number of damaged grain.

2.6. Mycotoxin analyses

Mycotoxin (aflatoxin and fumonisin) analyses were performed using AgraStrip® WATEX and AgraStrip® Quantitative Total Fumonisin (COKAS3000A) test kits provided by Romer Labs®, Inc. (Newark DE, USA). Aflatoxin testing was done using AgraStrip WATEX (lateral flow test for total aflatoxin) kits and procedures developed by Romer Labs. This involves three processes: sample grinding, extraction and test reading. Complete details of this procedure have been published previously (Danso et al., 2017). Also, complete instructions and methodologies and procedures for both tests are found on the manufacturer's instructions (Romer Labs Methods, romerlabs.com). Due to the expense of sampling and testing for mycotoxins sampling was done only at the beginning and end of each of the storage seasons.

2.7. Data analysis

Analysis of variance (ANOVA) methods were used with SAS Version 9.4 (Proc Mixed; SAS Institute, Cary, NC). A two-factor factorial arrangement (factors were month and market) was utilized in a completely randomized design. Raw data were transformed by square root analysis, and simple effects of each factor were calculated and significance assessed using the Mixed Procedure of SAS. Further analysis was done by examining differences between the three markets at each month for insect species, % IDK, and weight loss, and across months for an individual market. Tukey's Honestly Significant Difference test was used as an option in the Mixed Procedure to separate means ($P < 0.05$). Untransformed means and standard errors are reported in the Tables. Correlations between temperature, MC, and r.h. with insect pest levels, and damage data in relation to pest levels, were done using the Correlation Procedure of SAS, at $P < 0.05$.

3. Results

3.1. Moisture content and temperature

The environmental variables temperature, MC, and r.h. were all significant for the main effects sampling month (hereafter referred to as month) and market, with significant interactions as well (Table 1). However, when analyses were done to determine differences between markets at each sample month, there were only a few random instances where there were differences between markets (P generally ≥ 0.05). Temperatures ranged from 25.7 to 36.5 °C throughout the sample period, and in general temperatures were within the range favorable to insect growth and development (Fig. 1A). Moisture content and r.h. declined from September to December, which was the storage time for the major season crop, then gradually increased January to April, when the minor season crop was in the markets (Fig. 1B and C, respectively).

Table 1
ANOVA for main effects sampling month (Month) and market (Market), and interactions (*), for moisture content (MC), temperature (T) and relative humidity (r.h.).

Variable	Source	df	*F*	*P*
MC	Month	7, 207	380.03	<0.001
	Market	2, 207	8.26	<0.001
	*	14, 207	2.61	0.0016
	Month	7, 207	280.24	<0.001
T	Market	2, 207	48.24	<0.001
	*	14, 207	22.38	<0.001
r.h.	Month	7, 207	393.39	<0.001
	Market	2, 207	10	<0.001
	*	14, 207	2.29	0.0062

