Evaluation of Integrated Management Options to Protect Stored Wheat and Maize from Insects

BY
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Evaluation of Integrated Management Options to Protect Stored Wheat and Maize from Insects

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Bahir Dar, Ethiopia
April, 2019
DECLARATION

I, the undersigned, certify that research work titled “Evaluation of Integrated Management Options to Protect Stored Wheat and Maize from Insects” is my work. The work has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged.

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BIOGRAPHICAL SKETCH

Mr. Karta Kaske Kalsa was born in 1979 and grew up in a rural area of the former Gamo Gofa administration, Ethiopia. He attended his elementary school at Ezzo and Kulfo Elementary Schools in Ezzo and Arba Minch. He attended his high-school at the then Arba Minch Comprehensive High-school, Arba Minch. After he completed high-school, Karta joined the then Alemaya University in 1998 and got his B.Sc. in Agriculture (Plant Sciences) in 2002. Later he joined the then Ethiopian Agricultural Research Organization (EARO) in 2003 at Kulumsa Agricultural Research Center and served at capacities of Junior Researcher and Assistant Researcher. In 2007 Mr. Karta joined Haramaya University to pursue his M.Sc. in Seed Science and Technology. In his M.Sc. study, he evaluated the vigor performance of stored vetch seed. Until September 2015, Karta served in the same institution as Associate Researcher and Researcher-I and authored and co-authored several peer-reviewed articles and conference papers. Karta started his Ph.D. study in October 2015 in Postharvest Technology at the Faculty of Chemical and Food Engineering of Bahir Dar University.
ማስታወሻነቱ ለታላቅ ወንድሜ አቶ ከታ ካስኬ ይሁንልኝ፡፡ ከልጅነቴ የሕይወት አቅጣጫዎቹ እንዲቀየር እግዚአብሔር እንተን እንደተጠቀመ አምናለሁ፡፡
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"አድራነትን እንደነት ከእነደ ያለፈነ ከመስማት ሊሸጥ ከምህርተናት.”

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Evaluation of Integrated Management Options to Protect Stored Wheat and Maize from Insects

Karta Kaske Kalsa
Bahir Dar University, 2019
## CONTENTS

ACKNOWLEDGMENTS ................................................................................................. i

LIST OF TABLES ........................................................................................................ vi

LIST OF FIGURES ...................................................................................................... viii

ACRONYMS ................................................................................................................ x

አፅህሮት ................................................................................................................... xi

ABSTRACT ................................................................................................................... xii

Chapter 1 : Introduction ........................................................................................... 1

References ................................................................................................................. 5

Chapter 2 : Assessment of major insect pests and their associated losses of farm-stored wheat seed .......................................................... 9

Abstract ..................................................................................................................... 9

2. 1 Introduction ......................................................................................................... 9

2. 2 Materials and Methods ...................................................................................... 10

2. 3 Results ................................................................................................................ 13

2. 4 Discussion .......................................................................................................... 18

2. 5 References .......................................................................................................... 22

Chapter 3 : Maize storage losses due to insects in five districts of Ethiopia ............... 25

Abstract ..................................................................................................................... 25

3. 1 Introduction ......................................................................................................... 25

3. 2 Materials and Methods ...................................................................................... 26

3. 3 Results ................................................................................................................ 29

3. 4 Discussion .......................................................................................................... 35

3. 5 References .......................................................................................................... 39

Chapter 4 : Evaluation of postharvest preservation strategies for wheat seed in Ethiopia ..... 42

Abstract ..................................................................................................................... 42
Chapter 5: Mortality of *Sitophilus granarius* (L.) and *Rhizopertha dominica* (F.) adults exposed to different concentrations of filter cake in stored wheat ................................................. 64

Abstract .................................................................................................................. 64

5. 1 Introduction ...................................................................................................... 64

5. 2 Materials and Methods .................................................................................. 65

5. 3 Results ............................................................................................................ 67

5. 4 Discussion ...................................................................................................... 70

5. 5 References ..................................................................................................... 72

Chapter 6: Evaluation of Ethiopian wheat varieties against *Sitophilus granarius* (L.) and *Sitophilus oryzae* (L.) infestation at optimal and sub-optimal temperatures ................................................. 74

Abstract .................................................................................................................. 74

6. 1 Introduction ...................................................................................................... 74

6. 2 Materials and Methods .................................................................................. 76

6. 3 Results ............................................................................................................ 78

6. 4 Discussion ...................................................................................................... 85

6. 5 References ..................................................................................................... 88

Chapter 7: On-farm performance and Assessment of farmers’ perceptions of hermetic bags for farm-stored wheat and maize in NorthWestern Ethiopia ......................................................... 93

Abstract .................................................................................................................. 93

7. 1 Introduction ...................................................................................................... 93

7. 2 Materials and Methods .................................................................................. 94

7. 3 Results ............................................................................................................ 96
7. 4 Discussion ..............................................................................................................101

7. 5 Reference.............................................................................................................103

Chapter 8 : Conclusion and Recommendation..........................................................106

8. 1 Conclusions ........................................................................................................106

8. 2 Recommendations ..............................................................................................106

Appendix – A: Checklist for assessment of farmers’ perceptions on utility of hermetic bags in Merawi and Wenberma districts, West Gojjam, Ethiopia .........................................................108

Appendix – B: Checklist for focus group discussion.................................................109
LIST OF TABLES

Table 2-1: Frequency of wheat varieties, chemical treated samples and samples with *Sitophilus* spp. ................................................................................................................................. 15
Table 2-2: Means (±SE) values of the abundance of *Sitophilus* spp., the percentage of insect-damaged kernels, and percentage weight loss .......................................................... 15
Table 2-3: Mean (±SE) percentage of germination, dead seed proportion and dockage of samples collected in June 2016 from different wheat growing districts of Ethiopia...17
Table 2-4: Percentage frequency of samples that comply with certified or emergency seed standards for germination ........................................................................................................... 18
Table 3-1: Mean (±SE) of major insects detected (counts per kg of maize) by maize growing districts ........................................................................................................................................ 32
Table 3-2: Mean (±SE) of grain weight loss (%) and insect damaged kernels (%) by maize growing districts ...................................................................................................................................... 32
Table 3-3: Pearson’s correlation insect abundance, temperature, relative humidity and grain moisture to the percentage of grain weight loss and insect-damaged kernels by maize growing districts ........................................................................................................................................ 35
Table 4-1: Mean (±SD) of live adults of *Rhyzopertha dominica* in wheat seed preserved using different strategies ................................................................................................................. 51
Table 4-2: Mean (±SD) of damage and weight loss of wheat seed preserved using different strategies. ................................................................................................................................................. 53
Table 4-3: Mean (±SD) of the bulk density of wheat seed preserved using different strategies. ................................................................................................................................................. 54
Table 4-4: Mean (±SD) of germination and vigor index (II) of wheat seed preserved using different strategies ......................................................................................................................... 56
Table 4-5: Pearson's correlation among seedling traits, seed biophysical traits, and some insect damage variables ...................................................................................................................... 57
Table 5-1: Mean± SE mortality (%) of *S. granarius* and *R. dominica* adults on untreated (control) wheat .......................................................................................................................... 67
Table 5-2: Mean (± SE) mortality (%) of *Sitophilus granarius* adults exposed to different concentrations of filter cake at three exposure times a, b, c .................................................. 68
Table 5-3: Mean (± SE) mortality (%) of *Rhyzopertha dominica* adults exposed to different concentrations of filter cake at three exposure times a, b, c .................................................. 68
Table 6-1: Single kernel characteristics of tested wheat varieties. ..........................78
Table 6-2: Mean (± SD) values of proximate composition of wheat varieties a ...............79
Table 6-3: Welch’s two-sample t-test between *Sitophilus granarius* and *Sitophilus oryzae*
infestation for live weevil counts, the percentage of insect-damaged kernels, grain
weight loss percentage and powder produced per gram of grain............................80
Table 6-4: Mean (± SD) values of live adult *Sitophilus granarius* and *Sitophilus oryzae*
counts per 30 g of wheat stored at two temperatures for 90 d a ..................................81
Table 6-5: Mean (± SD) percentage of grain weight loss of wheat varieties infested by
*Sitophilus granarius* and *Sitophilus oryzae* at two temperature for 90 d a ...............82
Table 6-6: Mean (± SD) percentage of insect-damaged kernels of wheat varieties infested by
*Sitophilus granarius* and *Sitophilus oryzae* at two temperatures for 90 d a ...............84
Table 6-7: Mean (± SD) amounts of powder produced in mg per gram of grain of wheat
varieties infested by *Sitophilus granarius* and *Sitophilus oryzae* at two temperatures
for 90 d a ..................................................................................................................85
Table 6-8: Multiple regression analysis of the effects of kernel characteristics on the
percentage of grain weight loss, the percentage of insect-damaged kernels, and
amount of powder produced. .....................................................................................86
Table 6-9: Multiple linear regression analysis of the effects of the proximate composition of
wheat varieties on weevil population development, the percentage of grain weight
loss, the percentage of insect-damaged kernels, and powder production. a, b, c ..........87
Table 7-1: Analyses of variance for live weevil counts, total weevil counts, the percentage
of insect-damaged kernels and grain weight loss of maize stored in farmers’ houses
between June and September 2016 ...........................................................................97
Table 7-2: Mean (±SE) of weevil abundance and number of insect-damaged kernels of wheat
seed stored in farmers’ houses at Wenberma from January to June 2017 ....................99
Table 7-3: Mean (±SE) of seed quality characteristics of farmstored wheat in hermetic bags.
a ..................................................................................................................................100
Table 7-4: Farmers’ perception on the utility of hermetic bags in Merawi and Wenberma
districts .......................................................................................................................101
Table 7-5: Probit analysis of factors influencing farmers’ tendency for future use of hermetic
bags a, b, c ..................................................................................................................103
LIST OF FIGURES

Figure 2-1: Map of wheat sampling districts ................................................................. 11

Figure 2-2: Relationship between weevil density and percentages of insect-damaged kernels and seed weight loss, a, b ........................................................................................................... 21

Figure 3-1: Map of maize sampling districts ................................................................. 27

Figure 3-2: Mean (±SE) relative humidity (%) and temperature (°C) within storage structures in five maize growing districts in June 2016. ................................................................. 30

Figure 3-3: Frequency (%) of samples with Sitotroga cerealella, Tribolium confusum, and Sitophilus zeamais in five maize growing districts in June 2016. ............................................ 31

Figure 3-4: Means of grain weight loss (%) by maize varieties used by farmers .......... 33

Figure 3-5: Means of grain weight loss (%) by type of storage structures used by farmers, a ............................................................................................................................... 34

Figure 3-6: Mean (±SE) of grain weight loss (%) by type of pesticide used by farmers. ...... 34

Figure 3-7: Effects of total live insect specimen abundance (counts per kg) on the percentage insect-damaged kernel, a, b .......................................................................................... 38

Figure 4-1: Mean (±SD) Oxygen and Carbon dioxide levels of wheat seed kept in Super GrainPro bag (SGB) and Purdue Improved Crop Storage (PICS) bags over six months of storage. Data are based on three replications ........................................................................ 49

Figure 4-2: Mean (±SD) moisture and inter-granular temperature of wheat seed preserved using different strategies .................................................................................................................. 50

Figure 4-3: Mean (±SD) loss of bulk density (%) of wheat seed preserved using different strategies .......................................................................................................................... 54

Figure 5-1: Linear regression of adult mortality rate of Sitophilus granarius at different rates of filter cake application and exposure time in stored wheat .................................................................... 69

Figure 5-2. Log-logistic binomial regression of mortality rate of adult insects of granary weevil (Sitophilus granarius) exposed to different application rates of filter cake for three days, a ........................................................................ 70

Figure 5-3: Dead adults of Sitophilus granarius (A) and Rhizopertha dominica (C) recovered from wheat grain treated with 10000ppm filter cake (B) at 3 days after treatment ........................................ 71

Figure 7-1: Mean (±SE) of weevil abundance (counts per kg of seed) of maize stored in farmers’ houses between June and September, 2016, a, b ........................................................................ 97
Figure 7-2: Mean (±SE) percentage of insect-damaged kernels and grain weight loss of maize stored in farmers’ houses between June and September 2016.\textsuperscript{a,b} ......................................................... 98

Figure 7-3: Mean (±SE) of seed weight loss (the %), the percentage of insect-damaged kernels and percentage loss of bulk density (test weight) of wheat seed stored using hermetic bags at farmers’ houses in Wenberma from January to June 2017 \textsuperscript{a,b}. ......................................................... 100

Figure 7-4: Damaged wheat kernels collected at the outset of on-farm storage experiment at Wenberma district in January 2017. ........................................................................................................... 102
### ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<tr>
<td>APHLIS</td>
<td>African Postharvest Information System</td>
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<tr>
<td>CIMMYT</td>
<td>International Maize and Wheat Improvement Center</td>
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<tr>
<td>CL</td>
<td>Confidence Limit</td>
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<tr>
<td>CSA</td>
<td>Central Statistical Agency</td>
</tr>
<tr>
<td>DF</td>
<td>Degrees of Freedom</td>
</tr>
<tr>
<td>ED50</td>
<td>Effective Dose for 50% mortality</td>
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<tr>
<td>ED95</td>
<td>Effective Dose for 95% mortality</td>
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<tr>
<td>GLM</td>
<td>General Linear Model</td>
</tr>
<tr>
<td>GPS</td>
<td>Geographic Positioning System</td>
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<tr>
<td>ISTA</td>
<td>International Seed Testing Association</td>
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<tr>
<td>NIRT</td>
<td>Near Infra-red Transmittance</td>
</tr>
<tr>
<td>PICS</td>
<td>Perdue Improved Crop Storage bag</td>
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<tr>
<td>ppm</td>
<td>Parts per Million</td>
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<tr>
<td>REGW</td>
<td>Ryan-Einot-Gabriel-Welsch</td>
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<tr>
<td>SAS</td>
<td>Statistical Analysis System</td>
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<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<td>Standard Error</td>
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<td>SNNPR</td>
<td>Southern Nations, Nationalities, and Peoples Region</td>
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Evaluation of Integrated Management Options to Protect Stored Wheat and Maize from Insects

Karta Kaske Kalsa, Ph.D. Dissertation, July 2019

ABSTRACT

Increasing food availability without any compromise to the environmental and social sustainability demands critical planning and exploitation of other solutions than field level yield increases. Reducing storage losses can be a viable strategy to increase food availability. Among others, insects are important causes of losses in stored cereals. The aim of the present studies was to understand the current status of storage insects and their associated losses under farmers’ storage conditions and to identify suitable insect management options for designing of an integrated approach for stored wheat and maize. One kg samples of stored wheat were collected from a total of 150 farmers in five districts viz. Ofila, Wenberma, Lemu, Gedebo, and Hetaosa. Similarly, maize samples were collected in June 2016 from a total of 150 farming households distributed in five maize growing districts viz. Merawi, Wenberma, Chelia, Toke Kutaye, and Alaba. Postharvest preservation options vis. (1) Metal silos, (2) Purdue Improved Crop Storage (PICS) bags, (3) Super GrainPro bags, (4) industrial filter cake dust applied to wheat in polypropylene bag, (5) plastic drums, 6) Triplex applied to wheat in polypropylene bag, 7) Triplex applied to wheat in plastic drum, and 8) polypropylene bag as control were tested for wheat storage. A separate study was also conducted to determine the efficacy of filter cake (silica-based inert dust) on the granary weevil, Sitophilus granarius (L.) and lesser grain borer, Rhyzopertha dominica (F.) in stored wheat. Filter cake dust of ≤0.4 mm particle size was admixed with 500 g of wheat seed to provide nominal rates of 10000, 7500, 5000, and 2500 ppm (mg/kg), while the control treatment consisted of wheat seeds that were untreated. In another study, the response of different varieties of wheat seed to the infestation by the granary weevil, Sitophilus granarius (L.) and rice weevil, Sitophilus oryzae (L.) at optimal and sub-optimal temperatures was determined. Seeds of six wheat varieties namely, Danda’a, Digalu, ET-13-A2, Kakaba, Millennium, and Pavon-76 were examined at temperatures of 19 and 30°C over a period of 90 d. Finally, two on-farm experiments (in Wenberma and Merawi districts of West Gojjam) and a perception survey were conducted to evaluate the effectiveness of hermetic storage bags and to assess farmers’ perceptions towards the utility of the technologies. The results showed that the storage loss of wheat to insects was 0.7 to 2.5% with a national average of 1.5%; and the predominant insects detected were Sitophilus spp (S. oryzae/ S. zeamais), Sitophilus granarius, Sitotroga cerealella. Storage loss of maize to insects was 4.2 to 8.1% with a national average of 6.0%; and the predominant primary insects detected were Sitophilus zeamais, Sitotroga cerealella. The inert dust such as filter cake and Triplex were effective in preserving wheat seed. Hard wheat varieties were least suitable for weevil population development at 30°C as well as 19°C temperatures and S. granarius was more devastating compared with S. oryzae. Future works should focus on the integration of the tested strategies in order to combat storage losses.

Keywords: Seed quality, stored product insect pests, Ethiopia, Hermetic storage, Inert dust
CHAPTER 1 : INTRODUCTION

The continuing world population growth and the resultant increase in food consumption call for comprehensive global approaches to ensure sustainable food security. Due to the limitation on the available land, the most likely scenario to feed the expected 9 billion people in 2050 is that more food will need to be produced from the same amount of land (Godfray et al., 2010). But, the yield trend in the four key global crops—maize, rice, wheat, and soybean—that currently produce nearly two-thirds of global agricultural calories is far below what is needed to meet projected demands (Ray et al., 2013). Increasing food availability without any compromise to the environmental and social sustainability demands critical planning and exploitation of other solutions than field level yield increases (Alexander et al., 2017; Chaboud & Daviron, 2017; Godfray et al., 2010).

Ethiopia is a leading producer of wheat and the 3rd largest producer of maize in sub-Saharan Africa (IndexMundi, 2019). Yield increasing technologies such as improved varieties, mineral fertilizer, and increased extension education have all contributed for significant improvement in productivity per unit area of grain crops in the country (Kotu & Admassie, 2016). In Ethiopia, wheat and maize yield increased from below 1.5 metric tons per ha before two decades to about 2.7 metric tons per ha and 3.9 metric tons per ha, respectively, in recent years (Central Statistical Agency, 2018). Currently, wheat and maize are making about 48% of the total cereals and 43% of the total grain production in the country with a total production of 13 million metric tons. However, poor postharvest storage results in loss of about 6.6% of wheat and 20.8% of maize in the country (APHLIS, 2019).

Reducing postharvest losses is a key pathway to food and nutrition security in sub-Saharan Africa (Affognon et al., 2015). However, postharvest loss estimates in the region remain scarce, or they are mainly based on self-reported loss measures from household surveys (Kaminski & Christiaensen, 2014). In their recent review, Sheahan & Barrett (2017) suggested that investing in a better understanding of the rate of postharvest loss is crucial before funneling more funds to postharvest loss reduction technologies or processes that may have little payoff. Therefore, a clear understanding of the extent of loss being incurred at every segment of the postharvest stage can provide platforms for an informed decision.

In a recent review, Chaboud & Daviron (2017) defined postharvest food losses as all food products produced for human consumption, which have changed availability, wholesomeness or quality, rendering them unfit for human consumption. Reducing food
losses would offer an important way of increasing food availability without requiring additional production resources (Kadjo et al., 2016; Tesfaye & Tirivayi, 2016; Godfray et al., 2010). Storage losses can be classified into two categories: direct losses, due to the physical loss of commodities; and indirect losses, due to the loss in quality and nutrition (Kumar & Kalita, 2017). Losses of quality or wholesomeness are explained by the loss of value of salable food. In Benin, a 10% increase in insect damage resulted in a 9% maize price discount (Kadjo et al., 2016). Reducing postharvest loss, therefore, not only increases food availability but also improves family income (Chegere, 2018). Quality losses can also be expressed as a loss of seed germination (Boxall, 2001) that affects the household future food security.

In the developing world, food losses are mainly attributable to the absence of food-chain infrastructure and the lack of knowledge or investment in storage technologies on the farm (Godfray et al., 2010). In Ethiopia, farm-storage loss of wheat is estimated to be 6.6% (FAO, 2017) while that of maize is about 7.8% (Chegere, 2018).

Wheat and maize storage losses can be caused by biological factors such as insects, molds, and rodents (Tefera, 2012; Tadesse et al., 2008; Abdulahi & Haile, 1991). The latter two are not within the scope of this dissertation. Reports on measured losses caused by stored product insects are fragmented and inconsistent in Ethiopia and other SSA countries (Sheahan & Barrett, 2017; Hodges, 2012; Tadesse et al., 2008; Tadesse & Basedow, 2004).

Insects are major causes of spoilage and loss of wheat stored by smallholder farmers of Ethiopia (Dessalegn et al., 2017). Recent studies on insect pests and associated losses of stored wheat are lacking in the country. However, Abdulahi & Haile (1991) listed out the most important insect pest species such as the granary weevil *Sitophilus granarius* (L), the rice weevil *Sitophilus oryzae* (L.), the maize weevil *Sitophilus zeamais* Motsch., *Ephestia cautella* (Hübner), lesser grain borer *Rhyzopertha dominica* (F.), Angoumois grain moth *Sitotroga cerealella* (Oliv.), merchant grain beetle *Oryzeaphilus mercator* (Fau-vel), saw-toothed grain beetle *Oryzeaphilus surinamensis* (L.), red flour beetle *Tribolium castaneum* (Herbst) and the confused flour beetle *Tribolium Confusum* (J.) before two decades. Previous reports also indicated that major stored maize insects recorded in Ethiopia were *R. dominica*, *Cryptolestes* spp., *S. zeamais*, *S. oryzae*, *S. cerealella*, *Carpophilus* spp., *E. cautella*, *Plodia interpunctella* (Hübner), *T. castaneum*, *T. confusum* (Tadesse et al., 2000). However, *S. zeamais* followed by *S. cerealella*, *S. oryzae* and *T. confusum* were reported as major pests of stored maize in traditional storage structures in Jimma, southwest of Ethiopia (Sori & Ayana, 2012).
Different management measures are taken by smallholder farmers to protect stored wheat and maize from insect damage. Farmers use such storage insect management practices as mixing the seed with botanicals and inert dust, treatment with synthetic chemicals, and physical methods such as smoking and drying (Dessalegn et al., 2017; FAO, 2017). Earlier reports also indicated that farmers had used different traditional methods to protect their seeds from infestation with storage insects (Blum & Bekele, 2001; Tadesse et al., 2000). The findings by Beyene & Ayalew (2015) also indicated that drying and malathion dust are the most commonly used (each 65%) control method followed by pirimiphos-methyl (Actellic) dust (34%), application of traditional herbs (21%) and fumigant (Phosphine gas) (20%). However, their low efficacy against target storage insects due to inappropriate application methods (Mlambo et al., 2018; Kumar & Kalita, 2017; Meikle et al., 2002), and probably the development of insecticidal resistance by insects as result of repeated use of chemicals (Boyer et al., 2012; Subramanyam & Hagstrum, 1996) are challenges in protecting seeds stored by smallholder farmers. Delayed treatment, adulterated chemicals, and incorrect dosage can reduce the efficacy of synthetic insecticides and result in high storage losses (Kumar & Kalita, 2017).

Various storage techniques such as use of hermetic bags, metal silos, inert dusts, botanicals, and varietal resistance which are proven as good alternatives to chemical use at small-scale level have been reported by researchers from Ethiopia and elsewhere (Martin et al., 2015; Gitonga et al., 2013; Demissie et al., 2011). Martin et al. (2015) reported that storing rice weevil infested wheat in Perdue Improved Crop Storage (PICSTM) bag (a triple layer with inner two layers made of high-density polyethylene and the outer layer made of the woven plastic bag as protection) arrested weevil population growth and preserved the seed well. However, research reports on the efficacy of such storage technologies are rarely available in Ethiopia. Metal silos have been reported as an effective method to protect stored cereals from insect damage at small-scale levels (Gotinga et al., 2013; Tefera et al., 2011; Yusuf & He, 2011). These reports, however, have lacked the efficacy of the metal silos in arresting population growth of insects in stored wheat under half-filled conditions. Demissie et al. (2008) evaluated the effectiveness of the diatomaceous earth Silicosec, a mineral industrial filter cake and domestic wood ash, applied at three different rates for the control of the maize weevil, Sitophilus zeamais, on three maize genotypes. However, the efficacy of filter cake dust on wheat seed has not been documented beyond laboratory scales (Tadesse and Subramanyam, 2018). In addition to the use of physical and biological techniques to
control insect infestation, previous studies have indicated that there is a growing interest in utilizing the inherent characteristics of resistance of crop varieties against insect damage (Tripathi et al., 2018; Demissie et al., 2015; Mwololo et al., 2012). Reports of variety resistance studies in Ethiopia are limited to maize, and studies on wheat varieties are rarely available in the literature.

The dissertation was organized based on the fact that information on storage losses of wheat and maize due to insects is still limited and subjective. Besides, stored wheat and maize protection by farmers is predominantly by application of synthetic pesticides. But, farmers are using pesticides improperly that there are health and environmental implication. Alternative management options are urgently needed, and if available, they have to be properly available for wider use.

The present dissertation study, therefore, aimed at understanding the current status of storage insects and their associated grain losses under farmers’ storage conditions and to identify suitable insect management techniques for designing of an integrated approach. Specific objectives were to: 1) estimate wheat and maize storage losses due to insects; 2) identify postharvest preservation strategies for small-scale storage of wheat; 3) determine the efficacy of different concentrations of filter cake powder against S. granarius and R. dominica; 4) determine relative susceptibility of Ethiopian wheat varieties to Sitophilus granarius and Sitophilus oryzae at optimal and sub-optimal temperatures, and 5) to evaluate the effectiveness of hermetic storage bags under farmers’ conditions and assess the perceptions of farmers towards the utility of hermetic bags.

