

# Major Insect Pests and their Associated Losses in Quantity and Quality of Farm-Stored Wheat Seed

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## አሀጽሮት

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## 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 the most significant insects and losses of farm-stored wheat in five districts in Amhara, Oromiya, Southern Nations, Nationalities and Peoples, and Tigray regional states of Ethiopia during 2016. One kg samples of stored wheat seed were collected over a period of eight months from 150 farmers. The samples were kept in the laboratory for approximately six weeks to allow the population of insects present to develop and emerge as adults. After adult emergence, the resultant weight loss, seed damage, and loss of seed germination were determined. Major primary insect pests identified were the granary weevil, *Sitophilus granarius*, *Sitophilus* spp., and the Angoumois grain moth, *Sitotroga cerealella*. Secondary pests such as *Tribolium* spp., the India meal moth, *Plodia interpunctella*, and *Liposcelis* spp. were detected in a few samples. Wheat experienced mean percentage kernel damage that ranged from 3.6 to 13.6%. Mean weight loss due to insects was 1.5%, while mean seed germination was only 72.3%. The present survey indicated that farmers are incurring a considerable loss in the quantity and quality of stored wheat due to insects. Hence, there is an urgent need to devise appropriate tactics for protecting the losses in farm-stored wheat in Ethiopia.

## Introduction

The main cause of postharvest crop losses in developing countries, including Ethiopia, is biological spoilage (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 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 and 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* (Abdulahi and Haile, 1991; Tadesse *et al.*, 2008). 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 and Arthur, 2018), but they have been uncommon in grain stores in 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 and 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 the debate 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 because 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 main wheat growing districts in Ethiopia.

## Materials and Methods

### The study areas

The study included five wheat-growing districts in Tigray, Amhara, Oromiya, and Southern Nations, Nationalities and Peoples Region (SNNP). The five districts were Ofla, Wenberma, Hetosa, Gedeb, and Lemo.

### Sampling

Wheat samples were collected over a period of eight months from 150 farm stores in five wheat-growing districts in Amhara, Oromiya, SNNP, and Tigray in June 2016. From each

district, one *kebele* was selected based on its surplus production. 30 farmers who grow wheat were randomly selected from each *kebele*. A household was used as a sampling unit. One sample was taken after every third household. When adult family members were not available to respond to storage information, the next household was considered.

Seed sampling was carried out by hand from storage structures and a representative sample of 1 kg was taken. At time of sampling, data on age of seed (how long it was stored after harvest), storage structure used, and approximate quantity of stored seed, whether or not wheat was treated with a pesticide and the type of pesticide used, grain moisture content, and wheat variety were recorded.

### **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 6 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 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 a 100 g of seed was obtained. From 100 g of seed, damaged and undamaged kernels were separated, counted, and weighed. Mechanical damage was included into 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:  $\text{Damage (\%)} = [\text{Number of damaged kernels} \div \text{Number of kernels in 100 g of seed}] * 100$ . Seed weight loss was estimated using the equation:

Seed weight loss (%) =  $[(WU*ND)-(WD*NU)]*100/ [WD*(NU+ND)]$ , where, WU is weight of undamaged seeds, NU is number of intact seeds, WD is weight of damaged seeds, ND is 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 using 100 seeds (by randomly picked damaged and undamaged seeds) in each run. Normal and abnormal seedlings and dead seeds were counted, 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 (%) =  $[Weight\ of\ sifted\ material\ and\ seeds\ damaged\ mechanically \div Total\ weight\ of\ sample]*100$ .

### **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).

## **Results and Discussion**

### **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 Digalu 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.

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 attributed to farmers' perception that these varieties are relatively high yielding, 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.

### **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.

Our findings are in agreement with Dessalegn *et al.* (2017) who reported 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 (Boxall *et al.*, 2002; Dessalegn *et al.*, 2017). However, *gota* and *gotera*, which are traditional storage structures, in general, are suboptimal for wheat storage as they provide access to insects (Boxall *et al.*, 2002; Tadesse *et al.*, 2008). Hence, farmers can benefit from the introduction and the scaling up of improved storage technologies such as hermetic bags (Kalsa *et al.*, 2019).

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.

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 chemicals 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 seed with fumigants; while malathion and primiphos-methyl dusts were used by about 20.8% and 9.4% ( $n=53$ ) of the farmers. This is 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 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).

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

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

The density of live adult *Sitophilus* spp. was assessed by study districts and by chemical treatments on 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 1). The mean densities of live *Sitophilus* spp. ranged from 73.0 to 418.3 insects per kg. Variation in insect density across districts could be attributed to the differences in climatic factors, harvesting conditions, and storage management. 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 mean values of *Sitophilus* spp. densities of samples which received chemical treatment at storage (227.0 insects per kg) were statistically similar ( $t = -0.51$ ;  $df=96$ ;  $P= 0.61$ ) 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.

