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Assessment of Storage Insect Pests, Methods and Management Practices for Rice (*Oryza sativa* L.) in Fogera, Northwestern Ethiopia

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ABSTRACT

Storage pests are a significant factor contributing to rice crop losses, adversely affecting both the quantity and quality of stored rice. This study was carried out to assess the current status of storage insect pests, storage methods, and management practices in Fogera district, Ethiopia, during the 2022 cropping season. The assessment was conducted based on interviews, visiting the individual households, and collecting a representative sample of rice grains from each store among 200 randomly selected farmer households. Data on the socio-economic characteristics, storage structures, durations of rice storage, pest management practices, relative abundance, grain damage, weight loss, and germination percentage were collected and analyzed using descriptive statistics. The result of the study showed that rice weevil (*Sitophilus oryzae*), lesser grain borer (*Rhyzopertha dominica*), red flour beetle (*Tribolium castaneum*), and angoumois grain moth (*Sitotroga cerealella*) insect pests were found in the surveyed areas. Among these, rice weevil and lesser grain borer predominantly occurred, and the majority of the respondents perceived them as the most common and damaging pests of rice. Most farmers used traditional storage structures like *Gota* (32%), *Shirfa* (27%), polypropylene bags (25%), and fertilizer bags (12%) for storing rice, which were susceptible to insect pest infestations, resulting in 2.26% grain damage. Farmers applied various storage insect pest control methods, including physical, chemical, and cultural practices, with chemical (29%) being the most commonly used. They repeatedly use insecticides that pose risks to both the environment and human health. Therefore, the study recommended the adoption of improved storage technologies to protect grains from pests, minimize insecticide use, and preserve grain quality. Additionally, training on effective storage methods, pest management, and healthy rice preparation is essential. These findings serve as a foundation for developing sustainable pest management methods in the study area, ultimately improving food security and farmer livelihoods.

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Introduction

Rice (*Oryza sativa* L.) is a cornerstone of global food security, providing sustenance for over 60% of the world's population (Babendreier et al., 2020). As a staple food, rice offers essential nutrients, including carbohydrates, fiber, protein, minerals, and vitamins. Its importance is particularly pronounced in Africa, where rice consumption is rapidly increasing, driven by population growth, urbanization, and changing dietary preferences (Arouna et al., 2021; Saito et al., 2023).

In Ethiopia, rice has become a vital livelihood for farmers and a key contributor to national food security (Agegnehu et al., 2019). The country boasts several major rice-producing areas, including Fogera, Pawi, Abobo, Chewaka, Gura-Ferda, May-Tsebri, and Gode (Alemu & Assaye, 2021). Fogera district, in particular, is a significant rice-growing region, accounting for a substantial portion of both the Amhara region and national rice production (Lema et al., 2017). Rice cultivation has transformed the livelihoods of farmers and created employment opportunities across the country (Desta et al., 2019).

However, the benefits of rice production are often threatened by post-harvest losses, particularly caused by storage insect pests. Stored rice is vulnerable to infestation, leading to both quantitative and qualitative losses,

impacting food security and farmer livelihoods (Mario et al., 2023). Globally, numerous insect species attack stored rice (Ishii et al., 2010), with *Sitophilus oryzae*, *Sitotroga cerealella*, *Tribolium castaneum*, and *Rhyzopertha dominica* being among the most damaging (Shafique & Ahmad, 2003; Guenha et al., 2014). These pests can rapidly reduce grain quantity, quality, nutritional value, and viability. Traditional storage structures, commonly used by smallholder farmers in developing countries (Tibagonzeka et al., 2018), are often inadequate, leading to grain quality degradation and increased pest vulnerability (Mapfeka et al., 2019).

Despite the importance of rice and the prevalence of storage pests, effective and sustainable storage practices are often lacking in the Fogera district, leading to significant post-harvest losses. Understanding the current status of storage insect pests, storage methods, and management practices is crucial for developing targeted and effective strategies to minimize post-harvest losses and improve food security in the district. Therefore, this study aims to assess the major storage insect pests of rice, storage structures, and insect pest management practices used by farmers in the study area.

Materials and Methods

Description of the Study Area

The study was conducted in the Fogera district, located in the Amhara National Regional State, of Ethiopia, during the 2022 cropping season. It lies between 11^0 46' to 11^0 59' North latitudes and 37^0 33' to 37^0 52' East longitudes. The district is bordered by Libo Kemkem district in the North, Dera district in the South, Lake Tana in the West, and Farta district in the East. Woreta is the administrative city of the district and is located 625 km northwest of Addis Ababa and 55 km from Bahir Dar, the administrative city of the Amhara region. The mean annual rainfall is 1216.3 mm, with "*Belg*" (short rain season) and "*Meher*" (the summer *season*) cropping seasons. It lies within an altitude range of 1774 up to 2410 m.a.s.l. allowing a favorable opportunity for wider crop production. The major crops grown in the district are teff, maize, finger millet, and rice, in order of area coverage. Rice is the major crop produced in the swamp areas of the district. The dominant soil type in the Fogera plains is black clay soil (ferric vertisols), while the mid and high-altitude areas are orthic Luvisols (IPMS, 2005).

