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Investigating the periodic physical disturbance method in Ghana to control adult *Sitophilus zeamais* in maize storage

Bernard Darfour[1] and Kurt A. Rosentrater[2]*

[1]Radiation Technology Centre, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, P. O. Box LG 80, Legon-Accra, Ghana.
[2]Agricultural and Biosystems Engineering Department, Elings Hall, Iowa State University of Science and Technology, Ames, Iowa 50011, USA.

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The maize weevil (*Sitophilus zeamais*) is an important cosmopolitan pest and the most detrimental insect of stored maize. This study aimed to investigate the efficacy of the periodic physical disturbance method on *S. zeamais* mortality. The potential adoption of the technology in Ghana was also considered. Farmers loaded 20 L buckets with maize grain and *S. zeamais,* non-hermetically. The physical disturbance was applied to the buckets twice a day for 30, 60 and 90 days. *S. zeamais* mortality was determined based on homogenized samples, and the analysis was done with one-way ANOVA. Generally, the physical disturbance method did not significantly cause *S. zeamais* mortality.

Key words: Periodic physical disturbance, Ghana, maize grain, *Sitophilus zeamais*, mortality.

INTRODUCTION

Maize rates at least 50% of Ghana's cereal cultivation and it is vastly consumed. Ghana loses about 18% of its yearly maize production to post-harvest losses (PHL) (ISSER, 2017). Maize is cultivated immensely in rain-fed conditions by smallholder farmers. The following statistics on maize production in Ghana were gathered in 2016. The harvested area was 883,031 ha and the average rate of annual growth was 4.04%. The yield area was 1,950 kg/ha (789 kg/ac) which grows annually at an average rate of 2.91%. Importantly, the production quantity in Ghana was 1,721,910 Mg, and the annual average rate of growth was 8.93% (Knoema, 2017). The quantity of maize produced in Ghana compared to most sub-Saharan Africa (SSA) nations is low. In the poultry and livestock industry, and to accomplish food security maize is considered a crucial crop. About 318,514 Mg of maize in Ghana is lost yearly due to PHL which represents about 18% of the country's annual maize production (Prime News Ghana, 2017). The losses are mostly caused by molds, rodents, improper handling, lack of storage facilities, and maize weevils (*Sitophilus zeamais*). *S. zeamais* is an economically important cosmopolitan pest (Demissie et al., 2008), and the most detrimental insect of maize grain (Danho and Haubruge, 2003). The

*Corresponding author. E-mail: karosent@iastate.edu. Tel: +001-515-294-4019.

best quality of grain is at harvest, and therefore preserving grain at storage cannot improve the grain quality better than the quality at harvest. According to Bern et al. (2013), the quality of grain at harvest cannot be improved by preservation, and deterioration cannot completely be stopped but can be decelerated. A combination of factors like moisture, temperature, and oxygen can commence degradation in stored grain. However, the determining factors controlling the biochemical oxidation of stored grain are moisture content (MC) and temperature.

The utilization of drying, refrigeration, ionizing radiation, mechanical isolation, and chemical treatment are the most common methods used in preserving maize grain (Bern et al., 2013). However, a physical disturbance technique is also considered an efficient grain preservation method.

The physical disturbance techniques are based on the application of force or activities that manipulate the storage environment to cause unfavourable conditions to pests (Banks, 1986; Paliwal et al., 1999). The physical disturbance technique used in controlling grain weevils has been around for decades (Banks, 1986).

The effect of bean tumbling to control bean bruchids during storage was investigated by Quentin et al. (1991). According to the outcome of that research, the physical disturbance was able to cause the demise of bean weevils. The mortality was attributed to the weevils exhausting considerable energy without gaining access to the cotyledon (starvation).

Worth noting are the recent research works carried out to control *S. zeamais* in stored maize (Bern et al., 2016; Suleiman et al., 2016). Suleiman et al. (2016) reported an overall percent mortality of 88, 96, and 98%, respectively at 30, 60, and 90 days of storage. According to Bern et al. (2016), although the live numbers of *S. zeamais* in the disturbed containers were significantly lower (ca. 46% lower) at day 40, about 93% of *S. zeamais* mortality was achieved at 160 days in the disturbed containers.

