Evaluation of Neem Seed and Citrus Peel Powder for the Management of Maize Weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) In Sorghum

***Kifle Gereziher*[1], *Mulatu Wakgari*[2] *and Muluken Goftishu*[2]**
[1]*Maythebri Shire Agricultural Research Center, Tigray, Ethiopia. E-mail: frgk2004@gmail.com*
[2]*Haramaya University, Haramaya, Ethiopia.*

Abstract

The study was conducted at the Plant Protection Laboratory of Haramaya University in a controlled environment of 28±2^{0}C temperature and 75±5% relative humidity. The objective was to determine the effective doses of *Azadirachta indica* and *Citrus sinensis* peel powder for the management of *Sitophilus zeamais*. The treatments were arranged in completely randomized design (CRD) with four replications. Fifty unsexed 3-6 days old maize weevil adults were introduced to each glass jar containing 1 kg *Sorghum bicolor* (L.), variety muyra-2 seeds. Neem seed and citrus peel powder were compared with Ethiolathion 5% dust and untreated control at the rate of 7.5, 15, 25, 50 and 100 g kg^{-1} of seeds. Parent adult maize weevil mortality, F_1 progeny emergence and percent protection, grain weight loss, damage and germination at all rates of citrus peel powder (CPP) and neem seed powder (NSP) showed significant differences over the untreated control ($P<0.01$), except for grain damage (%) at 7.5 g CPP ($P>0.01$). At the rate of 25, 50 and 100 g both test botanicals resulted in 100% adult weevil mortality, 95-100% grain protection, reduced weevil emergence, reduced grain damage, reduced grain weight losses and produced statistically comparable efficacy with Ethiolathion 5% dust ($P<0.01$). NSP at 7.5 and 15 g and all rates of CPP did not reduce grain germination rate, whereas at higher rate of 25- 100 g NSP statistically decreased germination of the treated grains ($P<0.01$). Further research is warranted to assess efficacy of these botanicals under farmer's storage condition.

Keywords: Botanicals, maize weevil, sorghum, management

Introduction

Sorghum, *Sorghum bicolor* (L.), is an important cereal crop ranking fifth in the world with an annual production of 63.89 million tons (USDA 2015). According to the same report, the most important sorghum producers are the United State, Nigeria, the Sudan, India, Ethiopia, Argentina, China, Australia, Burkina Faso and Mali. Further, it was stated that Africa has become the leading sorghum producer with an average annual production of greater than 25.6 million tons and with larger area coverage than other continents. Ethiopia is the third largest producer of sorghum in Africa after Nigeria and the Sudan making contribution of about 12% of annual production (Wani *et al.* 2011;

USDA 2015). Sorghum is the third most important crop in Ethiopia after tef and maize in area coverage and the second largest in total production after maize (CSA 2014). Sorghum is used as a source of nutrition for humans across the world, but mainly serves as a staple food for millions of people in Africa and Asia (Gabisa and Grenier 2005). In Ethiopia, one third of the cereal diet comes from sorghum, and it plays an important role for making a stable food called *injera* next to tef (Asfaw 2012).

Stored sorghum grains is attacked and damaged by a number of pests that lead to qualitative and quantitative deterioration or loss. Insects are by far the major post-harvest pests of sorghum both at the farmer and consumer level in the tropics, including Ethiopia. Maize weevil is among pests of stored sorghum grains in Ethiopia (Temesgen and Waktole 2013). Infestation by this weevil begins in the field, but significant damage happens in storage (Girma *et al.* 2008; Baidool *et al.* 2010). Damage by *S. zeamais* causes grain loss resulting in increased poverty, lowers nutritional values of seeds leading to increased malnutrition and causes reduced weight and market values of seeds (Temesgen and Waktole 2013). Under traditional storage facilities in Ethiopia, heavy infestation by *S. zeamais* can cause 41- 80% of weight losses to maize and sorghum seed (Waktole and Amsalu 2012).

Botanical products have played important roles in managing pest in traditional storage facilities in the tropics (Belmain *et al.* 2001). Poor farmers in many developing countries who could not afford synthetic pesticides against stored grain insect pests used botanicals for their control. Due to specific novel mode of action, plant extracts (botanicals) have advantages over synthetic insecticides against the storage insect pests and known to minimize cross resistance to specific target molecule (Betancur *et al.* 2010).

Neem, *Azadirachta indica*, seed powder completely hindered progeny emergence, percentage seed damage and seed weight losses caused to maize grains by maize weevil (Danga *et al.* 2015). The inhibition of *S. zeamais* progeny emergence and maize seed damage as a result of neem powder is probably due to the huge array of *azadirachtin* activities on the insect's hormone system (Abrham and Besedow 2005; Girma 2006; Danga *et al.* 2015). The mortality of maize weevil is lower in seeds treated with larger particle size of neem seed powder than small sized particles; because small sized *A. indica* seed powder completely covers the insect's body and suffocate them to death. In addition to causing mortality through suffocation, small size *A. indica* powder can be swallowed by the adult *S. zeamais* when feeding on seeds, causing death of the insect. The decrease in residual toxicity of *A. indica* powder is linked with the degradation of its main compound, *Azadirachtin*, as exposure time increases (Katamssadan *et al.* 2015).