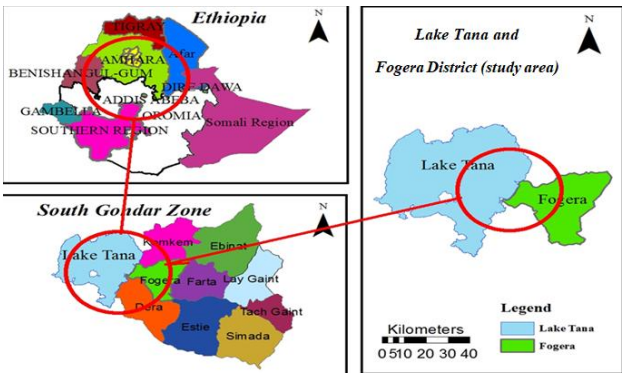

Figure 1. Location of the study area.

Sampling Procedures and Sample Size Determination

The assessment was carried out in a major rice-growing *kebele* (the smallest administrative unit below the district level) of the Fogera plains after storage, when an infestation and grain damage level were most likely to be prevalent. Fogera district has a total of 33 rural *kebele* administrations, of which 27 *kebele* are engaged in rice production (Dawit et al., 2018). From these *kebele*, a total of six rice-producing *kebele,* namely *Kuhar Abo*, *Kuhar Mikael*, *Shaga*, *Shina*, *Tiwazakana*, and *Woreta Zuria,* were selected for the study. The assessment sites were purposively selected to represent the key rice-producing areas in the district. The *kebele* administrations were chosen based on their rice-growing potential, as these are considered high-potential rice production areas in the district.

Within each selected *kebele*, farmers' stores were selected using simple random sampling methods, and one household farm store was sampled randomly. Key informants were directly interviewed at the household level using prepared checklists to obtain the required information. Open-ended questionnaires were employed to facilitate a free flow of data regarding the types of storage structures, storage durations, storage insect pest management practices, the months when storage insect pests mostly occurred, and the type of storage pests encountered.

A total of 500g of rice grain samples from each store were collected at three different depths within the store from the top, middle, and bottom. These three subsamples were then bulked together to create a composite sample. Each composite sample was placed in a labeled plastic bag, noting the site name, sample number, and date of collection. These samples were then brought to the laboratory for further analysis, where they were assessed for the presence and identification of storage insect pests. A stereo-zoom microscope was used to observe the morphological characteristics of the collected insects and match them to online species identification databases and resources. This allowed for the accurate taxonomic classification of the storage insect pest species present in the samples. Additionally, the grain samples were evaluated for other parameters, including weight loss, grain damage, and germination rate. The data from grain samples, along with insect pest identification, offered a thorough evaluation of pest infestation conditions in farmers' rice storage facilities.

There are various approaches available for determining the appropriate sample size in quantitative research. These include using published sample size tables, applying mathematical formulas to calculate the sample size, and other methods. This study adopted Yamane's (1967) sampling formula to calculate the required sample size at a 7% precision level. This level of precision is a common choice in many types of research, as it provides a balance between the desired accuracy and feasibility of data collection. So, by applying Yamane's formula and specifying the 7% precision level, a total of 200 store farms from the selected *kebele* were assessed (Table 1). The sample sizes were selected based on the formula given:

$$n = \frac{N}{1+N(e)2}$$

Thus, it obtained a total sample size of: n = 9,959/ $1+9,959(0.07)^2$ = 200, where, n = sample size; N = total households in the study area (9,959); e = level of precision (7%). Thus, out of 9,959 households in the study area, 200 respondents were selected.

Table 1. Sample population and total household number for the sampled *kebele* in Fogera district, Ethiopia.

No	Name of Kebele	THN	SH
1	Kuhar Abo	722	14
2	Kuhar Mikael	1929	39
3	Shaga	1825	37
4	Shina	2305	46
5	Tiwazakana	1626	33
6	Woreta Zuria	1552	31
Total sample households		9959	200

THN: Total Household Number, SH: Sampled Households

The formula for the determination of the required number of households in an individual *kebele* was:

$$S = \frac{TNH \times TSH}{THS}$$

Where S is the number of required household samples for each *kebele*; TNH is the total number of households in a *kebele*; TSH is the total number of sample households; and THS is the total households of all sampled *kebele* (Desta et al., 2022). Thus, for the *Kuhar Mikael kebele*: S = 1929 × 200/ 9959= 39. Therefore, out of 1929 households, 39 households were sampled in the *Kuhar Mikael kebele* administration.