The high *S. zeamais* mortality (%) achieved when the physical disturbance technique was used necessitate the trial of the technology in Ghana. This technology can replace the application of synthetic insecticides which have detrimental impacts on the environment and humans (Phillips and Throne, 2010).

The physical disturbance method is very simple, affordable, and safe for controlling stored-product insect pests in grain facilities (White et al., 1997; Suleiman et al., 2016).

This experiment involved farmers, researchers and extension officers. Farmers were included because they are the immediate beneficiaries of the technology.

This study aimed to investigate the efficacy of the periodic physical disturbance method on *S. zeamais* mortality. The potential adoption of the technology by farmers in Ghana was also considered to prevent reliance on synthetic insecticides.

MATERIALS AND METHODS

Research site and experimental design

The Tontro town in Ghana was the experimental site. This town is one of the major maize production areas in Ghana. Eight dedicated farmers were chosen, and each farmer was supplied with nine plastic buckets (20 L), and live *S. zeamais*. The *S. zeamais* were cultured in a laboratory of the Radiation Technology Centre, Ghana Atomic Energy Commission. The same variety of white maize grain was purchased from the individual study participants. Each bucket was loaded with 10 kg of grain which was about 50% of the bucket's full level. The MC of the grain used was 14.7±0.4%, which was measured (triplicate) with DICKEY-JOHN (Auburn, IL) mini GAC® plus hand-held Moisture Tester (Minigac1P). The number of *S. zeamais* loaded was 1,000 per bucket. *S. zeamais* weighing 36.72 g was estimated to be equal 1,000 in number (Bbosa et al., 2017). The grain MC and the number of *S. zeamais* used depicted the conditions that farmers experience. A preliminary study showed that 1 kg of grain was infested with 100±8 of *S. zeamais*. About 20 holes each of 0.148-inch diameter were created in the bucket covers for gaseous exchange (non-hermetic conditions). These holes were then covered with screens to prevent the *S. zeamais* from escaping. The buckets were then kept in storage rooms at a temperature of 27±5°C and relative humidity (RH) of 84±8%. On each day for 30, 60 and 90 days, each farmer applied 2.5 min of physical disturbance to the six treatment buckets in the morning and evening. The remaining three buckets (per farmer) served as the control (undisturbed). Two treatment buckets and one control bucket were picked on days 30, 60 and 90 for further analysis. About 2.5 kg grain was sampled from each homogenized bucket, and the numbers of dead and live *S. zeamais* were visually counted. The sampling was based on the quartering technique after the grain had been spread and homogenized on a dry clean rubber sheet (Schuler et al., 2014; Suleiman et al., 2016). The percent mortality of *S. zeamais* was calculated based on the equation by Omotoso and Oso (2005).

$$\text{Mortality (\%)} = \text{Number of dead insects} / \text{Total number of insects} \times 100 \quad (1)$$

Data analysis

The data set was analyzed with one-way ANOVA, and means with significant differences ($P < 0.05$) were separated with Tukey-Kramer HSD.

RESULTS

In Table 1, there was no significant difference in the mean mortality of *S. zeamais* between the disturbed and the undisturbed grain at 30, 60 and 90 days. This stipulates that *S. zeamais* mortalities in the disturbed and undisturbed buckets were similar irrespective of the days of storage. The percent mortality in the undisturbed buckets at 90 days happened to be the highest although it was not significantly different. Mortality was expected to increase correspondingly with increasing days of storage, but surprisingly that did not happen, and the lowest mortality was at 60 days. In Table 2, there was no significant difference in mortality between the disturbed buckets at 30, 60 and 90 days. In contrast, mortality in

Table 1. Comparing the percent mortality of *S. zeamais* between the disturbed and undisturbed samples at 30, 60 and 90 days of grain storage.

