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Abstract

Amaranth (*Amaranthus* spp.) is used as a vegetable, food, forage, and sometimes an ornamental. Amaranth grain has higher protein content than other cereals, making it a good choice for human consumption. Maize is among the three most widely grown grains in the world, but it can experience large postharvest losses during storage due to infestation by the maize weevil (*Sitophilus zeamais*). Due to the small size of amaranth seeds, this study postulated that amaranth grain can be blended with maize during storage to fill the intergranular spaces between maize kernels, reducing the overall void volume to minimize maize weevil movements to access the kernels, and thereby controlling the maize weevil population. The objective of this study was to investigate the effects on maize weevil control of blending maize with amaranth grain during storage versus storing maize alone. Three 208 L (55 gal) steel barrels were loaded with 160 kg (353 lb) of maize, and three were loaded with a maize-amaranth mixture (1:1 by volume), all with initial weevil populations of 25 live weevils per kg of maize. Blending maize with amaranth for storage reduced the number of live weevils after 160 days by 66% compared to storing maize alone. Additional reduction of live weevils could be accomplished if the maize were completely covered by amaranth grain, further restricting maize weevil access to the maize kernels.

Keywords

Broken corn and foreign material, Insects, Insect infestation, Mechanical damage, Moisture content, Postharvest losses, Relative humidity, Temperature, Test weight

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Food Science

Comments

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EFFECT OF BLENDING AMARANTH GRAIN WITH MAIZE KERNELS ON MAIZE WEEVIL CONTROL DURING STORAGE



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HIGHLIGHTS

- Mixing amaranth grain and maize is a promising pesticide-free method for controlling maize weevils in stored maize.
- A 1:1 mixture by volume of maize and amaranth reduced the number of live weevils by 66% after 160 d of storage as compared to maize stored without amaranth.
- A further reduction in live weevils could be achieved by completely covering all maize kernels with a layer of amaranth.
- Insect-infested maize-amaranth mixtures had reduced spoilage due to mold during storage as compared to insect-infested maize stored without amaranth.

ABSTRACT. *Amaranth* (*Amaranthus spp.*) is used as a vegetable, food, forage, and sometimes an ornamental. Amaranth grain has higher protein content than other cereals, making it a good choice for human consumption. Maize is among the three most widely grown grains in the world, but it can experience large postharvest losses during storage due to infestation by the maize weevil (*Sitophilus zeamais*). Due to the small size of amaranth seeds, this study postulated that amaranth grain can be blended with maize during storage to fill the intergranular spaces between maize kernels, reducing the overall void volume to minimize maize weevil movements to access the kernels, and thereby controlling the maize weevil population. The objective of this study was to investigate the effects on maize weevil control of blending maize with amaranth grain during storage versus storing maize alone. Three 208 L (55 gal) steel barrels were loaded with 160 kg (353 lb) of maize, and three were loaded with a maize-amaranth mixture (1:1 by volume), all with initial weevil populations of 25 live weevils per kg of maize. Blending maize with amaranth for storage reduced the number of live weevils after 160 days by 66% compared to storing maize alone. Additional reduction of live weevils could be accomplished if the maize were completely covered by amaranth grain, further restricting maize weevil access to the maize kernels.

Keywords. Broken corn and foreign material, Insects, Insect infestation, Mechanical damage, Moisture content, Postharvest losses, Relative humidity, Temperature, Test weight.

Maize is one of the three most widely grown crops in the world (CIMMYT, 2011). In 2011, maize was grown on more than 170M ha in the world, with about 35M ha in Africa (FAO-STAT, 2014). In low-income countries where maize plays an important role in the livelihood of smallholder farmers, production on about 23M ha resulted in about 43M Mg of maize in 2013 (FAOSTAT, 2014). Maize contributes 34% to 36% of daily caloric intake in countries such as Kenya and Tanzania (Zorya et al., 2011). Maize plays a significant role

in the diet of smallholder farmers, but it experiences large postharvest losses (PHLs) that, if minimized, could help to reduce the number of hungry people in the world. Most PHLs occur during storage, and the maize weevil (*Sitophilus zeamais*) is the critical PHL insect for stored maize in the tropics (Jacobs and Calvin, 2001; Longstaff, 1981, 1986). Iowa State University's Center for Sustainable Rural Livelihoods (<https://www.csrl.cals.iastate.edu>) conducts programs that improve the health, nutrition, food security and rural livelihood of people in the Kamuli district of Uganda. Most smallholder farmers there raise maize and experience maize weevil infestation in the maize they store. It is not unusual for farmers there to experience PHLs of 20% to 50% due to maize weevils.