Data Collected

The data collected in this study included information on the socio-economic characteristics and the types of storage structures used by farmers, storage durations of rice grains, storage insect pest management practices, the months when storage insect pests were most prevalent, and the specific types of storage pests. In addition to this percentage of weight loss in the stored grains, the percentage of grain damage, germination rate of the stored rice, and relative abundance of the different insect pest species were collected.

Relative abundance of insect pests: This parameter of relative abundance was determined after the insect pests were first identified and counted from the grain samples collected directly from the grain stores. It provides a measure of the proportional representation of each insect pest species relative to the total insect pest population observed in the grain samples. The relative abundance of each pest species was then calculated using the following formula, as described in a study by Rahaman et al. (2014):

$$RA = \frac{Number\ of\ individual\ insect\ species\ in\ the\ sample}{Total\ insect\ species\ in\ the\ sample} \times 100$$

RA : Relative abundance (%)

Grain weight loss: A representative sample of rice grains was taken randomly from each composite sample. Insect-damaged and non-damaged grains were identified and tallied using a hand lens to inspect for the presence of a hole or burrow. These samples were separated into damaged and undamaged grains. The number of damaged and undamaged grains was counted, and the weight of each category was measured. Using this data on grain counts and weights, the percentage of weight loss was determined following the count and weight method described by Gwinner et al. (1996).

$$\text{Weight loss (\%)} = \frac{(WU*ND)-(WD*NU)}{WU(ND+NU)} \times 100$$

Where, Wu = Weight of the undamaged grain, Wd = Weight of damaged grain, Nu = Number of the undamaged grain, and Nd = Number of damaged grains.

Grain damage: Insect-damaged grain was assessed by the count method. Representative seed samples were randomly taken from each composite grain sample and were determined using a hand lens by searching for the presence of holes in seeds. The number of damaged grains in the sample was then counted manually. The percentage of damaged grains was calculated according to the methods used by Wambugu et al. (2009) as follows:

$$\text{Grain damage (\%)} = \frac{Number\ of\ damaged\ grains}{Total\ number\ of\ grains} \times 100$$

Germination test: A germination test was conducted on one hundred randomly selected seeds from the collected samples. The seeds were treated with a 1% sodium hypochlorite solution for one minute to disinfect them and remove any fungal contamination, as described in the study by Adane et al. (2021). After the disinfection treatment, the seeds were rinsed with distilled water for an additional minute. The treated seeds were then placed on moist filter paper inside a germination box in four replications and maintained at room temperature. Percent germination was calculated following Ogendo et al. (2004) as follows:

$$\text{Germination (\%)} = \frac{Number\ of\ seeds\ germinated}{Total\ number\ of\ seeds} \times 100$$

Method of Data Analysis

The collected data from the sample respondents were analyzed using descriptive statistics such as mean, percentages, and frequency distribution analyzed by using the statistical tool of R- software.

Results and Discussion

Demographic Characteristics of Sampled Households

The study surveyed 200 households, with the majority (90%) headed by males, reflecting the typical gender distribution in agricultural activities in the study areas (Table 2). The average age of household heads was 43.8 years, ranging from 22-70 years, indicating a population primarily within the productive age group for farming. The average family size was 5.4 members, with a range of 2-10 persons, suggesting a potential for available labor within the households. This could significantly influence agricultural practices, particularly in rice cultivation and storage. Larger family sizes may lead to increased rice production, as more family members can contribute to planting, harvesting, and processing. Consequently, this could result in greater quantities of rice being stored for home consumption, ensuring food security for the family.

The average education level of family members was 2.5 years of schooling suggests a relatively low level of education within the community. This may significantly influence agricultural practices, particularly in terms of the adoption of new storage technologies and pest management methods. This limited education may hinder access to information about modern agricultural techniques, as education often plays a crucial role in understanding complex concepts and innovations. Families may be less likely to adopt improved storage methods or pest management practices, which could lead to inefficiencies and increased post-harvest losses. Farming was the primary economic activity for all respondents, and the average rice farming experience of the household heads was 12.2 years. This suggests that rice farming is a relatively recent activity in the area, which may influence the adoption of new storage practices compared to more established crops.