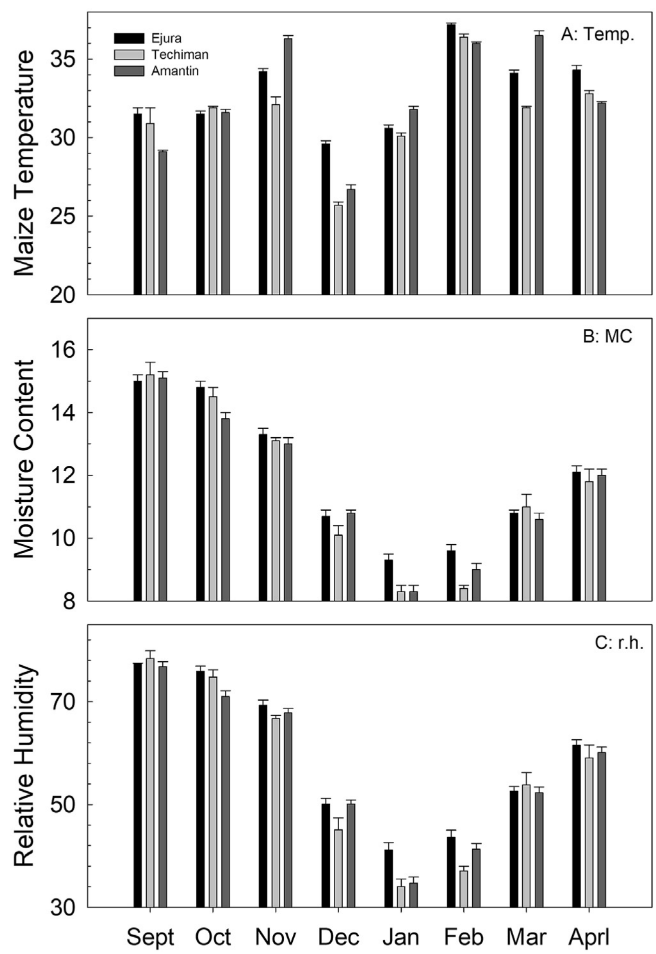

Fig. 1. Temperature (A), % moisture content (B) and % humidity r.h. (C) (means ± SE) of bagged maize, as measured by the PHL meter, for maize in Ejura, Techiman and Amantin markets in Ghana during the major season (Sept. to Dec.) and the minor season (Jan.to Apr.).

3.2. Insect pests per 500 g of maize from Ejura, Techiman and Amantin markets

Six insect species were found in the maize samples: *Cryptolestes ferrugineus* (Stephens), the rusty grain beetle, *Cathartus quadricollis* (Guerin-Meneville), the square-necked grain beetle, *Carpophilus dimidiatus* (F.), the corn sap beetle, *S. cerealella*, *S. zeamais*, and *T. castaneum*. For the overall analyses, month and market (main effects), and the interaction, were significant for *C. ferrugineus*, *C. quadricollis*, *C. dimidiatus*, and *S. cerealella*. However, only month was significant for *T. castaneum* and *S. zeamais* (Table 2). Each species will be reported separately.

There was no difference in the numbers of *C. ferrugineus* in samples from the three markets except in December (Table 3). Also, average numbers were <1 in the 500 g-maize samples in all months except in December, when there were far more collected in those samples than in the other months (Table 3). There were significant differences between markets for average numbers of *C. dimidiatus*, but when these differences occurred there was variation with no consistent trend (Table 3). Average numbers were greatest in December in Ejura and Techiman, but initial populations in Amantin were greatest in September, with a decline after that time. Sample populations ranged from 0 to 0.6 from January to April with few significant differences with respect to month for any of the three markets (Table 3). There was a high initial population of *C. quadricollis* in September in Ejura, and also in April in all three markets, and again when differences occurred between markets there was little consistency. Sample populations of *S. cerealella* were greatest in December for all three markets compared to the other months, with an apparent increase in the Techiman and Amantin markets in April (Table 3). Again, differences between markets when they occurred were variable with no consistent trends (Table 3). For all four species, any differences between markets appeared to be local variations within a month. There was no interaction between month and market for *T. castaneum* and *S. zeamais*, but similar trends were noted for these species as described for the previous four species. Populations of *T. castaneum* peaked in December in all three markets and then decreased until April (Table 3). Similarly, populations of *S. zeamais* were present in September, increased to a maximum in December, and then declined again until April, with no differences between markets (Table 3).

Correlation analyses were done between temperature, MC, and r.h. and each of the insect species, using monthly mean values for insects. Mean values were used due to the large number of samples where no insects were detected. There were only a few instances where there were any significant correlations. These were between temperature and *S. zeamais* in Techiman ($r = 0.75$, $P = 0.03$), between MC and *C. dimidiatus* for Amantin ($r = 0.86$, $P = 0.0054$), and between r.h. and *C. dimidiatus* in Amantin ($r = 0.83$, $P < 0.001$). None of the three environmental variables were correlated with the average number of insects found in the samples ($P \geq 0.05$).

Table 2
ANOVA for main effects sampling month (Month) and market (Market), and interactions (*) for number of *S. zeamais* (SZ), *C. ferrugineus* (CF), *C. dimidiatus* (CD), *T. castaneum* (TC), *C. quadricollis* (CQ) and *S. cerealella* (SC).