There are multiple approaches to control maize weevil damage during storage of grain on smallholder farms. An obvious approach is treating maize with insecticides or fumigants, but this is accompanied by food safety concerns along with other problems that may include grain marketing,

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export restrictions, and insufficient container sealing (Phillips and Throne, 2010). Hermetic storage can control weevils by limiting their oxygen supply (e.g., Yakubu et al., 2011; Baoua et al., 2014) and therefore does not have the risks of insecticides. It is effective, but maintaining a hermetic seal may be difficult due to potential storage container leaks and related insufficient sealing issues.

Another method is reducing the intergranular spaces between maize kernels in storage to restrict the movement of the weevils, which in turn denies them access to the kernels, limiting their reproduction. Laswai et al. (2013) observed varying degrees of maize weevil control when they blended maize with actellic super dust (a synthetic insecticide with active ingredients pirimphos methyl and permethrin), rice husks, crotalaria (sunn hemp) seeds, finger millet, and sorghum. The effectiveness of control (percent reduction in live weevils) after 84 d of storage was 84.5% for actellic super dust, 73.9% for sunn hemp seeds, 65.5% for rice husks, 58.3% for finger millet, and 55.9% for sorghum.

Amaranth (genus *Amaranthus*) is estimated to comprise 60 species, most of which are cosmopolitan weeds (Kauffman and Weber, 1990). Certain species of amaranth are used as a vegetable, food, forage, and sometimes an ornamental (Brenner et al., 2000). Amaranth is an annual herbaceous plant, pollinated by wind and insects, that can grow in diverse conditions. Amaranth for human consumption (*Amaranthus* spp.) can be either the vegetative part of the plant or amaranth grain. Amaranth grain has higher protein content than several other cereals as well as dietary fiber, lipids rich in unsaturated fatty acids, desirable levels of minerals, vitamins, and other nutritionally beneficial bioactive components such as phytosterols, squalene, fagopyritols, saponins, and polyphenols (Alemayehu et al., 2015). Table 1 lists the general composition of amaranth grain as compared to maize. Amaranth grain can be a good choice for human consumption and may help improve global food security (Tagwira et al., 2006; Alemayehu et al., 2015). Amaranth is increasingly grown in low-income countries like Uganda, particularly in the Kamuli district, as an alternative to maize.

Table 1. Composition and density of maize and amaranth grain.

Constituent/Density	Maize	Amaranth
Crude protein (% d.b.)	9.6 ^[a]	14.9 ^[d]
Crude fat (% d.b.)	4.3 ^[a]	9.1 ^[d]
Carbohydrate (% d.b.)	75.0 ^[b]	70.3 ^[d]
Crude fiber (% d.b.)	2.5 ^[a]	2.8 ^[d]
Saturated fatty acids (% of fat)	13.1 ^[c]	26.9 ^[e]
Monounsaturated fatty acids (% of fat)	24.2 ^[c]	23.9 ^[e]
Polyunsaturated fatty acids (% of fat)	62.7 ^[c]	49.2 ^[e]
Isoleucine (% of protein)	3.4 ^[a]	5.2 ^[f]
Leucine (% of protein)	11.8 ^[a]	7.9 ^[f]
Lysine (% of protein)	3.1 ^[a]	9.2 ^[f]
Methionine (% of protein)	2.1 ^[a]	2.2 ^[f]
Cysteine (% of protein)	2.1 ^[a]	4.2 ^[f]
Bulk density (kg m ⁻³)	727 ^[b]	800 ^[g]
Individual kernel/seed density (kg m ⁻³)	1260 ^[b]	1380 ^[g]
Percent void space (calculated)	42%	42%

^[a] Calculated from NRC (1994).

^[b] Watson (1987).

^[c] Calculated from Weber (1987).

^[d] Bressani (1994).