In chapter 2 and 3 of this dissertation, 150 samples collected from five districts for each of farm-stored wheat and maize were collected, and losses due to insects were analyzed. The wheat districts were Ofla, Wenberma, Gedeb, Hetosa, and Lemo whereas maize districts were Merawi, Wenberma, Chelia, Toke Kutaye, and Alaba. In chapter 4, strategies for postharvest preservation of wheat seed were evaluated. Seven strategies such as the PICS bag, Super GrainPro bag, the metal silo, plastic drum, filter cake powder, and triplex powder were compared with storing seed in polypropylene bags without any treatment. In chapter 5, reduced concentrations of the filter cake powder were evaluated against adult mortality of S. granarius and R. dominica. In chapter 6, responses of Ethiopian wheat varieties to S. granarius and S. oryzae infestations were evaluated at 19°C and 30°C. Wheat varieties included Danda’a, Digalu, ET-13-A2, Kakaba, Millennium, and Pavon-76. In chapter 7, results from the on-farm performance of hermetic storage bags such as Super GrainPro bag
and PICS bag are presented from Merawi and Wenberma districts in West Gojjam zone. Besides, perceptions of farmers towards the utility of hermetic bags were assessed. Finally, chapter 8 presents the conclusions and recommendations based on the results obtained in the present dissertation.

References


Ethiopia.


Hodges, J. (2012). *Postharvest Weight Losses of Cereal Grains in Sub- Saharan Africa*
Postharvest Weight Losses of Cereal Grains in Sub-Saharan Africa


CHAPTER 2: ASSESSMENT OF MAJOR INSECT PESTS AND THEIR ASSOCIATED LOSSES OF FARM-STORED WHEAT SEED

Abstract

There is considerable debate over the importance of losses associated with insect pests of stored wheat at the farm level in Ethiopia. A survey was conducted to assess major insects and their associated losses of farm-stored wheat in five districts from Amhara, Oromiya, SNNP and Tigray regional states of Ethiopia in the year 2016. One kg samples of eight months stored wheat seed were collected from a total of 150 farmers, randomly selected. The samples were kept in the laboratory for ca. six weeks to allow the development and emergence of insects present inside the seed. Data were collected for different parameters after six weeks, the samples were sieved to separate insect from the seeds and the resultant live and dead insects, seed weight loss, seed damage, and loss of seed germination were determined. Results showed that major primary insect pests identified were *Sitophilus granarius*, *Sitophilus* spp. (*S. oryzae* / *S. zeamais*), and *Sitotroga cerealella*. Secondary pests such as *Tribolium* spp., *Plodia interpunctella*, and *Liposcelis* spp. were detected only in few samples. Wheat experienced mean percentage kernel damages ranging from 3.6% to 13.6%. The overall mean weight loss to insects was 1.5% while mean seed germination percentage was only 72.3%. The present survey indicated that farmers are incurring a considerable loss of stored wheat due to insects. Hence, there is an urgent need to devise appropriate options for protecting the loss of farm-stored wheat in Ethiopia.

Keywords: wheat; stored-product insect pests; germination; weight loss; storage

2.1 Introduction

Among others, biological spoilage is the main cause of postharvest crop losses in developing countries, including Ethiopia (Hodges et al., 2011). Regardless of the causes, postharvest crop loss during storage in developing countries is about 5 to 10% in general (Hodges et al., 2011) and about 14-23% in wheat during various stages of handling in Ethiopia (Dessalegn et al., 2017).

The major of primary insect pests of global importance in cereals include the genus *Sitophilus*; lesser grain borer, *Rhyzopertha dominica* (F.); greater grain borer, *Prostephanus truncatus* (Horn); and Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Athanassiou & Arthur, 2018). Similarly, in Ethiopia, the dominant primary storage insect pests associated with stored wheat include the granary weevil, *Sitophilus granarius* (L.); rice weevil,
Sitophilus oryzae (L.); maize weevil, Sitophilus zeamais Motschulsky; (R. dominica; and S. cerealella (Tadesse et al., 2008; Abdulahi & Haile, 1991). Major secondary storage pests in wheat include Oryzaephilus spp.; the red flour beetle, Tribolium castaneum (Herbst); confused flour beetle, Tribolium confusum Jacquelin du Val; and almond moth, Cadra cautella Walker (Tadesse et al., 2008). Psocids are also becoming severe pests and drawing global attention (Athanassiou & Arthur, 2018), but they have been uncommon in grain stores of Ethiopia (Tadesse et al., 2008).

Based on a recent survey, 83% of 200 wheat farmers in Ethiopia perceived that postharvest losses during storage are caused mainly by insect pests (Dessalegn et al., 2017). However, the perceptions of wheat farmers remain unsubstantiated by measurement of such losses in storage. Earlier reports on losses associated with insects of stored wheat under farmers’ conditions are fragmented and inconsistent. A report by Boxall (1998) indicated that wheat loss in Ethiopia due to storage insects is estimated to be about 0.5%, but in some parts of the country, losses due to Sitophilus spp. were as high as 4.2% (Abdulahi & Haile, 1991). Hence, there is a limited consensus among researchers regarding the extent of losses being incurred by Ethiopian wheat farmers due to storage insects.

Due to limited information on the importance of insect pests on stored wheat, postharvest protection research did not receive adequate attention. Besides, limited information exists in the literature concerning losses of seed germination as a result of insect damage to wheat seed. Therefore, the present study was initiated to assess major insects of stored wheat and their associated losses in quantity and quality (germination) in the main wheat growing districts in Ethiopia.

2.2 Materials and Methods

Description of study areas

The study covered five major wheat growing districts across four regional states, namely Tigray, Amhara, Oromiya, and Southern Nations, Nationalities and Peoples Region (Figure 2-1). The five districts were Ofla, Wenberma, Hetosa, Gede, and Lemo. Georeferenced readings of all visited sites lie between 7.093°N-12.553°N and 37.925°E-39.4910C with altitudes ranging from 2046m to 2468m above sea level.

Sampling

The assessment was conducted after eight months of storage. Wheat samples were collected from a total of 150 farm stores in five potential wheat growing districts, in Amhara,
Oromiya, SNNP, and Tigray in June 2016. From each district, one kebele was selected based on its surplus production. A total of 30 farmers who grow wheat were randomly selected from each study kebele. A household was used as a sampling unit. One sample was taken after every third household. When adult family members were missing for responses on storage information, the next household was considered.

Seed sampling was carried out by hand from storage structures, and a representative sample of about 1kg was taken. At times of sampling, data on the age of seed (how long it was stored from harvest), storage structure and approximate quantity of stored seed, any pesticide treatment (the type of pesticide), grain moisture content, and wheat variety were recorded.

![Figure 2-1: Map of wheat sampling districts](image)

**Types, incidence, and densities of storage insects**

All of the 1 kg seed samples from each farmer was brought to the laboratory and sifted using three layers of standard sieves (Supertek Scientific, Illinois, USA) (2.3 mm, 1.6 mm, 0.4 mm served as the top, middle and lower sieve, respectively) with a bottom pan to receive dust. All live and dead adults of each insect species were counted. Dockage (excluding dead/live adult insects) was returned to the sample and placed in a 1-L jar to be incubated for approximately six weeks under room temperature and humidity conditions to recover insects which did not complete their development. After six weeks of incubation,
samples were sifted again, and insects that emerged were removed and counted by species. The two counts were summed to get the total live adult insects in the sample.

Insects were collected and morphologically identified to genera and species level, where possible, using a stereomicroscope, following identification keys as described in Reichmuth et al. (2007). *S. oryzae* and *S. zeamais* were identified by observing four reddish-orange spots on the elytra and puncture-free medial longitudinal area on the pronotum of the *S. oryzae*. Where confusions arise between *S. oryzae* and *S. zeamais*, the aedeagus of male genitalia were assessed for the presence or absence of grooves. The apex of Y-sclerite of female genitalia was also assessed to determine if it was round or pointed (Hidayat et al., 1996). However, to avoid possible errors in identification, the phrase *Sitophilus* spp. was used throughout this document. Identification of *Liposcelis* spp. was to the genus level. For all other insects including *S. granarius*, identifications were done to the species level.

**Seed damage and weight loss assessment**

Whole seed samples were divided following the quartering and conning technique until a final sample of around 100 g of seed was obtained. From 100 g of seed, damaged and undamaged kernels were separated, counted, and weighed. Mechanical damage was included in dockage (when it was <50% of the average size). Insect damaged kernels were visually identified based on holes made by boring insects and destruction of germs by larvae of *P. interpunctella*. Seed damage rates were calculated using the following equation (Mohammed and Tadesse, 2018): Damage (%) = Number of damaged kernels ÷ Number of kernels in 100 g of seed. Seed weight loss was estimated using the equation:

Seed weight loss (%) = \[(WU*ND)-(WD*NU)]*100\/[WD*(NU+ND)], where, WU is the weight of undamaged seeds, NU is the number of intact seeds, WD is the weight of damaged seeds, ND is the number of damaged seeds.

**Germination testing**

Seed samples were subject to germination testing using the standard method as prescribed for wheat in ISTA (2014) with modifications. Germination test was carried out in two runs of 100 seeds. Seeds (randomly picked damaged and undamaged seeds) were placed in plastic bowls on top of 15cm diameter sterile germination papers. The germination papers were soaked in distilled water before sowing the seeds. The bowls, then, were covered with a glass lid and placed in a germination room adjusted at 20°C temperature. Normal and
abnormal seedlings and dead seeds were assessed eight days after sowing, and percentages were calculated.

Dockage

The 1 kg samples brought to the laboratory were sifted, and components such as whole seed and dockage were weighed separately. All inert matters below the sieve containing the sound seed were combined and weighed together, and percentage of dockage was calculated as: Dockage (%) = [Weight of sifted material and seeds damaged mechanically ÷ Total weight of sample] * 100.

Data analysis

Qualitative and quantitative data collected through checklists and measurements on samples were subjected to statistical analysis using R Version 3.5.0 (The R Foundation for Statistical Computing, 2018). Cross-tabulations were constructed for nominal parameters, and descriptive statistics were calculated to summarize data on wheat varieties grown, storage methods, insecticide application, and insect incidence. Association between nominal parameters was tested using two-sided Fisher’s exact test (Zar, 1987).

Measurement variables were subject to one-way analysis of variance to detect differences among samples from the five study districts. Parametric inferences (regardless of the population distribution) were used on randomly selected 30 samples from each district. Multiple comparisons of means were carried out using Tukey’s Honest Significant Difference test. Welch two-sample t-test was carried out to examine the association of measurement and count variables for pesticide application and wheat varieties (old/obsolete and new/recent). Varieties were grouped old/obsolete based on that they were no longer appropriate for the purpose of disease resistance due to the availability of better alternatives regarding such traits. Student’s t-test for one sample (McDonald, 2014) was performed to compare the overall weight loss (%) with a previously reported loss (theoretical expectation) for wheat due to insects in Ethiopia (Boxall, 1998).

2.3 Results

Wheat varieties

There were significant differences among seed samples regarding the wheat variety they belonged to across all districts ($P < 0.01$). All the samples from Wenberma district and Gedeb district were seeds of Kakaba and Kubsa, respectively. Kubsa (70%) was also produced in Hetosa district. About 43.3% of samples from Lemo district were varieties
Danda’a and Hidasie; while older varieties Galama and Digelu constituted about 56.7% of the sample. A majority (73.3%) of samples from Ofla district were new/recent wheat varieties, Danda’a and Hidasie, while only a few of the samples were grouped as mixtures or local varieties. Overall, 49.3% samples belonged to new/recently released varieties while the rest were from old/obsolete varieties. The most common new/recently released varieties grown by farmers in the studies areas were Danda’a, Hidasie, Kakaba, Kingbird, and Ogolcho.

Storage methods and insecticide use

Farmers in the studied districts mainly used traditional containers for storage of wheat seed but differed highly significantly \((P < 0.01)\) in the type of storage structure they use. Traditional storage containers of wheat seed in the surveyed areas included woven bags (jute bags and polypropylene bags) (90.7%, \(n=150\)), gota or gotera (8.0%) and metal/plastic drums (1.3%). All sample households in Gedeb, Hetosa, and Lemo districts, 73.3% \((n=30)\) in Ofla, and 80.0% \((n=30)\) in Wenberma districts stored wheat seed in polypropylene bags. Gota, godo or gotera storage was used for wheat seed storage in both Ofla and Wenberma districts.

Regarding type of insecticides used, farmers reported that they used primiphos-methyl dust, malathion dust, and aluminum phosphide fumigant against insects in stored wheat. One farmer in Lemo district and two farmers in Wenberma district used neem tree \((Azadirachta indica\ A.\ Juss)\) leaves and hot pepper powder, respectively. A farmer in Lemo district layered neem tree leaves after filling every 100 kg of bulk wheat. Farmers reported that they mixed hot pepper powder with the seed at the beginning of the storage.

The type of chemical used by farmers was cross-validated through focus group discussions with experts from offices of agriculture, local development agents, and farmers. About 62.3% \((n=53)\) of farmers, mainly in Hetosa and Ofla districts, treated their grain with fumigants; while malathion and primiphos-methyl dusts were used by about 20.8% and 9.4% \((n=53)\) of the farmers, respectively.

Types, incidence, and densities of storage insects

*Sitophilus* spp. (primarily *S. oryzae* and *S. zeamais*) were detected in samples from almost all districts (Table 2-1). Out of 150 samples collected from the five districts, about 81.3% were positive to *Sitophilus* spp. Within each district the frequency of *Sitophilus* spp. occurrence ranged from 50.0 to 100 % (Table 2-1).

The density of live adult *Sitophilus* spp. was assessed by study districts and by chemical treatments on the stored seed. Live adult *Sitophilus* spp. density per kg of seed
sample indicated that there were significant differences ($P < 0.01$) among samples across studied districts (Table 2-2). The mean densities of live *Sitophilus* spp. ranged from 73.0 to 418.3 insects per kg. It was learned from our focus group discussions that the higher rate of insect infestation in samples from Wenberma district could be attributed to the unseasonal rain that occurred during harvesting.

Our results also demonstrated that the means of *Sitophilus* spp. densities of samples which received chemical treatment at storage (227.0 insects per kg) were statistically similar ($t = -0.51; \text{df} = 96; P = 0.61$) to those which did not receive any treatment with synthetic insecticides (259.4 insects per kg). This could be due to inappropriate use of chemicals by farmers.

Table 2-1: Frequency of wheat varieties, chemically treated samples, and samples with *Sitophilus* spp. a, b, c

<table>
<thead>
<tr>
<th>Study Districts</th>
<th>Samples of a New/Recent variety (%)</th>
<th>Chemical treated samples (%)</th>
<th>Samples with <em>Sitophilus</em> spp (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gedeb</td>
<td>0.0 a†</td>
<td>6.7a†</td>
<td>86.7 a†</td>
</tr>
<tr>
<td>Hetosa</td>
<td>30.0b</td>
<td>63.3bc</td>
<td>100.0a</td>
</tr>
<tr>
<td>Lemo</td>
<td>43.3b</td>
<td>0.0a</td>
<td>83.3 a</td>
</tr>
<tr>
<td>Ofla</td>
<td>73.3c</td>
<td>36.7b</td>
<td>50.0 b</td>
</tr>
<tr>
<td>Wenberma</td>
<td>100.0d</td>
<td>70.0c</td>
<td>86.7a</td>
</tr>
<tr>
<td><strong>P-values</strong></td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

aNew/Recent varieties (Danda’a, Hidasie, Kakaba, Kingbird, Ogolcho); Old/Obsolete varieties (Galama, Kubsa, Digelu, Local, Mixture).
bChemical insecticides reported as used by farmers included Malathion, Actellic (primiphos-methyl), and Phosphine tablets.
cGroups sharing a letter are not significantly different at Fisher’s 5% level of significance (two-sided).

Table 2-2: Means (±SE) values of the abundance of *Sitophilus* spp., the percentage of insect-damaged kernels, and percentage weight loss. a, b

<table>
<thead>
<tr>
<th>Study Districts*</th>
<th><em>Sitophilus</em> spp. (counts/kg)</th>
<th>Insect-Damaged Kernels (%)</th>
<th>Seed weight loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gedeb</td>
<td>206.1±49.0ab ‡</td>
<td>3.8±0.6b ‡</td>
<td>0.8±0.2b ‡</td>
</tr>
<tr>
<td>Hetosa</td>
<td>234.6±55.7ab</td>
<td>4.8±0.9b</td>
<td>1.2±0.2</td>
</tr>
<tr>
<td>Lemo</td>
<td>260.2±73.7ab</td>
<td>3.6±1.3b</td>
<td>0.7±0.3</td>
</tr>
<tr>
<td>Ofla</td>
<td>73.0±27.9b</td>
<td>11.1±3.1ab</td>
<td>2.5±0.8</td>
</tr>
<tr>
<td>Wenberma</td>
<td>418.3±76.4a</td>
<td>13.6±3.1a</td>
<td>2.3±0.6</td>
</tr>
<tr>
<td><strong>F₄, 145</strong></td>
<td>3.92</td>
<td>4.54</td>
<td>2.19</td>
</tr>
<tr>
<td><strong>P-values</strong></td>
<td>&lt;0.01</td>
<td>0.002</td>
<td>0.073</td>
</tr>
</tbody>
</table>

aMeans with the same letter are not significantly different at Tukey’s 5% level of significance.
bData are Means ± SE based on 30 samples from each district.

Prevalence of *S. granarius*, *S. cerealella*, *R. dominica*, *Liposcelis* spp. and *P. interpunctella* was limited to one or two districts. *S. granarius* was detected in 70% of
samples from Ofla district while it was not detected in samples from other districts. The mean density of *S. granarius* in samples from Ofla district was 209.4 (min/max = 0/1277) insects per kg (N=30). *S. cerealella* was detected in few samples from Wenberma (13.3%, N=30) and Hetosa (3.3%, N=30) districts with mean (N=30) abundance of 4.3 (min/max =0/47) insects per kg and 0.03 (min/max =0/1) insect per kg, respectively. *R. dominica* was mainly detected in Wenberma district in two samples at densities of four insects per kg and one insect per kg. *P. interpunctella* is primarily detected in samples from Wenberma district at a mean density of 4.3 (min/max =0/58) live adult insects per kg (N=30).

*Tribolium* spp. and psocids were also prevalent in some samples. *Tribolium* spp. was mainly detected in 13.3% (N=30) of samples from Wenberma district at a mean density of 1.2 (min/max=0/24) insects per kg. Prevalence of *Tribolium* spp. in the samples from Wenberma district is an indication that primary insects severely damaged the samples. Moreover, psocids (*Liposcelis* pp.) were detected in five samples (16.7%, N=30) from Ofla district at densities ranging from 31 insects per kg to 200 insects per kg of wheat seed. The moisture content of wheat samples where psocids were detected ranged from 13.5% to 14.2%.

**Percentage of insect-damaged kernels and seed weight loss**

Significant differences (*P*<0.01) were detected among wheat samples across all districts regarding percentage means of insect-damaged kernels (Table 2-2). The means of insect-damaged kernels (%) ranged from 3.6% to 13.6%. The overall mean percentage of insect-damaged kernels across the sampled areas was about 7.4% (N=150). There were significant (*P*<0.01) correlations between the percentage of insect-damaged kernels and the densities of *S. granarius* (*r*=0.39), *Sitophilus* spp. (*r*=0.57), and *P. interpunctella* (*r*=0.41).

Non-significant differences (*P*=0.073) were detected in percentage weight loss across study districts. However, samples from Ofla and Wenberma districts exhibited relatively higher rates of seed weight loss (Table 2-3).

Means of seed weight loss percent also varied with wheat variety used. The weight loss percentage of wheat varieties (new/recent varieties, old/obsolete) showed a significant (*t*=3.03, DF=89.4, *P*<0.01) difference. Mean seed weight loss in new/recent varieties was about 2.2% (N=74) while that of old/obsolete varieties was 0.9% (N=76) with 95% confidence interval of 0.4% to 2.1%. Insecticide-treated samples exhibited more means of percentage of insect-damaged kernels and seed weight loss percent. The mean of percentage seed damage was significantly higher (10.9%) in samples treated with pesticides (*t*=2.33;
DF=81; \( P=0.02 \) while those samples which did not receive any treatment exhibited average damage rate of 5.5%. Likewise, wheat seed samples with pesticide treatment showed an average weight loss of 2.1% while those with no pesticide application exhibited relatively lower (1.2%) rate of weight loss. This is on the contrary to the expectation that pesticides are used to reduce storage losses.

Seed germination and other physical characteristics

There were non-significant differences (\( P=0.051 \)) among samples in the percentage of seed germination across surveyed districts (Table 2-4). However, seed germination ranged from 59.7% to 79.9%. The low germination rate of seed samples from Wenberma district could be attributed to the untimely rain at the time of harvesting and the prevalence of \( P. \) interpunctella.

Table 2-3: Mean (±SE) percentage of germination, dead seed proportion and dockage of samples collected in June 2016 from different wheat growing districts of Ethiopia\(^{a,b}\)

<table>
<thead>
<tr>
<th>Districts</th>
<th>Germination (%)</th>
<th>Dead Seed (%)</th>
<th>Dockage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gedeb</td>
<td>79.9±3.4</td>
<td>10.1±2.6b</td>
<td>5.6±1.2ab</td>
</tr>
<tr>
<td>Hetosa</td>
<td>69.8±5.1</td>
<td>16.6±5.1ab</td>
<td>2.2±0.4b</td>
</tr>
<tr>
<td>Lemo</td>
<td>78.4±5.5</td>
<td>13.4±4.8ab</td>
<td>7.5±1.1a</td>
</tr>
<tr>
<td>Ofla</td>
<td>73.9±5.7</td>
<td>15.7±5.0ab</td>
<td>3.0±1.3b</td>
</tr>
<tr>
<td>Wenberma</td>
<td>59.7±5.9</td>
<td>30.1±5.8a</td>
<td>3.5±1.1ab</td>
</tr>
<tr>
<td>( F_{4,145} )</td>
<td>2.416</td>
<td>2.57</td>
<td>4.00</td>
</tr>
<tr>
<td>( P)-value</td>
<td>0.051</td>
<td>0.040</td>
<td>0.004</td>
</tr>
</tbody>
</table>

\(^{a}\)Means with the same letter are not significantly different at Tukey's 5% level of significance.

\(^{b}\)Data are Means ± SE based on 30 samples from each district.

Generally, insect-infested samples exhibited significantly (\( t=2.97; \) DF=34; \( P<0.01 \)) lower mean germination (70.3%) than insect-free samples (80.5%). Any form of damage on the seed can cause a significant reduction in seed capacity of producing a healthy seedling.

Significant differences (\( P<0.05 \)) were detected among samples concerning dead seed proportions across study districts (Table 2-4). Mean dead seed proportions ranged from 10.1% in Gedeb district to 30.1% in Wenberma district. As expected, dead seed proportions showed a significant and positive correlation with seed damage (\( r=0.31; \) \( P<0.01 \)) and live \( Sitophilus \) spp. density (\( r=0.25; \) \( P<0.01 \)).

There were highly significant differences (\( P<0.01 \)) among samples in dockage percentage across districts (Table 2-4). Mean dockage in wheat samples was about 4.3% (SD=6.0%, \( N=150 \)). Dockage was not only due to insect damage but also resulted from improper mechanical harvesting. In wheat districts such as Gedeb and Hetosa, wheat
harvesting is mainly carried out using combine harvester. However, improper operation of the combine harvester may result in more number of broken seeds contributing to increased dockage proportion.

Seed samples differed significantly \((P<0.01)\) in their conformity to national wheat seed germination standards of Ethiopia for certified seed (Table 2-5). About 52\% (N=150) had met the germination requirement for certified seed. A majority of samples (60\%, N=150) met the requirement of emergency seed. Loss of germination in farm-stored wheat seed has important implications for future food security of the farming household. The seed which has lost germination may not give good crop stand and consequently will result in reduced yield. Due to lost germination, farmers may be subject to additional expenses such as increasing the seeding rates and purchase of new seed.

Table 2-4: Percentage frequency of samples that comply with certified or emergency seed standards for germination.\(^a, b\)

<table>
<thead>
<tr>
<th>Districts</th>
<th>Certified Seed (≥85% Germination) (\dagger)</th>
<th>Emergency Seed (≥80% Germination)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complying</td>
<td>Not-Complying</td>
</tr>
<tr>
<td>Gede (n=30)</td>
<td>60.0a(\dagger)</td>
<td>40.0a</td>
</tr>
<tr>
<td>Hetosa (n=30)</td>
<td>40.0ab</td>
<td>60.0ab</td>
</tr>
<tr>
<td>Lemo (n=30)</td>
<td>70.0a</td>
<td>30.0a</td>
</tr>
<tr>
<td>Ofla (n=30)</td>
<td>66.3a</td>
<td>33.3a</td>
</tr>
<tr>
<td>Wenberma (n=30)</td>
<td>23.3b</td>
<td>76.7b</td>
</tr>
</tbody>
</table>

\(P\)-value: 0.342

\(a\) Samples were categorized based on Ethiopian Standards for Wheat Seed (ES 414-2012).

\(b\) Groups sharing a letter are not significantly different (alpha = 0.05) based on Fisher’s exact test; two-sided.

2. 4 Discussion

Wheat varieties such as Kubsa and Galama, both released in 1996, and Digalu (released in 2005), were excluded from the formal seed supply system due to their susceptibility to yellow rust and stem rust, respectively (Atilaw et al., 2017). However, the main reason why those obsolete varieties were dominant in the studied areas might be attributed to farmers’ perception that these varieties are relatively high yielding (Kalsa, 2019), despite their susceptibility to rust diseases. Such perceptions could be changed in those studied areas through increased supply of certified seed of new varieties with competitive advantages of yield and disease resistance.
Our findings on farmers’ storage systems are in agreement with Dessalegn et al. (2017) who found that the most popular storage methods used by wheat farmers in Ethiopia are bags (jute bags, polypropylene bags), gotera and warehouses. Bags are flexible to store different types and different quantities of seed, the commodity can easily be removed for consumption, and the stores can be easily inspected (Dessalegn et al., 2017; Boxall et al., 2002). However, gota and gotera, which are traditional storage structures, in general, are suboptimal for wheat storage as they provide access to insects (Tadesse et al., 2008; Boxall et al., 2002). Hence, farmers can benefit from the introduction and the scaling up of improved storage technologies.