Citrus, *Citrus sinensis*, peel powder is effective in arresting adults of *S. zeamais* on sorghum seeds (Suleiman *et al.* 2012). The effect of *C. sinensis* peel powder on adult emergence of *S. zeamais* on sorghum seeds increases with increasing dosage and exposure time (Suleiman *et al.* 2012; Musa and Adewale 2014). The effectiveness of *C. sinensis* peel powder was found to be due to its silica or silica like component, the particles of which adhere to the seed and provide physical protection (Dawit and Bekele 2010).

Citrus peel powder has direct toxic effect and blocks the spiracles of the insect's thus impairing respiration and leading to death (Abdullahi *et al.* 2010). They also opined that citrus peel powder is known to inhibit oviposition and adult emergence of *S. zeamais*. The current study was carried out to assess the efficacy of neem seed and citrus peel powder against maize weevil, *S. zeamais*, and provide better insight on the use of these botanicals in maize weevil management program.

Materials and Methods

Description of Experimental Site

The study was conducted at Haramaya University Plant Protection Research Laboratory. It is located at 42^0 3'E longitude and 9^0 26'N latitude and at an altitude of 2006 m above sea level. The mean annual rain fall at the station is 780mm and the mean annual temperature is 23.4^0c.

Experimental Materials

Establishment of Maize Weevil Culture

Maize weevil, *S. zeamais*, was reared on a sorghum variety, Muyra-2 in order to obtain similar age weevils for this experiment. Twenty kilogram of sorghum seed was collected from Haramaya University Sorghum Improvement Research Program. Seeds with visible damage symptoms were removed from the assort manually and the healthy seeds were kept in a deep freezer at -20 ± 2 °C for two weeks to disinfest any pest or foreign materials. The seeds were then transferred to plastic bags and kept at rearing room conditions for two weeks (Fikremariem *et al.* 2009; Muluken and Ketema 2014).

Unsexed maize weevil was collected from previously identified weevils of Haramaya University Plant Protection Laboratory. The weevils were reared on cleaned and disinfested sorghum seeds (Muyra-2) in five glass jars, each jar with 2 L capacity. Each jar contained 500 g seeds to which 100 unsexed adult weevils were introduced. Subsequently, the jars were covered with muslin cloth and fixed with rubber band to prevent escape of weevils and to allow aeration. The infested seeds were kept in an incubator adjusted at 25±2°C (Fikremariam *et al.* 2009). Seven days after oviposition, all parent weevils were removed from each jar and the seeds were kept at 25±2°C to get similar aged weevils. Forty days after introduction of weevils in each plastic container, the emerged progeny were removed daily and transferred to fresh seed for three days until 1000 progenies were collected. The weevil progenies used for the experiment were multiplied from the first generation weevil reared in ten glass jars containing 500 g clean and disinfected sorghum seeds to obtain adult weevil population with synchronized age group of 3-6 days old for the experiment.

Collection and Preparation of Botanicals

Fresh and matured citrus/orange fruit *C. sinensis* and neem (*A. indica*) seeds were collected from Dire Dawa Tony Farm. The orange fruit of the variety Valencia was used as this variety is widely cultivated and easily available throughout the country. The orange peel and neem seed were dried under shade in Plant Protection Laboratory, Haramaya University.

Preparation of Powder

The dried citrus peels and neem seeds were pounded separately into powder using High Speed Smashing Machine and were sieved through 0.25 mm pore size mesh sieve to obtain uniform particle size powder. The resulting powders were kept separately in glass containers at room temperature in dark place in the Laboratory until needed for the experiment.

Treatment Protocol

One hundred grams of disinfested seeds were placed in glass jars of 300 ml capacity. The glass jars which were used for the experiment were heat sterilized in an autoclave at 60 ^{0}C for three hours to kill any insects and fungal spores that might have been housed inside as well as outside the jars. Citrus peel and neem seed powders were applied at a rate of 7.5, 15, 25, 50 and 100 g kg^{-1} of sorghum seeds. The powders were thoroughly mixed with the seeds for five minutes with the aid of a glass rod to ensure thorough admixture. Synthetic insecticide Ethiolathion 5% dust was used at the recommended rate of 0.5 g kg^{-1} seed as a standard check. For comparison untreated check was also included. Fifty unsexed and newly emerged adult weevils were placed in each treated jar, jar with standard check and control. The jars were placed in an incubator at 28±2 ^{0}C temperature and 70±5% relative humidity, optimal condition for weevil growth and multiplication (Tadele *et al.* 2010). The relative humidity within the incubator was maintained by placing four jars having 20 cm diameter each with two litter capacity containing one litters of water. The jars were refilled daily to replace the evaporated water. Temperature and relative humidity readings were taken two times per day using Hygro-termometer. The glass jars were covered with muslin cloth which was secured in position with rubber band. The muslin cloth not only prevented weevils from escape but also ensured sufficient ventilation for the weevils. Prior to the start of the experiment, each treatment, standard check and control was arranged in Completely Randomized Design (CRD) with four replications each.