^[e] Alvarez-Jubete et al. (2009).

^[f] PISAŘKOVÁ et al. (2005).

^[g] Kudos and Solanki (2018).

Amaranth seeds are spherical with an average diameter of 1 to 3 mm (Resio et al., 2006; Saunders and Becker, 1984) and a seed count of approximately 270 seeds g⁻¹ (Myers and Putnam, 1988). This seed geometry could effectively reduce the intergranular spaces between maize kernels, potentially limiting maize weevil movement to infest new kernels. Adult maize weevils are 2.5 to 4.0 mm long and 1.0 to 3.7 mm wide (Mason and McDonough, 2012). The stacking of spherical seeds of 1 to 3 mm diameter would leave little room between them for weevils to maneuver.

Storing a blend of maize and amaranth grain would allow smallholder farmers to use a non-insecticidal approach and locally available material to control maize weevils. If amaranth is more widely grown for food, there could be an increased production of amaranth grain that could be blended with maize during storage. If desired, amaranth and maize can be easily separated after storage by passing the mixture over hardware cloth (screen) with openings of 3 to 6 mm. Such screen material is readily available in low-income countries.

The objective of this study was to investigate the effect on maize weevil control of blending maize with amaranth during storage as compared to maize stored without amaranth.

METHODS AND MATERIALS

STORAGE CONTAINERS

Six 208 L (55 gal) open head, unlined, steel barrels (model 882-35, Sioux Chief Mfg. Co., Peculiar, Mo.) were used as storage containers. The barrels had not been previously used. The barrels were cleaned with Ajax triple-action liquid soap, a large cotton mop, and a medium handle brush with warm water. After thorough rinsing, the barrels were left to dry.

MAIZE WEEVILS

Maize weevils from infested commercially comingled maize were separated by passing the maize through a dockage tester (Carter Day Intl., Minneapolis, Minn.) with a 4.76 mm (12/64 in.) screen to retain the maize and a 0.99 mm (2.5/64 in.) screen to retain the weevils. Three representative samples of weevils were used to determine an average weight of 3.672 g per 1,000 weevils. The weevil quantities used for infesting the barrels were measured by weight rather than by count. Each treatment was infested with 25 live weevils per kg of maize.

EXPERIMENTAL MAIZE AND AMARANTH

The commercial comingled bulk maize used in this experiment was purchased from a local grain elevator in central Iowa in January 2014 with an initial average moisture content of 13% wet basis (w.b.). The amaranth used in the experiment was organic whole-grain amaranth of variety *Amaranthus hypochondriacus* grown in western Nebraska in 2013 with an initial average moisture content of 11.7% w.b. (fig. 1). Upon receipt in the fall of 2013, the amaranth was stored at 4°C until the experiment commenced in January 2014.