Parameter	Day 30	Day 60	Day 90
Disturbed	42.2 ± 11.7	32.2 ± 10.6	44.2 ± 18.2
Undisturbed	40.3 ± 5.1	31.1 ± 10.9	51.4 ± 14.6
F-value	0.19	0.05	0.91
df	23	21	23
P-value	0.67	0.83	0.35

The means ± standard deviation in the same column are not significantly different at P < 0.05.

Table 2. Comparing the percent mortality of *S. zeamais* in the disturbed or undisturbed samples at 30, 60 and 90 days of grain storage.

Parameter	Disturbed	Undisturbed
Day 30	42.2±11.7	40.3±5.1^{b}
Day 60	32.2±10.6	31.1±10.9^{b}
Day 90	44.2±18.2	51.4±14.6^{a}
F-value	3.26	12.99
df	46	45
P-value	0.05	<0.0001

Table 3. Comparing the percent mortality of *S. zeamais* in the disturbed samples per each farmer at 30, 60 and 90 days of grain storage.

Days	Farmers							
	1	2	3	4	5	6	7	8
30	38.0±1.3	38.2±1.8	48.5±10.1	60.3±13.6	42.6±12.7	46.2±1.2^{ab}	38.1±12.4	25.5±4.0
60	37.3±2.8	28.4±6.8	30.6±12.8	42.8±7.9	51.2±4.2	27.2±4.9^{b}	22.5±3.5	27.0±16.9
90	37.8±3.3	39.7±17.7	34.8±5.9	31.3±14.2	47.2±9.5	83.9±14.8^{a}	40.3±15.0	38.9±0.5
F-value	0.05	0.62	1.74	2.86	0.21	20.50	1.45	1.07
df	5	5	5	5	4	5	5	5
P-value	0.95	0.59	0.32	0.20	0.83	0.02	0.36	0.45

The means ± standard deviations in the same column with different connected letters are significantly different at P < 0.05.

the undisturbed buckets at 90 days was significantly high compared to the 30 and 60 days.

In Table 3, *S. zeamais* mortality in the disturbed buckets at 30, 60 and 90 days based on the individual farmers was not significantly different except for the sixth farmer. The sixth farmer recorded a significantly higher mortality of *S. zeamais*, but it did not follow any particular trend.

DISCUSSION

Although the mortality of *S. zeamais* (percent) in the disturbed buckets was not significantly different from that of the undisturbed buckets at 30, 60 and 90 days, however, at 30 days the result was expected. Because at 30 days, the effect of the applied force might not have substantially manipulated the internal storage environment in the buckets. Hence, the *S. zeamais* comfortably survived, and mortality was low. Optimistically, obtaining adequate unfavourable internal changes in the buckets might have demanded a physical disturbance of quite a few more days above 30 days. Nonetheless, some findings support the results of this study. Bern et al. (2016) reported no significant difference in *S. zeamais* mortality between the disturbed and undisturbed at 40 days when maize grain of 13.6% MC was used. In contrast, Suleiman et al. (2016) recorded significant *S. zeamais* mortality between the disturbed and undisturbed maize grain even at 30 days.

The non-significant *S. zeamais* mortality between the disturbed and undisturbed at 60 and 90 days was not anticipated but realistic. There is no specific reason attributable to the unanticipated results obtained, however, the speculation that human error might have been the cause cannot be ignored. The reason is that the sixth farmer obtains a significant difference between the days of treatment although it did not follow any specific pattern. It might be that the farmers did not apply the quantum of force that could have effectively resulted in a significant *S. zeamais* mortality*.* According to the FAO (2017), attaining higher weevil mortality demands sufficient violent disturbance and small grain quantity. However, the extent or quantum of the sufficient violent disturbance was not specified. The violent disturbance might be the reason for the high mortality of bean bruchid weevils as they were dislodged from accessing nutrients from the grain (Quentin et al., 1991). Quentin et al. (1991) attributed the 97% mortality to the inability of the first instar larvae to penetrate through the grain testa in 24 h due to the disturbance. Suleiman et al. (2016) surmised that *S. zeamais* mortality was also due to starvation. The speculation notwithstanding, the mortality of *S. zeamais* could be ascribed to many conditions. Joffe and Clarke (1963) disclosed that rice weevil (*Sitophilus oryzae)* mortality depended on factors like the type, timing, and frequency of the disturbance. The most vulnerable stages of *S. oryzae* to physical disturbance were the immature and adult stages. Hence, the findings of this study which were contrary to other findings of Bern et al. (2016) and Suleiman et al. (2016) could be linked to the aforementioned factors.