Data Collection

Effect of neem seed and citrus peel powders on adult weevil mortality and F$_1$ progeny emergence

Parent adult mortality was recorded at 1, 7, 14, 21 and 28 days after treatment application, when deceased insects were removed and counted. Twenty eight days after infestation, weevils were removed from the jars and the number of live and dead insects was counted and rate of mortality from each treatment was determined. F$_1$ progeny emergence was started after 34 days of treatment application or after 6 days from removal of the parent weevils. The generation time of maize weevil ranges from 28-56 days, depending on the environmental condition, such as temperature, humidity and host. The assessment period was selected based on earlier reports by (Dobie 1974). Weevils that survived the treatments were maintained under the same test conditions and F$_1$ progeny rate was assessed. F$_1$ progeny emergence was assessed daily for 70 days after adults were removed from test jars.

Seed weight loss

Seventy days after the experiment started, 1000 seeds were randomly withdrawn from each test, standard check and control treatments and were sorted into damaged and undamaged categories. The seeds in each category were counted and weighed. Percentage weight loss was calculated using count and weight method for each replication of all the treatments (Adams 1976) using the following formula.

$$\text{Weight loss} = \frac{(Wu \cdot Nd)-(Wd \cdot Nu)}{Wu \cdot (Nu+Nu)} X\ 100$$

Where; Wu: Weight of undamaged seed, Nu: Number of undamaged seed, Wd: Weight of damaged seed, and Nd: Number of damaged seed

Percentage seed damage

Percentage seed damage was estimated by converting the proportion of damaged seeds (seeds with visible holes) from the total number of sample seeds in each replication.

$$\%\ \text{damage} = \frac{Nd}{TNG} X\ 100$$

Where: Nd: number of damaged grains (seeds) and TNG: total number of grains (seeds)

Efficacy of treatments

The effectiveness of different treatments in protecting the seed was calculated using the formula employed by El-Ghar *et al.* (1987).

$$\%\ \text{protection} = \frac{\text{T F1 PC - TF1P T}}{\text{TF1PC}} \times 100$$

Where; TF_1PC: total F_1 progeny in control and TF1PT: total F_1 progeny in treatment

Treatment effects on seed germination

Seed germination test was carried out at the end of the experiment. One hundred seeds were randomly taken from each replicate and were treated with 1% sodium hypochlorite (Chlorox) solution for one minute and rinsed with distilled water for another one minute to remove fungal contamination. The seeds were placed on moist filter paper in germination box and maintained at room temperature. Seed germination rate for each treatment was assessed after ten days. The percent germination was computed using the following formula employed by Fikremariam (2009).

$$\text{Germination (\%)} = \frac{NG \times 100}{TG}$$

Where; NG: number of seeds germinated and TG: total number of seeds tested in each Petri dish.

Statistical Analysis

Adult weevil mortality data in each replication was expressed as a percentage of the total number of adult weevils introduced. Mortality data were corrected for control mortality using Abbott's correction formula (Abbott 1925).

$$(\%)CM = \frac{(\%T - \%C)}{(100 - \%C)} X\ 100$$

Where; CM is corrected mortality, T is mortality in treated seed and C is mortality in untreated seed.

Percentage of damaged and germinated seeds was expressed as a percentage of the total number of damaged seed to the total number of seeds sampled from each replicate. The percentage data on mortality, damaged seed, germination and protection (efficacy) were arcsine or angular transformed. F_1 progeny emergence was log transformed, while percentage weight loss was square root transformed prior to statistical analysis to alleviate the variance heterogeneity. The analysis of variance (ANOVA) was carried out using SAS version 9.00 (SAS Institute Inc. 2002) at 1% level of significance. Treatment mean separation was accomplished by the Student Newman Keuls Test (SNKT) to determine difference among the means of the treatments. Correlation analysis was done among the variables using SAS at 1% level of significance. ANOVA, mean comparison and correlation analysis was done using the transformed values of the original data.

Results and Discussion

Effect of Citrus peel and Neem Seed Powder on Maize Weevil

Effect on Adult Weevil Mortality

Both citrus peel powder (CPP) and neem seed powder (NSP) treatments caused different mortality rates on maize weevil (Table 1). Higher weevil mortality was recorded at 25, 50 and 100 g kg^{-1} CPP and NSP starting from seven days.

Twenty four hours after treatment introduction, CPP at rate of 100 g kg^{-1} resulted in significant higher adult weevil mortality than the control ($P<0.01$) whereas the other dosage rates of both botanicals did not provide significantly higher weevil mortality than the control ($P>0.01$). On the contrary, Ethiolathion 5% dust caused 100% adult maize weevil mortality within 24 hours of application. Dawit and Bekele (2010) reported that the toxicity of CPP was low within 24 hours exposure period treated on *Z. subfaciatus* infested beans. The result indicated that even at higher dosages, NSP and CPP have no effect on adult maize weevil mortality with in 24 hour.