Generally, the majority of samples (64.7%, \(N=150\)) were not treated with insecticides against storage insects of wheat. According to Dessalegn et al. (2017), most wheat farmers in Ethiopia do not use chemical insecticides on stored wheat. Drying was applied by 79% (\(n=200\)) of the farmers and is the most common postharvest protection strategy. Such a tendency of farmers places a tremendous opportunity to introduce improved and cost-effective insect management systems. However, there were significant differences (\(P < 0.01\)) among samples regarding chemical treatment in stored wheat across study districts. A considerable proportion of samples from Hetosa and Wenberma districts received insecticide treatments.

The types of insecticides used by farmers are in agreement with Dessalegn et al. (2017) who reported that 35, 28, and 27 (\(n=200\)) of wheat farmers used aluminum phosphide, malathion dust, and primiphos-methyl dust, respectively. The drivers that encourage the use of chemical pesticides might be the susceptibility of modern varieties to insect attack, increased pest incidence, lack of advice on alternative methods, and poor attention to the economics of pest control (Abate et al., 2000).

In the present survey, we came across with Psocids in Ofla district. Tadesse et al. (2008) reported in their comprehensive review that Liposcelis pp. uncommon in grain stored of Ethiopia. However, with the increasing global importance of the pest, there is a need to further substantiate the present finding with a targeted sampling.

Sitophilus spp. (S. oryzae/ S. zeamais) prevailed in almost all of the surveyed districts but S. granarius and other species were limited to one or two districts. The distribution pattern of storage insects is a function of ecological adaptation, mostly determined by temperature and the grain species (Wu & Yan, 2018). In Ethiopia, the most suitable areas for wheat production fall between altitudes 1900 and 2700 m (Gebre-Mariam et al., 1991) where
the mean annual temperature is about 18°C (White et al., 2001). *S. granarius* was detected mainly in samples from Ofala district. This is in agreement with an earlier report that *S. granarius* has particular importance in highlands where altitudes were above 2500m above sea level (Abdulahi & Haile, 1991).

Relatively higher means of seed weight loss percent of samples from Ofala district could be attributed to high infestation by *S. granarius* which is known to be the most destructive among weevils infesting wheat (Campbell & Sinha, 1976). A higher rate of weight loss in Wenberma district, however, can be more explained by the occurrence of erratic rainfall at wheat harvesting. Dessalegn et al (2017) noted that rain at harvesting would cause a higher rate of storage loss.

The mean of nationwide weight loss of stored wheat, particularly due to insects only, was 0.5% (Boxall, 1998). The survey by Dessalegn et al (2017) indicated 2.7% loss of weight in stored wheat, but the authors did not specify whether the loss was due to insects only or not. Results from our present study indicated that the weight loss percentage due to insects only was significantly higher (*t*=4.68, DF=149, *P*<0.01) than the value previously reported by Boxall (1998). The weight loss ranged from 0.0% to 16.7%, but the mean weight loss across all sampled districts was 1.5 % (N=150) with a 95% confidence interval of 1.1% to 1.9%. The mean of weight loss in our study, however, is far below the 4.1% loss reported by Abdulahi and Haile (1991) which was limited to wheat districts in North Shewa. In any of the cases, weight loss was strongly associated with live weevil density (Figure 2-2).

Previous studies underscored losses due to insects can be influenced by wheat varieties since insect multiplication can be much lower on some wheat varieties than others (Throne et al., 2000). However, the traits that confer wheat varieties with the resistance to storage insects are not adequately considered in the early breeding programs.

While *P. interpunctella* is among insects of minor importance in Ethiopia (Tadesse et al., 2008), the insect can cause substantial loss of germination on predisposed seed lots since the larvae mainly feed on the germ (Stejskal et al., 2014).
Figure 2-2: Relationship between weevil density and percentages of insect-damaged kernels and seed weight loss.\textsuperscript{a,b}

\textsuperscript{a} Mean counts of live insect specimens were calculated based on 1) 109 samples within the range of \([0,336]\); 2) 16 samples within the range of \((336,672]\); 3) 11 samples within the range of \((672,1010]\); 4) 11 samples within the range of \((1010,1340]\); and three samples within the range of \((1340,1680]\).

\textsuperscript{b} Insect specimen considered were internal feeders: \textit{Sitophilus oryzae}, \textit{S. zeamais}, and \textit{S. granarius}.

Germination of seeds decreased significantly with damage level (Koptur, 1998). Damages hasten the loss of nutrients during initial phases of seed germination that the seed fails to develop into normal seedlings. In our study, the percentage of insect-damaged kernels and density of live adult \textit{Sitophilus spp.} demonstrated significant correlations \((r=-0.38; t=-5.04; \text{DF}=148; P<0.01; \text{and } r=-0.36; t=-4.74; \text{DF}=148; P<0.01, \text{respectively})\) with seed germination percent.

Wheat farmers in Ethiopia use protectants as well as fumigant insecticides on stored wheat (Dessalegn et al., 2017). However, in our present study, samples which had received insecticide treatment exhibited significantly \((t=2.33; \text{DF}=90; P=0.02)\) lower rate of seed
germination (64.5%) than that of samples without any insecticide treatment (76.6%). It can be speculated that whether farmers might be using insecticides inappropriately (Dessalegn et al., 2017) or storage insects might have developed a certain level of insecticide resistance (Boyer et al., 2012).

In conclusion, wheat stored under farmers’ storage facilities experiences up to 14% loss due to insects. Important pests of stored wheat included Sitophilus spp. and Sitotroga cerealella. Plodia interpunctella may also cause a significant loss of seed germination if established. The predominant storage method in wheat growing areas was bag storage. Farmers should be properly advised on how and when to use pesticides, if necessary. But, the health hazard in association with chemical pesticides and the concern for environmental sustainability calls for exploring integrated insect management options in stored wheat.

The present study is limited to one-time sampling that it may not represent the insect dynamics throughout the wheat postharvest system. The study also was focused on farm-stored wheat while market storage may also incur considerable losses due to insects. This study did not address situations in low moisture and hot wheat growing areas where Rhyzopertha dominica could be more prevalent.

2.5 References


CHAPTER 3: MAIZE STORAGE LOSSES DUE TO INSECTS IN FIVE DISTRICTS OF ETHIOPIA

Abstract

Maize is an important food security crop in sub-Saharan Africa. In Ethiopia, maize production increased due to improved input use and extension services. However, undeniable losses, mainly due to insects, arise by the time of storage. This paper assesses storage losses caused by insects in five maize growing districts of Ethiopia. Maize samples were collected in June 2016 from a total of 150 farming households distributed in five maize growing districts in Amhara, Oromiya and SNNP regional states of Ethiopia. Results indicated that the mean of grain weight loss of maize to storage insects was about 6.0% (SD=5.5%). The magnitude of weight loss due to insects was consistent with previous reports. The percentage of insect-damaged kernels was 24.4% (SD= 22.1%), but there were significant variations (P<0.05) across districts. *Sitophilus zeamais* was detected in about 95% (n=150) of samples, whereas *S. cerealella* and *Tribolium confusum* were detected in 59% and 42.0% of samples, respectively. The present study showed that there is a considerable loss of farm-stored maize due to insects. Hence, efforts towards food security achievement in Ethiopia and other sub-Saharan African countries should not only emphasis on increased production but also improvement of postharvest handling systems of the product.

**Keywords**: Maize, Ethiopia, Food security, Storage, Postharvest loss, Insect Pests

3.1 Introduction

One of the key constraints to improving food and nutritional security in sub-Saharan Africa is poor postharvest management that leads to grain weight losses of 20–30 % (Tefera, 2012). In the sub-continent, the percentage weight loss estimate of maize stored as grain is 4.2 to 5.4% due to insects (Hodges, 2012). In Ethiopia, maize production increased due to improved input use and extension services (Abate et al., 2015), but undeniable losses arise by the time of storage, mostly due to storage insects (Hengsdijk & de Boer, 2017). Tadesse & Basedow (2004) reported a mean percent weight loss of 5.3% and the mean percentage of insect-damaged kernels of 29.3%.

The most economically important postharvest pests of maize in Africa include the maize weevil (*Sitophilus zeamais* Motschulsky), the larger grain borer (*Prostephanus truncates* Horn), the Angoumois grain moth (*Sitotroga cerealella* Olivie) and the rice weevil
(Sitophilus oryzae L.) (Tefera, 2012). Tadesse et al. (2000) reported that arthropod pests of regular importance in maize stores in Ethiopia were S. cerealella and S. zeamais. A report by Sori & Ayana (2012) also indicated that S. zeamais followed by S. cerealella, S. oryzae and Tribolium spp. were the major pests of stored maize in Jimma area, southwest of Ethiopia.

Postharvest losses to insects can be minimized when insect infestations are checked, and appropriate management options are implemented. However, updated data on the insect infestation and the magnitude of storage losses due to insects are limited concerning a wider geographic area in Ethiopia (Tadesse & Basedow 2004). The objective of this study was to identify major stored product insects and determine losses due to insects in five maize growing districts of Ethiopia.

3.2 Materials and Methods

Description of study areas and grain sampling

The study included five maize growing districts in Amhara, Oromiya, and Southern Nations, Nationalities and Peoples Region (Figure 3-1). The five districts were Merawi, Wenberma, Chelia, Toke Kutaye, and Alaba. Merawi and Wenberma are districts from Amhara regional state, and good potential of maize production characterizes them. Chelia and Toke Kutaye are located in West Shewa zone of Oromiya regional state. Alaba is a district of high maize production in the SNNPR. The study areas fall within the coordinates of 7.295-11.403°N and 36.845-38.143°E at altitudes ranging from 1710m to 2342m above sea level (based on GPS information recorded during sampling). Toke Kutaye and Merawi districts have a relatively lower monthly temperature ranging from slightly below 15°C in December to slightly below 19°C in April. Other districts have relatively higher mean monthly temperatures ranging from slightly below 18°C in December to about 20°C in April.

Farm-stored maize samples harvested between November and December 2015 were collected from a total of 150 farm stores in June 2016. From each district, one kebele (the lowest administrative division) was selected based on its surplus production. A total of 30 farmers who grow maize were randomly sampled from each study kebele. A household was used as a sampling unit. One sample was taken after every third household. When adult family members were missing for responses on storage information, the next household was considered. About 1kg samples of maize were taken by a cup from different parts of the containers and placed in plastic bags and labeled for further identification of pests, and counting and weighing. According to Boxall (1986), not to receive false results, damaged
maize kernels were grouped according to size before weighing in comparison to undamaged kernels.

**Grain characteristics and storage conditions**

At times of sampling, time of harvest (month of the year), type of storage structure, any pesticide treatment (the type of pesticide), temperature and relative humidity of the storage structure, and maize variety were recorded. Seed moisture content was measured using the John Deere Moisture Check-Plus Grain Moisture Tester (AHW LLC, Waseka, Illinois, USA). Relative humidity and inter-granular temperature were measured using a moisture meter developed by Armstrong et al. (2017).

![Map of maize sampling districts](image)

**Figure 3-1:** Map of maize sampling districts

**Distribution and abundance of storage insects**

All of the 1kg maize samples from each farmer were brought to the laboratory and sifted using three layers of standard sieves (Supertek Scientific, Illinois, USA) (2.3mm, 1.6mm, 0.4mm for a top, middle and lower sieves, respectively) with a bottom pan to receive dust. All live and dead adults of each insect species were counted. Dockages (excluding dead/live adult insects) were returned to samples and placed in a 1-liter jar to be incubated for ca. 6 weeks under room temperature and humidity to recover insects which did not complete their development. After six weeks of incubation, samples were sifted again, and insects
emerged were removed and counted by species. The two counts were summed to get the total number of the live adult insect.

Insects were collected and morphologically identified to genera and species levels (where possible), using a stereomicroscope, following identification keys as described in Reichmuth et al. (2007). Where confusions arise between *S. oryzae* and *S. zeamais*, the aedeagus of male genitalia were assessed for the presence or absence of grooves. The apex of Y-sclerite of female genitalia was also assessed if it was round/pointed. In this regard, no specimens of *S. oryzae* were detected in the present survey.

**Percentage of weight loss and insect-damaged kernels**

Each of the maize samples was divided following the quartering and conning technique until a final sample of around a 100g of maize was obtained. From a 100g of sound maize, damaged and undamaged kernels were separated, counted and weighed. Mechanical damages were included in dockages (when it was <50% of the average size). Insect damaged kernels were visually identified based on holes made by boring insects.

Maize weight loss was estimated using the equation (Mohammed and Tadesse, 2018):

\[
\text{Maize Weight Loss (\%) } = \left(\frac{\text{WU} \times \text{ND} - \text{WD} \times \text{NU}}{\text{WD} \times (\text{NU} + \text{ND})}\right) \times 100
\]

where, WU is weight of undamaged maize, NU is number of intact maize, WD is weight of damaged maize, ND is number of damaged maize.

Grain damage rates were calculated using the equation:

\[
\text{Percentage of Insect-Damaged Kernels } = \frac{\text{Number of Insect-Damaged Kernels} \times 100}{\text{Number of Kernels in 100g of Maize}}
\]

**Data analysis**

Qualitative and quantitative data collected through checklists and measurements on samples were subjected to statistical analysis using R Version 3.5.0. Cross-tabulations were constructed for nominal parameters, and descriptive statistics were calculated to summarize data on maize varieties grown, storage methods, insecticide application, and insect incidence.

Measurement variables were subject to one-way analysis of variance to detect differences among samples from the five study districts. Parametric inferences (regardless of the population distribution) were used on randomly selected 30 samples from each district. Multiple comparisons of means between study districts were carried out using Tukey's Honest Significant Difference test. One sample t-test was performed to compare the overall weight loss (%) and percentage of insect-damaged kernels with a previously reported loss for maize due to insects in Ethiopia and in sub-Saharan Africa. The Kruskal-Wallis non-parametric test was employed to examine the association of grain weight losses and the
percentage of insect-damaged kernels with storage structures, synthetic chemicals used by farmers, and maize varieties.

3.3 Results

Storage structures and management characteristics

In the present study, samples were obtained mainly from three storage structures such as gotera, gota, and polypropylene bags. However, a majority (77%; N=150) of samples were obtained from polypropylene bags. Samples obtained from gotera and gota were about 11% and 12%, respectively. In areas which the present study included, gotera is mainly used to store maize in cobs while gota (dibighit) and bags in the house are mostly used for shelled grain. Maize is shelled between March and April, and the shelled maize is mostly stored in woven bags.

About 77% of samples were obtained from farmers who used synthetic insecticides to protect stored maize. Farmers used synthetic insecticides vis. Actellic dust (primiphos-methyl), malathion dust, and Phosphine (Aluminium phosphide) in their stored maize. About 42% of households used Phosphine tablets solely or in combination with Actellic or Malathion dust.

The mean of maize moisture content in our study was 14.0% (SD =1.1%; N=150). However, there were significant differences ($F_{4, 142} = 55.5; P<0.01$) among maize sample in their moisture content across all studied districts. The mean moisture content of samples ranged from 11.8% to 17.3% across districts. A majority (81%; N=150) of samples exhibited high moisture between 13.1 and 17.3%.

The inter-granular temperature at the time of sampling demonstrated a significant difference ($F_{4, 142} = 691.4; P<0.01$) among maize samples across the districts. The means of inter-granular temperature in each study districts were between 20.8 and 27.1°C (N=30) with the overall mean temperature of 23.5°C (SD = 3.1°C; N=150) (Figure 3-2).

Relative humidity inside the traditional storage structures ranged from ca. 62% to slightly above 70% (Figure 3-2). There were significant differences ($F_{2, 142} = 24.8; P<0.01$) among maize storage structures in their relative humidity level. The overall mean RH was 67.7% (N=150; SD = 5.4%) with the extreme values of 54.4% and 86.9%.
Figure 3-2: Mean (±SE) relative humidity (%) and temperature (°C) within storage structures in five maize growing districts in June 2016.
* The number of samples per district was 30 whereas total number of samples was 150.

Distribution and abundance of insects

Figure 3 shows the frequency of most abundant insects detected in samples collected from five maize growing districts of Ethiopia. We have confirmed in our study that S. zeamais is still a widely encountered species (detected in 95% of samples; N=150) followed by S. cerealella, in 59% of samples. We have detected Tribolium confusum in 42.0% of maize samples. On the other hands, there were significant differences (P<0.05) in the distribution and abundance of storage insects among samples across surveyed districts. The frequency of maize samples infested with S. zeamais ranged from 76.7% to 100% (N=30). The frequency of samples in which S. cerealella was detected ranged from 43% in Merawi to 90% in Toke Kutaye (N=30). Tribolium confusum was detected in 3.3% of samples from Toke Kutaye to 90% (N=30) of samples from Chelia district.
The abundance of commonly detected insect species in samples collected from five maize growing districts of Ethiopia is depicted on Table 3-1. Significant differences (P<0.05) were detected among samples across all the districts in the density of insects per unit weight of maize. *S. zeamais* infested at high densities ranging from 93.8±2.7 insects per kg to 359.3±2.3 insects per kg. The lowest density of *S. zeamais* was in samples from Wenberma district. The highest density of *S. zeamais* was in samples from Chelia and Merawi districts. *S. cerealella* was the next most abundant species in maize samples collected from different districts of Ethiopia. Mean density of live adults of *S. cerealella* ranged from 3.5±2.1 insects per kg to 88.3±10.0 insects per kg. *Tribolium confusum* was also detected in samples from all districts at densities ranging from 1.0±0.9 insects per kg to 29.9±3.3 insects per kg. The highest densities of *Tribolium confusum* were detected in samples from Chelia and Alaba districts. The two districts are characterized by relatively higher mean monthly temperature.

**Grain weight loss (%)**

In our study we have observed that the estimated magnitudes of weight loss were significantly different (P<0.05) among samples across the studied maize growing districts within Ethiopia (Table 3-2). Overall, the mean of grain weight loss (%) was about 6.0% (SD=5.5, N=150). But, the mean of percentage weight loss to insects in each district ranged from 4.2% to 8.1%. The highest mean of weight loss percentage was recorded in samples from Chelia district while the lowest mean was in samples from Merawi district. The
difference in the magnitude of weight loss between districts might be due to differences in the postharvest handling practices by farmers or the predominant varieties being used.

Table 3-1: Mean (±SE) of major insects detected (counts per kg of maize) by maize growing districts

<table>
<thead>
<tr>
<th>District</th>
<th>Total Live Insects</th>
<th>Sitophilus zeamais</th>
<th>Tribolium confusum</th>
<th>Sitotroga cerealella</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chelia</td>
<td>405.8±61.2a</td>
<td>359.3±56.4a</td>
<td>29.9±14.1a</td>
<td>16.6±4.6ab</td>
</tr>
<tr>
<td>Alaba</td>
<td>148.0±31.5b</td>
<td>118.6±31.9b</td>
<td>24.5±8.9b</td>
<td>4.8±2.0b</td>
</tr>
<tr>
<td>Merawi</td>
<td>313.6±56.0a</td>
<td>307.9±55.8a</td>
<td>2.1±0.8b</td>
<td>3.5±1.3b</td>
</tr>
<tr>
<td>Toke Kutaye</td>
<td>167.8±34.1ab</td>
<td>99.1±28.0b</td>
<td>1.0±1.0b</td>
<td>67.7±19.6a</td>
</tr>
<tr>
<td>Wenberma</td>
<td>184.4±43.1b</td>
<td>93.8±30.1c</td>
<td>2.3±1.6b</td>
<td>88.3±31.3a</td>
</tr>
</tbody>
</table>

F (4, 145) 8.7 15.4 17.5 6.2
P-value 0.00 0.00 0.00 0.00

Means within a column followed by the same letter are not different at Tukey’s 5% level of significance.

Figure 3-4 shows the relationships between grain weight losses and maize varieties used by farmers. Significant differences (P<0.05) were detected among samples of different maize varieties in grain weight loss percent. The highest mean of weight loss was recorded in BH661 while the lowest was in BH540. Weight loss percent of samples of a popular maize variety Limu (ca. 37% of samples belonging to this variety, N=150) was about 5.4%.

Table 3-2: Mean (±SE) of grain weight loss (%) and insect damaged kernels (%) by maize growing districts

<table>
<thead>
<tr>
<th>District</th>
<th>Grain weight loss (%)</th>
<th>Insect-Damaged Kernels (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chelia</td>
<td>8.1±1.0a</td>
<td>34.4±1.0a</td>
</tr>
<tr>
<td>Alaba</td>
<td>5.9±0.9b</td>
<td>17.0±1.2ab</td>
</tr>
<tr>
<td>Merawi</td>
<td>4.2±1.4ab</td>
<td>23.2±1.6b</td>
</tr>
<tr>
<td>Toke Kutaye</td>
<td>5.9±0.8ab</td>
<td>20.6±1.0ab</td>
</tr>
<tr>
<td>Wenberma</td>
<td>5.8±0.9ab</td>
<td>26.6±1.4ab</td>
</tr>
</tbody>
</table>

F (4, 145) 3.2 3.5
P-value 0.01 0.01

Means within a column followed by the same letter are not different at Tukey’s 5% level of significance.

There was a significant association (Chi. Sq =6.7; df = 2; P= 0.03) of grain weight-loss percentage of maize samples with different storage structures used by farmers. The mean (±SD) values of weight loss percent in gota, gotera and polypropylene bags ranged from 3.3±3.7% to 6.4±3.9% (Figure 3-5). The highest grain weight loss to insects was recorded in samples from polypropylene bags, followed by those from gotera.
Figure 3-4: Means of grain weight loss (%) by maize varieties used by farmers. Means with the same letter are not statistically significant at Tukey’s 5% level of significance.

Insect damaged kernels (%)

There were significant differences (P<0.05) among samples across the studied maize growing districts in the percentage of insect-damaged kernels (Table 3-2). Overall, the mean of the percentage of insect-damaged kernels was about 24.4% (SD=22.1%, N=150). The percentage of insect-damaged kernels ranged from 17.0% to 34.4%. The highest mean of grain weight loss percentage was recorded in samples from Chelia district while the lowest mean was in samples from Merawi district.

However, there was a significant association (Chi. Sq. = 12.1; df= 5; P=0.04) between the percentage of insect-damaged kernels and type of pesticides used. The percentage of insect-damaged kernels ranged from 18.2% (SD =19.2%) in samples treated with Malathion to 27.6% (SD = 22.0%) in samples treated with Phosphine (Figure 3-6).
Figure 3-5: Means of grain weight loss (%) by type of storage structures used by farmers. a

*a Means with the same letter are not statistically significant at Tukey’s 5% level of significance.

Figure 3-6: Mean (±SE) of grain weight loss (%) by type of pesticide used by farmers. Means with the same letter are not statistically significant at 5% level of significance.

The correlation of insect abundance, temperature, RH, and moisture to grain loss

Table 3-3 shows Pearson’s correlation coefficients of the abundance of different insect species and grain loss parameters. There were significant relationships (P<0.05)
between the abundance of *S. zeamais* and *S. cerealella* to the percentage of insect-damaged kernels. Only the abundance of *S. zeamais* had a significant correlation with the percentage of grain weight loss. However, the total count of all insect specimens exhibited significant correlations with both the percentage of insect-damaged kernels and weight loss.

Relative humidity within the storage structure and the grain moisture had positive and significant (P<0.05) correlations with both the percentage of insect-damaged kernels and grain weight loss. Temperature has a non-significant correlation with both the percentage of insect-damaged kernels and grain weight loss.

Table 3-3: Pearson’s correlation insect abundance, temperature, relative humidity and grain moisture to the percentage of grain weight loss and insect-damaged kernels by maize growing districts

<table>
<thead>
<tr>
<th>District</th>
<th>Grain weight loss (%)</th>
<th>Insect-Damaged Kernels (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sitophilus zeamais</em></td>
<td>0.40**</td>
<td>0.60**</td>
</tr>
<tr>
<td><em>Sitotroga cerealella</em></td>
<td>0.05NS</td>
<td>0.19*</td>
</tr>
<tr>
<td><em>Tribolium confusum</em></td>
<td>0.15NS</td>
<td>0.12NS</td>
</tr>
<tr>
<td>Total insect count</td>
<td>0.42**</td>
<td>0.66**</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>0.01NS</td>
<td>-0.16NS</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>0.22*</td>
<td>0.30**</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.18*</td>
<td>0.29**</td>
</tr>
</tbody>
</table>

* *, **Correlations are significant at 5% and 1% levels of significance. NS= Correlations are not significant at 5% level of significance. The number of observations was 150 for all correlations variables.

3.4 Discussion

Postharvest loss is among important food security threats in sub-Saharan Africa (Chegere, 2018; Kaminski & Christiaensen, 2014; Tefera, 2012). The urgency of the need to reduce the postharvest loss of maize in the sub-continent depends largely on the magnitude of such losses incurred by smallholder farmers (Sheahan & Barrett, 2017). To this end, sufficient scientific data should be available on the magnitude of loss so that practical interventions can be sought. However, farm level estimates of weight losses in the sub-continent are inconsistent and vary largely from one place to another (Manandhar et al., 2018; Sheahan & Barrett, 2017). Moreover, several recent reports did not provide explicit information regarding losses caused by storage insects (Chegere, 2018; Manandhar et al., 2018; Sheahan & Barrett, 2017). The present study provides us with the information on the most important insect species associated with maize postharvest loss in Ethiopia and the magnitude of loss associated with those insects. The findings of our study show that the overall mean of weight loss (%) is about 6.0% (SD=5.5, N=150). Our finding is consistent with those reported by Tadesse & Basedow (2004) and Hodges (2012) in the Ethiopian
context. The consistency of weight loss estimates for nearly two decades could be indication that there had been no adequate intervention to reduced storage loss of maize due to insects. Or, probably the climate change has not aggravated the PHL as one expects.