Storage Insect Pests of Rice

A survey of rice grain storage in Fogera district revealed the presence of four key insect pest species (Table 3). The rice weevil (*Sitophilus oryzae*) and the lesser grain borer (*Rhyzopertha dominica*) were the most prevalent, with *S. oryzae* accounting for 26% of the identified pests. *R. dominica* was the second most abundant, representing 17% of the observed pests and was the predominant storage pest in farmers' grain storages (Figure 2). The angoumois grain moth (*Sitotroga cerealella*) and the red flour beetle (*Tribolium castaneum*) were present at lower levels, comprising 14% and 9% of the recorded pests, respectively. The high prevalence of *S. oryzae* and *R. dominica* suggests that these species pose the greatest threat to stored rice in the study areas and require comprehensive pest management strategies. In addition to insect pests, rodents and termites were also observed, further contributing to post-harvest losses.

Rodents were identified as the major pest problem in rice storage within the surveyed district, causing significantly more damage than insect pests. They posed a primary threat to rice quality and quantity, leading to extensive losses. Farmers reported that controlling rodents was consistently challenging due to their year-round presence in storage areas, resulting in considerable annual losses from feeding, spoiling, and contamination. In the assessed areas, rodents accounted for 32% of storage pests, while termites comprised only 2%. Infestations of rodents were the most prevalent and problematic storage pests in the surveyed district, causing significantly greater losses to rice grains than other pests. Termite infestation and damage were very low and easy to manage compared to the rodent issue. Overall, rodents emerged as the dominant threat to rice storage.

Research indicates that rodents are significant postharvest pests, leading to considerable losses and contamination of stored grains, thereby impacting food security and smallholder farmers' incomes (Brown et al., 2013). In addition, storage insect pests can severely affect the quality and quantity of stored rice if not properly controlled. Notably, the Coleoptera and Lepidoptera insect orders, including pests like the *S. oryzae*, *R. dominica*, *T. castaneum*, and *S. cerealella*, have been highlighted as the main storage insect pests of rice (Khare, 1994, as cited in Ahmad et al., 2021; Bhargava & Kumawat, 2010).

Table 2. Demographic characteristics of the sampled households in the study area (N=200).

Household characteristics	Mean/Percent
Sex of the household (Male)	90.00
Age of the household	43.80
Household size	5.40
Education level	2.50
Rice farming experience	12.20

Table 3. Identified storage insect pests of rice in the study area.

Order	Family	Common name	Scientific name
Coleoptera	Curculionidae	Rice weevil	*Sitophilus oryzae* (L.)
Coleoptera	Bostrichidae	Lesser grain borer	*Rhyzopertha dominica* (Fabricius)
Coleoptera	Tenebrionidae	Red flour beetle	*Tribolium castaneum* (Herbst)
Lepidoptera	Gelechiidae	Angoumois grain moth	*Sitotroga cerealella* (Olivier)

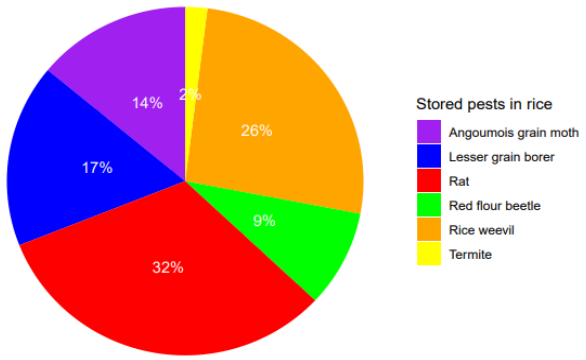

Figure 2. Major storage insect pests of rice in the study area.

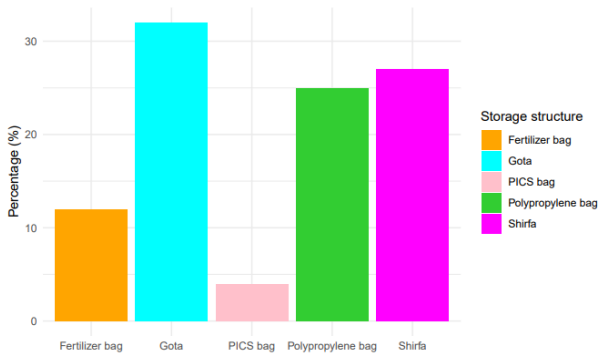

Figure 3. Methods of storing rice grain percentages in the study area.

The rice weevil and angoumois grain moth have been identified as the most economically damaging species (Togola et al., 2010; Hamed & Nadeem, 2012). Additionally, the lesser grain borer has been widely reported as a common and problematic insect pest of stored rice grains (Mutters & Thompson, 2009; Covele et al., 2020). In the Fogera district, a study by Misganaw (2020) revealed that 27.2% of respondents reported very low severity of weevils, 21% low, 35.8% high, 8.6% very high, and 6.2% indicated no weevils in their rice storage.