Variable	Source	df	*F*	*P*
SZ	Month	7, 567	122.66	<0.001
	Market	2, 567	1.02	0.3612
	*	14, 567	0.51	0.9307
CF	Month	7, 567	84.79	<0.001
	Market	2, 567	4.45	0.0121
	*	14, 567	5.98	<0.001
CD	Month	7, 567	20.9	<0.001
	Market	2, 567	6.56	0.0015
	*	14, 567	8.52	<0.001
TC	Month	7, 567	37.96	<0.001
	Market	2, 567	1.88	0.1534
	*	14, 567	1.59	0.0785
CQ	Month	7, 567	11.62	<0.001
	Market	2, 567	5.06	0.0066
	*	14, 567	2.7	0.0007
SC	Month	7, 567	17.29	<0.001
	Market	2, 567	3.81	0.0227
	*	14, 567	2.56	0.0014

Table 3
Mean (±SE) numbers of four insect species in a 500-g sample of maize from three different markets sampled during 2015–2016. Significant differences within a market for the 8 months are denoted with different lower-case letters and differences for a market within each month are denoted by different upper-case letters, ($P < 0.05$, SAS, Tukey's Honestly Significant Difference Test).

Insect Species	Month	Ejura	Techiman	Amantin
C. ferrugineus	Sept.	0.0 ± 0.0b	0.0 ± 0.0c	0.0 ± 0.0b
	Oct.	0.4 ± 0.2b	0.3 ± 0.2c	0.2 ± 0.1b
	Nov.	0.9 ± 0.3b	0.7 ± 0.2bc	0.4 ± 0.2b
	Dec	7.8 ± 1.0aA	4.9 ± 1.0aB	8.3 ± 0.8aA
	Jan.	0.0 ± 0.0b	0.1 ± 0.1c	0.0 ± 0.0b
	Feb	0.0 ± 0.0b	0.1 ± 0.1c	0.0 ± 0.0b
	Mar.	0.3 ± 0.2b	0.3 ± 0.1bc	0.1 ± 0.1b
	Apr.	0.5 ± 0.2b	0.3 ± 0.2bc	0.7 ± 0.4b
C. dimidiatus	Sept.	2.3 ± 0.9abA	0.0 ± 0.0cB	3.2 ± 4.0aA
	Oct.	0.8 ± 0.3bcAB	0.1 ± 0.4cB	1.2 ± 0.4Abc
	Nov.	1.2 ± 0.3b	0.7 ± 0.2bc	1.3 ± 0.4bc
	Dec	3.4 ± 0.6aA	1.3 ± 0.3abB	0.1 ± 0.1cC
	Jan.	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c
	Feb	0.0 ± 0.0c	0.0 ± 0.0c	0.1 ± 0.1c
	Mar.	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c
	Apr.	0.2 ± 0.1c	0.6 ± 0.2bc	0.5 ± 0.2c
C. quadricollis	Sept.	3.4 ± 0.9aA	0.4 ± 0.3bB	0.2 ± 0.2bB
	Oct.	0.6 ± 0.3bc	0.4 ± 0.3b	0.4 ± 0.2b
	Nov.	1.4 ± 0.5b	1.1 ± 0.3a	0.4 ± 0.2b
	Dec	1.3 ± 0.5bA	1.4 ± 0.5aA	0.3 ± 0.2bB
	Jan.	0.0 ± 0.0c	0.1 ± 0.1b	0.0 ± 0.0b
	Feb	0.3 ± 0.1c	0.6 ± 0.3ab	0.3 ± 0.1b
	Mar.	0.0 ± 0.0c	0.1 ± 0.1b	0.0 ± 0.0b
	Apr.	2.2 ± 0.6abAB	1.1 ± 0.4aAB	2.6 ± 0.8aA
S. cerealella	Sept.	0.5 ± 0.3bB	0.2 ± 0.2cB	1.1 ± 0.3bA
	Oct.	0.5 ± 0.2b	0.2 ± 0.1c	0.8 ± 0.1bc
	Nov.	0.6 ± 0.2b	0.8 ± 0.2b	0.8 ± 0.2bc
	Dec	2.0 ± 0.4aA	1.4 ± 0.6abAB	3.4 ± 0.6aA
	Jan.	0.1 ± 0.1b	0.1 ± 0.1c	0.1 ± 0.1c
	Feb	0.2 ± 0.1b	0.2 ± 0.1c	0.3 ± 0.1c
	Mar.	0.1 ± 0.1b	0.1 ± 0.1c	0.1 ± 0.1c
	Apr.	0.3 ± 0.1bB	2.9 ± 0.9aA	1.5 ± 0.4Ab
T. castaneum	Sept.	0.2 ± 0.2c	0.2 ± 0.2c	0.4 ± 0.4c
	Oct.	0.1 ± 0.1c	0.3 ± 0.2c	0.1 ± 0.1c
	Nov.	1.0 ± 0.6c	0.7 ± 0.2c	0.1 ± 0.1c
	Dec	6.4 ± 1.3a	4.7 ± 1.5a	4.3 ± 0.6a
	Jan.	0.3 ± 0.3c	0.0 ± 0.0c	0.0 ± 0.0c
	Feb	0.9 ± 0.5c	1.6 ± 0.7b	1.1 ± 0.4c
	Mar.	0.5 ± 0.2c	0.8 ± 0.3bc	0.6 ± 0.2c
	Apr.	2.6 ± 0.7bAB	4.3 ± 1.1aA	1.9 ± 0.4bB
S. zeamais	Sept.	3.2 ± 1.2c	8.2 ± 3.5c	7.7 ± 2.5c
	Oct.	10.2 ± 1.6b	6.5 ± 1.1c	8.8 ± 1.3c
	Nov.	17.1 ± 4.1b	18.9 ± 4.4b	20.1 ± 7.7b
	Dec	39.7 ± 6.0a	45.0 ± 5.4a	44.5 ± 8.0a
	Jan.	0.8 ± 0.4c	1.6 ± 0.6d	1.7 ± 0.7c
	Feb	1.2 ± 0.7c	0.7 ± 0.3d	0.9 ± 0.3c
	Mar.	1.9 ± 0.6c	2.6 ± 1.0b	2.2 ± 1.3c
	Apr.	7.3 ± 3.2c	12.5 ± 2.5c	7.0 ± 2.3c