Smallholder farmers in developing countries use conventional storage structures and handling systems such as woven bags or cribs to store grain (Manandhar et al., 2018). We have observed that most subsistent farmers included in our study do not have separate stores for maize grain, and they store it where they perform most of their household activities. A majority of samples in the present study were obtained from polypropylene bags stored in the house. The finding in our present study is in agreement with a recent report by Hengsdijk & de Boer (2017) who indicated that the most important method of storing cereals was a bag in the house. But, regardless of the traditional storage structures used by farmers, maize suffered a considerable loss due to insects. The farmers’ tendency to store maize grain in woven bags provides a good opportunity for the introduction of hermetic storage bags which are already tested in Ethiopia (Kals et al., 2019) and other parts of sub-Saharan Africa (Baoua et al., 2018; Manandhar et al., 2018).

A previous report indicated that synthetic insecticides were used by 70% of maize farmers (Tadesse & Basedow, 2004). Synthetic insecticides, in combination or solely, were used by 77% of households while 23% reported that they used no synthetic insecticide. However, there was a non-significant difference between samples which were treated with insecticides and those which were not in percentage insect damaged kernel, grain weight loss, or relative abundance of insect specimens. Insecticides can effectively control insect infestations and prevent grain losses; however, their effectiveness is being questioned by farmers (Manandhar et al., 2018; Mlambo et al., 2018). Inefficiencies of synthetic insecticides could be due to adulterations and improper handling and application by the farmers. Strong extension works are required to address such bottlenecks associated to improper use of postharvest insecticides.

Factors such as grain moisture, temperature, and relative humidity influenced the conditions for insect multiplication during grain storage. It is evident from this and previous studies that the traditional storage structures in sub-Saharan Africa are poorly managed and create suitable environments for insect population development (Tefera, 2012; Abass et al., 2014; Manandhar et al., 2018). High grain moisture provides suitable conditions for the proliferation of insects in stored cereals (Weinberg et al., 2008; Danso et al., 2017). High
moisture storage of maize in sub-Saharan Africa is a common challenge subjecting the grain to loss to insects (Abass et al., 2014; Danso et al., 2017).

Temperatures in the range of 25 to 35°C create favorable conditions for the rapid growth of most storage insects (Beckett 2011). It is evident from our study that about 40% (N=150) of samples were obtained from storage structures with inter-granular temperatures between 26.6 and 27.7°C. Though temperature has weak correlation with loss, a high temperature in combination with high RH in the inter-granular environment of stored maize provides suitable conditions for the development of insects (Throne & Weaver, 2013).

We have confirmed in our study that *S. zeamais* is still a widely encountered species (detected in 95% of samples; N=150) followed by *S. cerealella*, in 59% of samples. The distribution of storage insects over different geographical locations are influenced by the climate and food item (Corrêa et al., 2013; Wu & Yan, 2018). The storage insects encountered in 96% (n=150) of maize samples belonged to at least one of five genera. *Prostephanus truncatus* Horn, the devastating pest in some East African countries (Tadesse & Basedow, 2004; Tefera, 2012) was not detected in maize samples during the present survey. Tadesse & Basedow (2004) indicated that the most frequent species of stored maize insects in Ethiopia are *S. zeamais* and *S. cerealella*. It is evident from previous studies that *S. zeamais* is the most prevalent insect in shelled maize in developing countries (Manandhar et al., 2018). In our study, percentage of insect-damaged kernels was strongly associated with the combined abundance of both *S. zeamais* and *S. cerealella* (Figure 3-7). Therefore, management strategies which aim at the control *S. zeamais* and *S. cerealella* will be the most important interventions in combating insect infestations in stored maize. Earlier reports indicated that *Tribolium* spp. is of minor importance in maize stores in Ethiopia (Tadesse & Basedow, 2004). But, we have detected *T. confusum* in about 42% samples. This shows that the pest has grown from minor to major concern! Our finding is in agreement with that of Sori & Ayana (2012) who also reported that *T. confusum* was among major pests of stored maize in Jimma area, Ethiopia.
Figure 3-7: Effects of total live insect specimen abundance (counts per kg) on the percentage insect-damaged kernel.  

Mean of Live Insect Specimens (counts per kg maize)

In the present study, we have observed *Sitophilus zeamais* at densities of 42.2 live adults per kg and 45.9 adults per kg in samples from Oromiya and Amhara regional states, respectively. Total abundance of insects ranged from ca. 148 live insects per kg to 405 live insects per kg. Tadesse & Basedow (2004) found nearly 500 insects/kg of maize in Oromiya, > 200 in Amhara and < 200 in SNNPR. A recent study in Jimma, Ethiopia, showed the total insect abundance in farm stored maize could be as high as 800 specimens per kg of maize (Sori & Ayana, 2012). Previous studies showed that the abundance of *S. zeamais* in farm storage maize was ca. 150 insects per kg in Oromiya, >90 insects per kg in Amhara (Tadesse & Basedow, 2004). The same species was recorded at a mean density of ca. 700 insects per kg in Jimma, Ethiopia (Sori & Ayana, 2012). Variation in the abundance of insects in stored maize could be attributed to the variation in the maize varieties grown (Abebe et al., 2009) and management practices employed before and during grain storage (Tadesse & Basedow, 2004; Nwosu, 2018).
Tadesse & Basedow (2004) had observed mean density of >90 insects per kg in Oromiya, >50 insects per kg in SNNPR, and ca. 30 insects per kg in Amhara regional state. Sori & Ayana (2012) also observed a mean density of >100 insects per kg in maize samples collected from Jimma, Ethiopia. The inconsistency in the abundance of insects might be due to differences in sampling districts and techniques of sampling.

In conclusion, we have observed that maize stored in traditional storage structures suffered a large magnitude of loss due to insects. The most prevalent storage insects attacking maize are *Sitophilus zeamais* and *Sitotroga cerealella*. The abundance of insects ranged from 184 to 405 insects per kg of maize grain. Maize weight loss due to insects was between 4.2% and 8.1%. The magnitude of percentage weight loss and type of insects causing that loss are consistent with the previous findings. Hence, the results from our present study provide us the opportunity to suggest the urgent need for extension support to smallholder farmers regarding proper postharvest handling of maize.

However, our study is limited to five maize growing districts, and it did not consider areas from lower altitudes where other insect pests might be important. Moreover, the dynamics of insect population from the time of harvesting to the end of the postharvest period is not known.

3.5 References


CHAPTER 4: EVALUATION OF POSTHARVEST PRESERVATION STRATEGIES FOR WHEAT SEED IN ETHIOPIA

Abstract

Limited information exists on postharvest preservation strategies of stored wheat in Ethiopia. The present study was conducted to evaluate the effectiveness of on-the-shelf postharvest storage strategies of stored wheat in the country. The experiment consisted of eight treatments; (1) Metal Silos, (2) Purdue Improved Crop Storage (PICS) bags, (3) Super GrainPro bags, (4) industrial filter cake dust applied to wheat in polypropylene bag, (5) plastic drums, 6) Triplex applied to wheat in polypropylene bag, 7) Triplex applied to wheat in plastic drum, and 8) polypropylene bag as control. Each treatment was repeated three times at each period of storage. Measurements of oxygen and carbon dioxide levels, live adults of insects per kg, percentage seed damage, and percentage of weight loss, germination and seedling vigor were determined every two months for six months. Results indicated that storage strategies such as PICS and Super GrainPro bags, filter cake in polypropylene bag, Triplex in polypropylene bag, and plastic drums led to a significantly lower live insect density compared to the control. Besides, Triplex and filter cake dust or use of hermetic bags also resulted in a significantly lower rate of seed weight loss (%) compared to the control. After six months of storage, means ±SD germination of seed from the polypropylene bag (control) had decreased from above 95% to 68.0±6.1% while wheat in all other storage strategies exhibited means ±SD germination capacity ranging from 92.0±3.6% to 98.0±1.0%. The present results demonstrate the potential of preserving stored wheat without relying on synthetic insecticides by using hermetic bags, filter cake, and Triplex, with advantages over traditional strategies used by smallholder farmers in Ethiopia. We recommend that hermetic bags, filter cake dust, and Triplex powder should be promoted for use by farmers for the postharvest preservation of their stored wheat.

Keywords: Hermetic bags; Filter Cake; Triplex; Seed Germination

4.1 Introduction

Wheat (*Triticum* spp.) has a share of 13.8% of the total cereal production in Africa (FAO, 2017). Currently, Ethiopia is a leading producer of wheat in sub-Saharan Africa with an annual production of about 4.5 million tons harvested from 1.7 million hectares (CSA, 2017; FAO, 2017). Different factors such as improved varieties, use of inorganic fertilizer
and increased awareness through extension education have contributed to significantly improve wheat productivity per unit area (Bishaw & Atilaw, 2016). Despite these advances, Ethiopia still imports wheat for local consumption. On the other hands, the country is incurring a substantial amount of loss. In this context, improved postharvest management practices may enhance food security in many African countries (Tefera, 2012; Dessalegn et al., 2017; Hengsdijk & de Boer, 2017).

Farm-stored wheat is commonly damaged by insects such as the granary weevil, *Sitophilus granarius* (L.) (Coleoptera: Curculionidae); lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae); rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae); and maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) (Tadesse et al., 2008). Boxall (1998) indicated that wheat loss in Ethiopia in storage due to insects was measured to be about 0.5%. A recent survey conducted in 2016 on nearly 150 farm stores found that the mean weight loss due to storage insects was about 1.5% (Chapter 2 in this dissertation).

In Ethiopia, about 90% of the total area of wheat in the country relies on seed from local sources (CSA, 2016), or from seed saved by farmers (Alemu & Bishaw, 2015; Bishaw & Atilaw, 2016) which farmers store under poor conditions. Poorly stored seed has inferior performance in the field which can lead to yield reduction and threaten food security (Nithya et al., 2011; Wimalasekera, 2015).

Various storage techniques such as use of hermetic bags, metal silos, inert dusts, and botanicals are recommended by researchers as alternatives to chemical pesticides against storage insects (Demissie et al., 2008a; Demissie et al., 2011; Gitonga et al., 2013; Martin et al., 2015). Storage of *S. oryzae* infested wheat in Purdue Improved Crop Storage (PICS) bag considerably decreased weevil population and preserved seeds (Martin et al., 2015). Moreover, the metal silo has been reported as an effective method to protect stored cereals from insect damage in small-scale farmer level (Tefera et al., 2011; Yusuf & He, 2011; Gitonga et al., 2013). The use of inert dusts has long been reported as a safe alternative to synthetic pesticides (Subramanyam & Roesli, 2000). Diatomaceous earth (Silicosec®), a mineral industrial filter cake, and domestic wood ash, were reported to be effective against *S. zeamais* on three maize genotypes (Demissie et al., 2008a). Recent reports also indicated that the filter cake dust could be effective against *S. granarius* and *R. dominica* (Kalsa et al., 2017) and *S. zeamais* (Tadesse & Subramanyam, 2018a) under lower rates than the previously reported. A factory by-product of a local plant known as endod (*Phytolacca*...
dodecandra L.) with the name Triplex has been reported as being effective at a rate of 0.25% on against S. zeamais (Demissie et al.; 2008b). A result report by Tadesse & Subramanyam (2018a) on the same material indicated that Triplex could be effective at a concentration of 10g/m2 on concrete arenas.

Use of all the alternatives may reduce the loss of farm-stored wheat, but limited information is available on the management of stored wheat in Ethiopia. Strategies such as use of filter cake, Triplex, and metal silos were tested for postharvest preservation of maize in the country. Recent reports by Kalsa et al. (2017) and Tadesse & Subramanyam (2018b) are only available studies related to the efficacy of filter cake and Triplex dusts on stored wheat. Those studies gave the information on concentration-mortality responses of S. granarius, S. zeamais, S. oryzae, and R. dominica when exposed to filter cake and Triplex, but the efficacy under prolonged wheat storage is not well understood. On the other hands, the knowledge base on effectiveness of hermetic bags for wheat storage is also limited (Martin et al., 2015). Limited studies are available on use of metal silos for stored wheat (Tefera et al., 2011). Above all, the comparative effectiveness of those technologies are not well documented in the literature. Hence, the objective of the present study was to investigate the comparative effectiveness and advantages of a range of storage pest management options for small-scale storage of wheat seed.

4.2 Materials and Methods

Wheat seed and source

The certified wheat seed of "Kakaba" variety, a most widely grown variety by wheat farmers in Ethiopia, was purchased from Ethiopian Seed Enterprise, Bahir Dar Center, Bahir Dar, Ethiopia. All the seed was acquired from the same lot as defined in International Rules of Seed Testing (ISTA, 2014) and there was no need for further homogenization. The seed was harvested in March 2015 (off-season production) and had not been treated with any pesticide. After purchase, the wheat seed was kept under ambient conditions (temperature of 24.6±1.0°C and relative humidity of 48.2±10.4%) until it was used in our experiments.

Experimental setup and design

The experiment was carried out for over a six-month period (April 22 to October 22, 2016) under ambient conditions described below, at the College of Agriculture and Environmental Sciences, Bahir Dar University, Ethiopia. The experiment consisted of eight
different treatments. The experiment consisted of eight treatments; (1) metal silos, (2) Purdue Improved Crop Storage (PICS) bags, (3) Super GrainPro bags, (4) industrial filter cake dust applied to wheat in polypropylene bag, (5) plastic drums, 6) Triplex applied to wheat in polypropylene bag, 7) Triplex applied to wheat in plastic drum, and 8) polypropylene bag as control. All containers except the plastic drum received 50 kg wheat while 25 kg of wheat was placed in each plastic drum. The metal silo, PICS bags, and Super GrainPro bags were not tested with a combination of powders, because they work on the principle of oxygen depletion and would, therefore, not benefit from the application of the dusts. Triplex was applied at a recommended rate of 0.25% (w/w) (Demissie et al., 2008b), while filter cake was applied at a rate of 1% (w/w) as recommended by Demissie et al. (2008a), providing concentration of 2.5 g/kg of Triplex and 10 g/kg of filter cake. Triplex dust was then mixed with seed using a spade. Both filter cake and Triplex were applied only once, at the beginning of the experiment. The treatments were arranged in a randomized complete block design with three replications and each replication was treated separately. The treatments were placed in a laboratory room (L×W×H ≈1200m³) and all the treatments were kept under ambient conditions.

Opening at the top and the spout at the bottom of metal silos were sealed by tying with self-fusing double sided butyl rubber tape (Shenzhen You-san Technology Co. Ltd, Shenzhen, Bao’an, China) of 10 mm width to seal any openings. Plastic portions above the seed in PICS and Super GrainPro bag were squeezed to remove excess air. The openings were then closed by tightly twisting the free portion and sealing it with strings.

The temperature and relative humidity in the storage room were recorded on a daily basis using HOBO® portable temperature and relative humidity sensors. Mean storage temperature was 24.5±2.3°C (33.61/19.49°C), and the ambient relative humidity was 54.1±8.6% (70.56/24.29%). The temperature of inter-granular space, however, was measured at the time of sampling.

Description of experimental treatments

Locally manufactured polypropylene bags of 50 kg capacity and plastic drums with a capacity of 30 liters were bought from the local market in Bahir Dar, Ethiopia. Super GrainPro bags of 100 kg capacity were obtained from local agent HiTEC Trading PLC, Addis Ababa, Ethiopia. Super GrainPro bags are produced by GrainPro™ Company (Concord, Massachusetts, USA) consists of a single layer of 78 μ of plastic film made of two
polyethylene films between which is sandwiched a plastic layer that is highly impermeable to oxygen. PICS bags consists of one woven polypropylene bag surrounding two layers of high-density polyethylene (HDPE), each of 80 µ thick were obtained from local agent Shayashone Trading PLC, Addis Ababa, Ethiopia. Hermetic bags were carefully examined for any leaks, before filling, and in case that there were leakages; they were not used in the experiment. The metal silos were made from 24 gauge galvanized metal sheets with a round opening from the top for filling and a cylindrical outlet at the side bottom, had a grain-holding capacity of 100 kg (Obeng-Oferi, 2011). They were obtained from trained local artisans. Non-toxic botanical Triplex powder is a by-product of Mohammed International Development Research and Organization Companies (MIDROC) soap factory obtained from Star Soap and Detergent Industries (SSDI) private limited company, Addis Ababa, Ethiopia. The filter cake is a by-product of aluminum sulfate factory and obtained from Awash Melkassa Aluminum Sulphate & Sulphuric Acid Share Company, Awash Melkassa, Ethiopia.

Seed sampling

Baseline samples were taken at the outset of the experiment. Consecutive sampling was done at two monthly intervals during the sixth months’ storage period. At each time of sampling, a wheat sample of about 5 kg was taken from each container following a hand sampling technique as described in International Seed Testing Association (ISTA, 2014). The 5 kg sample was then thoroughly mixed, and reduced to 1 kg for ease of assessment of insects through the conning and quartering method as described in Boxall et al. (2002). The 1 kg sample was put in plastic bags and kept in the laboratory until used for data collection the next day.

Data collected

Inter-granular temperature and wheat moisture: Seed moisture content and inter-granular temperature were measured using the John Deere Moisture Check-Plus Grain Moisture Tester (AHW LLC, Watseka, Illinois, USA) and a moisture meter developed by Armstrong (2014) at each sampling time. Every sample was tested three times, and the mean of the reading was recorded for seed moisture content.

Gas composition in hermetic bags: Oxygen and carbon dioxide levels in hermetic bags were checked at each sampling occasion using a Mocon PAC Check Model 325 Headspace analyzer (Mocon, Minneapolis, Minnesota, USA) fitted with a 20-gauge hypodermic needle for sampling through rubber septum. The first reading was taken at the
start of the experiment. Subsequent levels were checked at each sampling occasion before the bags were open for wheat sampling. Oxygen and carbon dioxide levels were measured with the aid of Mocon headspace analyzer's sampling needle.

**Numeration of insects:** The number of live adults was counted at each sampling occasion by sifting the one kg sample through the supertech standard test sieves (Supertek Scientific, Addison, Illinois, USA) 2 mm and 0.425 mm mesh size openings held over a bottom pan. Live and dead adults separated from wheat were enumerated.

**Seed damage and weight loss:** From the 1 kg of sifted samples, sub-samples of 100 g were obtained and damaged and undamaged kernels were counted and weighed separately. The damaged kernels were separated, and each proportion was subject to counting with the INDOSAW Seed Counter (Osaw Industrial Products Pvt. Ltd, Salarheri, Haryana, India). Seed weight loss to insects was assessed using the count and weigh method using the following equation:

\[
\text{Weight Loss \%} = \frac{(W_u \times N_d) - (W_d \times N_u)}{W_u \times N_u} \times 100,
\]

where \(W_u\) = weight of undamaged seeds, \(W_d\) = weight of damaged seeds, \(N_d\) = number of damaged seeds, and \(N_u\) = number of undamaged seeds (Adams and Schulten, 1978; Boxall, 1986). The extent of seed damage by insects was assessed using the equation:

\[
\text{Seed damage (\%)} = \left(\frac{\text{Number of damaged kernels}}{\text{Number of Kernels in 100 g of Seed}}\right) \times 100.
\]

**Seed bulk density:** Seed bulk density was measured on each sampling occasion. Sifted seed samples from each experimental unit were filled into a standard bulk density measurement unit of 0.5 liter volume and weighed at the precision to 0.1g. To avoid variation of bulk density with moisture contents, weights were adjusted to standard moisture content (13\%) using the following equation:

\[
\text{Adjusted bulk density (kg/m}^3) = \frac{100 - \text{m.c.}}{87} \times \text{bulk density of the seed},
\]

where m.c. is the moisture content of wheat (modified from Boxall et al., 2002).

**Thousand seed weight:** The 1000 seed weight was measured by counting and weighing a thousand kernels from sifted samples using INDOSAW Digital Seed Counter (Osaw Industrial Products Pvt. Ltd). The weight of each sample was adjusted to the standard moisture content using the equation described for bulk density.

**Germination:** Germination tests were carried out according to the procedures prescribed in ISTA (2014) with slight modifications. Three hundred kernels in triplicates, were taken from sifted samples and placed on top of wet blotter paper (Seedburo Equipment
Co., Des Plaines, Illinois, USA), in three replications, placed in a bowl of 15cm diameter. Germination test was carried out in a germination room with air conditioning system adjusted at 20°C. All seed samples were pre-chilled at 5°C for one week before germination test as recommended by ISTA (2014) for the breaking of possible dormancy. Germination percentage (number of normal germination out of 100) was recorded eight days after placing kernels on germination paper.

**Seedling dry weight and vigor index:** From the standard germination test, ten normal seedlings were selected and placed in an envelope to be oven dried at 80°C for 24 h (Fiala, 1987). The dry weight of 10 seedlings was measured using an electronic balance at a precision of 0.1mg. The value was divided by 10 to obtain the mean dry weight of a single seedling. Seedling dry weights were then expressed in milligrams. Seedling vigor index was calculated by multiplying percentage of kernels that germinated by mean dry weight (mg) of a single seedling.

**Data analysis**

All data were subjected to two-way ANOVA to detect significant effects of storage strategies within each period of storage and significant effects of storage periods within each storage strategy. Homogeneity of variances among different storage strategies or storage periods was tested using Bartlett's test. Insect count data were log transformed before analysis of variance. Student-Newman–Keul (SNK) Test was used to separate the means when there were significant differences at \( P \leq 0.05 \). Pearson’s correlation coefficients were used to determine association of other parameters with seed quality (germination and seedling vigor index). R software Version 3.4.3 was used for data analysis. Graphs were plotted using SigmaPlot software Version 12.5 (Anonymous, 2013).

4. 3 Results

**Oxygen and carbon dioxide levels in hermetic bags**

In both Super GrainPro bag and PICS bag, gas composition showed changes as storage time progressed. Mean oxygen level in Super GrainPro bag at the onset of storage was 20.87%. The oxygen level dropped to 17.88%, 15.36%, and 10.22% after two, four and six months of storage, respectively (Fig. 4-1). In PICS bags oxygen level dropped from 20.87% (baseline) to 11.80%, after two months of storage. The levels of oxygen in PICS bags did not go down at four and six months of storage. The corresponding carbon dioxide level in Super GrainPro bag at the beginning of the experiment was recorded at 0.00%. Gradual
increases were observed after two, four and six months of storage with respective concentrations of 2.00%, 3.72%, and 7.34% (Fig. 4-1). Similarly, in PICS bags there were increases of carbon dioxide from 0.01% (baseline) to 2.99%, 2.74%, and 5.02%, after two, four and six months of storage, respectively.

![Graph showing changes in oxygen and carbon dioxide levels in Super GrainPro (SGB) and Purdue Improved Crop Storage (PICS) bags over six months of storage.](image)

**Figure 4-1:** Mean (±SD) Oxygen and Carbon dioxide levels of wheat seed kept in Super GrainPro bag (SGB) and Purdue Improved Crop Storage (PICS) bags over six months of storage. Data are based on three replications.

**Inter-granular temperature and wheat moisture content**

There were slight changes of moisture content after different storage periods. In the beginning, the mean moisture content was about 10.4%. However, at 2months the moisture content of seed from storage units such as polypropylene bags (control), metal silo, plastic drum, PICS bag, and Super GrainPro bag increased to 11.7°C, 11.7°C, 12.0°C, 11.9°C, and
11.7°C, respectively (Fig. 4-2). Increases in moisture content within the sealed containers such as metal silos, plastic drums, and hermetic bags were strange phenomena. Seed mixed with filter cake and Triplex dust exhibited lower moisture up to 2months storage though it increased during the subsequent storage periods.

As of temperature, it decreased in all storage units as storage period increased from 0months to 4months in all storage units (Fig. 4-2). However, the temperature in controls, plastic drums, and PICS bags slightly increased from 22.1°C, 22.0°C, and 21.5°C at 4months of storage to 23.3°C, 22.8°C, and 22.2°C at 6months of storage, respectively. The temperature in storage units that received filter cake remained similar at 4months (22.3°C) and 6months (22.4°C) of storage.

Figure 4-2: Mean (±SD) moisture and inter-granular temperature of wheat seed preserved using different strategies. CT=Polypropylene bag (control), DT= Triplex in plastic drum 25kg size, FC=Filter Cake in polypropylene bag, SGB= Super GrainPro bag, MB=Metal silo of 100kg size, PD=Plastic drum of 25kg size, PICS= Purdue Improved Crop Storage bag, TR=Triplex in polypropylene bag. Data are based on three replications.
Numeration of Insects

At the outset of the experiment, natural infestation levels of storage insects were assessed, and during this process, no live insects were detected. *R. dominica* was the only live adult species detected throughout the six months period of storage and data are presented in Table 4-1.

Table 4-1: Mean (±SD) of live adults of *Rhizopertha dominica* in wheat seed preserved using different strategies.

<table>
<thead>
<tr>
<th>Storage Strategies</th>
<th>2 Months</th>
<th>4 Months</th>
<th>6 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene bag (control)</td>
<td>6.3±3.2a</td>
<td>28.3±8.7a</td>
<td>134.7±34.8a</td>
</tr>
<tr>
<td>Filter Cake in a polypropylene bag</td>
<td>0.0±0.0c</td>
<td>1.0±1.0cd</td>
<td>0.3±0.6d</td>
</tr>
<tr>
<td>Triplex in a polypropylene bag</td>
<td>1.0±1.0b</td>
<td>3.7±1.2cd</td>
<td>0.3±0.6d</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>1.7±1.2b</td>
<td>3.0±1.7c</td>
<td>3.0±1.0c</td>
</tr>
<tr>
<td>A plastic drum of 25kg size</td>
<td>2.0±1.0b</td>
<td>9.0±3.5b</td>
<td>32.0±7.2b</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>11.0±1.0a</td>
<td>1.0±1.7d</td>
<td>89.0±13.9a</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>0.0±0.0c</td>
<td>2.7±1.2cd</td>
<td>2.0±1.0d</td>
</tr>
<tr>
<td>PICS bag</td>
<td>3.0±1.7b</td>
<td>2.7±0.6cd</td>
<td>4.0±1.0c</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td><strong>23.15</strong></td>
<td><strong>18.06</strong></td>
<td><strong>125.06</strong></td>
</tr>
<tr>
<td>P-Value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Means followed by the same letters within each column are not significantly different (*P* > 0.05) by SNK test. Data are based on three replications.