The particular storage insect pest species present during the storage period can depend on a variety of factors, such as moisture, temperature, and the type of grain being stored. In the context of Ethiopia, numerous storage insect pests have been known to attack cereal crops during storage. Among the major storage pests identified in the region, the maize weevil (*Sitophilus zeamais*) was found to be the most prevalent, followed by the *S. cerealella*, the *S. oryzae*, and the confused flour beetle (*Tribolium confusum*) (Waktole & Amsalu, 2012). This finding is further supported by Tefera's (2016) report that the *S. oryzae* and the *S. cerealella* are considered major insect pests of cereal crops in Ethiopia.

Storage Structures Used by Farmers

Farmers in the surveyed areas used a variety of traditional storage structures, with "*Gota*" (32%) being made from mud and straw inside the house and "*Shirfa*" (27%) made from a bamboo split. These, followed by a polypropylene bag (25%) and fertilizer bag (12%), were found for rice grain storage materials (Figure 3). In total, 96% of farmers used traditional storage methods, while only 4% utilized improved Purdue Improved Crop Storage (PICS) bags. This indicates that improved storage materials were not used by most farmers in the surveyed areas, and they are negligibly used modern storage structures. The "*Gota*" storage structure was particularly dominant for long-term rice storage. Polypropylene bags were preferred by most farmers for their convenience and availability in the market, but had higher storage losses due to damage from pests like rats and animals compared to the local storage materials.

Farmers often use fertilizer bags for short-term rice storage until traditional structures like "*Gota*" or "*Shirfa*" can be arranged. In some cases, they may use these bags for up to a year if other storage options are unavailable. Overall, traditional storage methods dominated, which were more susceptible to pest infestations. In Ethiopia, many farmers rely on poorly constructed traditional storage made from local materials, which offers limited protection against pests like insects and rodents, leading to significant grain losses. Farmers store their harvested grain in various traditional structures, including mud and thatched roofs, bamboo bins, gotera, wooden walls, polypropylene, and jute bags. These conventional storage options, made from locally available materials, often create an ideal environment for the proliferation of storage pests. Consequently, conventional grain storage practices often fail to effectively protect against infestations and post-harvest losses (Desta & Yeshitila, 2024).

Traditional grain storage practices in Ethiopia are often characterized by poor hygiene, which can lead to infestations of insect pests and rodents (Negasa et al., 2021). Various studies have examined the storage methods used by Ethiopian farmers. Tadesse & Basedow (2004) and Adugna (2006) found that farmers utilized a variety of traditional storage containers. This study in line with other studies conducted in Jimma, Ethiopia revealed that the most common storage structures were plastered "*Gotera*" (14.1%), unplastered "*Gotera*" (25.5%), "*Gumbi*" or "*Gota*" (13.8%), polypropylene sacks (41.4%), and PICS bags (5.3%). These findings suggest that the majority of farmers still rely on traditional storage structures (Nezif et al., 2020). Similarly, Dubale et al. (2012) reported that 93.3% of Ethiopian farmers use traditional storage methods, exposing their stored grains to insect pests, mold, and other loss factors.

Traditional storage structures are primarily utilized by smallholder farmers in developing countries (Tibagonzeka et al., 2018). However, these traditional storage options are not very reliable, as the grain quality can easily be compromised, and the structures themselves can deteriorate over time (Mapfeka et al., 2019). Studies have shown that traditional storage and handling facilities are often ineffective against the proliferation of mold and insect pests (Sankara et al., 2016; Kumar & Kalita, 2017; Manandhar et al., 2018). This suggests a clear need to improve the post-harvest systems and existing traditional storage structures utilized by smallholder farmers (Nezif et al., 2020). Furthermore, smallholder farmers must adopt improved grain storage technologies, such as metal silos and PICS bags, which have shown promising results in reducing post-harvest losses in many African countries (Tefera, 2012; Gitonga et al., 2013). Similarly, recent research by Tesfaye & Tirivayi (2018) observed that the implementation of improved storage technologies in Ethiopia has the potential to enhance the country's overall food and nutritional security.

Damage and Germination Test Assessment

Weight loss: The study found an average weight loss of 0.84% for rice grains stored by farmers in the assessed areas. The maximum weight loss was recorded in *Kuhar Mikael* at 1.13% followed by *Woreta Zuriya* at 1.02%, likely due to these grains being stored for longer periods. The minimum weight losses were recorded in *Tiwazakana* (0.63%), followed by *Shaga* (0.70%) (Table 4). The differences in weight loss across the areas were attributed to variations in the storage duration. Factors like pest consumption, changes in temperature and moisture content, chemical changes, and spoilage can contribute to the decrease in grain weight over time in storage (Adane et al., 2021). Gonzalez-Torralba et al. (2013) found that grain weight loss was closely related to storage duration. Specifically, they noted that as the storage time increased, there was a significant loss in grain weights.