Seven days after treatment, CPP at 7.5 and 15 g kg^{-1} seed showed non-significant difference in weevil mortality over the untreated control ($P>0.01$). NSP at 50 and 100 g kg^{-1} seed caused 100% weevil mortality whereas similar dosage of CPP caused 91 and 97.5% mortality, respectively seven days after treatment statistically similar to Ethiolathion 5% dust. According to Katamssadan *et al.* (2015), NSP caused 100% mortality of maize weevil when applied at 40 g kg^{-1} of maize seed achieved and 22.2% mortality when used at 5 g kg^{-1} seed 7 days after application. The results of this experiment showed that the efficacy of both NSP and CPP is dosage and exposure time dependent as was also reported by Temitope (2014), Abdullahi *et al.* (2010), Girma (2006) and Danga *et al.* (2015). Dawit and Bekele (2010) reported 67% mortality of *Z. subfaciatus* exposed to beans treated with 15 g of sun dried powder of orange peel.

Two weeks after treatment with CPP and NSP powder, adult weevil mortality increased significantly ($P<0.01$) compared with the untreated control. However, 7.5 g kg^{-1} of CPP did not cause significantly more weevil mortality than the untreated control ($P>0.01$). The efficacy of both NSP and CPP at the rates of 25, 50 and 100 g kg^{-1} sorghum seeds was similar to that of Ethiolathion 5% dust. Katamssadan *et al.* (2015) reported 100% mortality of maize weevil when treated with 40 g kg^{-1} maize seed of NSP and only 32% mortality when treated with 5 g NSP/ kg 14 days after treatment. While result of the current study showed no adult maize weevil mortality when treated with 7.5 g

kg^{-1} CPP over the treatment period. Temitope (2014) reported that lower dosages of CPP was ineffective during the first week of treatment but showed some efficacy starting from the second week. Similar reported by Danga *et al.* (2015) shows that 7.5 g kg^{-1} of NSP resulted in 43% mortality of adult maize weevil 14 days after treatment. Nukenine *et al.* (2010) reported that at 40 g kg^{-1} and 5g kg^{-1} NSP caused 86 % and 20.33% adult maize weevil mortality, respectively, 14 days after treatment. In general two weeks after treatment, mortality of maize weevil from NSP was higher than to the same rates of CPP.

Three weeks after application, all dosages of both CPP and NSP treatments caused significantly higher ($p<0.01$) adult weevil mortality than the untreated control. Both NSP and CPP caused 100% weevil mortality three weeks after application when used at 25, 50 and 100 g kg^{-1}. The efficacy of both NSP and CPP when used at 15 g kg^{-1} sorghum seed consistently increased after 21 days of treatment but more abruptly with NSP. Similar to the observation made by Temitope (2014), the mortality of weevil increased with increase in exposure time when lower dosages of both NSP and CPP were used. The trend was the same four weeks after weevil exposure to the treatments. Effect of higher dosages of both NSP and CPP was similar to Ethiolathion 5% dust 14 days after treatment. Suleiman *et al.* (2012) found that CPP used at 0.5, 1 and 2 g/20 g sorghum seed resulted in 47.5, 65 and 82.5% mortality of maize weevil, respectively within 28 days. The current result concurs with this finding.

In general, adult *S. zeamais* mortality was increased with increase in dosage and exposure time with both NSP and CPP treatments. The increase in mortality with *C. sinensis* treatment indicates that the effect is directly proportional to the amount used and exposure time (Girma 2006; Suleiman *et al.* 2012). However, from 7 days up to 28 days after treatment application, the potency of NSP was higher than that of CPP on *S. zeamais* mortality. Twenty eight days after treatment, mortality indicated the effects of 15, 25, 50 and 100 g NSP- kg^{-1} and 25, 50 and 100 g CPP kg^{-1} of sorghum seed was effective as Ethiolathion 5% dust, while the mortality due to NSP at 7.5 g kg^{-1} and CPP at 7.5 and 15 g kg^{-1} was below 50%. The effectiveness of the botanical powders on mortality of *S. zeamais* could probably be due to fumigant, repellent and consumption of lethal dosages of the plant powders treated on the seed, thereby leading to stomach poisoning which agrees with the report of Simbarashe *et al.* (2013) on the different rates of *Eucalyptus tereticornis, Tagetes minuta* and *Carica papaya* powders. Adedire and Ajayi (1996) and Dawit and Bekele (2010) indicated that orange peel powder attributed to stomach poison since the weevils feed directly on the seeds. Further Dawit and Bekele (2010) explained that this phenomenon is due to the presence of silica like component of *C. sinensis* peel powder, which is adhesive and adhere to the seed. Similarly, Danga *et al.* (2015) reported that the active ingredient of neem seed oil *azadirachtin* caused high mortality of maize weevil.

Table 1: Effect of different rates of neem seed and citrus peel powders on parent adult maize weevil mortality