3.3. Percentage weight loss (WL) and percentage of insect damaged kernels (IDK) and percentage discolored kernels (DK) per 500 g of maize in markets

Percentage WL, % IDK, and % DG were all significant for main effects market and month; interactions were significant for % WL and % DG but not % IDK (Table 4). The % WL, % IDK, and % DG values reported were a result of infestations by all insect species. In general, weight loss followed the same patterns as insect numbers, with steadily increasing weight loss from September to December, followed by a decline and then slight increase to April, with the only difference between markets occurring in December (Table 5). The % IDK also increased from September through December, possibly because of the high populations of *S. zeamais* during that time, with

Table 4
ANOVA for main effects sampling month (Month) and market (Market), and interactions (*) for % weight loss (% WL), % percent insect damaged kernels (% IDK), % discolored grains (DG), aflatoxin level (AF), and fumonisin level (FM).

Variable	Source	df	*F*	*P*
% IDK	Month	7, 567	234.41	<0.001
	Market	2, 567	5.19	0.006
	*	14, 567	1.37	0.161
% WL	Month	7, 567	204.2	<0.001
	Market	2, 567	4.15	0.016
	*	14, 567	1.79	0.036
% DG	Month	7, 567	77.32	<0.001
	Market	2, 567	6.45	0.002
	*	14, 567	2.54	0.002
AF	Month	3, 108	16.53	<0.001
	Market	2, 108	2.6	0.079
	*	6, 108	1.28	0.271
FM	Month	3, 108	13.87	<0.001
	Market	2, 108	1.86	0.160
	*	6, 108	1.89	0.089

Table 5
Mean percent weight loss (% WL), percent insect damaged kernels (% IDK), and percent discolored grain (% DG) (means ± SEs) in 500-g samples of maize from three different markets sampled from September (Sept.) to April (Apr.) of 2015–2016. Significant differences within a market for the 8 months are denoted with different lower-case letters and differences for a market within each month are denoted by different upper-case letters, (P < 0.05, SAS, Tukey's Honestly Significant Difference Test). If there are no upper-case letters there was no significant difference between markets ($P \geq 0.05$).