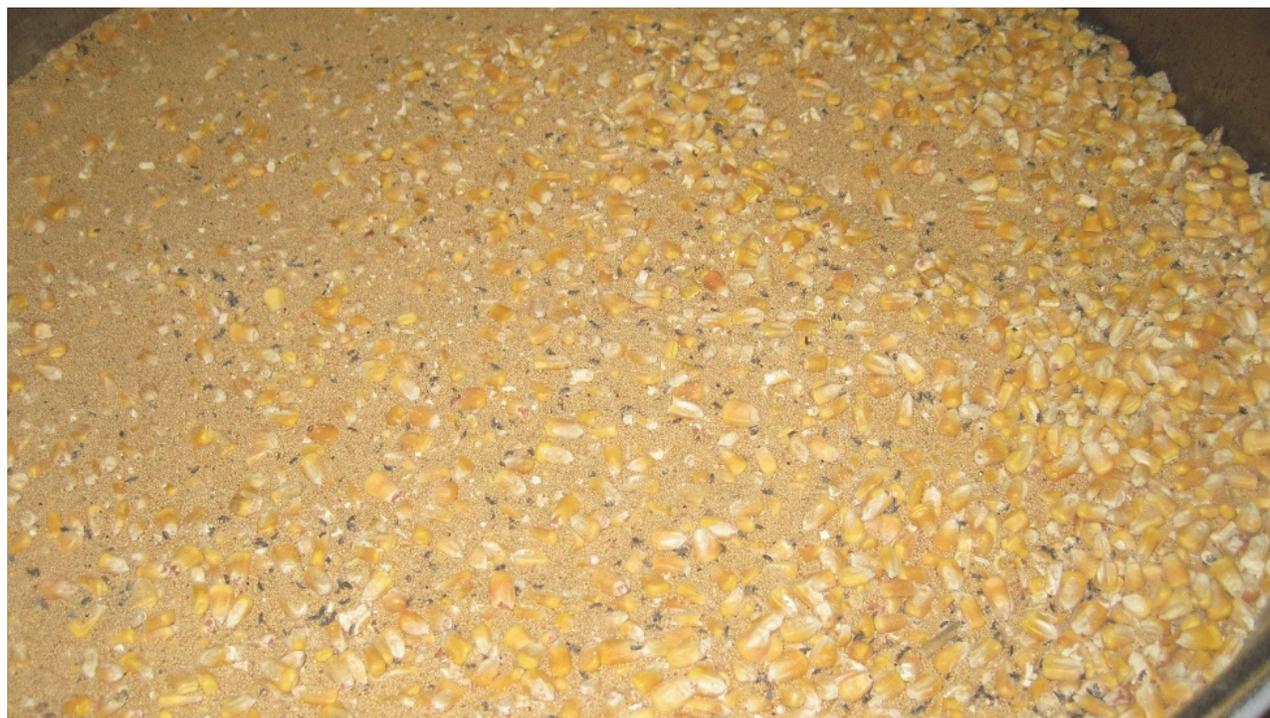


Figure 1. Amaranth grain blended with maize kernels after 160 d of storage.

There were three replications each of two treatments: (1) maize stored alone, and (2) maize blended with amaranth (1:1 by volume). Three of the six barrels were selected randomly, and each was loaded with 160 kg (353 lb) of uninfested commercial comingled bulk maize. A portion of the desired number of weevils was placed in the barrel after each of four 40 kg portions of maize was added. The remaining three barrels were loaded with the maize-amaranth mixture (fig. 1). After approximately 21 kg of maize was loaded into each barrel, approximately 24 kg of amaranth was added and stirred by hand so that the amaranth filled the voids between the maize kernels, and a portion of the desired number of weevils was placed in the barrels. A total of 84 kg (185 lb) of maize was blended with 96 kg (212 lb) of amaranth, a ratio of approximately 1:1 by volume.

After the barrels were loaded, they were stored at approximately 27°C with their open tops facing upward. The tops were covered with long ultra-sun block charcoal solar screens (New York Wire, Mt. Wolf, Pa.) to allow air circulation and prevent weevil escape.

MEASUREMENTS AND STATISTICAL ANALYSIS

Representative samples were drawn at 40, 80, 120, and 160 d using a brass sampling probe (Seedburo, Des Plaines, Ill.) inserted three times into each barrel at a diagonal angle (to increase the sampling area). Subsamples from the probe's partitions were combined for analysis. Weevil numbers were determined as described by Gullan and Cranston (2010). Samples were analyzed for broken corn and foreign material (BCFM) (USDA, 2013), moisture content (ASABE, 2017), test weight (USDA, 1996), and mechanical damage (Steele et al., 1969). Mechanical damage included insect damage. The temperature and relative humidity of the air inside the

barrels were measured using temperature and humidity loggers (HAXO-8, Log Tag Recorders Ltd., Auckland, New Zealand). Two-way ANOVA and Tukey's means comparison were performed to compare the differences in treatments at $\alpha = 0.05$ using JMP Pro (ver. 10, SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

LIVE WEEVILS

Figure 2 and table 1 show the mean numbers of live maize weevils over time for the two treatments. As the experiment progressed, most of the live weevils in the maize-amaranth barrels were found within the top 2 cm of the grain mixture. At 80 d, the numbers of weevils in the two treatments were