		Parent adult mortality after treatment application (%)				
Treatment	Rate (g/ kg)	1DAT	7DAT	14 DAT	21DAT	28DAT
CPP	100	3.5^{b}	97.5^{b}	100^{a}	100^{a}	100^{a}
	50	1.0^{c}	91.0^{c}	99.5^{a}	100^{a}	100^{a}
	25	0.0^{c}	81.0^{c}	99.5^{a}	100^{a}	100^{a}
	15	0.0^{c}	1.0^{g}	10.5^{c}	22.9^{c}	45.3^{b}
	7.5	0.0^{c}	0.0^{g}	0.0^{d}	6.2^{d}	25.0^{c}
NSP	100	0.5^{c}	100^{a}	100^{a}	100^{a}	100^{a}
	50	0.0^{c}	100^{a}	100^{a}	100^{a}	100^{a}
	25	0.0^{c}	88.0^{c}	99.5^{a}	100^{a}	100^{a}
	15	0.0^{c}	13.0^{e}	33.5^{b}	73.9^{b}	95.1^{a}
	7.5	0.0^{c}	4.0^{ef}	9.5^{c}	19.4^{c}	43.6^{b}
Ethiolathion 5% dust	0.5	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
Untreated control	-	0.0^{c}	0^{g}	0^{d}	0^{e}	0^{d}
CV		20.7	5.4	5.8	4.0	10.6
SE		3.6	7.0	11.1	6.3	57.5

Means in columns with same letter are not significantly different at α = 0.01. SE, Standard error; DAT, Days after treatment; CPP, citrus peel powder; NSP, neem seed powder; Mean separation was analyzed using SNKT.

Effect of Botanical Powders on F_1 Progeny Emergence and Seed Protection

All the treatments significantly lowered the number of F_1 progeny and gave higher percent of seed protection over the untreated control (Table 2). There was no F_1 progeny emergence from sorghum seeds treated with NSP at 25, 50 and 100 g kg^{-1} similar to the effect of Ethiolathion 5% dust. Higher numbers of F_1 progeny weevils (95.8) emerged from the lowest rate of 7.5 g kg^{-1} NSP than all the NSP treatments. There was no F_1 progeny emergence from seeds treated with 50 and 100 g kg^{-1} CPP similar to the effect of Ethiolathion 5% dust. The highest number of F_1 progeny weevils emerged (243.5) from 7.5 g kg^{-1} CPP than all the CPP treatments. The result indicated that at higher rates of NSP and CPP, there was lower number of F_1 progeny emergence. Many studies have shown that lower number of progeny emerged from seeds treated with higher rates of *C. sinensis* (Dawit and Bekele 2010; Suleiman *et al.* 2012) and neem seed powders (Girma 2006). Danga *et al.* (2015) reported that the active ingredient of NSP, *azadirachtin* caused high mortality to maize weevil and completely hindered or significantly reduced progeny emergence at 3 g kg^{-1} of maize seed. Generally, the number of F_1 progeny emerged from the lower dosage of CPP was higher than equal amount of NSP applied.

On the basis of daily progeny count, there were few dead progenies due to treatment with higher rates of NSP and CPP. This low mortality of the newly emerged maize weevil may be due to slow acting nature of botanical powders and the potency of the powders decease with increase in storage time.

All rates of NSP and CPP significantly gave protection to sorghum seed from maize weevil infestation compared to the untreated control. NSP and CPP at dosages of 25-100 g kg^{-1} gave more than 95% seed protection statistically similar to Ethiolathion 5% dust. Many studies have shown that percentage protection of seeds from weevil damage was higher when higher rates of CPP (Dawit and Bekele 2010) and NSP (Nukenine *et al.* 2010;

Katamssadan *et al.* 2015). Among the botanical powder treatments, 7.5 g kg^{-1} CPP showed the lowest percent protection (36.9%) of the treated seeds from weevil infestation.

Table 2. Effect of different rates of neem seed and citrus peel powders on F_1 progeny emergence and percentage protection

Treatment	Rate (g/ kg)	F_1 progeny emergence	Percentage protection
CPP	100	0.0^f	100^a
	50	0.5^f	99.9^a
	25	17.5^e	95.4^a
	15	103.3^c	73.2^d
	7.5	243.3^b	36.9^e
NSP	100	0.0^f	100^a
	50	0.0^f	100^a
	25	0.5^f	99.9^a
	15	37.0^d	90.4^c
	7.5	95.8^c	75.2^d
Ethiolathion 5% dust	0.5	0.0^f	100^a
Untreated control	-	385.5^a	0.0^f
CV		8.5	2.5
SE		0.3	3.0

Means within columns with same letter are not significantly different at α = 0.01. SE, Standard error; Mean separation was analyzed by SNKT.

Effect of Botanical Powders on Seed Weight Loss, Damage and Germination

There was highly significant (p<0.01) difference among the treatments in percentage of seed weight loss, damage and germination over the untreated control (Table 3). NSP at the rate of 25, 50 and 100 g kg^{-1} showed the lowest seed weight loss equal to Ethiolathion 5% dust. Significantly high weight loss (2.31%) was recorded from 7.5 g kg^{-1} NSP than the rest treatments of NSP. CPP at 50 and 100 g kg^{-1} showed the lowest seed weight loss equal to Ethiolathion 5% dust. Significantly high weight loss 4.43% was recorded from 7.5 g kg^{-1} CPP than the other treatments of CPP. The result indicated that from both types of the botanical powders the weight loss decreased with increased rate of powders. According to the current studies, it could be possible to store sorghum seed treated with 25 g kg^{-1} NSP and 5g kg^{-1} CPP for 70 days without weight loss due to maize weevil infestation. Ileke and Oni (2011) reported that there is neither seed damage nor weight loss recorded in the treated wheat seeds with a concentration of 2.5. 5.0 % (w/w) *A. indica* powders.