	Month	Ejura	Techiman	Amantin
% WL	Sept.	0.1 ± 0.0d	0.3 ± 0.1d	0.5 ± 0.1d
	Oct.	1.3 ± 0.2c	1.0 ± 0.2c	1.5 ± 0.3c
	Nov.	3.5 ± 0.3b	4.1 ± 0.4b	4.1 ± 0.1b
	Dec	5.6 ± 0.4aB	6.3 ± 0.7aAB	7.7 ± 0.8aA
	Jan.	0.1 ± 0.1d	0.2 ± 0.0d	0.2 ± 0.0d
	Feb	0.2 ± 0.0d	0.2 ± 0.0d	0.3 ± 0.1d
	Mar.	0.3 ± 0.0d	0.3 ± 0.0d	0.5 ± 0.1d
	Apr.	0.9 ± 0.1c	1.3 ± 0.2c	1.0 ± 0.1c
% IDK	Sept.	0.8 ± 0.1c	1.6 ± 0.5bc	2.3 ± 0.5c
	Oct.	2.7 ± 0.4c	2.4 ± 0.4bc	3.2 ± 0.5c
	Nov.	8.7 ± 1.0a	9.3 ± 1.2a	9.1 ± 0.8b
	Dec	10.2 ± 1.0a	10.5 ± 1.1a	13.2 ± 2.2a
	Jan.	0.5 ± 0.1c	0.7 ± 0.1c	0.8 ± 0.2c
	Feb	0.6 ± 0.1c	0.8 ± 0.2c	1.1 ± 0.3c
	Mar.	0.7 ± 0.1cB	0.8 ± 0.1cB	1.2 ± 0.1cA
	Apr.	1.2 ± 0.2c	2.6 ± 0.6c	2.0 ± 0.2c
% DG	Sept.	3.6 ± 0.3b	2.9 ± 0.7c	3.3 ± 0.9c
	Oct.	3.8 ± 0.8b	3.6 ± 0.3c	4.2 ± 0.5c
	Nov.	8.4 ± 0.9aA	5.1 ± 0.6bB	6.1 ± 0.9bAB
	Dec	9.9 ± 0.6aA	7.5 ± 0.8aB	10.2 ± 1.0aA
	Jan.	0.9 ± 0.2cB	1.3 ± 0.2cdB	2.3 ± 0.2cA
	Feb	2.1 ± 0.2bc	2.1 ± 0.3cd	2.7 ± 0.3c
	Mar.	2.5 ± 0.3bcA	2.2 ± 0.4cdA	0.3 ± 0.3dB
	Apr.	2.8 ± 0.3bcB	3.4 ± 0.3cAB	4.1 ± 0.2cA

no consistency with respect to differences between markets (Table 5). The % DG followed the same pattern, a gradual increase until maximum levels in December, then a second gradual increase from January to April (Table 5). There was no correlation between the three environmental variables (temperature, MC, and r.h.) and % WL, % IDK, or % DK for any market ($P \geq 0.05$). However, when insect species were totaled by month and correlations done between insect totals for each market and the damage variables, all correlations were strongly significant ($P < 0.01$).

3.4. Aflatoxin (ppb) and fumonisin (ppm) levels of maize samples from the markets

Only month was significant for levels of aflatoxin and fumonisin (Table 4). The aflatoxin level across markets for September (beginning of major season) was 38.2 ± 8.0 ppb, but this increased significantly to 64.0 ± 12.5 ppb in December (end of major season, Table 6). The lowest aflatoxin levels were found in January and April (beginning and end, respectively, of minor season, 2.9 ± 0.1 to 3.4 ± 0.3 ppb). Fumonisin levels were similar in the three markets between December and April (Table 6). The September fumonisin levels were significantly higher than those found in December, January and April (Table 6).