Likewise, Tefera (2012) also reported that storage losses were dependent on humidity and temperature, which can favor the growth of mold and infestation by insects. This finding aligns closely with the rice storage loss of 1.01% reported by Ardakani & D'Amico (2020). However, these results are lower compared to the previous findings of Shafique & Ahmad (2003), who recorded losses in rice varieties ranging from 4.09% to 12.61%. Additionally, a study by Togola et al. (2013) found weight losses in stored rice varying from 1.64% to 5.47%. These variations can be

attributed to factors such as low-storage insect pest infestation in the study areas, differences in storage methods, varying storage durations, or environmental locations. Furthermore, farmers' use of chemical insecticides as a preventive measure could be a reason for the lower weight losses observed in the study areas. In Ethiopia, the typical grain losses due to storage insect pests are estimated to be between 10-30% (MoARD, 2010), due to the major storage insect pests of cereal crops like *Sitophilus spp*. and *Sitotroga cerealella* (Demissie et al., 2008; Tefera, 2016).

Grain damage: The grain damage in rice due to insects showed that the damage percentage ranged from 1.73% to 2.85%, with a mean of 2.26% observed in the samples collected from the study areas (Table 4). The maximum grain damage was recorded in *Kuhar Mikael* at 2.85%, followed by *Woreta Zuriya* at 2.67%. Conversely, the minimum grain damage was observed in *Tiwazakana* at 1.73%, followed by Shaga at 1.89%. This variation could be attributed to the longer storage period of rice grains in *Kuhar Mikael* and *Woreta Zuriya* compared to the other sampled areas. Several factors may have contributed to the high grain damage by storage insect pests, such as storage method, storage duration, and management practices (Tefera, 2012). Poor storage systems can make grains more vulnerable to attacks by insects, leading to significant losses during grain storage. Storage of insect pests are crucial biotic factor that can reduce grain quality during storage through their feeding activities. This can result in weight loss, reduced viability, and decreased nutritional value, ultimately making the grains unsuitable for human consumption (Herbert, 2012).

According to Rajendran (2003), the major internal-feeding pests of rice are *R. dominica*, *S. oryzae*, and *S. cerealella*, which feed inside the seed and on the seed germ (embryo). These storage insect pests cause damage by consuming the carbohydrates, vitamins, and protein contents of the seed. Similar findings of higher grain damage were reported by Chattha et al. (2016) on grains stored in traditional grain storage, which were attributed to primary insect pests. Different from this result, the study by Togola et al. (2013) found that the infested grain percentage in stored rice ranged from 3.29% to 10.94%. Likewise, Togola et al. (2010) recorded infestations by the *S. cerealella* in many rice-producing zones of Benin, causing an estimated 3-18% damage to grain, depending on the area and length of storage.

In Ethiopia, a study conducted by Tadesse & Basedow (2004) reported that the proportion of grains damaged due to insect pests reached up to 29.3% in farmers' storage. Similarly, Tadeos (2018) found that grain damage reached up to 29.27%, which is higher than the findings of the current study. The relatively low grain damage observed in this study, compared to other findings, might be attributed to several factors. These include a lower level of storage insect pest infestation, farmers storing rice grains in conditions with low moisture and temperature, and the application of synthetic insecticides before the occurrence of storage insect pests.

Germination test: The seed germination test showed that the overall mean germination rate was 92.17%, with a range from 86.67% to 96.00% among the collected rice grain samples in the study area. The highest germination rates were recorded for rice grain samples collected from *Shaga* at 96.00% followed by *Kuhar Abo* at 95.67%, while the lowest was observed in *Shina* at 86.67% followed by *Kuhar Mikael* at 87.67%. Other study areas had intermediate germination rates, with *Tiwazakana* at 95.00% and *Woreta Zuria* at 92.00% (Table 4). Germination could be affected by factors such as grain storage duration, type, pest infestation, and management practices (Adane et al., 2021). However, the results indicated that germination was not significantly affected by storage insect pests. This suggests that seeds with minor pest damage may still germinate similarly to healthy seeds, as noted by Tigist (2004). This result contradicts a previous study reported by Chattha et al. (2015) indicated that insect grain damage decreases seed germination percentage in seeds stored in traditional storage structures.