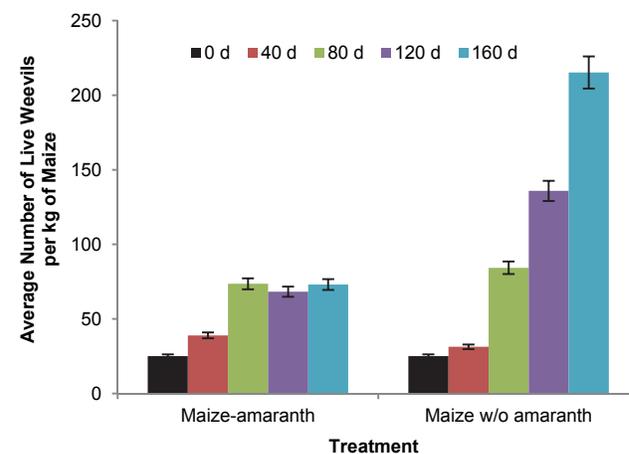


Figure 2. Live weevils per kg of maize after different storage times for maize-amaranth mixture and maize stored alone. Values are means of three replications, and error bars indicate one standard deviation.

Table 2. Tukey's means comparison of live weevils and maize quality values for maize-amaranth mixture versus maize stored without amaranth as a function of storage time. Values are means of three replications.^[a]

Item	Treatment	Storage Time				
		0 d	40 d	80 d	120 d	160 d
Number of live weevils per kg	Maize-amaranth	25 ±0 Ab	39 ±4 Ab	74 ±11 Aa	68 ±10 Aa	73 ±14 Aa
	Maize	25 ±0 Ab	31 ±6 Ab	84 ±34 Aab	136 ±64 Aab	215 ±82 Ba
Temperature (°C)	Maize-amaranth	-	25.9 ±4.9 Ga	28.4 ±3.4 Gc	26.7 ±1.7 Gb	28.3 ±1.1 Gc
	Maize	-	27.2 ±8.7 Hc	30.0 ±5.0 Hab	29.2 ±5.7 Hb	30.6 ±7.0 Ha
Relative humidity (RH, %)	Maize-amaranth	-	65.6 ±4.5 Aa	59.5 ±9.9 Abc	57.9 ±11.6 Ac	60.9 ±9.3 Ab
	Maize	-	67.4 ±5.5 Bd	68.4 ±2.7 Bc	69.6 ±1.4 Bb	71.6 ±1.6 Ba
Moisture content (MC, %)	Maize-amaranth	13.0 ±1.9 Ma	12.1 ±2.6 Mc	12.2 ±1.9 Mc	12.2 ±1.7 Mc	12.6 ±1.6 Mb
	Maize	13.1 ±1.8 Ma	12.8 ±1.0 Ma	12.6 ±0.6 Na	12.7 ±0.8 Na	12.7 ±1.7 Na
Mechanical damage (MD, %)	Maize-amaranth	16.1 ±1.9 Pa	15.7 ±2.6 Pa	16.3 ±1.9 Pa	16.7 ±1.7 Pa	16.9 ±1.6 Pa
	Maize	14.9 ±1.8 Pb	16.2 ±1.0 Pb	24.3 ±0.6 Qa	25.9 ±0.4 Qa	26.9 ±1.7 Qa
Broken corn and foreign material (BCFM, %)	Maize-amaranth	5.1 ±0.4 Ka	5.1 ±0.3 Lab	4.8 ±0.1 Lab	4.7 ±0.1 Lab	4.1 ±0.2 Lb
	Maize	4.8 ±1.0 Kb	7.1 ±0.6 Ka	7.4 ±0.5 Ka	7.5 ±0.5 Ka	7.8 ±0.5 Ka
Test weight (TW, lb bu ⁻¹)	Maize-amaranth	56.6 ±0.2 Ra	56.1 ±0.0 Rb	56.0 ±0.0 Rb	55.5 ±0.3 Rc	54.5 ±0.1 Rd
	Maize	56.6 ±0.5 Ra	56.0 ±0.2 Rab	55.8 ±0.1 Sb	54.9 ±0.2 Rc	53.8 ±0.3 Sd

^[a] Means followed by different uppercase letters within each treatment and means followed by different lowercase letters at each time for each item are significantly different at the 0.05 probability level.

not significantly different. This was probably due to the maize-amaranth treatment having some maize exposed to the weevils on top of the grain surface, where the weevils could reproduce. The number of live weevils was significantly higher at 160 d for the maize stored without amaranth as compared to the maize-amaranth blend. The weevil population for the maize-amaranth blend was not significantly different at 80, 120, and 160 d.

