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Impact of moisture content and maize weevils on maize quality during hermetic and non-hermetic storage

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ABSTRACT

The objective of this study was to determine the impact of moisture content and *Sitophilus zeamais* Motschulsky on maize quality during hermetic and non-hermetic storage conditions. Commercial Channel 211-97 hybrid maize kernels were conditioned to 14, 16, 18, and 20% moisture content (wet basis), and then three replications of 300 g of maize grain were stored in glass jars or triple Ziploc® slider 66-μm(2.6-mil) polyethylene bags at four conditions: hermetic with weevils, hermetic no-weevils, non-hermetic with weevils, non-hermetic no-weevils. All jars and bags were stored in an environmental chamber at 27 °C and 70% relative humidity for either 30 or 60 d. At the end of each storage period, jars and bags were assessed for visual mold growth, mycotoxin levels, gas concentrations, pH level, the numbers of live and dead *S. zeamais*, and maize moisture content. The maize stored in non-hermetic conditions with weevils at 18 and 20% exhibited high levels of mold growth and aflatoxin contamination (>150 ppb). Conversely, very little mold growth was observed in maize stored in hermetic, and no aflatoxins were detected in any moisture level. CO_2 increased and O_2 gradually decreased as storage time increased for maize stored in hermetic conditions (with or without weevils) in all moisture level. No significant difference in pH was observed in any storage conditions ($P < 0.05$). Total mortality (100%) of *S. zeamais* was observed in all hermetically stored samples at the end of 60 days storage. Moisture content for hermetically stored maize was relatively constant. A positive correlation between moisture content and storage time was observed for maize stored in non-hermetic with weevils ($r = 0.96$, $P < 0.05$). The results indicate that moisture content and the number of *S. zeamais* weevils plays a significant role in maize storage, both under hermetic and non-hermetic conditions.

1. Introduction

Maize is among the major cereal crops in the world. Over 100 million metric tons of maize was produced in 2015, with the United States, China, Brazil, and Africa producing 34, 21, 7.8, and 7% of the total production of maize, respectively (FAO, 2016). Maize is a preferable food and cash crop in sub-Saharan Africa (SSA). However, despite huge increases in maize production, postharvest losses (PHLs) of maize during storage remain a significant challenge for many farmers in developing countries (Abass et al., 2014). In SSA, postharvest losses have been estimated to be around 5–18% (APHLIS, 2015) and as high as 40% for untreated maize stored in traditional storage structures (Rugumamu, 2004).

The PHLs of maize in tropical countries are contributed by biotic and abiotic factors. The biotic factors include insect pests and molds (FAO, 2009) while abiotic factors that influence the rate of the PHLs are moisture content and temperature (Giorni et al., 2008). The interactions between these factors can determine the level of PHLs during storage (Cairns-Fuller et al., 2005). A very important stored product pest of maize in SSA are the maize weevil, *Sitophilus zeamais* and the larger grain borer, *Prostephanus truncatus* (Hon). *S. zeamais* Motschulsky is a major postharvest pest of maize in tropical and subtropical countries (Baoua et al., 2014; Suleiman et al., 2015). A six-month study conducted by Mulungu et al. (2007) revealed postharvest losses of maize due to *S. zeamais* in Tanzania to be around 17.5%. The devastation of *S. zeamais* relies on its ability to multiply in a very short time (Cosmas et al., 2012; Baoua et al., 2014) and its ability to migrate between field and storage (Suleiman and Kurt, 2015).

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Furthermore, while most losses result from infestation by insect pests, another significant proportion of total loss results from fungal contamination (Pomeranz and Zeleny, 2009). In addition to direct economic losses, fungal growth causes deterioration of the maize grain, reduces the weight of grain, produces off flavors, and several mycotoxins (Hell et al., 2000; Pomeranz and Zeleny, 2009; Olstorpe et al., 2010). Mycotoxin contamination such as aflatoxins may be detrimental to the health of humans and animals (Burger et al., 2013).

Hermetic storage or airtight storage is the promising storage system that protects grains from damage caused by insect pests (Navarro et al., 1993). Hermetic storage works under the principle of a bio-generated modified atmosphere (Sanon et al., 2011), where oxygen (O_2) concentration dramatically decreases while carbon dioxide (CO_2) levels proportionally increase (Quezada et al., 2006). This is attained by the aerobic respiration of the grain, insects, and molds (Moreno-Martinez et al., 2000). Low oxygen environment or anaerobic conditions inhibit growth and development of insect pests, mold, and aerobic yeast (Sanon et al., 2011), which are the major sources of grain deterioration during storage (Weinberg et al., 2008).