There was a significant increase (*F<sub>2, 4</sub>=25.92; *P*<0.01) in the number of live *R. dominica* counts per kg of seed in polypropylene bags (control) as storage time increased. The highest mean live adult density (134.7 insects per kg) was recorded after six months of storage, respectively (Table 4-1). Storage time effect on the performance of metal silo was also significant (*F<sub>2, 4</sub>=107.14; *P*<0.01). It exhibited a surprisingly high density of *R. dominica* adults after two months (11.0 insects per kg of wheat) and six months (89.0 insects per kg of wheat) of storage (Table 4-1).

All storage strategies other than the metal silo demonstrated significantly lower live adult density compared to the control (Table 4-1). Super GrainPro bag and PICS bags exhibited live adult densities of 0.0 to 4.0 insects per kg. Seed treated with Filter Cake dust had insect densities of 0.0 to 0.3±0.6 insects per kg. Live adults were rarely detected after six
months of storage in seeds treated with Filter Cake or Triplex dust and placed in polypropylene bags.

**Percentage seed damage and weight loss**

Storage time posed a significant effect on percentage seed weight loss for the control (polypropylene bag) \((F_{2, 4}=2060.20; P<0.01)\), plastic drum with Triplex \((F_{2, 4}=8.59; P<0.05)\), and Super GrainPro bag \((F_{2, 4}=7.18; P<0.05)\). Likewise, significant differences of percentage seed damage were detected among storage periods for the polypropylene bags (control) \((F_{2, 4}=27.86; P<0.01)\) and PICS bag \((F_{2, 4}=9.52; P<0.05)\).

It was observed from the baseline assessment of percentage seed damage and weight loss that there was about 0.5% seed damage and 0.0% seed weight loss due to insects. During the first four months of storage, none of the storage strategies exhibited significant difference \((\alpha=0.05)\) concerning seed damage (Table 4-2). However, seed stored in polypropylene bags (control) exhibited significantly higher rates of seed damage (14.3%) at 6 months time.

Storage strategies posed significant effects \((F_{2, 7}; P<0.01)\) on seed weight loss (%) after all periods of storage (Table 4-2). Percentage weight loss increased until the end of the storage period, regardless of the storage method. Percentage weight loss at two months was 0.0% to 0.2%. Percentage weight loss at four months of storage was 0.1% - 0.6%. The highest rate of percentage weight loss at four months was in the polypropylene bag (control). As six months, percentage weight loss in the control (polypropylene bag) was 9.6%. Application of Triplex and Filter Cake dust and use of hermetic bags and plastic drums resulted in a substantially lower rate of percentage weight loss (%) compared to the control and metal silo.

**Loss of seed bulk density**

The baseline bulk density of untreated wheat seed was 825.7kgm\(^{-3}\). Bulk density continued to decline across all storage periods in all strategies of storage (Table 4-3). After two months of storage, seed stored in PICS bag, Super GrainPro bag, metal silo, and plastic drum demonstrated superior bulk densities ranging from 810.4kgm\(^{-3}\) to 807.4kgm\(^{-3}\). Reduction in bulk density from those storage strategies during the same period of storage ranged from 1.8% to 2.2% (Figure 4-3).

The bulk density of seed treated with Filter Cake or Triplex remained inferior to all other strategies of storage, including the control up to four months of storage. Six months after storage, the rate of reduction in bulk density was as high as about 9.4% in the control
while it was only 2.9% in Super GrainPro bag. Seed stored in PICS bags exhibited 4.5% mean reduction in bulk density. Seed mixed with filter cake and triplex dust demonstrated 8.1% to 8.8% reduction in bulk density.

Table 4-2: Mean (±SD) of damage and weight loss of wheat seed preserved using different strategies.

<table>
<thead>
<tr>
<th>Storage Strategies by Month</th>
<th>Seed Damage (%)</th>
<th>Seed Weight Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>0.4±0.1</td>
<td>0.2±0.0ab</td>
</tr>
<tr>
<td>Filter Cake in polypropylene bag</td>
<td>0.5±0.1</td>
<td>0.1±0.1bc</td>
</tr>
<tr>
<td>Triplex in polypropylene bag</td>
<td>0.6±0.5</td>
<td>0.1±0.0bc</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>0.4±0.2</td>
<td>0.1±0.0c</td>
</tr>
<tr>
<td>Plastic drum of 25kg size</td>
<td>0.7±0.4</td>
<td>0.1±0.0bc</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>0.4±0.2</td>
<td>0.2±0.0a</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>0.7±0.5</td>
<td>0.0±0.0c</td>
</tr>
<tr>
<td>PICS bag</td>
<td>0.4±0.3</td>
<td>0.2±0.0ab</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td>0.49</td>
<td>7.31</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.83</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>4 months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>0.8±0.5</td>
<td>0.6±0.1a</td>
</tr>
<tr>
<td>Filter Cake in polypropylene bag</td>
<td>1.3±0.7</td>
<td>0.2±0.1b</td>
</tr>
<tr>
<td>Triplex in polypropylene bag</td>
<td>0.7±0.2</td>
<td>0.1±0.0b</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>0.6±0.2</td>
<td>0.2±0.1b</td>
</tr>
<tr>
<td>Plastic drum of 25kg size</td>
<td>0.8±0.2</td>
<td>0.2±0.1b</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>1.1±0.7</td>
<td>0.2±0.1b</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>1.2±1.0</td>
<td>0.1±0.0b</td>
</tr>
<tr>
<td>PICS bag</td>
<td>0.8±0.2</td>
<td>0.2±0.0b</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td>0.56</td>
<td>25.72</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.78</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>6 Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>14.3±4.3a</td>
<td>9.6±0.3a</td>
</tr>
<tr>
<td>Filter Cake in a polypropylene bag</td>
<td>0.7±0.4b</td>
<td>0.2±0.1c</td>
</tr>
<tr>
<td>Triplex in a polypropylene bag</td>
<td>0.2±0.5b</td>
<td>0.2±0.1c</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>0.6±0.1b</td>
<td>0.2±0.1c</td>
</tr>
<tr>
<td>A plastic drum of 25kg size</td>
<td>0.8±0.2b</td>
<td>0.2±0.1c</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>1.9±1.1b</td>
<td>0.7±0.5b</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>1.0±0.5b</td>
<td>0.2±0.1c</td>
</tr>
<tr>
<td>PICS bag</td>
<td>1.2±0.4b</td>
<td>0.2±0.1c</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td>29.80</td>
<td>629.66</td>
</tr>
<tr>
<td>P-Value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Means followed by the same letters within each column are not significantly different (P>0.05) by SNK test.
Data are based on three replications.
Table 4-3: Mean (±SD) of the bulk density of wheat seed preserved using different strategies.

<table>
<thead>
<tr>
<th>Storage Strategies</th>
<th>Bulk Density (kg m⁻³) by month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2Months</td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>795.9±7.5a</td>
</tr>
<tr>
<td>Filter Cake in a polypropylene bag</td>
<td>769.7±6.2b</td>
</tr>
<tr>
<td>Triplex in a polypropylene bag</td>
<td>768.7±3.9b</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>780.6±9.0b</td>
</tr>
<tr>
<td>A plastic drum of 25kg size</td>
<td>807.4±1.8a</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>809.5±6.6a</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>809.8±0.9a</td>
</tr>
<tr>
<td>PICS bag</td>
<td>810.4±4.5a</td>
</tr>
<tr>
<td>F₀.₁₄</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>P-Value</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letters within each column are not significantly different (P>0.05) by SNK test. Data are based on three replications.

Figure 4-3: Mean (±SD) loss of bulk density (%) of wheat seed preserved using different strategies.
CT=Polypropylene bag (control), DT=Triplex in plastic drum 25kg size, FC=Filter Cake in polypropylene bag, SGB=Super GrainPro bag, MB=Metal silo of 100kg size, PD=Plastic drum of 25kg size, PICS=Purdue Improved Crop Storage bag, TR=Triplex in polypropylene bag. Data are based on three replications.

Germination and seedling vigor index

Mean germination % was recorded based on the number of normal seedlings (ISTA, 2014) developed from 100 seeds sown (Table 4-4). Germination at the beginning of the experiment was about 95.3%. A significant effect of storage strategies on germination percent was detected after six months of storage. During that period of storage, germination of seed from the control (polypropylene bag) was reduced to 68.0%. The germination percent in all other storage strategies ranged from 92.0% to 98.0%.
Seedling vigor index at the onset of the experiment was 979.2 mg % while significant differences were noted in seedling vigor among storage strategies after six months of storage. Following the trend of germination percent, the lowest vigor index was recorded on seed stored in polypropylene bag (control) (Table 4-4). Seed stored in the metal silo and plastic drum had exhibited lower vigor index, but that was not significantly different from storage strategies which demonstrated the superior performance of this parameter. The highest vigor index recorded after six months of storage was from seed treated with Triplex in polypropylene bag treatment. The same treatment also exhibited relatively low seed damage due to insects.

**Association of parameters with seed quality**

Seed germination exhibited significant correlation with physical characteristics such as bulk density and thousand seed weight (Table 4-5). Seed germination demonstrated strong and negative association to live adult insect counts per kg \((r = -0.64)\), damage of seed \((r = -0.87)\) and seed weight loss \((r = -0.88)\) (Table 5). The linear correlations of germination percentage with those parameters were highly significant \((p<0.001)\). Seed bulk density and thousand seed weight were positively correlated \((r = 0.30,\) and \(r = 0.43,\) respectively) with seed germination percent.

Seedling vigor index also demonstrated significant \((p<0.01)\) correlation with density of live adult insects per kg \((r = -0.48)\), seed damage \((r = -0.45)\), and seed weight loss \((r = -0.45)\). Unlike that of percentage germination, seedling vigor index did not show significant correlation with thousand seed weight.

### 4.4 Discussion

The present data provide us the opportunity to compare different storage strategies for preservation of wheat seed under small-scale conditions. There was a high numbers of *R. dominica* per kg developed in the polypropylene bag, a method commonly used by farmers for the storage of wheat seed grain, in Ethiopia (Dessalegn et al., 2017; Hengsdijk and de Boer, 2017). Live insect population showed a continuous increase and, at six months of storage, the kernel damage rate and weight loss in polypropylene bag were nearly 14% and 10%, respectively. A rise in moisture content of the seed due to increased respiration from grains and insects as storage period progressed might have contributed to insect population build up.
<table>
<thead>
<tr>
<th>Storage Strategies by Month</th>
<th>Germination (%)</th>
<th>Vigor Index (mg. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>94.7±1.5</td>
<td>946.9±40.1</td>
</tr>
<tr>
<td>Filter Cake in a polypropylene bag</td>
<td>97.3±2.1</td>
<td>1159.5±128.2</td>
</tr>
<tr>
<td>Triplex in a polypropylene bag</td>
<td>93.3±1.5</td>
<td>1123.6±48.2</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>96.7±0.6</td>
<td>1117.0±164.5</td>
</tr>
<tr>
<td>A plastic drum of 25kg size</td>
<td>96.3±2.5</td>
<td>1118.2±141.9</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>97.3±1.5</td>
<td>1061.7±83.9</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>95.7±1.5</td>
<td>1134.7±94.3</td>
</tr>
<tr>
<td>PICS bag</td>
<td>93.0±2.0</td>
<td>1075.5±51.9</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td>2.66</td>
<td>1.18</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.06</td>
<td>0.38</td>
</tr>
<tr>
<td>4 months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>95.3±3.2</td>
<td>1079.7±41.8ab</td>
</tr>
<tr>
<td>Filter Cake in a polypropylene bag</td>
<td>95.7±1.5</td>
<td>1095.9±80.1ab</td>
</tr>
<tr>
<td>Triplex in a polypropylene bag</td>
<td>95.7±0.6</td>
<td>1161.2±109.8a</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>92.3±2.5</td>
<td>1079.8±101.5ab</td>
</tr>
<tr>
<td>A plastic drum of 25kg size</td>
<td>93.0±1.7</td>
<td>1090.6±49.0ab</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>93.3±3.2</td>
<td>1057.9±73.4ab</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>93.0±3.0</td>
<td>934.3±62.0b</td>
</tr>
<tr>
<td>PICS bag</td>
<td>95.7±3.5</td>
<td>1010.7±70.9ab</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td>1.14</td>
<td>2.63</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.39</td>
<td>0.06</td>
</tr>
<tr>
<td>6 Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polypropylene bag (control)</td>
<td>68.0±6.1b</td>
<td>791.2±46.4b</td>
</tr>
<tr>
<td>Filter Cake in a polypropylene bag</td>
<td>92.0±3.6a</td>
<td>835.6±33.5ab</td>
</tr>
<tr>
<td>Triplex in a polypropylene bag</td>
<td>92.7±4.2a</td>
<td>1148.3±44.9a</td>
</tr>
<tr>
<td>Triplex in plastic drum 25kg size</td>
<td>97.7±0.6a</td>
<td>1058.1±29.8ab</td>
</tr>
<tr>
<td>A plastic drum of 25kg size</td>
<td>98.0±1.0a</td>
<td>987.1±185.5ab</td>
</tr>
<tr>
<td>Metal silo of 100kg size</td>
<td>97.7±1.5a</td>
<td>954.3±138.3ab</td>
</tr>
<tr>
<td>Super GrainPro bag</td>
<td>94.7±4.5a</td>
<td>1012.9±149.1ab</td>
</tr>
<tr>
<td>PICS bag</td>
<td>97.0±1.7a</td>
<td>1051.7±35.4ab</td>
</tr>
<tr>
<td>F&lt;sub&gt;7, 14&lt;/sub&gt;</td>
<td>24.14</td>
<td>2.99</td>
</tr>
<tr>
<td>P-Value</td>
<td>&lt;0.01</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Means followed by the same letters within each column are not significantly different ($P>0.05$) by SNK test.
Mean percentage of germination at the beginning of the experiment was about 95.3±0.3%. Data are based on three replications.
Table 4-5: Pearson’s correlation among seedling traits, seed biophysical traits, and some insect damage variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Germination (%)</th>
<th>Vigor Index (mg.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density (kg/m³)</td>
<td>0.30*</td>
<td>0.17\textsuperscript{NS}</td>
</tr>
<tr>
<td>Thousand Seed Weight (g)</td>
<td>0.43***</td>
<td>0.16\textsuperscript{NS}</td>
</tr>
<tr>
<td>Moisture Content (% wb)</td>
<td>-0.06\textsuperscript{NS}</td>
<td>-0.03\textsuperscript{NS}</td>
</tr>
<tr>
<td>Live \textit{R. dominica} (count)</td>
<td>-0.64***</td>
<td>-0.48***</td>
</tr>
<tr>
<td>Seed Weight Loss (%)</td>
<td>-0.88***</td>
<td>-0.45***</td>
</tr>
<tr>
<td>Seed Damage (%)</td>
<td>-0.87***</td>
<td>-0.45***</td>
</tr>
<tr>
<td>Normal Germination (%)</td>
<td></td>
<td>0.43***</td>
</tr>
</tbody>
</table>

\*\*, ***Pearson’s correlation is significant at 5, 1 and 0.1% levels of significance. \textsuperscript{NS}Correlation is not significant at 5% level of significance.

The lethal effects of filter cake and Triplex to adults of \textit{S. zeamais} have been well documented in maize grains (Demissie et al., 2008a, b; Tadesse & Subramanyam, 2018a). In the current study, application of Filter Cake or Triplex dusts to infested wheat seed provided substantial control of \textit{R. dominica} population development. In our study, Filter cake and Triplex were applied at rates of 1% (w/w) and 0.25 % (w/w), respectively, and maintained a live adult population of \textit{R. dominica} at a negligible level, even at 6 months of storage. It was also reported recently that filter cake dust caused complete mortality of \textit{R. dominica} adults at application rates of 0.25% (w/w) to 1% (w/w) within 14 days (Kalsa et al., 2017). Besides, Demissie et al. (2008a) had observed that Filter Cake caused 100% mortality in \textit{S. zeamais} after 15 days of exposure at the rate of 1% (w/w). In a different study, Demissie et al. (2008b) also reported that the Triplex was as effective as Malathion 5% and pirimiphos-methyl 2% on the mortality rate of \textit{S. zeamais}.

Earlier studies demonstrated that the metal silo kills any insect that may be inside by eliminating oxygen (Tefera et al., 2011; Yusuf & He, 2011). Unlike those reports, metal silo did not cause sufficient reduction in live adult insect population after six months of storage in the present study. Proponents of the technology highly recommend the addition of burning candle to the headspace of silos, but a recent report by Dowell & Dowell (2017) indicated that the addition of a candle to a closed container does little to create conditions that affect insect activity. An earlier finding by Belcher and McElwain (2008) also showed that the lower oxygen limit for combustion to occur is 15%. Such level of oxygen, however, is sufficient for insect activity (Dowell & Dowell, 2017). While proponents of the metal silo stressed on complete filling of the unit in order to get adequate control of insects (Tefera et
al., 2011), this is not always possible since smallholder farmers will often have a large headspace in their metal silos as the amount of stored product varies among different periods.

Effectiveness of hermetic technologies such as Super GrainPro and PICS bags against insects is well documented (De Groote et al., 2013; De Bruin et al., 2014; Guenha et al., 2014; Mutambuki et al., 2014; Martin et al., 2015; Mlambo et al., 2017). Baoua et al. (2013) observed that there was a statistically non-significant difference in performance between the two technologies against live adult *Callosobruchus maculatus* (Fab.) population in cowpeas (*Vigna unguiculata* Walp). In our experiment, the live adult population of *R. dominica* has been maintained at a very low level until the end of the experiment period. Bagging infested seed in plastic bags leads to hypoxia due to respiration of insects living in the seed mass (Baoua et al., 2012). In the current study, the level of oxygen in hermetic bags has declined while the carbon dioxide level increased in both types of bags as storage time increased. Limited oxygen availability could be attributed to the retarded population growth. This, in turn, has resulted in lower rates of seed damage and weight loss. However, the rate of decline in oxygen level and rise in carbon dioxide level in hermetic bags is inconsistent with that reported in the literature (Mutungi et al., 2014). At the onset of the storage period, there was no live adult insect detected in seed samples. This might have contributed to a lower rate of depletion of oxygen and a slow rise in carbon dioxide levels.

In our study, the bulk density of seed treated with Filter Cake or Triplex remained inferior to all other strategies, including the control up to four months of storage. Since it didn't decline over time, this was just the effect of admixing filter cake or Triplex dust with the seed, indicating that even at 0 months it would have been 8.8% less than untreated seed. Hence, reduction in bulk density of dust treated seed is mainly due to reduced mobility of the seed mass (Subramanyam & Roesli, 2000).

The incidence of seed deterioration is inevitable, but it can be slowed down through the application of improved postharvest preservation strategies. The significance of hermetic storage technologies is widely accepted for long-term storage of a variety of seeds to preserve germination potential and vigor (Essien et al., 2010). Our study also indicates that hermetic technologies such as Super GrainPro bag and PICS bag are good alternatives to small-scale storage of wheat seed. Moreover, seedling vigor index of seed treated with Triplex is comparable with that of hermetic bags. Previous studies did not have any report on seed germination or seedling vigor associated with Triplex treatment (Demissie et al., 2008b; Tadesse & Subramanyam, 2018). However, it can be speculated from the present study that
higher seedling vigor index of seed treated with Triplex could be attributed to the lower seed damage rate.

In general, the current study demonstrates that the use of Filter Cake and Triplex dusts provided the highest degree of control of *R. dominica* population growth during six months of wheat seed storage followed by hermetic bags. The differences in percentage of seed damage, weight loss, and germination among improved strategies are not remarkable. It should be noted, however, that availability of the Filter Cake and Triplex dusts as factory by-products and their superior efficacy against *R. dominica*, *S. granarius*, and *S. zeamais* (Demissie et al., 2008a; Demissie et al., 2008b; Kalsa et al., 2017; Tadesse & Subramanyam, 2018a) would make them the best choices to help smallholder farmers. Besides, chemical composition determined by scanning electron microscopy and energy dispersive X-ray spectrometry indicated that filter cake and Triplex are free of heavy metals (Tadesse & Subramanyam, 2018a). However, safety concerns concerning application techniques and removal of dust after storage need further investigation.

Finally, it is essential to further investigate efficient and practical strategies of oxygen depletion from metal silo headspaces. Moreover, since most of the studies on filter cake and Triplex dust are at an experimental level, emphasis can be given to the broader application of the products through on-farm participatory studies.

### 4.5 References


Demissie, G., Tefera, T., Tadesse, A., 2008a. Efficacy of Silicosec, filter cake and wood ash against the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) on three maize genotypes. *Journal of Stored Products Research*, 44,


FAO. (2017). Food and agriculture data, FAOSTAT. Rome, Italy.


CHAPTER 5: MORTALITY OF *SITOPHILUS GRANARIUS* (L.) AND *RHYZOPERHTHA DOMINICA* (F.) ADULTS EXPOSED TO DIFFERENT CONCENTRATIONS OF FILTER CAKE IN STORED WHEAT

Abstract

Silica-based inert powders are eco-friendly alternatives to control stored grain insect pests due to environmental and health concerns associated with the use of synthetic insecticides. A study was conducted to determine the efficacy of filter cake (silica-based inert dust) on the granary weevil, *Sitophilus granarius* (L.) and lesser grain borer, *Rhyzopertha dominica* (F.) in stored wheat. Filter cake dust of ≤0.4 mm particle size was admixed with 500 g of wheat seed to provide nominal rates of 10000, 7500, 5000, and 2500 ppm (mg/kg), while the control treatment consisted of wheat seeds that were untreated. The bioassays were carried out using a liter-sized plastic jar in a completely randomized design with three replications. Experiments were maintained at 23.1±1.7°C and 61.0±4.3% relative humidity. Mortality data were collected at 3, 7, and 14 d after treatment. Results indicated that the mean mortality rate at 3 d after treatment ranged from 41.3 to 70.0% in *S. granarius* and 73.3 to 93.3% in *R. dominica*. Mean mortality of *S. granarius* adults at 14 d in filter cake treatments was 84.0 to 98.7%, whereas that of *R. dominica* was 98.3 to 100%. The present results show that filter cake dust can be used to control these two species in stored wheat. Filter cake has potential in the protection of wheat from *S. granarius* and *R. dominica* infestations in storage.

**Keywords:** Filter cake, wheat, *Rhyzopertha dominica*, *Sitophilus granarius*

5.1 Introduction

Wheat is one of the major cereal crops grown in Ethiopia and it is well adapted to highlands, which range between 1500-2800 m above the sea level (Gebre-Mariam et al., 1991). Wheat is produced on 1.7 million hectares of land (CSA, 2017). Despite increases in wheat yield due to use of improved production technologies and inputs (Mann & Warner, 2015; Kotu & Admassie, 2016), the country remains a net importer of wheat.

Poor postharvest handling of wheat grains results in quality and weight losses due to spoilage by insect and mold (Boxall, 1998), contributing to the shortage of wheat supply. Stored product insects are important factors that cause quality and weight loss of wheat and other cereals under smallholder conditions in Ethiopia. Major stored product insect species on wheat include the granary weevil *Sitophilus granarius* (L.), rice weevil *Sitophilus oryzae* (L.), and maize weevil *Sitophilus zeamais* Motschulsky. The red flour beetle *Tribolium castaneum*
(Herbst), confused flour beetle *Tribolium confusum* Jacquelin de Val, and almond moth *Cadra cautella* (Walker) (Gebre-Mariam et al., 1991). Generally, *S. granarius* is a major pest in higher altitudes (Tadesse et al., 2008).

Silica-based inert dust are eco-friendly alternatives to control stored grain insect pests due to environmental and health concerns associated with the use of synthetic insecticides. Previous studies highlighted susceptibility of insects to silica-based inert dust as affected by insect species, grain moisture, and storage temperature (Stathers et al., 2004; Vayias Stephou, 2009; Fields & Korunic, 2013; Prasanta et al., 2015; Gana et al., 2016). Cook & Armitage (2000) reported that *S. granarius* population was totally suppressed within 12 weeks after surface applications of 3-5 g/kg Dryacide, diatomaceous earth dust on, wheat of 16% moisture content at 15°C. However, it took about 22 weeks to achieve 100% suppression of the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) population under similar conditions. Sousa et al. (2013) also concluded that lower concentrations are more effective at high temperatures and longer exposure times the *S. zeamais* control. Kavallieratos et al. (2015) underscored that *T. confusum* was the least susceptible species to three diatomaceous earth formulations compared to *R. dominica* and *S. oryzae*.

Demissie et al (2008) evaluated a material, filter cake, locally available in Ethiopia, found that it is effective against *S. zeamais* at a rate of 1% (w/w) or higher. A recent study showed that the composition (w/w) in filter cake dust has a considerable amount of silicon dioxide (Tadesse & Subramanyam, 2018). Efficacy of the inert dust at lower concentrations also needs to be investigated since applying at a rate of >1% (10000 ppm) may be too high, since commercial formulations of the diatomaceous earth are normally used at rates as low as 3500 ppm (0.35%) (Shah & Khan 2014). This study, therefore, was initiated to investigate the efficacy of filter cake dust against adults of *S. granarius* and *R. dominica* in stored wheat.

5.2 Materials and Methods

Test insects

Test insects of *S. granarius* were collected from farmers’ stores in Ofa district, Tigray, Ethiopia, at an altitude of about 2509 m above the sea level with geographic coordinates of N12°30.939' E039°30877' in early June 2016. Approximately 200 unsexed live adults of mixed ages were recovered from wheat samples and placed in 1-liter plastic jars filled with around 200 g of disinfested wheat. The jar was then covered with cotton fabric for rearing under room conditions at the College of Agriculture and Environment Sciences, Bahir
Dar University, Ethiopia. Original insects were then removed after 15 d. Additional disinfested grain was added to plastic jars to provide food to the growing insect culture. Adults that were about three to six weeks were collected and used in bioassays during the end of September 2016.

Adults of *R. dominica* were recovered during the end of August 2016 from certified seed samples purchased from the Ethiopian Seed Enterprise, Bahir Dar Center. About 150 to 200 adults were reared in plastic jars filled with 200 g of disinfested wheat. Additional insect free grain was added to plastic jars to avoid food limitation to the insects. Original adults were not removed in the case of lesser grain borer but sifted at the end of the incubation period (42 d). Newly emerged adults from cultures were collected for about two weeks until sufficient numbers were obtained for bioassays.