Rice Storage Periods and Seasons of Storage Insect Pests Occurred

The assessment revealed that farmers in the study area store their rice grains for periods ranging from 6 months to 2 years. All farmers expressed that they store rice for at least 6 months. The majority (59%) of farmers stored their rice grains for 1 year, typically for household consumption until the next harvest. Other storage durations included 15% of farmers stored their grains for 10 months, 9% for 14 months, 7% for 2 years, 5% for 8 months, 3% for 18 months, and 2% for 6 months (Figure 4). In total, 81% of farmers stored their rice grains for 6 months to 1 year, likely selling or consuming the stored rice during this period. The remaining 19% of farmers stored their rice grains for over 1 year, up to 2 years. An economically mature farmer was found to store their rice grains for up to 2 years. This condition was an opportunity for insect pests to develop and cause damage to the stored rice. As the storage duration increases, the occurrence and impact of storage insect pests are likely to be higher, leading to greater grain damage.

Table 4. Percentage of weight loss, grain damage, and germination in stored rice grain in the study area.

Kebele	Weight loss (%)	Grain damage (%)	Germination (%)
Kuhar Abo	0.81±0.23	1.94±0.29	95.67±1.45
Kuhar Mikael	1.13±0.16	2.85±0.26	87.67±1.45
Shaga	0.70±0.13	1.89±0.46	96.00±1.15
Shina	0.77±0.07	2.46±0.09	86.67±2.03
Tiwazakana	0.63±0.26	1.73±0.19	95.00±1.53
Woreta Zuria	1.02±0.26	2.67±0.40	92.00±1.15
Mean	0.84	2.26	92.17

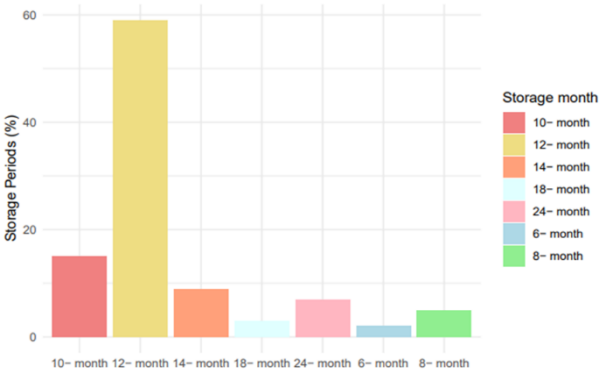

Figure 4. Storage periods of rice in the study area

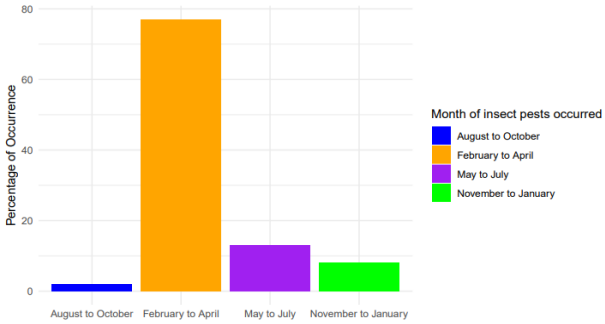

Figure 5. Season of storage insect pests occurred in the study area.

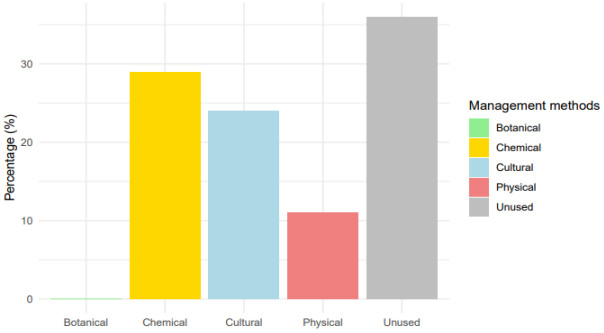

Figure 6. Control methods used by farmers in the study area.

Farmers in the study district were found to store their rice grains for over one year through repeated applications of chemical insecticides to control storage insect pests. However, these insecticide applications are costly for the farmers and can also reduce the quality of the stored grains and leave harmful residual effects on the grains, posing a health problem for consumers. Previous studies have shown that grain is often not stored for more than 8 months in Ethiopia due to poor storage techniques and inadequate pest management systems (Ali & Abraham, 2018). In the current study, most of the farmers in the study area stored their rice grains for up to one year, with only a small proportion storing them for up to two years. This assessment result aligns with Nezif et al. (2020), who stated that most farmers in the Jimma, West Shoa, and East Wollega zones of southwestern Ethiopia do not store grain for more than one year. However, contradict to the result found that a small proportion of farmers stored their rice grains for up to two years.