Throne (1995) indicated that insect mortality varies with age, oxygen (O_2) concentration, temperature and MC, and the number of larvae per kernel. In this study, 1,000 *S. zeamais* per bucket might be a huge number to achieve a higher *S. zeamais* mortality by the physical disturbance technique. Thus, the physical disturbance applied might not be proportionally effective to cause appreciable *S. zeamais* mortality. In comparison to this study, many studies that achieved insect mortality even at 30 days did not use large numbers of *S. zeamais* (Suleiman et al., 2016) used <100. The grain MC at the beginning of the study was 14.7±0.4% while after the study 17.4±2.2% MC was obtained. The respiratory activities of *S. zeamais* and grain, and high RH of 76 to 92% might have been the cause of the increased grain MC. The increase in grain MC was conducive to fungal development and spoilage, especially in the undisturbed buckets. A low grain MC results in higher *S. zeamais* mortality caused by desiccation, a condition due to loss of water from the body of *S. zeamais* (Navarro, 1978). Hare (2017) suggested that grain MC has to be below 12.5% w/w to have safe storage. Despite the absence of molds in the disturbed buckets, the high grain MC, a large number of *S. zeamais*, high temperature (27±5°C) and RH (84±8%) might have resulted in insignificant *S. zeamais* mortality. In such storage conditions, insects' fecundity tends to increase. Above 20°C, the population growth of insects increases with increasing temperature and MC (Throne, 1995). The summation of RH (%) and temperature (°F) was above 100%, and this constituted an extremely unsafe storage condition that required precautionary measures (Copeland and McDonald, 1999; Bewley et al., 2013).

The farmers failed to clean the grain after shelling, and a lot of foreign materials were found in the grain. Lack of proper threshing and sorting methods resulted in a huge amount of foreign materials (broken ears and seeds, chaff, dust, debris, and moldy grain) in the stored grain. These foreign materials might have resulted in hot spots being created within the undisturbed buckets, mostly close to the bottom of the buckets due to limited aeration. Hot spots increase grain temperature and thereby enhance the growth and survival of *S. zeamais*. The absence of molds in the disturbed buckets could be asserted to the physical disturbance as grains were aerated due to their movement. Unlike the grains that were disturbed, the undisturbed grain formed a "cake" (thus, grains were moistened and clustered) at the bottom of the buckets. The grain looked discoloured, and moldy which could be attributed to the hot spots created within the buckets. Therefore, 51% of *S. zeamais* mortality in the undisturbed buckets at 90 days could be attributed to the fungi effect as a large number of *S. zeamais* were trapped inside the "cake". Alternatively, the foreign materials might have impeded airflow to the bottom of the undisturbed buckets, hence, denying *S. zeamais* of oxygen. To have safe grain storage, low MC grain should be well-cleaned to maintain quality (Uthayakumaran and Wrigley, 2017).

Conclusion

Generally, the physical disturbance method did not significantly cause *S. zeamais* mortality. Although the cause of the failure of the technique in this study cannot be pinpointed, it can be speculated to be due to human error (thus, the applied physical disturbance was not efficient enough to cause *S. zeamais* mortality). Also, the large number of *S. zeamais* used inundated the disturbance technique, or the high temperature, RH and grain MC favoured the growth and development of *S. zeamais*. A combination of the outlined factors could be the reason for the failure of the periodic disturbance technique in this study. Noteworthy, despite the failure of the physical disturbance in causing *S. zeamais* mortality, the quality of grain in the disturbed buckets was maintained. But the grain in the undisturbed was moldy, "caked", and discoloured. Since the periodic disturbance technique is not standardized farmers should not rely much on its usage for now.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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