There were highly significant (p<0.01) differences among the treatments in percentage seed damage due to maize weevil infestation. Except the lowest rate of CPP at 7.5 g kg^{-1}, all the botanical powder treatments gave significantly lower seed damage than the untreated control. NSP at the rates of 25, 50 and 100 g kg^{-1} showed almost zero percent seed damage, which was similar to Ethiolathion 5% dust. NSP at 7.5 g kg^{-1} resulted higher seed damage (6.22%) than the other rates of NSP. CPP at 50 and 100 g kg^{-1} showed no seed damage similar to Ethiolathion 5% dust. Higher damaged seed (11.85%) was recorded at the lower rate 7.5 g kg^{-1} of CPP than the rest of CPP rates. The result indicated that sorghum seeds treated with the higher rates (25, 50 and 100 g kg^{-1}) of botanical powders could be stored for 70 days without any damage by *S. zeamais*. Similarly, Girma (2006) reported that the highest percentage of damaged seeds occurred due to the lowest rate of 0.5% NSP while the highest damage was recorded at 2% NSP treatment. Suleiman *et al.* (2012) also indicated that of *C. sinensis* powder is effective in protecting the sorghum seeds from damage by maize weevil.

Sorghum seeds treated with higher rates of CPP at 15, 25, 50 and 100 g kg^{-1} and lower rates of NSP at 7.5 and 15 g kg^{-1} showed higher percentage seed germination similar to Ethiolathion 5% dust. The result showed that CPP could not affect the germination percent of sorghum seeds. Higher rates of NSP at 25, 50 and 100 g kg^{-1} treated sorghum seeds resulted in reduced seed germination. This reduction in seed germination was due to mold growth as the moisture content of the treated seeds was increased by the oils present within the NSP. Girma (2006) reported that some of the botanical treatments, such as Mexican tea powder were affected by fungi ,resulting in decreased seed germination percent on maize genotypes. In the case of lower rates, the reduction in seed germination was resulted from maize weevil damage to the seeds. Botanical pesticides in the form of powders (*Lantana camara* L. and *Tephrosia vogelii* Hook) and storage duration of 120 days and above influences the viability and moisture content of stored maize seeds (Ogendo *et al.* 2004). However Tabu *et al.* (2012) reported that leaf powder of botanicals and inert materials did not affect the viability of treated chickpea seeds.

Table 3 Effect of botanical powders on seed weight loss, damage and germination

Treatment	Rate (g/kg)	Weight loss (%)	Damage (%)	Germination (%)
CPP	100	0.0^{f}	0.0^{d}	91.3^{a}
	50	0.0^{f}	0.0^{d}	91.8^{a}
	25	0.6^{e}	1.9^{c}	89.5^{ab}
	15	1.9^{c}	5.3^{b}	90.8^{ab}
	7.5	4.4^{b}	11.9^{a}	82.5^{bc}
NSP	100	0.0^{f}	0.0^{d}	74.0^{d}
	50	0.0^{f}	0.0^{d}	81.5^{c}
	25	0.2^{f}	0.9^{d}	86.0^{bc}
	15	1.1^{d}	2.9^{c}	92.3^{a}
	7.5	2.3^{c}	6.2^{b}	88.5^{abc}
Malathion5%dust	0.5	0.0^{f}	0.0^{d}	92.3^{a}
Untreated control	-	5.5^{a}	14.7^{a}	58.5^{e}
CV		7.8	11.4	3.7
SE		0.01	0.04	6.24

Means within columns with same letter are not significantly different at α = 0.01. Mean separation was analyzed by Student-Newman-Keuls Test (SNKT).

Simple Correlation Coefficient among the Variables

The simple linear association was highly significant ($p< 0.01$) among the variables: adult weevil mortality, F_1 progeny emergence, percentage protection, weight loss, damage and seed germination (Table 4). Adult weevil mortality was positively correlated with percentage protection (r = 0.95%) and germination (r = 0.52) but negatively correlated with F_1 progeny emergence (r = -0.95), percentage weight loss (r = -0.95) and damage (r = -0.92). F_1 progeny emergence was positively correlated with percentage weight loss (r = 0.99) and damage (r = 0.97) and negatively correlated with percentage protection (r = -0.98) and germination (r = -0.50). Percentage protection was negatively correlated with percentage weight loss (r = -0.96) and percentage seed damage (r = -0.93) and positively correlated with germination percentage (r = 0.60). Weight loss was positively correlated with seed damage (r = 0.97) and negatively correlated with seed germination (r = -0.51). Seed damage was negatively correlated with percentage seed germination.

Table 4. Correlation coefficient among maize seed and maize weevil variables from CPP and NSP treatments at different dosages

Variables	AWM	F_1	PP (%)	WL (%)	SD (%)	GP (%)
AWM	-					
F_1	-0.96**	-				
PP (%)	0.95**	-0.98**	-			
WL (%)	-0.95**	0.99**	-0.96**	-		
GD (%)	-0.92**	0.97**	-0.93**	0.97**	-	
GP (%)	0.52**	-0.50**	0.60**	-0.51**	-0.47**	-

**highly significant at α = 0.01; AWM, Adult weevil mortality; F_1; F_1 progeny emergence; PP, Percentage protection; WL, weight loss; SD, seed damage; GP, Germination percentage.