Temperature and relative humidity of the laboratory room during the period between July and end of September was recorded hourly using HOBO® temperature/relative humidity sensors (Onset® Computer Corporation, Bourne, Massachusetts, USA). The average room temperature and humidity were 23.1±1.7°C and 61.0±4.3%, respectively.

**Wheat treatment**

Wheat samples were sifted and disinfected by refrigerating at 5°C for two weeks. Grain samples were acclimatized for 48 h at room conditions. Damaged grains were removed and only undamaged grains were used in bioassays.

Filter cake dust was applied to wheat of 12.5% moisture content (wet based) to provide concentrations of 10000 ppm, 7500 ppm, 5000 ppm, 2500 ppm, and 0 ppm (control). The untreated and filter cake treated 500 g wheat were placed in 1000 ml plastic jars covered with woven cotton fabric. Fifty adults of *S. granarius* and 20 adults of *R. dominica* were placed in each plastic jars. The jars were placed in the laboratory under room conditions as described above, in a completely randomized design with three replications.

**Data collection**

Insect mortality was examined at 3, 7, and 14 d after treatment. Dead insects were removed at each time of counting. All live insects were returned to the jars until the end of data collection (14 d). Mortality data were corrected in treatments for mortality in control based on the following equation provided by Rosenheim & Hoy (1989):

\[
P_{corr} = 1 - \left(\frac{1 - T}{1 - C}\left(\frac{K}{1 - C}\right)\right) \times 100 \quad \text{and} \quad K = \left(\frac{Var(C) + 2}{(1 - C)^2 ne}\right)
\]
where, \( P_{corr} \) = corrected proportion of dead adults, \( T \) = mortality in treated grain and \( C \) = mortality in untreated grain, \( n_c \) = number of replications used for estimating \( C \), and \( t \) = value of \( t \) distribution \( nc-1 \) degrees of freedom at \( \alpha = 0.05 \). Percentage data were transformed to angular values (Zar, 1984). However, in tables untransformed corrected mortality data are presented.

Data analysis

Corrected mortality data were subject to one-way analysis of variance (ANOVA) by day using the GLM procedure because the mortality over time was measured on same three replicates at each concentration (SAS Institute, 2012). Significant differences in mortality by day among concentrations were determined by Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGW) at \( \alpha = 0.05 \) (SAS Institute, 2012).

5.3 Results

Insect mortality at different filter cake concentrations

The mortality of \( S. granarius \) and \( R. dominica \) adults in the control treatment ranged from 0.7 to 13.3 % (Table 5-1).

<table>
<thead>
<tr>
<th>Insect species</th>
<th>3 d</th>
<th>7 d</th>
<th>14 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S. granarius )</td>
<td>0.7±0.7</td>
<td>3.3±1.3</td>
<td>4.7±1.3</td>
</tr>
<tr>
<td>( R. dominica )</td>
<td>1.7±1.7</td>
<td>1.7±1.7</td>
<td>13.3±1.7</td>
</tr>
</tbody>
</table>

Analysis of variance showed that there was a statistically significant difference (\( P<0.05 \)) in mortality of \( S. granarius \) adults among concentrations at 3 and 14 d but not at 7 d (Table 5-2). This can be attributed to the high coefficient of variation (Table 5-2).

The corrected mortality of \( R. dominica \) adults was not significant (\( P>0.05 \)) at 3, 7, and 14 d after treatment (Table 5-3). The coefficient of variation at 3 days after treatment was high showing that the observations could be less reliable. However, 100% mortality of \( R. dominica \) was observed at 5000, 7500, and 10000 ppm but mortality of \( S. granarius \) adults never reached 100 % (Table 5-2).
Table 5-2: Mean (± SE) mortality (%) of *Sitophilus granarius* adults exposed to different concentrations of filter cake at three exposure times\(^{a,b,c}\)

<table>
<thead>
<tr>
<th>Filter Cake Concentration (ppm)</th>
<th>3 days</th>
<th>7 days</th>
<th>14 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>70.0±4.0a</td>
<td>95.3±2.9</td>
<td>98.7±1.3a</td>
</tr>
<tr>
<td>7500</td>
<td>62.7±1.8ab</td>
<td>91.3±5.2</td>
<td>98.7±0.7ab</td>
</tr>
<tr>
<td>5000</td>
<td>52.7±1.8b</td>
<td>85.3±2.4</td>
<td>90.7±2.8bc</td>
</tr>
<tr>
<td>2500</td>
<td>41.3±2.4c</td>
<td>74.0±4.0</td>
<td>84.0±3.1c</td>
</tr>
</tbody>
</table>

Mean 56.7 86.5 93

F-value 21.05 3.59 9.4
CV% 5.64 11.84 6.87
P-Value 0.00 0.07 0.01

a) Each mean is based on n=3; b) df = 3, 8 for all; c) At each exposure time, means followed by the same letter are not significant (P>0.05, REGWQ test)

Table 5-3: Mean (± SE) mortality (%) of *Rhizopertha dominica* adults exposed to different concentrations of filter cake at three exposure times\(^{a,b,c}\)

<table>
<thead>
<tr>
<th>Filter Cake Concentration (ppm)</th>
<th>3 days</th>
<th>7 days</th>
<th>14 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>93.3±6.7</td>
<td>98.3±1.7</td>
<td>100±0.0</td>
</tr>
<tr>
<td>7500</td>
<td>80.0±7.6</td>
<td>95.0±2.9</td>
<td>100±0.0</td>
</tr>
<tr>
<td>5000</td>
<td>78.3±4.4</td>
<td>93.3±3.3</td>
<td>100±0.0</td>
</tr>
<tr>
<td>2500</td>
<td>73.3±7.2</td>
<td>93.3±1.7</td>
<td>98.3±1.7</td>
</tr>
</tbody>
</table>

Mean 81.3 95 99.6

F-value 2.53 0.89 1.00
CV% 15.86 10.3 4.19
P-Value 0.13 0.49 0.44

a) Each mean is based on n=3; b) df = 3, 8 for all; c) At each exposure time, means followed by the same letter are not significant (P>0.05, REGWQ test)

**Time-dose-response relationships**

A regression analysis for the relationship between adult insect mortality (%) and the filter cake application rate demonstrated a strong linear association. For every increase in parts per million of filter cake application rate, there was an increase in mortality rate of *S. granarius* adults by 0.00384% (R\(^2\)=0.873, F-value=76.7), 0.0028% (R\(^2\)=0.621, F-value=19.0), and 0.00208% (R\(^2\)=0.68, F-value=24.4) at 3, 7 and 14 days after application, respectively (Figure 5-1). However, to achieve 100% mortality within the range of one to two weeks, one has to apply 7500 to 10000ppm of filter cake dust, i.e. 0.75 to 1.00g of filter cake dust for every kilogram of wheat grain (Figure 5-1). Doses that result in 100% mortality within a shorter period are important to continued protection of grains. Slow effects may allow adequate time for oviposition resulting in a certain level of damages from progenies. In
fact, higher doses such as 10000ppm may result in total mortality within eight days but this may not be attractive to flour plants. In the present case, use of 7500ppm may be adequate to cause 100% mortality within less than ten days (Figure 5-1).

As exposure time increased from 3 to 14 days, constants of the regression equation increased from 32.7% to 80.0%. This could be attributed to the fact that only mortality (but not a new emergence of progenies) is considered as population parameter (in this study); and hence once exposed, *S. granarius* adults are subject to death in a given course of time regardless of the filter cake concentration.

**Log-logistic relationship**

Effective doses for median mortality (ED$_{50}$) and 95% mortality (ED$_{95}$) were estimated using the log-logistic two-parameter model as suggested by Ritz *et al.* (2015) for dose-response binomial data. The estimated effective dose for ED$_{50}$ of *S. granarius* after 3 days of exposure was 3917.8±407.7ppm (~3.9g of filter cake dust per kilogram of wheat grain) (Figure 5-2). Both parameters (ED$_{50}$ and the slope) were highly significant (p<0.001) with t-
values of 9.562 and 5.5691 that S. granarius mortality data at 3 days exposure time has fit to the two-parameter log-logistic model. The estimate for ED$_{95}$ was 57473.5±25364.0ppm with 95% CL of 2677.8ppm to 112269.3ppm.

![Log-logistic binomial plot, ED50 as parameter](image)

Figure 5-2. Log-logistic binomial regression of mortality rate of adult insects of granary weevil (Sitophilus granarius) exposed to different application rates of filter cake for three days. $^a$

$^a$ Slope ($b$) =-1.096±0.197 (t-value =-5.5691, p<0.001); Residual Standard Error =3.91; ED50 ($c$) =3917.8±409.7(t-value=9.562, p<0.001, 95%CL=3032.7-4803.0); ED95 =57473.5±25364.0 (95%CL = 2677.8-112269.3)

5.4 Discussion

An earlier report by Demissie et al. (2008) indicated that filter cake at rate of 1% (w/w) can achieve 100% mortality of S. zeamais at 15 d after treatment. The difference in mean mortality between highest and lowest concentrations of filter cake treatment in our study was 14.7%. There is no previous report on the efficacy of filter cake dust against S. granarius adults, but studies on other silica-based dusts indicated that longer exposure times may be required to achieve complete mortality S. granarius adults (Cooks and Armitage, 2000). In the present study, the maximum mortality (98.7%) of S. granarius adults was achieved at a concentration of 10000 ppm after two weeks. This could be attributed to higher tolerance of S. granarius adults to desiccant dust as reported by Desmarchelier and Dines (1987). We observed that R. dominica can be controlled at lower concentrations of the filter cake, which is consistent with previous findings on diatomaceous earth (Kavallieratos et al., 2015).
In the present study, *R. dominica* exhibited more average mortality rate when compared to *S. granarius*. This is in line with a previous finding by Desmarchelier & Dines (1987), who concluded that *R. dominica* adults were more sensitive to silica-based dust. Silica-based dust increase rates of water loss from the insect’s body by adsorbing cuticle the cuticle leading to faster death by desiccation (Malia et al., 2016). The lower sensitivity of *S. granarius* to filter cake dust could be due to less pick up of filter cake particles compared to *R. dominica* (Figure 5-3).

**Figure 5-3**: Dead adults of *Sitophilus granarius* (A) and *Rhizopertha dominica* (C) recovered from wheat grain treated with 10000ppm filter cake (B) at 3 days after treatment. Dust particles adhered to insect bodies with higher density on *R. dominica*

In conclusion, the present study revealed that filter cake is effective against *S. granarius* and *R. dominica* adults. Filter cake adheres more to the cuticle of *R. dominica* body than *S. granarius* and might cause impairment of water balance in a similar manner that was observed with other silica-based products (Malia et al., 2016). Reducing filter cake concentration up to 5000 ppm (0.5%) did not show any significant reduction in effectiveness after 14 d in both species. However, further studies should be undertaken to understand the effects of grain moisture on the efficacy of filter cake. Filter cake has the potential for control of *S. granarius* and *R. dominica* in stored wheat.
5.5 Reference


CHAPTER 6 : EVALUATION OF ETHIOPIAN WHEAT VARIETIES AGAINST *SITOPHILUS GRANARIUS* (L.) AND *SITOPHILUS ORYZAE* (L.) INFESTATION AT OPTIMAL AND SUB-OPTIMAL TEMPERATURES

Abstract
Integrating varietal resistance with temperature manipulation during storage may provide a better option for protection of stored grains and may decrease reliance on the use of synthetic chemicals. The current study was conducted to determine the susceptibility of different varieties of wheat seed to the infestation by the granary weevil, *Sitophilus granarius* (L.), and rice weevil, *Sitophilus oryzae* (L.), at optimal (30ºC) and sub-optimal (19ºC) temperatures. Kernels of six wheat varieties, namely, Danda’a, Digalu, ET-13-A2, Kakaba, Millennium, and Pavon-76 were examined for 90 d. Significant interactions were detected between wheat varieties and storage temperature for progeny emergence, percentage of insect-damaged kernels, grain weight loss, and amount of powder produced per gram of wheat. Kernels of Danda’a, infested with *S. oryzae* at 30ºC exhibited significantly lower mean progeny counts (13.3 live insects), a lower percentage of grain weight loss (4.2%) and insect-damaged kernels (6.4%), and powder production (1.5 mg/g). Kernel weight and hardness index were negatively associated with the percentage of insect-damaged kernels and grain weight loss. Kernel diameter was positively associated with both percentage of insect-damaged kernels and grain weight loss. Wheat varieties with high Zeleny sedimentation values had a lower percentage of insect-damaged kernels and grain weight loss. These results indicated that kernel weight, hardness index, and protein content are predominant factors contributing to wheat resistance against *S. granarius* and *S. oryzae*. The varieties Millennium and Danda’a can be considered with other integrated pest management approaches to reduce stored grain losses of wheat in Ethiopia.

*Keywords*: Wheat, *Sitophilus granarius*, *Sitophilus oryzae*, variety resistance, kernel texture, proximate composition

6.1 Introduction

Ethiopia is the largest producer of wheat in sub-Saharan Africa and its production contributes 15.17% (4.6MT) of the total cereal production (CSA, 2017). Insect triggered
global losses of staple grains such as rice, maize, and wheat are projected to increase under warming climate scenarios (Deutsch et al., 2018). On the other hand, traditional storage structures in use by smallholder farmers are not suitable for the application of insecticides, especially fumigants (Williamson et al., 2008; Dowell and Dowell, 2017).

Targeting stored seed resistance to insects for improving grain storage traits has drawn increasing attention in combating global food security challenges (Godfrey et al., 2012). Host plant resistance is a critical component of integrated pest management in stored grains because it is inherent to grains and causes no hazard to the environment, and it is compatible with other control methods (Keneni et al., 2011). Besides, the use of insect-resistant cultivars may slow down the rate of development of insect populations and resistance to insecticides (Khan et al., 2015). The literature is replete with the utilization of crop variety resistance to protect stored grains (Keneni et al., 2011).

Studies showed that resistant varieties bear the potential for managing stored grain losses under subsistence farming conditions such as that seen in countries like Ethiopia (Abebe et al., 2009; Keneni et al., 2011). In a recent study, Saad et al. (2018) found that different wheat varieties exhibited significant differences in the percentage of insect-damaged kernels when exposed to the rice weevil, *Sitophilus oryzae* (L.) and lesser grain borer, *Rhyzopertha dominica* (F.). They reported that kernel hardness contributed to the resistance in the wheat varieties tested. In a different study, Ali et al. (2011) observed a significant variation among 15 wheat varieties from Pakistan in their resistance to the red flour beetle, *Tribolium castaneum* (Herbst). While all wheat varieties suffered losses, the degree of susceptibility differed among varieties. Hassan et al. (2017) also reported varietal differences regarding population growth of *T. castaneum* and the Khapra beetle, *Trogoderma granarium* Everts, on five wheat varieties. Such studies, however, are lacking with wheat varieties grown in Ethiopia. More than a hundred and fifty wheat varieties were registered in Ethiopia over the last five decades (CIMMYT, 2014), and about a hundred are reported to be currently under production (Ministry of Agriculture, 2014).

One of the most promising biorational management tools for farm-stored grain is temperature management (Phillips and Throne, 2010). At optimal temperatures of 25 to 33°C, most insects have the maximum rate of development whereas development stops at sub-optimal temperatures between 13 and 20°C (Fields, 1992; Fields et al., 1998). Stored-product insects are adversely affected by suboptimal temperatures even though their performance (egg-to-adult development and reproduction) may vary depending on the food substrate and
insect species (Fields et al., 1998; Jian et al., 2015). Hence, integrating sub-optimal temperatures with tolerant varieties may provide better options for control of insects in stored wheat. Despite the release of high yielding wheat varieties, an important concern is the possible vulnerability of these varieties to stored grain insect pests.

There is a dearth of complete and updated information on responses of Ethiopian wheat varieties to different storage insects under optimal and sub-optimal temperatures and their biophysical and biochemical characteristics that contribute to insect resistance. Therefore, the present study was undertaken with the objective to determine the response of different wheat varieties to the granary weevil, *Sitophilus granarius* (L.) and *S. oryzae* (L.) under optimal and sub-optimal temperatures and to recommend the most insect tolerant varieties for safe storage to reduce pest and economic losses of stored wheat.

6. 2  Materials and Methods

*Wheat varieties*

The wheat varieties Danda’a, Digalu, ET-13-A2, Kakaba, Millennium and Pavon-76, were obtained from the Kulumsa Agricultural Research Center of the Ethiopian Institute for Agricultural Research, National Wheat Program, Kulumsa, Ethiopia. The grains were cleaned of straw, chaff, light grains and other impurities before use in tests. Kernels with any form of damage were removed and samples were frozen in deep freezer at -18°C for two weeks to kill any live insects originating from natural infestation. Samples were then acclimatized in woven cotton bags at room temperature (~24.5°C and 76% r.h.) for one week. Kernel hardness was determined using Single Kernel Characterization System (SKCS, Perten Instruments North America Inc., Springfield, Illinois, USA) based on development by Martin et al. (1993), at the Food Science Laboratory of Kulumsa Agricultural Research Center.

*Insect cultures*

Adults of *S. granarius* and *S. oryzae*, obtained from farmers’ stores in major wheat growing districts of Ethiopia, were used to establish insect cultures. *S. oryzae* and *S. zeamais* were identified by dissecting and examining the morphology of genitalic structures (Hidayat et al., 1996).

Weevils were allowed to oviposit on clean, uninfested wheat grain in one-liter plastic jars for two weeks, and subsequently, adults were separated and discarded. The openings of the plastic jars were covered with muslin cloth held in place by rubber bands. To get enough number of adults of uniform age, newly emerged adults were subsequently released onto
fresh disinfested grain. They were reared at a temperature of 30 ± 1°C and a relative humidity of 72 ± 4%. Two to three weeks aged weevils from cultures were used in experiments.

**Experimental setup**

The experiment was conducted using temperature controlled incubators (Model 513, Vindon Scientific, Oldham, UK) with two temperature settings, 19±1°C and 30±1°C. Temperature sensors (HOBO® data loggers; Onset Computer Corp., Bourne, Massachusetts, USA) were placed in each chamber to monitor temperature and relative humidity. The relative humidity of chambers was 72 ± 4% at 30°C and 66±6% at 19°C. Six 30 g samples of each wheat variety were placed in 60 ml plastic jars and kept in each environmental chamber. Twenty unsexed adults of *S. granarius* or *S. oryzae* were introduced into each jar at a density of 667 insects per kg of seed. Control samples included each variety without insects kept in each chamber. The jars were covered on top with perforated plastic lids and kept for 90 d after which the necessary data were collected as described below. Completely randomized design with three replications was employed for the experiments.

**Data collection**

Proximate analysis for protein, starch, wet gluten, moisture, and Zeleny sedimentation values for all wheat varieties was assessed at the outset of the experiment by Near-Infrared Transmittance (NIRT) spectroscopy using Infratec™ 1241 Grain Analyzer (FOSS, Hillerod, Denmark) as per the guideline described in NIRT handbook (USDA, 2006). At the end of the experimental period of 90 d, live adults of *S. granarius* and *S. oryzae* were counted. Each sample was sieved through 1.2mm mesh screen and the powder that passed through was weighed. The powder produced was expressed as mg of powder per gram of seed at a standard moisture content (13%). The samples were reweighed to determine weight loss. The numbers of damaged and undamaged kernels (seeds) in each sample were recorded. Percentage of insect-damaged kernels was calculated by dividing the number of insect-damaged kernels by the total number of insect-damaged and undamaged kernels. Percent weight loss of wheat was determined by subtracting the value of infested samples from that of the control samples.

**Data analysis**

All data were subject to analysis of variance (ANOVA) using the R Software version 3.5.1. Count data and percentage data were transformed to log scale and angular values,
respectively, prior to analysis (Zar, 1984). If ANOVA results were significant, means were compared using Tukey’s test at 5% level of significance as well as two-sample $t$-tests. Multiple linear regression analyses were employed to estimate the effects of kernel characteristics and proximate composition on weevil population development and seed damage parameters.

6.3 Results

Physico-chemical characteristics of wheat varieties

Single kernel characteristics such as hardness index, seed diameter, seed weight, and grain color of wheat varieties tested in the experiment are depicted in Table 6-1. Hardness index ranged from 17.50 to 69.49, whereas the seed diameter and seed weight ranged from 2.57 to 3.11 mm and 31.98 to 39.70 mg, respectively. All varieties except Millennium exhibited white grain color. Millennium is a hard red spring wheat variety.

Table 6-1: Single kernel characteristics of tested wheat varieties.$^a$

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Weight (mg)</th>
<th>Hardness Index</th>
<th>Seed Diameter(mm)</th>
<th>Grain Color</th>
<th>Year of release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danda’a</td>
<td>38.62</td>
<td>66.69</td>
<td>2.93</td>
<td>White</td>
<td>2010</td>
</tr>
<tr>
<td>Digalu</td>
<td>37.46</td>
<td>17.50</td>
<td>2.75</td>
<td>White</td>
<td>2005</td>
</tr>
<tr>
<td>ET13-A2</td>
<td>31.98</td>
<td>26.54</td>
<td>2.57</td>
<td>White</td>
<td>1981</td>
</tr>
<tr>
<td>Kakaba</td>
<td>39.70</td>
<td>58.24</td>
<td>3.11</td>
<td>White</td>
<td>2010</td>
</tr>
<tr>
<td>Millennium</td>
<td>34.42</td>
<td>19.19</td>
<td>2.72</td>
<td>Red</td>
<td>2007</td>
</tr>
<tr>
<td>Pavon-76</td>
<td>36.79</td>
<td>69.49</td>
<td>2.81</td>
<td>White</td>
<td>1982</td>
</tr>
</tbody>
</table>

$^a$Varieties were judged hard or soft by the SKCS. Values were based on data averaged over 300 kernels for each variety.

Proximate compositions of the six wheat varieties are presented in Table 6-2. The results indicated that wheat varieties varied significantly ($P < 0.01$) in all biochemical parameters recorded. Variety Millennium had the highest protein concentration (14.4%), while Pavon-76 had the lowest concentration (12.3%). The average protein content of the hard wheat varieties was significantly lower ($t = -5.20; \text{DF} = 15.7; P < 0.01$) when compared with that of soft wheat varieties. Moisture content ranged from 9.5 to 10.6% and there was no significant difference in moisture content between hard and soft wheat varieties ($t = 0.93; \text{DF} = 13.3; P = 0.368$). The starch content ranged from 55.8% in Danda’a to 59.0% in Digalu. However, there was no significant difference between hard and soft wheat varieties concerning their starch content ($t = 0.40; \text{DF} = 15.4; P = 0.696$). Zeleny’s sedimentation value was lowest for variety Kakaba, whereas the variety of Millennium exhibited the highest sedimentation value. There was a significant difference ($t = -3.16; \text{DF} = 11.6; P = 0.009$) in
sedimentation values between hard and soft wheat varieties. The sedimentation value of soft wheat varieties was generally higher.

Table 6-2: Mean (± SD) values of proximate composition of wheat varieties

<table>
<thead>
<tr>
<th>Wheat Varieties</th>
<th>Protein (%)</th>
<th>Moisture (%)</th>
<th>Starch (%)</th>
<th>Wet Gluten (%)</th>
<th>Sedimentation Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danda’a (Hard)</td>
<td>13.3±0.2 c</td>
<td>9.5±0.1 c</td>
<td>55.8±0.3 c</td>
<td>32.4±0.5 c</td>
<td>50.8±1.2 ab</td>
</tr>
<tr>
<td>Digalu (Soft)</td>
<td>13.4±0.1 c</td>
<td>9.7±0.1 bc</td>
<td>59.0±0.4 a</td>
<td>32.7±0.2 c</td>
<td>49.7±1.2 b</td>
</tr>
<tr>
<td>ET-13-A2 (Soft)</td>
<td>13.8±0.1 b</td>
<td>10.0±0.2 b</td>
<td>56.3±0.3 c</td>
<td>33.9±0.2 b</td>
<td>52.5±1.2 b</td>
</tr>
<tr>
<td>Kakaba (Hard)</td>
<td>12.7±0.2 d</td>
<td>10.6±0.2 a</td>
<td>58.2±0.1 b</td>
<td>30.5±0.5 d</td>
<td>39.9±1.2 c</td>
</tr>
<tr>
<td>Millennium (Soft)</td>
<td>14.4±0.1 a</td>
<td>10.4±0.1 a</td>
<td>56.0±0.1 c</td>
<td>35.8±0.3 a</td>
<td>55.5±1.2 a</td>
</tr>
<tr>
<td>Pavon-76 (Hard)</td>
<td>12.3±0.1 e</td>
<td>10.6±0.2 a</td>
<td>58.0±0.4 b</td>
<td>29.5±0.2 e</td>
<td>48.0±1.2 b</td>
</tr>
</tbody>
</table>

$F$-value (DF = 5, 12) 149.5 30.4 61.2 142.7 21.0
$P$-value <0.001 <0.001 <0.001 <0.001 <0.001

*a Means followed by different letters are significantly different ($P < 0.05$; by Tukey’s test).

Adult progeny production

The differences between the means of *S. granarius* and *S. oryzae* live adult populations after 90 d of storage were statistically significant ($P < 0.01$) under both storage temperatures across all wheat varieties tested (Table 6-3). Live adult *S. granarius* populations were consistently higher both at optimal and sub-optimal temperatures for all varieties.