Moreover, several changes occur during grain storage even under suitable storage conditions. Chemical, biochemical, physiological, quality and nutritional changes occur in grain because the seeds are living, respiring organisms that age (Tipples, 1995; Fleurat-Lessard, 2002). The respiration of seeds, fungi, and insects releases heat, CO_2, and water vapor. This causes the grain to increase in temperature and moisture, which makes insect pests and fungi to grow much faster (Sauer, 1988). Consequently, grain quality may be deteriorating, resulting in qualitative and quantitative losses. Qualitative losses include poor appearance, discoloration, nutritional degradation, loss of seed viability, off-odors, rancidity, presence of insect fragments and infection (Weinberg et al., 2008), as well as a reduction in processing quality and dry matter, heating, caking, mold contamination and production of secondary metabolites such as mycotoxins (Sauer, 1988; Suleiman et al., 2013). The acids formed include fatty acids, acid phosphates, and amino acids (Pomeranz and Zeleny, 2009). The objective of this study was to determine the impact of moisture content and *S. zeamais* on maize quality during hermetic and non-hermetic storage conditions.

2. Material and methods

2.1. Experiment design

A complete randomized design (CRD) was used (Table 1). Three replications, four storage conditions namely, hermetic with weevils (HW); hermetic no weevils (HNW), non-hermetic with weevils (NHW), and non-hermetic no weevils (NHNW), two storage times (30 days and 60 days), and four target levels of moisture content (14, 16, 18, and 20%) were used. Samples were stored in a Forma environmental chamber at 27 °C and 70% relative humidity (Model 3940 series, Thermo Scientific Inc., Marietta, OH 45750). The *S. zeamais* used in these experiments were obtained from the stock of *S. zeamais* maintained in the grain quality laboratory, Department of Agricultural and Biosystems Engineering at Iowa State University.

2.1.1. Moisture content and sample preparations

The maize used in this experiment was Channel 211-97 hybrid yellow dent corn variety harvested during 2014. Maize was cleaned on a Carter-Day dockage tester with a 12/64-inch round-hole screen to remove broken corn and foreign material (BCFM). Maize was not innoculated. Six samples of maize were drawn randomly to determine moisture content. The initial moisture content of maize was determined to be 13.5% with samples of 30 g in three replications at 103 °C for 72 h (ASAE, 2001). To obtain the desired target moisture content (14, 16, 18, and 20%) maize was rewetted by adding distilled water mixed thoroughly and then hermetically sealed in polyethylene bags and stored at 10 °C for 48 h to allow moisture equilibrium. Maize was mixed well and about 300 g was randomly drawn for each treatment. The four actual levels of adjusted moisture content of maize were 14.01 ± 0.12, 15.91 ± 0.29, 18.18 ± 0.37, and 20.15 ± 0.09% wet basis.

2.1.2. Maize storage conditions

For the hermetic storage condition, triple Ziploc® slider 66-μm (2.6-mil) polyethylene freezer bags (SC Johnson, Racine, WI 53403) one inside the other were used. For non-hermetic storage 246-mL glass jars with screened lids were used. All glass jars were sanitized at 120 °C for 30 min in a PRIMUS PSS5-A-MSSD- Autoclave (PRIMUS Sterilizer Company, Inc., Omaha, NE, USA). Lids and screens were soaked in bleach overnight, rinsed, dried and sanitized with 95% ethanol before use. Each jar and Ziploc bag was loaded with 300 g of maize, then 20 mixed-age unsexed *S. zeamais* were introduced for the weevil treatment, based on (Suleiman et al., 2015). The total number of experimental units was 48 for the hermetic (with and without weevils) and 48 for the non-hermetic (with and without weevils). Three jars and Ziploc® slider bags for each treatment were then stored in a Forma environmental chamber for either 30 or 60 days.

2.2. Data collection

2.2.1. Visual mold assessment and mycotoxin determination

Maize in each treatment was visually observed for signs of fungal growth and a picture was taken daily for each treatment to monitor fungi growth. After analyzing all parameters, three replications of each treatment were mixed together and analyzed for aflatoxins using lateral-flow test strips. Aflatoxin was analyzed using ROSA®FAST for Feed and Grain (Charm, Sciences, Inc., Lawrence, MA, USA) according to package instructions.

Table 1
Experimental design.[a]

Moisture content % (wet basis)					
Type of storage		14	16	18	20
Hermetic (H)	W	1	2	3	4
	NW	5	6	7	8
Non-hermetic (NH)	W	9	10	11	12
	NW	13	14	15	16

Each experimental unit consisted of a set of three replicated samples.
W= With weevils, NW= No weevils.
[a] The same experimental design was used for both 30 and 60 days storage time.