Summary and Conclusions

NSP and CPP treatments resulted in higher adult weevil mortality and seed protection. Higher weevil mortality resulted with NSP and CPP 14 to 28 days after treatment application. Similar to Ethiolathion 5% dust, higher dosages of NSP and CPP resulted in greater than 95% adult maize weevil mortality. There was no mortality of maize weevil within 24 hours after treatment application, except with 50 and 100 g kg^{-1} CPP and Ethiolathion 5% dust. In general, the rate of adult maize weevil mortality increased with increase in dosage and exposure time by all NSP and CPP dosages. There was no F_1 progeny emergence from the higher rates of botanicals and Ethiolathion 5% dust. The result indicated that at higher rates both botanical powders showed lower weevil progeny emergence. The seeds treated with NSP and CPP were more protected from damage by F_1 progeny than control.

The botanical powders at higher rates gave the lowest seed weight loss and damage similar to the Ethiolathion 5% dust. With both botanicals, percentage weight loss and seed damage decreased with the increase in the dosages of botanical powders. CPP did not affect the germination capacity of treated sorghum seeds as dosage increased, but higher rates of NSP reduced seed germination.

Therefore, it can be concluded that, the efficacy of NSP and CPP increased with increase in the applied dosages. NSP at 25 g and CPP at 50 g kg^{-1} sorghum seeds effectively control maize weevil infestation for 70 days. Seed germination was not affected with the increase in the rate of CPP, whereas the germination due to NSP treatment was decreased as the rate exceeded 15g kg^{-1} sorghum seeds. When lower dosages of the botanical powders used, germination percent was reduced due to *S. zeamais* damage on endosperm of the sorghum seed. Therefore, seed which is intended for sowing and consumption can be treated with the botanical powders. Moreover preparation of powders from both botanicals is easy, less costly, takes short time and simple for application. So under smallholder farmers' condition, botanical powders prepared from both the neem seed and orange peel can be preferably used to protect sorghum seeds from *S. zeamais* infestation.

References

Abbot WS. 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18: 265-267.

Abdullahi N, Muhammed A, Tukur Z. 2010. Assessment of the efficacy of citrus peel powder against *Tribolium castaneum (Coleoptera: Tenebionidae)* infesting stored products. Bioscience Research Communication 22 (5): 283-286.

Abrham Tadesse, Basedow T. 2005. Laboratory and field studies on the effect of natural control measures against insect pests in stored maize in Ethiopia. Journal of plant diseases and protection 112 (2): 156 -172.

Adams JM. 1976. Weight loss caused by development of *Sitophilus zeamais* Motsch. In maize. Journal of Stored Products Research 12: 269-272.

Adedire CO, Ajayi TS. 1996. Assessment of the insecticidal properties of some plant extracts as seed protectants against the maize weevil, *Sitophilus zeamais* Motsch. Nigerian Journal of Entomology 13: 93-101.

Asfaw Adugna. 2012. Population genetics and ecological studies in wild sorghum [*Sorghum* bicolor (L.)] in Ethiopia: PhD Thesis, Addis Ababa, Ethiopia.

Baidool PK, Mochiah MB, Akyaw MO. 2010. Levels of infestation on three different portions of the maize cob by the weevil *Sitophilus zeamais* (Motschulsky). Journal of Science and Technology 30 (3): 21-26.

Belmain SR, Neal GE, Ray DE, Golob P. 2001. Insecticidal and vertebrate toxicity associated with ethnobotanicals used as post-harvest protectants in Ghana. Food Chemistry Toxicity 39: 287-291.

Betancur JG, Concepción AJ, Fischer S, Zapta N. 2010. Insecticidal activity of Peumus boldus molina essential oil against *Sitophilus zeamais* Motschulsky. Journal of Agricultural Research 70 (3): 399-407.

Danga SP, Nukenin EN, Fotso GT, Adle C. 2015. Use of Neem product to control maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae) on three maize varieties in Cameroon. Agriculture and Food Security 4 (1): 2-7.

Dawit KZ, Bekele J. 2010. Evaluation of orange peel *Citrus sinensis* (L.) as a source of repellent, toxicant and protectant against *Zabrotes* *subfasciatus* (Coleoptera: Bruchidae). Mekelle University Journal of Science 2 (1): 61-75.

El-Ghar AE, El-sheikn G, Ghar AE, Gesa E. 1987. Effectiveness of some plant extracts as surface protectant of cowpea seed against the pulse beetle, *Callasobruchus. chinensis* Phytoparasistica 15: 109-113.

Esayas Mendesil, Chemeda Abdeta, Abush Tesfaye, Zekarias Shumeta, Habte Jifar. 2007. Farmers' perceptions and management practices of insect pests on stored sorghum in southwestern Ethiopia. Crop Protection 26 (12): 1817-1825.

Fekadu Gemechu, Waktole Sori, Santiago R. 2012. Evaluation of plant powders and cooking oils against maize weevil, *Sitophilus zeamais* M. (Coleopteran: Curculionidae) under laboratory conditions. Journal of Molecular Entomology 3 (2): 4-14.