3.5. Differences between the major and minor seasons

In Ghana, the major and minor cropping seasons in the Middle Belt occur during the periods April–August and September–December, respectively. However, the typical storage periods after harvest of major and minor cropping seasons are September–December and January–April, respectively. Since there were generally little differences between the three markets in respect to insect species, data were combined for these time periods and for the three markets for each of the insect species to determine differences in population levels from maize obtained from these seasons and held in markets. There were clearly more insects detected in maize originating from the major versus the minor season (Table 7). Data for weight loss, %IDK, and % DG were similarly combined for the three markets, and all were significantly greater in maize from the major than the minor season (Table 7). Because data were collected for aflatoxin and fumonisin analyses only in months 1, 4, 5, and 8, no comparisons were made between maize from the two seasons.

4. Discussion

Temperature in bagged maize in the three markets fluctuated during the storage seasons, but there was no correlation between temperature and insect numbers. This was an expected result since temperatures from September to April were within the ranges listed for optimum development of stored product insects (Howe, 1965; Fields, 1992). In addition, MC and r.h. declined from September to December, with no correlation with insect population levels. According to Hell and Mutegi (2011), maize that is above 13% MC is vulnerable to insect and fungal infestations in sub-Saharan Africa, yet insect populations seemed to increase as MC decreased, even with the lack of correlation. One possible reason for this lack of correlation is the large number of samples where no insects were detected, which could have biased the results even though mean monthly values were used for the correlation analysis. However, other reports document a pattern of increasing insect pest populations as the storage season progresses in sub-Saharan Africa (Tefera et al., 2011).

Other factors besides temperature and MC may have been responsible for the increase in insect populations during September to December. In a previous study, insect pest populations were compared in maize on-farm in the post-drying, heaped, and harvest stages (Danso et al., 2017). *Cathartus quadricollis*, *C. dimidiatus*, *S. cerealla*, and *S. zeamais* were the dominant species detected, and were present at some levels in all the above stages. This raises the possibility that the maize was infested at the time it was brought into the markets. But, in this same Danso et al. (2017) study, insect populations were generally greater in the minor season than in the major season, and the reverse was true in the current study. The outdoor markets in Ghana have multiple sites where bagged maize is stored by individual sellers, thus infestations can easily spread between locations within the market. Also, in the Danso et al. (2017) study, insect infestation was measured primarily in the field either before or immediately after harvest, while this study

Table 6
Mean aflatoxin (AF, ppb) and fumonisin (FM, ppm) (±SEs) in maize from three markets in Ghana. Differences between sampling months denoted by different lower-case letters, and differences between markets (data combined for eight sampling months) are denoted by different upper-case letters ($P < 0.05$). Data are based on the sample volume of 500 g taken from each bag.

Variable	Market	Overall Average	September	December	January	April
AF	Ejura	34.8 ± 8.7A				
	Techiman	30.9 ± 8.2AB				
	Amantin	15.6 ± 4.7B				
			38.2 ± 8.0b	64.0 ± 12.5a	2.9 ± 0.1c	3.4 ± 0.3c
FM	Ejura	1.5 ± 0.3A				
	Techiman	1.0 ± 0.2A				
	Amantin	1.0 ± 0.1A				
			2.3 ± 0.4a	0.7 ± 0.1b	0.8 ± 0.1b	0.8 ± 0.1b

Table 7
Comparison of insect species, % weight loss (WL), % insect damaged kernels (IDK), and % discolored kernels (DK) (means ± SEs) between maize in corn markets that originated from the major and minor season harvests. In all instances, means were greater for major than for minor season maize ($P < 0.01$, Proc *t*-test, SAS).