There was a significant effect of storage time ($F = 7.93$, $p = 0.0018$) and treatment ($F = 10.86$, $p = 0.0046$) on the number of live weevils. The interaction between time and treatment was also significant ($F = 4.41$, $p = 0.0193$). The interaction was expected, as the maize-amaranth blend restricted the weevils' ability to reproduce over time. There were no significant differences between treatments at 40, 80, and 120 d, but the number of weevils was significantly higher for maize stored without amaranth at 160 d (table 2). The number of live weevils was significantly higher at 80, 120, and 160 d than at 0 and 40 d (table 2) for the maize-amaranth mixture. On average, the maize-amaranth mixture reduced the weevil population by 66% at 160 d. Because we suspect that accessibility affected the weevil infestation at the top of the barrels, we recommend that future research explore the impact of completely covering the exposed maize kernels with a layer of amaranth.

TEMPERATURE AND RELATIVE HUMIDITY

The temperature inside the grain mass was higher than the ambient temperature at all times, although it was higher for the maize stored without amaranth than for the maize-amaranth mixture. This was likely due to respiration of the stored products and maize weevils (Bern et al., 2013). There was a significant effect of storage time ($F = 96.47$, $p < 0.0001$) and treatment ($F = 199.41$, $p < 0.0001$) on temperature. The interaction between time and treatment was also significant ($F_{3,1,3} = 4.72$, $p = 0.0028$).

The relative humidity (RH) of the air in the maize-amaranth mixture ranged between 57.9% and 65.6% on average, whereas the RH of the air in the maize without amaranth ranged from 67.4% to 71.6% on average. The RH for the maize-amaranth mixture decreased from 40 to 120 d, and there was a slight increase at 160 d. This could have been

due to the presence of amaranth, which affected the equilibrium RH. Likewise, the RH of maize without amaranth increased with time. The effects of storage time ($F = 22.40$, $p < 0.0001$) and treatment ($F = 702.23$, $p < 0.0001$) on RH were significant. The interaction between time and treatment was also significant ($F = 51.10$, $p < 0.0001$). The RH for maize without amaranth was always significantly higher (table 2).

When emptying the barrels, the maize stored alone was observed to be warm, and some moldy kernels were clinging to the sides of the barrels, whereas the maize-amaranth mixture was noticeably cooler with no moldy kernels. The RH of the air in the maize without amaranth was closer to the level of 70% generally considered necessary for storage molds to grow (Delcour and Hosney, 2010). The maize-amaranth mixture had lower insect activity, which resulted in lower RH. Thus, a maize-amaranth mixture could help reduce spoilage of insect-infested maize in storage.

MAIZE MOISTURE CONTENT

There was a decrease in moisture content for both treatments in the first 40 d, probably due to the establishment of moisture equilibrium between the stored products and the surrounding environment (Bern et al., 2013) and moisture exchange between amaranth and maize (table 2). After 40 d, there was an increase in the average moisture content, probably due to respiration of maize weevils (Bern et al., 2013) as modeled by the combustion of carbohydrate equation. There was no significant effect of storage time ($F_{3,1,3} = 1.89$, $p = 0.1726$), although a significant effect of treatment ($F_{3,1,3} = 28.42$, $p < 0.0001$) on moisture content was detected. The interaction between time and treatment was not significant ($F_{3,1,3} = 2.08$, $p = 0.1437$). Moisture content was not significantly different between the two treatments at 0 and 40 d, but it was significantly higher for maize stored alone (control) at 80, 120, and 160 d (table 2). This could be due to moisture produced by the greater population of weevils in the control barrels. The moisture content of each treatment was analyzed over time (table 2). There were no significant changes in the control barrel moisture content over time.