The season of occurrence of storage insect pests in the study areas was assessed. The results showed that the peak season for these pests was from February to April, accounting for 77% of the occurrences. This was followed by a decline from May to July (13%), November to January (8%), and August to October (2%) (Figure 5). The assessment indicated that storage insect pests were present throughout the year, but their level of infestation varied by season. This was likely due to changes in temperature, moisture, and other storage conditions across the different seasons. The findings suggest that the February to April period provides the most favorable environment for the proliferation of rice storage pests, which might be an appropriate temperature and humidity for rice storage pest infestations. This result is in line with a previous study by Adane et al. (2021), which reported a similar peak season of storage insect pests for sorghum observed from February to April in the Jawi district of Northwestern Ethiopia.

Management Practices Used by Farmers

Farmers in the study area employed a range of storage insect pest management methods, including chemical, cultural, and physical practices. However, chemical control was the most prevalent approach, with 29% of households in the Fogera district relying primarily on this method (Figure 6). The most commonly used chemicals were Malathion 5% dust and fumigant (phosphine gas), which were often applied both preventatively and after infestation. Cultural practices were the second most common approach, utilized by 24% of farmers. These practices included sanitation, cleaning storage structures, removing old grains, and avoiding mixing old and new rice. While these practices are beneficial, their effectiveness may be limited by the prevalence of traditional storage structures.

Physical methods, such as sun drying to reduce moisture content, were employed by 11% of farmers. This helped reduce the infestation and create an environment where storage insect pests could not easily reproduce and survive. Farmers also used ash as a physical control method, which can cause physical and physiological injuries to insect pests. It affects their respiratory system and kills them by causing suffocation (Jean et al., 2015). Interestingly, no farmers reported using botanical management methods. Furthermore, a significant proportion (36%) of farmers did not apply any management practices at all, consistent with findings by Geteneh (2020) in central Gondar. This may be attributed to the perception that rice is less susceptible to storage insect pests compared to other crops grown in the area, such as grass peas, chickpeas, and maize, particularly when stored in low moisture and temperature conditions, and kept separate from kitchen areas. This reliance on chemical control and the lack of adoption of botanical methods highlight the need for promoting integrated pest management strategies that are both effective and environmentally sustainable.

The survey results indicate that in the Fogera district, the majority of farmers used chemical insecticides as both preventive and curative methods for controlling the storage of insect pests in their rice grains.

This finding aligns with the investigation conducted by Adane et al. (2021), who articulated that farmers in the Jawi district of northwestern Ethiopia predominantly used chemical control methods over other management practices. The widespread use of chemical insecticides for storage pest control is currently the most common approach employed by farmers. This is further supported by the findings of Nezif et al. (2020), whose survey results in the Jimma, West Shoa, and East Wollega zones of southwestern Ethiopia revealed that the majority of farmers used chemical insecticides. These insecticides are the most popular practice, where an average of 96% of the respondents used synthetic insecticides as the primary practice for managing storage insect pests.

Conclusion

This study confirms that storage pests and traditional storage methods contribute significantly to post-harvest rice losses in Fogera district. The rice weevil (*S. oryzae*) and the lesser grain borer (*R. dominica*) were identified as the predominant insect pests infesting rice grains stored in traditional storage structures. The traditional storage methods used by farmers in the study areas were not effective in protecting their stored grains from losses caused by storage pests. To address this challenge, it is crucial to promote the adoption of improved storage technologies, such as PICS bags and hermetic metal silos, which have proven effective in protecting stored grains from pest infestations and minimizing insecticide use. Currently, most farmers rely on chemical control, which poses risks to both the environment and human health. So promoting these alternative storage methods is essential. Furthermore, providing farmers with training on effective storage methods, pest management, and safe rice preparation is essential for long-term sustainability. Implementing these strategies will help to reduce post-harvest losses, improve grain quality, and enhance food security and farmer livelihoods in Fogera district.

Declarations

Ethical Approval Certificate

The procedures of this study were approved by the College of Agriculture and Environmental Sciences, Bahir Dar University, on 11 July 2022, approval date, and number: 03-1-3-4, and the research was also approved by the Knowledge Management and Intellectual Property Protection Directorate (KMIPPD) of the Ethiopian Institute of Agricultural Research.

Author Contribution Statement

Esuyawkal Demis: Conceptualization, methodology, conducted assessment, data curation, formal analysis, writing-original draft, editing, visualization, and validation.

Abaynew Jemal: Methodology, supervision, editing, visualization, and validation.

Tesfaye Melak: Methodology, supervision, editing, visualization, and validation.

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Conflict of Interest

The authors declare no conflict of interest.

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