	Major	Minor
C. ferrugineous	2.1 ± 0.4	0.1 ± 0.03
C. quadricolis	1.2 ± 0.1	0.1 ± 0.01
C. dimidiatus	1.2 ± 0.1	0.1 ± 0.01
S. cerealella	1.2 ± 0.1	0.2 ± 0.04
T. castaneum	1.8 ± 0.2	0.7 ± 0.2
S. oryzae	17.1 ± 0.5	1.5 ± 0.2
% WL	2.6 ± 0.2	0.5 ± 0.3
% IDK	5.4 ± 0.4	0.8 ± 0.6
% DK	5.3 ± 0.3	2.2 ± 0.1

assesses insect infestation during storage and distribution. In the earlier study, there was a decline in infestation after drying, thus the differences between the two studies supports the possibility that insect abundance and distribution in the marketplace may not necessarily derive from pre-harvest sources.

There were far more insects collected during the major season storage compared to the minor season storage, in some cases as much as 10× or more during the major season. The maize crop harvested in the field during the rainy season is exposed to more moisture, and thus at more risk of infestation from insects and mycotoxins. In the current study, moisture content of the stored maize was generally greater during the major season, which supports the idea that the major season crop may be more at risk from insect damage and mycotoxin contamination, and perhaps more emphasis should be placed on management of the stored major season crop compared to the minor season.

The increase in the externally-feeding insect species *C. ferrugineus* and *T. castaneum* followed the same pattern of increase recorded for *S. zeamais*. In a study by Shadia (2011), *C. ferrugineus* were found in large numbers in association with *Sitophilus oryzae* (L.), the rice weevil, which is in the same genus as *S. zeamais*. The strong positive correlations between total insects, weight loss, and damage show how pest populations can reduce grain quality (Tefera et al., 2011). The jute and polypropylene bags used by maize traders allowed constant exchange of moisture between grains and the ambient air, which might have helped to reduce MC during the December–February period and thus limit pest population growth of the maize obtained from the major and minor season crop. However, additional protection of bagged maize is available by using hermetic storage bags that limit exchange of gases between inside and outside of bags (Murdock and Baoua, 2015). In addition, the ZeroFly® bags manufactured by Vestergaard, which incorporate the pyrethroid deltamethrin into the laminate of bag packaging, have also shown potential for reducing insect pest populations and preventing damage of bagged maize in Ghana (Paudyal et al., 2017).

The percentage weight loss in the maize samples was generally below estimated weight losses of 5–25% reported by other researchers in Ghana (Ayertey, 1982; Anankware et al., 2013). Other publications report damage estimates as high as 30–40% for sub-Saharan Africa (Darfour and Rosentrater, 2016; Kumar and Kalita, 2017). Variations in sampling methodology, specific climatic conditions, and possible over-inflation of loss values could account for the lower loss values obtained in our study. The % IDK levels found during the periods September to October and January to April (≤2.7%) were below the acceptable threshold of 5% set by the Ghana Standards Authority for trading and consumption of maize (GSA, 2013), but were above this threshold in November and December. The percentage of discolored grains ranged between 1 and 10%, which according to the Neergaard (1977) method for rating discolored grain, would be a grade of 2. The levels of total aflatoxin in maize from the markets in some cases exceeded the acceptable threshold of 15 ppb set by Ghana Standard Authority (GSA, 2013). Thus, this poses potential health concerns regarding exposure to aflatoxins. The fumonisin levels (0.7–2.3 ppm) were below the action limit of 4 ppm for Ghana.

One challenge to significant mitigation of the high maize post-harvest losses in Ghana is the lack of sufficient scientific data that provide a foundation for practical interventions to reduce losses. Also, currently there are no economic incentives in Ghana to improve stored maize quality. Should quality standards and corresponding prices be introduced this could be evaluated, but this study provides highly valuable baseline data on MC, insect infestation, and mycotoxins levels for maize in Ghana. Apart from providing useful information to guide formulation of mitigating measures, data from this study also provide useful information for risk management by stakeholders in the maize industry (value chain) such as local aggregators, commission agents, wholesalers, market-based retailers and consumers to facilitate trading and delivery of safe food through making informed decisions. Thus, the data obtained in this study provide stakeholders in the maize value chain with useful information to facilitate making decisions on where (markets) and when (months) to purchase maize to ensure quality and to take preventive measures against losses.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jspr.2018.02.004.

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