*S. granarius*: The differences in the mean adult population count between 19 and 30°C were statistically significant ($P < 0.05$) for all varieties except Millennium (Table 6-4). At 19°C, the mean live adult population counts for Digalu was significantly higher ($P < 0.05$) than those observed for other varieties. At 30°C, the mean live adult population counts for ET-13-A2 and Kakaba were significantly higher ($P < 0.05$) than for other varieties. At 30°C, Pavon-76, Danda’a, and Digalu had relatively lower numbers of live *S. granarius* adults compared to other varieties. Regarding population development, the susceptibility of the tested varieties to *S. granarius* can be arranged in ascending order as Millennium < Pavon-76 < Kakaba < Danda’a < ET-13-A2 < Digalu when stored at 19°C. At 30°C the order is as follows: Pavon-76 < Danda’a < Digalu < Millennium < Kakaba < ET-13-A2. Digalu was the most favorable for *S. granarius* population development at 19°C, whereas ET-13-A2 was favorable for development at 30°C. Millennium was the least suitable variety for *S. granarius* population development at 19°C. Pavon-76 and Danda’a, however, were least susceptible at 30°C.
Table 6-3: Welch’s two-sample t-test between *Sitophilus granarius* and *Sitophilus oryzae* infestation for live weevil counts, the percentage of insect-damaged kernels, grain weight loss percentage and powder produced per gram of grain

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Varieties</th>
<th>Live weevil count</th>
<th>Insect-damaged Kernels</th>
<th>Grain weight loss (%)</th>
<th>Powder produced (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>t-ratio</td>
<td>DF*</td>
<td>P-value</td>
<td>t-ratio</td>
</tr>
<tr>
<td>19℃</td>
<td>Danda’a</td>
<td>48.9</td>
<td>3.7</td>
<td>&lt;0.01</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>38.1</td>
<td>3.9</td>
<td>&lt;0.01</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>39.7</td>
<td>3.5</td>
<td>&lt;0.01</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>33.3</td>
<td>2.7</td>
<td>&lt;0.01</td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>24.0</td>
<td>3.2</td>
<td>&lt;0.01</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>18.5</td>
<td>2.8</td>
<td>&lt;0.01</td>
<td>18.6</td>
</tr>
<tr>
<td>30℃</td>
<td>Danda’a</td>
<td>17.9</td>
<td>3.9</td>
<td>&lt;0.01</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>6.0</td>
<td>3.1</td>
<td>0.01</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>25.1</td>
<td>4.0</td>
<td>&lt;0.01</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>6.5</td>
<td>3.8</td>
<td>&lt;0.01</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>4.0</td>
<td>4.0</td>
<td>0.02</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>-8.8</td>
<td>3.9</td>
<td>&lt;0.01</td>
<td>-4.3</td>
</tr>
</tbody>
</table>

*Non-integer degrees of freedom are due to that equal variances are not assumed.
**S. oryzae:** There were significant ($P < 0.05$) differences in the mean adult progeny counts among tested varieties and between the two temperatures except for Danda’a and ET-13-A2 (Table 6-4). Live adult population counts at 30°C were significantly higher than that at 19°C for all varieties except Danda’a and ET-13-A2. At 30°C, the number of live adult population counts for Pavon-76 was significantly higher ($P<0.05$) than for other varieties except for Kakaba. In general, the susceptibility of the tested varieties to *S. oryzae* live adult population can be arranged in ascending order as Danda’a < ET-13-A2 < Digalu < Millennium < Kakaba < Pavon-76 when stored at 30°C. Danda’a was the least suitable variety while Pavon-76 was the most suitable to *S. oryzae* progeny production at 30°C.

Table 6-4: Mean (± SD) values of live adult *Sitophilus granarius* and *Sitophilus oryzae* counts per 30 g of wheat stored at optimal and sub-optimal temperatures for 90 d.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Variety</th>
<th><em>S. granarius</em></th>
<th><em>S. oryzae</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>19°C</td>
<td>Danda’a</td>
<td>178.7± 8.7 b</td>
<td>16.7±1.2 de</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>237.3±19.1 a</td>
<td>16.3±1.5 de</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>198.3±11.7 ab</td>
<td>17.7±1.5 cd</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>129.0±13.9 c</td>
<td>12.7±0.6 f</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>85.3± 8.5 ef</td>
<td>18.0±1.0 cd</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>91.0± 5.6 def</td>
<td>19.7±2.5 cd</td>
</tr>
<tr>
<td>30°C</td>
<td>Danda’a</td>
<td>63.0± 6.1 gh</td>
<td>13.3±1.5 ef</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>72.7± 7.5 fg</td>
<td>48.0±2.6 b</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>113.0± 9.2 cd</td>
<td>22.0±1.7 c</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>97.7± 4.0 de</td>
<td>76.0±4.0 a</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>74.7± 5.8 fg</td>
<td>57.3±4.9 b</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>57.0± 3.6 h</td>
<td>86.0±4.4 a</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>116.5</td>
<td>33.6</td>
</tr>
<tr>
<td>$F$-value (DF = 5,24)</td>
<td></td>
<td>41.2</td>
<td>137.5</td>
</tr>
<tr>
<td>$P$-value</td>
<td></td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

*Means for each weevil species followed by different letters are significant ($P < 0.05$; by Tukey’s test).

**Percentage of grain weight loss**

At 19°C, the mean percentages of grain weight losses due to *S. granarius* were significantly higher ($P<0.01$) compared with *S. oryzae* in all wheat varieties tested (Table 6-
At 30°C, there was no significant effect of weevil species on the weight loss of wheat varieties such as Digalu, Kakaba, and Pavon-76. However, the weight losses due to *S. granarius* in Danda’a, ET-13-A2, and Millennium at 30°C were significantly higher compared that that of *S. oryzae*.

**S. granarius:** The differences in the mean percentage of weight loss between 19°C and 30°C were statistically significant (*P* < 0.05) (Table 6-5). Percentage of grain weight loss was relatively lower at 30°C in all varieties except Millennium. The highest mean percentage of grain weight loss was recorded in Digalu at 19°C whereas Millennium exhibited the lowest percentage of grain weight loss at the same temperature. At 30°C, the highest mean percentage of weight loss was recorded in Kakaba, whereas Digalu and Pavon-76 exhibited the lowest weight loss. Based on weight loss at 19°C, wheat varieties can be arranged in an ascending order as Millennium < Pavon-76 < ET-13-A2 < Danda’a < Kakaba < Digalu. Pavon-76 suffered consistently low grain weight losses, both at 19°C and 30°C.

Table 6-5: Mean (± SD) percentage of grain weight loss of wheat varieties infested by *Sitophilus granarius* and *Sitophilus oryzae* at two temperature for 90 d.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Variety</th>
<th><em>S. granarius</em></th>
<th><em>S. oryzae</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>19°C</td>
<td>Danda’a</td>
<td>19.5±2.2 ab</td>
<td>8.0±0.6 c</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>25.5±5.2 a</td>
<td>4.7±0.2 e</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>17.5±1.5 bc</td>
<td>9.0±1.8 bc</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>22.1±5.2 ab</td>
<td>8.4±0.8 c</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>8.4±0.7 def†</td>
<td>5.4±0.2 de</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>12.6±1.3 cd</td>
<td>8.5±0.9 bc</td>
</tr>
<tr>
<td>30°C</td>
<td>Danda’a</td>
<td>9.5±1.4 def†</td>
<td>4.2±0.4 e</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>6.6±0.8 f</td>
<td>7.2±1.5 cd</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>12.1±1.4 cde</td>
<td>7.2±0.4 cd</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>17.6±2.5 bc</td>
<td>17.6±1.4 a</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>11.7±1.2 cde</td>
<td>7.2±0.2 cd</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>7.0±0.2 ef</td>
<td>11.4±1.6 b</td>
</tr>
</tbody>
</table>

|         | Mean      | 14.2         | 8.2          |
|         | *F*-value (DF = 5,24) | 18.6         | 29.5         |
|         | *P*-value       | <0.001       | <0.001       |

Means for each weevil species followed by different letters are significant (*P* < 0.05; by Tukey’s test).

**S. oryzae:** Mean percentage of grain weight loss ranged from 4.2 to 17.6% after *S. oryzae* infestation at 30°C (Table 6-5). The differences in the mean weight loss at 19 and
30°C were statistically significant ($P < 0.05$) for varieties Danda’a, Digalu and Kakaba. The mean weight loss of Danda’a was significantly higher ($P < 0.05$) at 19°C than at 30°C. In contrast, mean weight loss in Kakaba and Digalu were significantly lower ($P < 0.05$) at 19 than at 30°C. Digalu, ET-13-A2 and Millennium exhibited no significant difference of mean weight loss at the two storage temperatures.

**Percentage of insect-damaged kernels**

At 19°C, the percentage of insect-damaged kernels were significantly higher ($P < 0.01$) in wheat varieties infested by *S. granarius* compared to those infested by *S. oryzae* Table 6-3). Likewise, at 30°C, the percentage of insect-damaged kernels in all varieties except Kakaba and Pavon-76 were significantly higher ($P < 0.01$) in tests with *S. granarius* than in tests with *S. oryzae*. The effect of *S. granarius* infestation at 30°C on the percentage of insect-damaged kernels was significantly lower ($P < 0.01$) in Pavon-76. There was no significant difference between the infestations of *S. granarius* and *S. oryzae* in the percentage of insect-damaged kernels at 30°C.

**S. granarius:** There were statistically significant ($P < 0.05$) differences in the mean percentage of insect-damaged kernels between 19 and 30°C across all varieties tested (Table 6-6). At 19°C, the insect-damaged kernels ranged from 21.2 to 51.2%. The lowest grain damage at 19°C was in tests with Millennium. Wheat varieties such as Digalu, ET-13-A2 and Kakaba exhibited significantly higher ($P < 0.01$) percentage of insect-damaged kernel at 19°C. At 30°C, the insect-damaged kernels ranged from 17.5 to 39.6%. The mean percentage of insect-damaged kernel on variety Kakaba at 30°C was significantly higher ($P < 0.01$) than all other varieties. Danda’a and Pavon-76 exhibited the lowest insect damaged kernels at 30°C.

**S. oryzae:** The differences in the mean percentage of insect-damaged kernels between 19 and 30°C were significant ($P < 0.05$) across all varieties except ET-13-A2 (Table 6-6). At 19°C, there was no significant difference detected among wheat varieties in the percentage of insect-damaged kernels due to *S. oryzae* except between Digalu and ET13-A2 ($t= 3.73; \ DF = 48; P=0.023$). However, the percentage of insect-damaged kernels due to *S. oryzae* at 30°C was significantly lower ($P < 0.01$) in Danda’a than all other varieties.
Table 6-6: Mean (± SD) percentage of insect-damaged kernels of wheat varieties infested by *Sitophilus granarius* and *Sitophilus oryzae* at optimal and sub-optimal temperatures for 90 d.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Variety</th>
<th><em>S. granarius</em></th>
<th><em>S. oryzae</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>19°C</td>
<td>Danda’a</td>
<td>40.8±3.7 bc</td>
<td>9.7±0.7 fg</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>49.8±5.0 ab</td>
<td>7.9±0.4 gh</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>50.3±3.0 ab</td>
<td>16.2±2.2 de</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>51.2±6.5 a</td>
<td>12.5±1.2 ef</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>20.6±2.0 fg</td>
<td>9.7±0.9 fg</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>28.2±1.0 e</td>
<td>11.5±1.0 f</td>
</tr>
<tr>
<td>30°C</td>
<td>Danda’a</td>
<td>18.6±1.4 g</td>
<td>6.4±0.6 h</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>25.5±0.9 ef</td>
<td>23.4±2.0 bc</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>32.0±2.2 de</td>
<td>19.3±1.3 cd</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>39.6±3.2 cd</td>
<td>34.0±2.5 a</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>30.6±1.8 e</td>
<td>20.9±1.8 bc</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>17.1±1.5 g</td>
<td>24.4±2.6 b</td>
</tr>
</tbody>
</table>

|              | Mean        | 33.7          | 16.3        |
|              | *F*-value (DF = 5, 24) | 32.0          | 53.9        |
|              | *P*-value   | <0.001        | <0.001      |

* Means for each weevil species followed by different letters are significant (*P* < 0.05; by Tukey’s test).

**Powder production**

There was significantly higher (*P* < 0.01) powder production under the infestation of *S. granarius* than under *S. oryzae* at the two storage temperatures in all wheat varieties except Kakaba and Pavon-76 (Table 6-3). At 30°C, significantly higher (*P* < 0.01) mg of powder per g of seed was produced in Kakaba and Pavon-76 varieties under the infestation of *S. oryzae* than under *S. granarius*.

**S. granarius:** Analysis of variance showed that there were significant (*P* < 0.05) differences in the weight of powder produced among the different varieties tested both at 19 and 30°C (Table 6-7). Also, the differences in the mean weight of powder produced between 19 and 30°C were significant (*P* < 0.05) across all varieties except Digalu. At 19°C, *S. granarius* generated significantly higher amounts of powder (*P* < 0.01) in Danda’a and ET-13-A2, and significantly lower amounts of powder (*P* < 0.01) powder in Kakaba, Millennium and Pavon-76. The highest weight of powder at 19°C was in ET-13-A2, while the lowest was in Pavon-76.
Table 6-7: Mean (± SD) amounts of powder produced in mg per gram of grain of wheat varieties infested by *Sitophilus granarius* and *Sitophilus oryzae* at optimal and sub-optimal temperatures for 90 d.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Variety</th>
<th><em>S. granarius</em></th>
<th><em>S. oryzae</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>19°C</td>
<td>Danda’a</td>
<td>11.0±0.5 cd</td>
<td>1.2±0.1 g</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>14.3±1.0 b</td>
<td>1.9±0.2 ef</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>21.7±1.3 a</td>
<td>3.2±0.2 d</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>10.6±0.4 cd</td>
<td>1.2±0.2 ef</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>9.3±1.0 de</td>
<td>2.5±0.2 de</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>14.1±0.3 f</td>
<td>2.7±0.2 d</td>
</tr>
<tr>
<td>30°C</td>
<td>Danda’a</td>
<td>8.2±0.4 e</td>
<td>1.5±0.1 fg</td>
</tr>
<tr>
<td></td>
<td>Digalu</td>
<td>13.5±0.9b</td>
<td>9.2±0.4 b</td>
</tr>
<tr>
<td></td>
<td>ET-13-A2</td>
<td>14.7±0.8 b</td>
<td>4.9±1.1 c</td>
</tr>
<tr>
<td></td>
<td>Kakaba</td>
<td>12.8±1.0 bc</td>
<td>15.3±1.1a</td>
</tr>
<tr>
<td></td>
<td>Millennium</td>
<td>14.1±0.7 b</td>
<td>9.6±0.7 b</td>
</tr>
<tr>
<td></td>
<td>Pavon-76</td>
<td>5.4±0.7 e</td>
<td>9.7±0.9 b</td>
</tr>
</tbody>
</table>

Mean

<table>
<thead>
<tr>
<th></th>
<th><em>S. granarius</em></th>
<th><em>S. oryzae</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>11.9</td>
<td>5.3</td>
</tr>
<tr>
<td><em>F</em>-value (DF = 5, 24)</td>
<td>40.0</td>
<td>171.5</td>
</tr>
<tr>
<td><em>P</em>-value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a Means for each weevil species followed by different letters are significant (*P* < 0.05; by Tukey’s test).

*S. oryzae*: The differences in the mean weight of powder produced between 19 and 30°C were significant (*P* < 0.05) across all varieties except Danda’a (Table 6-7). The weight of powder produced at 30°C was significantly higher than at 19°C except for Danda’a. The weight of powder produced in Kakaba at 30°C was significantly higher (*P* < 0.01) than in all other varieties. *S. oryzae* generated the lowest powder in Danda’a at 30°C.

6.4 Discussion

Previous studies demonstrated that wheat varieties show differences in their responses to stored-product insects (Ahmad and Jaiswal, 2018; Saad et al., 2018; Tripathi et al., 2018; Hassan et al., 2017; Golizadeh and Abedi, 2016; Ali et al., 2011; Ahmedani et al., 2009). Our results showed that differences among wheat varieties are significant with respect to progeny production, grain weight loss, the percentage of insect-damaged kernels, and powder production. It is evident from Table 6-8 that white grain color and kernel diameter had positively influenced the percentage of grain weight loss and percentage of insect-damaged kernels, whereas the hardness index negatively influenced those same variables. Kernel hardness positively contributed to the resistance of wheat varieties to weevils (Saad et al., 2018). Results from our study also showed that hard wheat varieties such as Danda’a and
Pavon-76 demonstrated substantial tolerance to infestation by *S. granarius*. The positive association of kernel diameter and percentage of grain weight loss and percentage of insect-damaged kernels could be attributed to the fact that larger surface area of kernels favored more number of visits by ovipositing weevils (Campbell, 2002). However, this needs further assessment using a wider range of kernel diameters in free choice tests.

Table 6-8: Multiple regression analysis of the effects of kernel characteristics on the percentage of grain weight loss, the percentage of insect-damaged kernels, and amount of powder produced.

<table>
<thead>
<tr>
<th>Kernel characteristics</th>
<th>Weight loss (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Insect damaged kernels (%)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Powder produced (mg/g of grain)&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-33.1±13.9*</td>
<td>-54.3±32.3&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-5.9±13.1&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>Grain color (White)</td>
<td>5.7±2.2*</td>
<td>14.1±5.0**</td>
<td>3.6±2.0&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>Grain weight (mg)</td>
<td>-1.3±0.7*</td>
<td>-3.6±1.6*</td>
<td>-1.2±0.6&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>Kernel diameter (mg)</td>
<td>32.9±11.1**</td>
<td>75.4±25.8**</td>
<td>21.6±10.5*</td>
</tr>
<tr>
<td>Hardness index (HI)</td>
<td>-0.1±0.0&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-0.3±0.1**</td>
<td>-0.1±0.0**</td>
</tr>
</tbody>
</table>

| Adj. R²                | 0.14                        | 0.11                             | 0.09                                |
| F-value (DF = 4, 67)   | 3.80                        | 3.25                             | 2.65                                |
| P-value                | 0.008                       | 0.017                            | 0.041                               |

<sup>*Significant at P<0.05 level.  **Significant at P<0.1 level.</sup>

As shown in Table 6-9, Zeleny sedimentation values had negatively related to the percentage of grain weight loss and percentage of insect-damaged kernels in tests with both *S. granarius* and *S. oryzae*. Varieties with high Zeleny sedimentation values were less susceptible to infestation. Surma et al. (2015) observed that there was a strong and positive correlation between Zeleny sedimentation values and hardness index of wheat grain. Millennium, a variety with hardness index of 19.19, however, was the least suitable variety to *S. granarius* infestation regarding the tested traits at 30°C. Hence, Zeleny sedimentation value and hardness index might be independently influencing the susceptibility of wheat varieties to *Sitophilus* spp.

Our experiments were based on the assumption that the performance of weevils at 19°C would be similar to naturally aerated storage conditions in the wheat belt of Ethiopia. The mean monthly temperature in the major wheat growing areas in the country is between 12.6 and 22.2°C, with the hottest period occurring between March and May (White et al.,
2001; Mann and Warner, 2017). Allowing natural air movement within the grain mass is expected to substantially decrease grain temperature creating a suboptimal condition for weevil development.

Table 6-9: Multiple linear regression analysis of the effects of the proximate composition of wheat varieties on weevil population development, the percentage of grain weight loss, the percentage of insect-damaged kernels, and powder production.  

<table>
<thead>
<tr>
<th></th>
<th>Live adult counts - COUNT</th>
<th>Grain weight loss - WL (%)</th>
<th>Insect damaged kernels-IDK (%)</th>
<th>Powder (mg per g of grain)-PDR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S. granarius</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein - PRTN</td>
<td>24.4±20.7</td>
<td>0.30</td>
<td>3.0±2.3</td>
<td>0.32</td>
</tr>
<tr>
<td>Starch - STRC</td>
<td>8.7±9.6</td>
<td>0.19</td>
<td>0.1±1.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Moisture - MC</td>
<td>-56.5±21.7*</td>
<td>-0.44</td>
<td>-3.6±2.4</td>
<td>-0.26</td>
</tr>
<tr>
<td>Zeleny sedimentation value - Zeleny</td>
<td>-2.8±2.9</td>
<td>-0.26</td>
<td>-0.9±0.3*</td>
<td>-0.76</td>
</tr>
<tr>
<td>Adj. R²</td>
<td>0.11</td>
<td>0.14</td>
<td>0.18</td>
<td>0.29</td>
</tr>
<tr>
<td>F-value (DF = 4,31)</td>
<td>2.1</td>
<td>2.4</td>
<td>2.9</td>
<td>4.6</td>
</tr>
<tr>
<td>P-value</td>
<td>0.104</td>
<td>0.070</td>
<td>0.038*</td>
<td>0.005*</td>
</tr>
<tr>
<td><strong>S. oryzae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein - PRTN</td>
<td>-5.3±9.1</td>
<td>-0.14</td>
<td>-0.8±1.1</td>
<td>-0.15</td>
</tr>
<tr>
<td>Starch - STRC</td>
<td>4.8±4.2</td>
<td>0.23</td>
<td>-0.5±0.5</td>
<td>-0.17</td>
</tr>
<tr>
<td>Moisture - MC</td>
<td>22.8±9.5</td>
<td>0.40</td>
<td>2.8±1.1*</td>
<td>0.35</td>
</tr>
<tr>
<td>Zeleny sedimentation value - Zeleny</td>
<td>0.8±1.3</td>
<td>0.16</td>
<td>-0.3±0.2*</td>
<td>-0.47</td>
</tr>
<tr>
<td>Adj. R²</td>
<td>0.15</td>
<td>0.41</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>F-value (DF = 4,31)</td>
<td>2.5</td>
<td>7.0</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>P-value</td>
<td>0.062</td>
<td>0.000*</td>
<td>0.065</td>
<td>0.065</td>
</tr>
</tbody>
</table>

*Estimates are significant at 5% level.
**Estimates are significant at 1% level.

a IDK = 7.95 + 9.69 (PRTN) + 0.85 (STRC) – 5.97 (MC) – 1.84 (Zeleny) (S. granarius);
b PDR = -54.5 + 5.08 (PRTN) + 0.66 (STRC) – 2.33 (MC) + 0.31 (Zeleny) (S. granarius);
c WL = 33.98 – 0.75 (PRTN) – 0.49 (STRC) – 2.75 (MC) – 0.32 (Zeleny) (S. oryzae)

The *Sitophilus* spp. exhibit ecological preferences for climatic gradients (Back and Cotton, 1924; Longstaff, 1981; Nakakita and Ikenaga, 1997; Corrêa et al., 2013; Rita Devi et al., 2017). The difference in adaptations to storage temperatures of *S. oryzae* and *S. granarius* was reported by Fields et al. (1998). Results from our study showed that *S. oryzae* population development was extremely affected on all varieties tested at the lower temperature. This is partially in agreement with a previous report by Corrêa et al. (2013) that *S. oryzae* may not establish under low-temperature conditions unless it resides inside warmer storage units. As
storage temperature decreases, activities by adults of *S. oryzae* such as locomotion, mating, and feeding would decrease; and hence, population development slows down (Nakakita and Ikenaga, 1997). A recent report by Wu and Yan (2018) indicated that *S. oryzae* is mainly present in the south and the center of China. These authors argued that the observed difference in *S. oryzae* distribution was related to differences in temperature adaptation and food.

In our present study, decreasing storage temperature from 30 to 19°C enhanced the population growth of *S. granarius*. It was claimed in an earlier report that *S. granarius* is limited to higher altitudes between 2500 and 3000 m above sea level (McFarlane, 1969). A recent survey by Kalsa et al. (2018) on five wheat growing districts across Ethiopia indicated that the distribution of *S. granarius* was limited to a district with an altitude greater than 2400 m above sea level. In the present study, increased population growth of *S. granarius* at the lower temperature could be attributed to the fact that *S. granarius* is more cold hardy compared to *S. oryzae* (Back and Cotton, 1924). However, at 30°C, the population growth of *S. granarius* was still better compared to *S. oryzae*. This indicates that *S. granarius* is more of a serious pest than *S. oryzae* once established even under warmer conditions.

In conclusion, the present study showed that there is varietal difference among Ethiopian wheat varieties regarding their susceptibility to weevils. Besides, the response of weevils to a low temperature differs from one species to another. *S. granarius* can sufficiently establish both at optimum as well as sub-optimal temperatures prevailing in the wheat belt of Ethiopia, regardless of varieties grown. Hence, a management plan considering the integration of natural aeration with varietal resistance is not sufficient to control the population growth of *S. granarius*. However, further studies are needed to substantiate the genetic basis for resistance conferred by wheat varieties under a wider range of temperature regimes.

### 6.5 References


McFarlane, J. A. 1969. Special study of stored products problems in Ethiopia. Preliminary


CHAPTER 7: ON-FARM PERFORMANCE AND ASSESSMENT OF FARMERS’ PERCEPTIONS OF HERMETIC BAGS FOR FARM-STORED WHEAT AND MAIZE IN NORTHWESTERN ETHIOPIA

Abstract

Wheat and maize farmers rarely adopt technologies such as the metal silo and hermetic bags that reduce storage losses in Ethiopia. Two on-farm experiments and a perception survey were conducted to evaluate the effectiveness of hermetic storage bags and to assess farmers’ perceptions towards the utility of the technologies. The studies were conducted in Wenberma and Merawi districts of West Gojjam, Ethiopia in the years 2016 and 2017. Results showed that live adult weevil densities in hermetic storage bags such as PICS bag and Super GrainPro bag were below five insects per kg of maize. In wheat, no weevils were detected in hermetic storage bags after four months of storage. Weight loss was maintained at <1.0% both in wheat and maize. A majority of farmers (95.0%, N=80) perceived that the hermetic bags are effective against weevils and 87.3% (N=80) have shown their tendency towards hermetic bags in the future. The tendency of farmers who were interested in the future use of hermetic bags was positively influenced by their use of PICS bags in the past. In conclusion, our present study shows that the hermetic storage bags are effective under on-farm conditions and the smallholder farmers well accept them. Therefore, we recommend extensive promotion of the technologies and increasing their local availability.

Keywords: hermetic bags, farm storage, wheat, maize, insects

7.1 Introduction

The farmers’ poor knowledge and skills on postharvest management are largely responsible for the food losses in Ethiopia and elsewhere (Abass et al., 2014; Chegere, 2018; Hengsdijk & de Boer, 2017). Smallholder farmers store their grain until the next successful harvest, which might be a year or more. Grain produced by farmers should be stored to meet home consumption, for sale or for seed purpose (Kalsa, 2019; Tadesse et al., 2000). However, grain stored in traditional structures is subject to deterioration by biological and physical factors (Chegere, 2018; Hengsdijk & de Boer, 2017).