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  $\pm$ SD density of *S. granarius* in samples from Ofla district was  $209.4 \pm 388.8$  (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  $\pm$ SD ( $n=30$ ) density of  $4.3 \pm 12.4$  (min/max = 0/47) insects per kg and  $0.03 \pm 0.2$  (min/max = 0/1) insects per kg, respectively. *R. dominica* was mainly detected in Wenberma district in two samples at densities of 4 insects per kg and 1 insect per kg. *P. interpunctella* was primarily detected in samples from Wenberma district with a mean  $\pm$ SD density of  $4.3 \pm 14.3$  (min/max = 0/58) live adults per kg ( $N=30$ ).

Table 1. Frequency of wheat varieties, chemically treated samples and samples with *Sitophilus* spp. and mean  $\pm$ SD values of density of *Sitophilus* spp., the percentage of insect-damaged kernels, and weight loss

Study District <sup>a</sup>	Samples of a New/Recent variety (%) <sup>b</sup>	Chemical treated samples (%) <sup>c</sup>	Samples with <i>Sitophilus</i> spp. (%)	Density of <i>Sitophilus</i> spp. (counts/kg)	Insect-Damaged Kernels (%)	Seed weight loss (%)
Gedeb	0.0 a†	6.7 a†	86.7 a†	206.1 $\pm$ 268.4 ab‡	3.8 $\pm$ 3.1 b‡	0.8 $\pm$ 0.9 ‡
Hetosa	30.0 b	63.3 bc	100.0 a	234.6 $\pm$ 305.2 ab	4.8 $\pm$ 5.2 b	1.2 $\pm$ 1.3
Lemo	43.3 b	0.0 a	83.3 a	260.2 $\pm$ 403.5 ab	3.6 $\pm$ 7.1 b	0.7 $\pm$ 1.5
Ofla	73.3 c	36.7 b	50.0 b	73.0 $\pm$ 152.7 b	11.1 $\pm$ 17.0 ab	2.5 $\pm$ 4.4
Wenberma	100.0 d	70.0 c	86.7 a	418.3 $\pm$ 484.9 a	13.6 $\pm$ 17.2 a	2.3 $\pm$ 3.1
$F_{4, 145}$	-	-	-	3.92	4.54	2.19
<i>P</i> -value	<0.01	<0.01	<0.01	<0.01	0.002	0.073

<sup>a</sup>Thirty samples were taken at each district.

<sup>b</sup>New/Recent varieties (Danda'a, Hidasie, Kakaba, Kingbird, Ogocho); Old/Obsolete varieties (Galama, Kusba, Digelu, Local, Mixture). <sup>c</sup>Chemical insecticides reported as used by farmers included malathion, Actellic (primiphos-methyl), and phosphine tablets.

<sup>†</sup>Groups sharing a letter are not significantly different at Fisher's 5% level of significance (two-sided).

<sup>‡</sup>Groups sharing a letter are not significantly different at Tukey's 5% level of significance. Data were based on 30 samples from each district.

*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 with a mean  $\pm$ SD density of  $1.2 \pm 4.4$  (min/max=0/24) insects per kg. Prevalence of *Tribolium* spp. in the samples from Wenberma district might be an indication that primary insects severely damaged the samples. Moreover, psocids (*Liposceliss* spp.) 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%. Tadesse *et al.* (2008) reported in their comprehensive review that *Liposceliss* spp are uncommon in grain stored of Ethiopia. However, with the increasing global importance of the pest, there is a need to substantiate the present findings with more targeted sampling.

*Sitophilus* spp. 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 crop species (Wu and 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 Ofla district. This is in agreement with an earlier report that *S. granarius* has particular importance in highlands where altitudes were above 2500 m (Abdulahi and Haile, 1991).

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

Significant differences ( $P < 0.01$ ) were detected among wheat samples across all districts regarding percentage of insect damaged kernels (Table 1). The mean percentage of insect damaged kernels ranged from 3.6 to 13.6. The overall mean 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 the study districts. However, samples from Ofla and Wenberma districts exhibited relatively higher rates of seed weight loss (Table 1). Relatively higher mean percentage of seed weight loss was from samples of Ofla district, and this could be attributed to high infestation by *S. granarius*, which is known to be the most destructive among weevils infesting wheat (Campbell and Sinha, 1976). A higher rate of weight loss in Wenberma district, however, can be more easily 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 losses.

The mean percentage of weight loss of stored wheat in Ethiopia, particularly due to insects only was 0.5% (Boxall, 1998). 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. Results from our present study indicated that the percentage of weight loss 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 weight loss in our study, however, is far below the 4.2% loss reported by Abdulahi and Haile (1991), which was limited to wheat districts in North Shewa.