MECHANICAL DAMAGE

Visible mechanical damage in the maize-amaranth treatment did not change significantly during the experimental period, whereas that of maize stored alone (control) increased with time (table 2). The almost constant results for the maize-amaranth treatment were probably due to the weevils remaining on top of the grain because they most likely could not penetrate through the amaranth into the grain mass. Thus, the mechanical damage was concentrated in a specific area. The increasing percentage of mechanical damage in the maize (control) treatment was due to the increasing weevil population. There was a significant effect of storage time ($F_{3,1,3} = 16.73$, $p < 0.0001$) and treatment ($F_{3,1,3} = 112.54$, $p < 0.0001$) on visible mechanical damage. The interaction between time and treatment was also significant ($F_{3,1,3} = 11.02$, $p = 0.0004$). The significance of the interaction was expected because the maize-amaranth mixture was intended to restrict movement of the weevils, and thus they were unable to reproduce. Mechanical damage between treatments was not significantly different at 0 and 40 d, but it was significantly higher for the control at 80, 120, and 160 d. Laswai et al. (2013) observed an increasing trend of mechanical damage with small grains of crotalaria seeds, finger millet, and sorghum used as a physical measure to minimize mechanical damage in postharvest grain storage.

BROKEN CORN AND FOREIGN MATERIAL

The BCFM results for the maize-amaranth treatment were almost constant throughout the experimental period, whereas that of maize stored alone increased with time (table 2). The almost constant results for the maize-amaranth treatment were probably due to the weevils observed in the top layer of the grain. When the weevils crawled to the top of the grain, they could not penetrate again through the grain into the lower parts of the barrel because amaranth filled the intergranular spaces between the maize kernels. The increasing BCFM in the maize (control) treatment was due to the increasing weevil population. There was no significant effect of storage time ($F_{3,1,3} = 0.03$, $p = 0.9917$) on BCFM, although treatment had a significant effect ($F_{3,1,3} = 254.23$, $p < 0.0001$). The interaction between time and treatment was not significant ($F_{3,1,3} = 2.38$, $p = 0.1075$). The BCFM for the control was significantly higher at 40, 80, 120, and 160 d. The BCFM within each treatment was analyzed over time (table 2).

TEST WEIGHT

Test weight declined with time in both treatments, but there was a greater decline at 120 and 160 d for maize in comparison to maize-amaranth, probably due to more dry matter and/or endosperm loss caused by the increasing number of weevils. Weevils were observed on top of the maize-amaranth mixture, and the surface kernels had almost nothing left inside them due to consumption by weevil larvae and pupae. There was a significant effect of storage time ($F_{3,1,3} = 114.00$, $p < 0.0001$) and treatment ($F_{3,1,3} = 23.75$, $p = 0.0002$) on test weight, although the interaction between time and treatment was not significant ($F_{3,1,3} = 2.83$, $p = 0.0715$). Tukey's mean comparison of the two treatments was not sig-

nificantly different at 0, 40, and 120 d, but it was significantly higher for the maize-amaranth mixture at 80 and 160 d. Each treatment was analyzed over time (table 2). As moisture content increased, there was an expected decrease in test weight (Bern and Brumm, 2009). However, damage and/or deterioration of the kernels due to weevils may have contributed to the decline in test weight.

These experimental results agree with the results reported by Laswai et al. (2013) and support mixing of amaranth with maize as a pesticide-free approach to controlling maize weevils. The same experimental setup should be used with a layer of amaranth on top of the grain mixture to completely cover the maize kernels that are otherwise exposed to maize weevils. We postulate that this extra layer will reduce or eliminate the maize kernels that were available to weevils during the experiment reported here. In addition, because no moldy maize kernels were observed in the maize-amaranth barrels, future research should investigate the effect of blending maize with amaranth for reducing mold infestation.

CONCLUSIONS

Based on this research, we conclude that blending weevil-infested maize and amaranth (1:1 by volume) during 160 d of storage reduced the maize weevil population by 66% compared to maize stored alone, and the number of live weevils in the two treatments was significantly higher for maize stored alone at 160 days. Thus, mixing amaranth with maize is a promising pesticide-free method of controlling maize weevils.

Future work should involve conducting the same experiment with an extra layer of amaranth on top of the maize-amaranth mixture to completely cover the maize kernels that are otherwise exposed to maize weevils. This further investigation is postulated to help completely control the maize weevils. In addition, because no moldy maize kernels were observed in the barrels with the maize-amaranth mixture, future research should investigate whether reduced insect activity or the blending maize with amaranth reduces or eliminates mold infestation.

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