Fikremariam Abebe, Tadele Tefera, Stephen Mugo, Yoseph Beyene, Stefan Vidal. 2009. Resistance of maize varieties to the maize weevil, *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). African Journal of Biotechnology 8 (21): 5937-5943.

Gabisa Ejeta, Grenier C. 2005. Sorghum and its weedy hybrids. pp. 123–135. *In*: Gressel Journal (eds.). Crop frailty and volunteerism. Boca Raton, Florida, USA.

Gebeyaw Tilahun. 2015. Evaluating seed protectant efficacy of some botanicals against maize weevil, *Sitophilus zeamais* Motsch. World Journal of Agricultural Research 3 (2): 66-69.

Girma Demissie. 2006. Field Infestation of maize by *Sitophilus zeamais* (Mostch.) (Coleoptera: Curculionidae) at Bako and its management on stored maize. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

Girma Demissie, Tadele Tefera, Abrham Tadesse. 2008. Importance of husk covering on field infestation of maize by *Sitophilus zeamais* Motsch. (Coleoptera: Curculiodea) at Bako, western Ethiopia. African Journal of Biotechnology 7: 3774-3779.

Ileke KD, Oni MO. 2011. Toxicity of some plant powders to *Sitophilus zeamais* (Coleoptera: Curculionidae) on stored wheat seeds. African Journal of Agricultural Research 6(13): 3043-3048.

Katamssadan HT, Nukenine EN, Stähler M, Adler C. 2015. Insecticidal efficacy of *Azadirachta indica* powders from sun and shade-dried seeds against *Sitophilus zeamais* and *Callosobruchus maculatus*. Journal of Entomology and Zoology Studies 3 (1): 100-108.

Khakame SK, Likhayo P, Olubayo FM, Nderitu JH. 2012. Effect of grain moisture content and storage time on efficacy of inert and botanical dusts for the control of *Sitophilus zeamais* in stored maize. Journal of Stored Products and Postharvest Research 3 (10): 142-151.

Muluken Goftishu, Ketema Belete. 2014. Susceptibility of sorghum varieties to the *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). African Journal of Agricultural Research 9 (31): 2419-2426.

Musa AK, Adewale SO. 2014. Peel and leaf powders of three fruits and a vegetable as promising botanicals against bean beetle, *Callosobruchus maculatus* F. in stored cowpea. Research Journal of Agriculture and Environmental Management 3 (10): 506-510.

Nukenine EK, Goudoungou JW, Adler C, Reichmuth C. 2010. Efficacy of diatomaceous earth and botanical powders against the maize weevil, *Sitophilus zeamais* (Motsch) (Coleoptera: Curculionidae) on maize. 10th International Working Conference on Stored Product Protection. Department of Biological Sciences, University of Ngaoundere, Ngaoundere, Cameroon.

Ogendo JO, Deng AL, Belmain SR, Walker DJ, Musandu AAO. 2004. Effect of Insecticidal Plant Materials, *Lantana camara* L. and *Tephrosia vogelii* Hook, on the Quality Parameters of Stored Maize Seeds. The Journal of Food Technology in Africa 9 (1): 29-36.

SAS. 2000. Statistical soft ware version 9.0.

Simbarashe M, James C, Benny M. 2013. Evaluation of *Eucalyptus tereticornis*, *Tagetes minuta* and *Carica papaya* as stored maize seed protectants against *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). Journal of Agriculture, Forestry and Fisheries 2 (5): 196-201.

Suleiman M, Ibrahim ND, Majeed Q. 2012. Control of *Sitophilus zeamais* (Motsch) (Coleoptera: Curculionidae) on sorghum using some plant powders. International Journal of Agriculture and Forestry 2 (1): 53-57.

Tabu D, Selvaraj T, Singh SK, Mulugeta N. 2012. Management of Adzuki bean beetle (*Callosobruchus chinensis* L.) using some botanicals, inert materials and edible oils in stored chickpea. Journal of Agricultural Technology 8 (3): 881-902.

Tadele Tefera. 2012. Post harvest losses in African maize in the face of increasing food shortage. Food Security 4: 267–277.

Tadele Tefera, Stephen M., Regina T. Paddy L. 2010. Mass rearing of stem borers, maize weevil, and larger seed borer insect pests of maize. CIMMYT: Nairobi, Kenya.

Temesgen Keba, Woktole Sori. 2013. Differential resistance of maize varieties to maize weevil (*Sitophilus zeamais* Motsch.) (Coleoptera: Curculionidae) under laboratory conditions. Journal of Entomology 10: 1-12.

Temitope OO. 2014. Evaluation of the powder of three medicinal botanicals in the control of, *Sitophilus zeamais* Motschulsky. Journal of Nature and Science 12 (11): 184-190.

USDA (United States Department of Agriculture). 2015. World Sorghum Production 2014/2015. https://www.worldsorghumproduction.com/ Accessed on April 8, 2015.

Waktole Sori, Amsalu Ayana. 2012. Storage pests of maize and their status in Jimma Zone, Ethiopia. African Journal of Agricultural Research 7 (28): 4056-4060.

Wani SP, Albrizio R, Vaija NR. 2011. Sorghum: Crop yield response to water. FAO, Rome Italy.