Recent years have seen a growing interest in the use of hermetically-sealed containers to control stored grain and seed insect pests. Low oxygen concentration causes insect mortality, so hermetic storage such as Purdue Improved Cowpea Storage (PICS), super grain
bags, cocoons and others, are being promoted as cheap and effective ways to control storage insect pests in Asia (Quezada et al., 2006), and recently in Africa (Jones et al., 2011; Phiri and Otieno, 2008). PICS bags, consisting of a double layer of high density polyethylene (HDPE) bags, within the standard polypropylene woven bags, were shown to effectively protect cowpeas against bruchid beetles in West Africa (Baoua et al., 2013; Murdock et al., 2012). Super grain bags consist of a single high density polyethylene bag used as a liner in the standard polypropylene bags and have been successfully disseminated in Asia (Villers et al., 2008). Metal silos, also hermetically sealed but physically stronger, have been heavily promoted in Central America (Hellin and Kanampiu, 2008) and their feasibility is currently being explored in Sub-Saharan Africa (SSA) (Tefera et al., 2011).

Wheat and maize farmers rarely adopt technologies such as the metal silo and hermetic bags that reduce storage losses in Ethiopia (Hengsdijk & de Boer, 2017; Kalsa, 2019; Tesfaye & Tirivayi, 2018). On the other hands, the the adoption of recommended postharvest handling practices is highly correlated with the lower postharvest loss (Chegere, 2018). Hermetic storage techniques can be recommended to farmers without the use of insecticides provided they are inexpensive, and the farmers are trained on a proper application of the technologies (Abass et al., 2018). The present study aimed at 1) participatory evaluation of the effectiveness of hermetic storage bags in farmers’ houses, 2) assessment of farmers’ perceptions towards the utility of hermetic storage bags, and 3) identification of factors related to farmers’ tendency of future use of the hermetic storage bags.

7. 2   Materials and Methods

Two on-farm experiments and a survey were conducted to understand the performance of hermetic bags under farmer’s conditions and the perception of farmers towards the utility of the improved storage bags. The study was conducted in two districts (Merawi and Wenberma) of West Gojjam, Amhara Regional State. Descriptions of the study sites are available in Sections 2.2 and 3.2 of this dissertation.

*Treatment set up and experimental design*

Hermetic storage bags such as Purdue Improved Crop Storage (PICS) bags and Super GrainPro bags (high-density polyethylene bags reducing gas exchange) were compared with
traditional storage system (with polypropylene bags at Wenberma and with *gota* in Merawi district) under farmers’ conditions.

The treatments were set up in a randomized complete block design with nine replications. Farmers served as blocks in both wheat and maize studies. Each farmer stored two types of hermetic bags plus his own *gota* (for maize) and polypropylene bags for wheat. Polypropylene bags were purchased from a local market.

**Wheat on-farm storage experiment**

At Wenberma, the experiment consisted of three treatments: two hermetic bags (PICS and Super GrainPro bags) and polypropylene bags (control), replicated on seven smallholder farms. Farmers who have grown the maize variety Kakaba had participated in the study and all the farmers had placed untreated wheat in hermetic bags. In this experiment, wheat in polypropylene bag was not treated with any chemical.

Bags were filled with 50kg of wheat and sealed 30<sup>th</sup> January 2017 and they were opened on 10th June 2017, after 130 days of storage. The grains in the hermetic bags were kept for about four months, and sampling was carried out by randomly reaching top, middle, and bottom sections of the bags. The primary samples from a container were then homogenized, and one kg sample per container was brought to the laboratory.

**Maize on-farm storage experiment**

At Merawi, the experiment consisted of three treatments: two hermetic bags (PICS and Super GrainPro bags) and one traditional storage structure (*gushgusha*), replicated on nine smallholder farms. Farmers who have grown the maize variety Jabi (Pioneer 3253) had participated in the study, and all the farmers had placed untreated shelled grains in hermetic bags, while the grains in traditional storage structure were treated with Malathion 5% dust or fumigated with Phosphine or in combination.

Bags were filled with naturally infested grain (2 to 4 insects per kilogram, based on samples collected at the beginning of storage) and sealed on 7<sup>th</sup> to 10<sup>th</sup> June 2016; they were opened on 10<sup>th</sup> to 13<sup>th</sup> October 2016, after 125 days of storage. The grains in the hermetic bags were kept for about four months and sampling was carried out by randomly reaching top, middle, and bottom sections of the bags. The same trend was followed to get samples from traditional storage. The primary samples from a container were then homogenized and one kg sample per container was brought to the laboratory.

**Data collection from storage experiments**
Measurements of gas composition (CO₂ and O₂ levels) (done before the hermetic bags were opened), adult insect abundance (both live and dead), grain damage, weight loss, grain moisture content, grain bulk density, and thousand kernel weights were determined after four months of storage for both experiments.

One kg samples were divided following use of quartering and coning technique until the final sample of around a 100g of seed was obtained. From the 100g of whole seeds, damaged and undamaged kernels were counted and weighed. Percentages weight loss and of insect-damaged kernels were assessed using procedures described in Chapters 2, 4 and 5.

Wheat samples were subject to germination testing as described in Chapter 4. Seedling dry weight and vigor indices were also assessed based on the standard germination data.

Survey

A one-page checklist was prepared to assess farmers’ perception towards the utility of hermetic bags they used. A total of six villages were included: one from Merawi and five from Wenberma districts. Study districts are described in Sections 2.2 and 3.2. A total of 80 households, who were provided with hermetic bags during the year 2016 were included in the survey. To cross validate the survey responses, a focus group discussion with development agents and selected farmers was organized at Merawi.

Data analysis

All data from the on-farm storage experiments were subject to analysis of variance (ANOVA) using the R Software version 5.3.1. All count data were log transformed where required and the percentage data were square root transformed before analysis of variance. Where the ANOVA showed an overall significance, Tukey’s range test was employed to separate significantly different means at 5% level of significance. Survey data were coded and descriptive analyses were employed using the IBM SPSS statics version 20. Plots were created using the SigmaPlot Software version 12.5 (Anonymous, 2013).

7.3 Results

Maize on-farm storage: Weevil abundance

There was a significant effect (P<0.01) of storage structures on both live weevil count and total weevil specimen counts per kg of maize (Table 7-1). The abundance of live weevil specimen was significantly higher in the traditional gota structure compared with the
hermetic bags. Hermetic bags substantially decreased the population development of weevils in maize (Figure 7-1).

Table 7-1: Analyses of variance for live weevil counts, total weevil counts, the percentage of insect-damaged kernels and grain weight loss of maize stored in farmers’ houses between June and September 2016.

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>DF</th>
<th>Live Weevils (counts per kg)</th>
<th>Total Weevils (counts per kg)</th>
<th>Insect-damaged kernels (%)</th>
<th>Grain Weight Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F-value</td>
<td>P-value</td>
<td>F-value</td>
<td>P-value</td>
</tr>
<tr>
<td>Storage Structures</td>
<td>2</td>
<td>161</td>
<td>0.00</td>
<td>81.4</td>
<td>0.00</td>
</tr>
<tr>
<td>Farmers</td>
<td>8</td>
<td>0.7</td>
<td>0.70</td>
<td>0.5</td>
<td>0.81</td>
</tr>
<tr>
<td>Error Variance</td>
<td>16</td>
<td>0.02</td>
<td>0.01</td>
<td>0.17</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 7-1: Mean (±SE) of weevil abundance (counts per kg of seed) of maize stored in farmers’ houses between June and September, 2016.\(^{a, b}\)

\(^a\) Means followed by the same letter are not significantly different at Tukey’s 5% level of significance, and each mean is based on nine farmers.

\(^b\) SGB= Super GrainPro bag; PICS= Purdue Improved Crop Storage bag

Maize on-farm storage: grain weight loss and damage

Percentages of insect-damaged kernels and grain weight loss were significantly (P<0.01) influenced by storage structures (Table 7-1). The proportion of insect-damaged kernels was significantly higher in gota compared to hermetic bags (Figure 7-2). Likewise, the grain weight loss percentage was significantly higher in the traditional gota structure compared to hermetic bags. There was a non-significant difference between the PICS bag and Super GrainPro bag about either the percentage of insect-damaged kernels or the grain weight loss percent.
Wheat on-farm storage: baseline

At the outset of the on-farm storage experiment of wheat, the weevil abundance, test percentage of seed damage and grain weight loss, weight (bulk density), and seed germination and vigor were assessed. There was no live or dead insect specimen detected at the beginning of the storage experiment while the number of insect-damaged seed ranged from 12 to 26 seeds per 100g with a mean of 20.1 damaged seeds per 100g. Likewise, the percentage of insect damaged kernels ranged from 0.40% to 0.95% while grain weight loss percent was between 0.10% and 0.51%. The mean of percentage insect-damaged kernels and grain weight loss percent were 0.7% and 0.3%, respectively. Test weight (seed bulk density) between 751 kg m$^{-3}$ and 818 kg m$^{-3}$ with a mean of 781.8 kg m$^{-3}$. Percentage seed germination ranged between 87.0% and 99.0% with a mean of 94.1% whereas the seed vigor index was between 552 %mg to 1786 %mg. The mean of seedling vigor index at the beginning was 1043.9 %mg.

![Figure 7-2: Mean (±SE) percentage of insect-damaged kernels and grain weight loss of maize stored in farmers’ houses between June and September 2016.](image)

**Weevil abundance and number of damaged kernels in stored wheat**

Significant differences (P<0.01) between hermetic storage bags and the polypropylene bag were detected in both live insect abundance, and the number of insect-damaged kernels (Table 7-2). The highest mean number of live weevils was detected in wheat stored in
polypropylene bags. Likewise, the largest mean number of insect-damaged kernels was observed in the polypropylene bags.

*Weight loss and loss of bulk density in stored wheat*

There were significant differences between hermetic bags and the polypropylene bag regarding their effectiveness of containing losses. Grain weight loss was significantly higher ($F = 8.45; \text{DF} = 2, 32; P<0.01$) in polypropylene bags compared to the hermetic bags (Figure 7-3). There was no such difference between the two hermetic bags. Likewise, the percentage of insect-damaged kernels was significantly higher ($F = 16.82; \text{DF} = 2, 32; P<0.01$) on wheat stored in polypropylene bags. The loss of test weight (bulk density of the seed) was also significantly higher in the polypropylene bags compared to the hermetic bags. Seed bulk density was slightly higher in Super GrainPro bag compared to PICS bag, but the difference was not statistically significant.

Table 7-2: Mean (±SE) of weevil abundance and number of insect-damaged kernels of wheat seed stored in farmers’ houses at Wenberma from January to June 2017.

<table>
<thead>
<tr>
<th>Bag Type</th>
<th>Live Weevils (counts per kg)</th>
<th>Total Weevil (counts per kg)</th>
<th>Damaged Kernels (counts per 100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super GrainPro Bag</td>
<td>0.6 b</td>
<td>20.1 a</td>
<td>20.1 a</td>
</tr>
<tr>
<td>PICS bag</td>
<td>0.1 b</td>
<td>20.1 a</td>
<td>20.1 a</td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>2.6 a</td>
<td>50.1 b</td>
<td>50.1 b</td>
</tr>
<tr>
<td>$F \ (\text{DF} = 2, 26)$</td>
<td>17.07</td>
<td>21.98</td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.01$</td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td>0.3</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>

Means within the same column and followed by the same letter are not significantly different at Tukey’s 5% level of significance. Each mean is based on seven farmers and two replications per farmer.

*Seed quality in stored wheat*

Table 7-3 shows seed quality parameters such as percentage of seed germination, seedling dry weight, and seedling vigor index of wheat stored in different bag types. There was a non-significant difference among different types of bags regarding seed germination after four months of storage. However, there seedling vigor parameters of wheat stored in Super GrainPro bags was significantly higher compared to the polypropylene bags. There was no significant difference between PICS bag and polypropylene bag during four months of storage.
Figure 7-3: Mean (±SE) of seed weight loss (the %), the percentage of insect-damaged kernels and percentage loss of bulk density (test weight) of wheat seed stored using hermetic bags at farmers’ houses in Wenberma from January to June 2017.a,b.

a Means followed by the same letter are not significantly different at Tukey’s 5% level of significance, and each mean is based on nine farmers.

b SGB= Super GrainPro bag; PICS= Purdue Improved Crop Storage bag; PPB= Polypropylene bag (control)

Table 7-3: Mean (±SE) of seed quality characteristics of farm-stored wheat in hermetic bags. a

<table>
<thead>
<tr>
<th>Bag Type</th>
<th>Seed Germination (%)</th>
<th>Seedling Dry Weight (mg)</th>
<th>Seedling Vigor Index (mg. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super GrainPro Bag</td>
<td>94.7</td>
<td>9.4a</td>
<td>885.0a</td>
</tr>
<tr>
<td>PICS bag</td>
<td>94.5</td>
<td>8.1ab</td>
<td>763.0ab</td>
</tr>
<tr>
<td>Polypropylene bag</td>
<td>94.3</td>
<td>7.3b</td>
<td>687.0b</td>
</tr>
<tr>
<td>F (2, 32)</td>
<td>0.10&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>4.88*</td>
<td>4.59*</td>
</tr>
<tr>
<td>P-value</td>
<td>0.91</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>SEM</td>
<td>0.8</td>
<td>0.5</td>
<td>46.4</td>
</tr>
</tbody>
</table>

a Means within the same column and followed by the same letter are not significantly different at Tukey’s 5% level of significance. Each mean is based on seven farmers and two replications per farmer.

Farmers’ perceptions on the utility of hermetic bags

Table 7-4 shows the descriptive analysis of farmers’ perceptions of the utility of hermetic bags. About 95.0% of 80 household heads included in the study had believed that the bags protected their grains from weevil damages. About 93.8% of respondents (N=80) were indifferent or felt that the price is low, but only 6.3% of all respondents had claimed that bag prices are costly (price of PICS bag is ca. $1.47 and that of SuperGrain™ bag is ca. $2.44 at the time of survey). All farmers who were indifferent about bag price had the likelihood to use the improved bags in the future. However, the possibility of repeated use, reduced amount of loss, and health benefits from reduced/no use of insecticides can be positive drives for future use of hermetic bags by farmers in Ethiopia.
Table 7-4: Farmers’ perception on the utility of hermetic bags in Merawi and Wenberma districts

<table>
<thead>
<tr>
<th>Characters</th>
<th>Frequency (%)</th>
<th>Characters</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (n=80)</td>
<td></td>
<td>Level of infestation before bagging (n=80)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>77.5</td>
<td>High</td>
<td>11.3</td>
</tr>
<tr>
<td>Female</td>
<td>22.5</td>
<td>Low</td>
<td>21.3</td>
</tr>
<tr>
<td>Education (n=80)</td>
<td></td>
<td>Infested with live weevil after opening (n=80)</td>
<td></td>
</tr>
<tr>
<td>No formal education</td>
<td>57.5</td>
<td>Yes</td>
<td>21.2</td>
</tr>
<tr>
<td>Primary incomplete</td>
<td>38.8</td>
<td>No</td>
<td>78.8</td>
</tr>
<tr>
<td>Secondary incomplete</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bags Used (n=80)</td>
<td></td>
<td>Level of live weevil infestation after (n=80)</td>
<td></td>
</tr>
<tr>
<td>PICS</td>
<td>78.8</td>
<td>High</td>
<td>1.3</td>
</tr>
<tr>
<td>Super GrainPro</td>
<td>15.0</td>
<td>Low</td>
<td>20.0</td>
</tr>
<tr>
<td>Both types</td>
<td>6.3</td>
<td>None</td>
<td>78.8</td>
</tr>
<tr>
<td>Types of grain stored (n=80)</td>
<td></td>
<td>Believe bags effective on weevils (n=80)</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>25.0</td>
<td>Effective</td>
<td>95.0</td>
</tr>
<tr>
<td>Maize</td>
<td>46.3</td>
<td>Not effective</td>
<td>1.2</td>
</tr>
<tr>
<td>Both</td>
<td>28.8</td>
<td>Don’t know</td>
<td>3.8</td>
</tr>
<tr>
<td>Used Chemicals in bags (n=80)</td>
<td></td>
<td>How do you evaluate bag price? (n=80)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>14.7</td>
<td>Costly</td>
<td>6.3</td>
</tr>
<tr>
<td>No</td>
<td>86.3</td>
<td>Indifferent</td>
<td>33.8</td>
</tr>
<tr>
<td>Type of Chemicals (n=80)</td>
<td></td>
<td>Compare new bags to pp bags (n=80)</td>
<td></td>
</tr>
<tr>
<td>Malathion</td>
<td>2.5</td>
<td>Better</td>
<td>95.0</td>
</tr>
<tr>
<td>Phosphine</td>
<td>5.0</td>
<td>No difference</td>
<td>5.0</td>
</tr>
<tr>
<td>Both</td>
<td>6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>86.3</td>
<td>Do you plan to use hermetic bags in the future? (n=80)</td>
<td></td>
</tr>
<tr>
<td>Infested with live weevil before bagging (n=80)</td>
<td>Yes</td>
<td>87.3</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>67.5</td>
<td>No</td>
<td>12.7</td>
</tr>
<tr>
<td>No</td>
<td>32.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There was no significant difference between the ages of those who wanted to use hermetic bags in the future and those who did not want to. However, fishers exact test indicated that there was a significant association (P<0.05) between sex and the tendency to use hermetic bags in the future (odds ratio = 0.238). Farmers’ tendency to use hermetic storage bags did not have any significant association with the education status of the household head.

**7.4 Discussion**

In our present study, we have observed that the hermetic bags such as PICS bag and Super GrainPro bag have suppressed weevil population development and reduced the rates of
grain damage and weight loss both in maize and wheat under farmers’ conditions. The germination capacity of wheat seed was also maintained in a better condition.

However, the wheat seed stored in Wenberma district had exhibited about 20.1% damage and mean grain weight loss of 0.3% at the outset of the on-farm storage experiment. Our speculation is that it could be due to the wheat head armyworm (Figure 7-4) though we did not encounter the insect debris in any form. We present an expert judgment by Dr Jeff Whitworth, Kansas State University, Manhattan, USA, on damage characteristics on wheat kernels. “It looks like feeding damage that could have been caused by the Wheat Head Armyworm. If it is, it would have occurred in the field as that is where these pests infest the heads—not after harvest in storage”. Since our storage study was begun just a month after wheat harvest, there was no adequate evidence to conclude that the damage was caused by storage insects. In our discussion with key informants in Wenberma district, farmers indicated that “there were worms on heads of wheat in the field”. We speculate, therefore, that the wheat head armyworm might have occurred in the field and caused such damage.

![Figure 7-4: Damaged wheat kernels collected at the outset of on-farm storage experiment at Wenberma district in January 2017.](image)

Adoption of hermetic storage bags has been driven by the effectiveness, simplicity, low cost, durability, and accessibility the technologies (Baoua et al., 2012). Studies showed that some form of exposure by farmers to storage practices is related to improved adoption of the hermetic storage technologies (Moussa et al., 2014). In our on-farm experimentation with farmers, we have observed that farmers’ interest on a chemical-free storage technology was heightened. Though farmers were so suspicious to store their maize or wheat in hermetic bags without chemical treatment, they were very happy with the outcomes (Box 1). This shows that once farmers have the chance to look at the difference between their traditional storage
method and the improved technologies, they show a better tendency towards using hermetic storage bag.

The main determinants of adoption were household socio-economic characteristics such as age, land ownership, completion of a training course and quality of basic infrastructure (Bokusheva et al., 2012). Our study included only sex, age, and education as a social factor that determined farmers’ tendency to use hermetic storage bags. Age and education had no association with farmers’ tendency to use hermetic storage bags in the future. Regardless of their age and education status, farmers have applauded the chemical-free hermetic storage technology. The contemporary bag price, with additional awareness of farmers on reuse of the hermetic bags, does not have a negative influence on farmers’ tendency to use the hermetic storage bags in the future. However, the tendency of farmers towards future use of hermetic bags was positively influenced by using PICS bag (Table 7-5). This might be due to farmers’ perception about the triple bagged hermetic technology that it is less susceptible to tears and wears during handling.

Table 7-5: Probit analysis of factors influencing farmers’ tendency for future use of hermetic bags

<table>
<thead>
<tr>
<th>Variables</th>
<th>Estimate</th>
<th>SE</th>
<th>β- coefficients</th>
<th>t-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.516</td>
<td>0.119</td>
<td>0.198</td>
<td>4.343</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Sex (Male = 1; Female = 0)</td>
<td>0.116</td>
<td>0.086</td>
<td>0.189</td>
<td>1.807</td>
<td>0.075</td>
</tr>
<tr>
<td>Use PICS (Yes = 1; No = 0)</td>
<td>0.310</td>
<td>0.100</td>
<td>0.321</td>
<td>3.091</td>
<td>0.003</td>
</tr>
<tr>
<td>Insect Damaged Before (Yes = 1; No = 0)</td>
<td>-0.083</td>
<td>0.053</td>
<td>-0.167</td>
<td>-1.595</td>
<td>0.115</td>
</tr>
</tbody>
</table>

a Null deviance: 9.49 on 79 degrees of freedom
b Residual deviance: 7.71 on 76 degrees of freedom
c AIC: 49.84

In conclusion, there is a high rate of acceptability of hermetic storage technologies by farmers. The type of hermetic bag used by farmers determined the farmers’ tendency to the use of hermetic bags in the future. Introduction of the Super GrainPro bag with an external layer of polypropylene bag might increase farmers’ tendency to use it. Besides, local availability of hermetic bags should be improved so that farmers can easily access the bags at the time of their need.

7. 5 Reference

Postharvest food losses in a maize-based farming system of semi-arid savannah area of


International de Mejoramiento de Maiz y Trigo (CIMMYT).


CHAPTER 8: CONCLUSION AND RECOMMENDATION

8.1 Conclusions

Farm stored wheat and maize are suffering with an average loss of 1.5% and 6.1%, respectively, due to stored product insects. *Sitophilus* spp. and *Sitotroga cerealella* are most common primary pests in the studied districts both in wheat and maize. Farmers are using synthetic insecticides to protect their wheat and maize from stored product insects, but they still are incurring substantial loss.

Use of different storage options substantially decreased the loss of stored wheat and maize due to insects. Seed weight loss of wheat due to insect in polypropylene bags was as high as 9.6% after six months while that in all other treatments was not beyond 0.7%. All storage options except for the polypropylene bags were similar in their performance up to six months of storage. Only the cost of the storage option will dictate its use by the farmers.

Filter cake powder was relatively less effective against the granary weevil compared to the lesser grain borer. However, there is still a room to reduce the concentration as low as 5 g/kg of wheat.

Hard wheat varieties such as Danda’a and Pavon-76 lower level of loss due to insects. There was also negative relationship between hardness index and insect counts and seed weight loss. Higher protein content, such as in Millennium was also negatively correlated to insect infestation and seed weight loss. The granary weevil sufficiently established infestation both at 30°C and 19°C, regardless of varieties grown. A management plan considering the integration of ventilation with varietal resistance is not sufficient to control the population growth of *S. granarius*.

On-farm testing of hermetic bags showed that they are effective under farmers’ conditions. There were reduced development of insects and minimized rate of seed weight losses in both wheat and maize. About 87% farmers who had once used the hermetic bags had the tendency to use those bags in the future.

8.2 Recommendations

Based on the findings from the present studies, the following recommendations are forwarded:

- As there is a substantial amount of seed/grain weight loss in wheat and maize, there is an urgent need for extension support to smallholder farmers regarding
proper storage of both wheat and maize. Besides, wheat and maize storage options should be readily available at a reasonable price.

- Since most of the studies on filter cake and Triplex dust are at an experimental level, emphasis should be given to the broader application of the products through on-farm participatory studies. Moreover, the dehydration kinetic of the filter cake power should be investigated in detail to explain its effects on insect mortality.

- The metal silo, in this study, was not effective, and it is essential to further investigate efficient and practical strategies of oxygen depletion from its headspaces.

- Control of the granary weevil should consider natural aeration and variety resistance together with other options such as inert dusts.

- Introduction of the Super GrainPro bag with an external layer of polypropylene bag might increase farmers’ tendency to use it. Besides, local availability of hermetic bags should be improved so that farmers can easily access the bags at time of their need.
Appendix – A: Checklist for Assessment of Farmers’ Perceptions on Utility of Hermetic Bags in Merawi and Wenberma Districts, West Gojjam, Ethiopia

Checklist for individual discussions

1. Name: ___________________ Gender: _______Age:_____ Level of Education: ________________

2. Which bag did you use? PICS____ GrainPro____

3. Which crop you placed in the bag? Wheat____ Maize ____

4. How much amount did you put in the bag? ________kg

5. How was the condition of grain you put in bag?
   a. High insect infestation
   b. Low insect infestation
   c. No insect infestation

6. Do you believe that the technology you have used is useful to protect your wheat/maize grain from insect damage?

7. What do you feel about hermetic storage methods you used for the last four months?
   a. Ease of use
   b. Effect on insects
   c. Cost (unit prices to be explained for the beneficiary)
   d. Effect on fungi
   e. Effect on grain quality

8. Do you plan to use the technology in the future? Yes ____ No___

9. If no, what is your reason for rejection? (ask for explanation, and note every detail of farmer’s perception)

10. What improvements do you suggest on the technology?

11. Have you showed the technology you are using for anyone else? Yes ____ No ____

12. If yes, what was his/her feedback? (ask for the feeling about those who observed the technology)
APENDIX – B: CHECKLIST FOR FOSUS GROUP DISCUSSION

1. Do you believe that the technology you have used is useful to protect your wheat/maize grain from insect damage?

2. What do you feel about hermetic storage methods you used for the last four months?
   a. Ease of use
   b. Effect on insects
   c. Cost (unit prices to be explained for the beneficiary)
   d. Effect on fungi
   e. Effect on grain quality

3. Do you plan to use the technology in the future? Yes ____ No___

4. If no, what is your reason for rejection? (ask for explanation, and note every detail of farmer’s perception)

5. What improvements do you suggest on the technology?
List of Publications


National and International Conferences