Mean percentage of seed weight loss varied with wheat variety. The percentage of weight loss of wheat varieties (new/recent varieties, old/obsolete) showed a significant difference ( $t=3.03$ ,  $df=89.4$ ,  $P < 0.01$ ). 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%. 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.

Insecticide treated samples exhibited more mean percentage of insect damaged kernels and seed weight loss. The mean percentage of 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 weight loss (1.2%). This is on the contrary to the expectation that pesticides are used to reduce storage losses. However, Williamson *et al.* (2008) indicated that some maize farmers in Ethiopia had observed a tremendous occurrence of weevils in the granaries where they had used synthetic insecticides. This could be attributed to improper use of chemicals or insect resistance.

### 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). However, seed germination ranged from 59.7% to 79.9%. The low germination rate of seed samples from Wenberma district could be attributed rain at the time of harvesting (FGD) and the prevalence of *P. interpunctella*. 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).

Table 2. Physiological and physical characteristics of seed samples

District	Germination (%)*	Dead seed (%)	Dockage (%)
Gedeb	79.9±18.5	10.1±14.1b	5.6±6.7ab
Hetosa	69.8±28.1	16.6±27.8ab	2.2±2.0b
Lemo	78.4±30.3	13.4±26.1ab	7.5±5.9a
Ofla	73.9±31.2	15.7±27.2ab	3.0±7.0b
Wenberma	59.7±32.4	30.1±31.7a	3.5±6.1ab
$F_{4,145}$	2.416	2.57	4.00
$P$ -value	0.051	0.040	0.004

‡Means with the same letter are not significantly different at Tukey's 5% level of significance. †Data are means ± SD. Data were 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 to the seed can cause a significant reduction in seed capacity of producing a healthy seedling. Germination of seeds decreased significantly with damage level (Koptur, 1998). Damage hastens the loss of nutrients during initial phases of seed germination and the seed fails to develop into normal seedlings. In our study, the percentage of insect-damaged kernels and density of live adult *Sitophilus* spp. demonstrated significant correlations ( $r=-0.38$ ;  $t=-5.04$ ,  $df=148$ ,  $P < 0.01$ ; and  $r=-0.36$ ;  $t=-4.74$ ,  $df=148$ ;  $P < 0.01$ , 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 ( $t=2.33$ ,  $df=90$ ,  $P=0.02$ ) lower rate of seed germination (64.5%) than samples that did not receive 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).

Significant differences ( $P < 0.05$ ) were detected among samples concerning dead seed across study districts (Table 2). Mean percentage of dead seeds ranged from 10.1 in Gedeb district to 30.1 in Wenberma district. As expected, dead seed 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). Mean dockage in wheat samples was about 4.3% with a SD of 6.0%. Dockage was not only due to insect damage but 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.

Seed samples differed significantly ( $P < 0.01$ ) in their conformity to National Wheat Seed Germination Standards of Ethiopia for certified seed (Table 3). About 52% ( $n=150$ ) had met the germination requirement for certified seed. A majority samples (60%,  $n=150$ ) met the requirement of emergency seed. Loss of germination in farm-stored wheat seed has important implications towards future food security of the farming household (Kalsa, 2019). Seed that has lost germination may not give good standing crop, and consequently will result in reduced yield. Due to lost germination, farmers may be subject to additional expenses such as increasing the seeding rates or by purchasing new seeds.

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 *S. cerealella*. *P. 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. The health hazards associated with chemical pesticides and the concern for environmental sustainability calls for exploring integrated insect management tactics in stored wheat. The present study is limited to one-time sampling that it may not represent the insect dynamics throughout the wheat post-harvest system. The study also was focused on farm-stored wheat while wheat in markets may also incur considerable losses due to insects. This study did not address situations in low moisture and hot wheat growing areas where *R. dominica* could be more prevalent. Occurrences of insecticide resistance also need investigation.

Table 3. Percentage frequency of samples that comply with certified or emergency seed standards for germination (based on samples collected in June 2016 from different wheat growing districts)

District	Certified seed (≥85% germination) †		Emergency seed (≥80% germination)	
	Complying	Not-complying	Complying	Not-complying
Gedeb (n=30)	60.0a††	40.0a	63.3	36.7
Hetosa (n=30)	40.0ab	60.0ab	53.3	46.7
Lemo (n=30)	70.0a	30.0a	70.0	30.0
Ofla (n=30)	66.3a	33.3a	66.7	33.3
Wenberma (n=30)	23.3b	76.7b	46.7	53.3
P- value	<0.001		0.3421	

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

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

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