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Assessment and Efficacy of Selected Locally Available Naturalproducts Against Rice Weevil (Sitophilus Oryzae L.) on Stored Sorghum Sorghum Bicolor L.) Under Laboratory Condition in Dejen Woreda, Eastgojjam, Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTEMENT OF PLANT SCIENCES

GRADUATE PROGRAM IN PLANT PROTECTION

ASSESSMENT AND EFFICACY OF SELECTED LOCALLY AVAILABLE NATURAL PRODUCTS AGAINST RICE WEEVIL (*Sitophilus oryzae* L.) ON STORED SORGHUM (*Sorghum bicolor* L.) UNDER LABORATORY CONDITION IN DEJEN *WOREDA*, EAST GOJJAM, ETHIOPIA

M.Sc. Thesis

By

Haimanot Mesfin Chanie

July, 2023

Bahir Dar, Ethiopia

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN PLANT PROTECTION

Name of Major Advisor

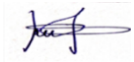
Abaynew Jemal (Ph.D.)

July, 2023

Bahir Dar, Ethiopia

AUTHOR STATEMENT

This is to certify that the thesis entitled "**Assessment and Efficacy of Selected Locally Available Natural Products Against Rice Weevil (***Sitophilus Oryzae* L**.) On Stored Sorghum (***Sorghum Bicolor* L**.) Under Laboratory Conditions In Dejen *Woreda,* East Gojjam, Ethiopia",** was submitted in partial fulfillment of the requirements for the award of the degree of **Master of Science** in the Department "**Plant Protection**" at **Bahir Dar University**, is a record of original work carried out by me, and has never been submitted to this or any other institution to get any other degree or certificate. The assistance and help I received during the course of this investigation have been duly acknowledged.

Haimanot Mesfin Chanie		16/6/2023
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DECLARATION

I hereby certify that I have supervised, read, and evaluated this thesis or dissertation, entitled **"Assessment and Efficacy of Selected Locally Available Natural Products Against Rice Weevil (***Sitophilus Oryzae* L**.) On Stored Sorghum** (*Sorghum Bicolor* L.) **Under Laboratory Conditions In Dejen *Woreda*, East Gojjam, Ethiopia",** by **Haimanot Mesfin Chanie,** prepared under my guidance. I recommend the thesis or dissertation be submitted for oral defense.

Abaynew Jemal, (Ph.D.)		16/6/2023
Advisor's name	Signature	Date

THESIS APPROVAL SHEET

As members of the Board Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Mrs. **Haimanot Mesfin** entitled **"Assessment and Efficacy of Selected Locally Available Natural Products Against Rice Weevil (***Sitophilus Oryzae* L**.) On Stored Sorghum** (*Sorghum Bicolor* L.) **Under Laboratory Conditions In Dejen *Woreda,* East Gojjam, and Ethiopia"** We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **Plant Protection**.

Board examiner

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DEDICATION

To my devoted mother, Tinebeb Belay, and families.

LIST OF ABBREVIATIONS AND ACRONYMS

COMESA	Common Market for Eastern and Southern Africa
CRD	Completely Randomized Design
CSA	Central Statistical Agency
EIAR	Ethiopia Institute of Agricultural Research
HPR	Host plant Resistance
IPM	Integrated Pest Management
PICS	Purdue Improved Crops Storage
SNNP	South Nation Nationality people

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By

Haimanot Mesfin Chanie
Advisor: Abaynew Jemal (Ph.D.)

ABSTRACT

Storage insect pests cause serious damage to sorghum crops. An assessment and experimental study were carried out in Dejen Woreda during the 2022 cropping season to evaluate botanical and locally available products as grain protectants against S. oryzae and to analyze the level of storage insect pest infestation. A total of 100 store farms were evaluated during the survey in the Dejen Woreda's four villages of Geligele, Kurar, Miniji, and Zemetin. This employed interviews, house visits, and the gathering of a representative sample of sorghum grains. According to the survey results, storage insect pests were prevalent in all storage structures. The rice weevil and maize weevil were the two most prevalent sorghum storage insect pests in the research area, with the Angoumois grain moth being the most common. Most of the farmers (41%) use pesticides to preserve their sorghum grains from storage pests and store them in traditional methods such as underground pits (48%), gota (25%), fertilizer bags (20%), and PICS bags (7%). The experiment includes locally available products such as Teff 20%, Ashe 10%, Malathion 5%, dust as a standard check, and an untreated control, as well as botanicals like seed and leaf powders of A. indica, C. macrostachys, P. dodecandra, A. sativum bulb, and Z. officinale rhizome at a rate of 5% w/w. After treatment applications, data on the number of dead weevils, progeny emergence, percent protection, weight loss, grain damage, and germinated seeds were collected and analyzed using SAS software. When compared to the control, all treatments significantly increased weevil mortality, decreased progeny emergencies, and reduced weight loss. Similar to Malathion dust 5%, A. indica seed powder, P. dodecandra leaf powder, and P. dodecandra seed powder all killed S. oryzae at 100%. P. dodecandra seed powder (1.67%), A. indica seed powder (1.93%), and P. dodecandra leaf powder (2.87) were found to have the least amount of grain damage. The study generally demonstrated that P. dodecandra seed, P. dodecandra leaf, and A. indica seed powders were the most effective botanicals, followed by A. sativum, indicating an appropriate alternative management technique for rice weevil.

Keywords: Botanical insecticides, Grain damage, Mortality, Storage pests, Storage structure**,**

1. INTRODUCTION

1.1 Background and Justification

Sorghum (*Sorghum bicolor* L.) Moench is a cane-like grass with a varied morphology that grows to a height of 6 meters (NRC, 2004). There are two root systems: primary and secondary. Its leaves are typically green, grassy, flat, and narrower than maize leaves. The plant's stem is solid, hydrated, succulent, and sweet. Sorghum inflorescence is a compact panicle. During threshing and/or harvesting, glumes partially cover the ripe seed (grain) of sorghum. (Arebu Hussen *et al*., 2021). Ethiopia is third in Africa in terms of sorghum production, after Sudan and Nigeria, with an amount of around 12% in yearly production (Wani *et al*., 2011). Sorghum accounts for one-third of Ethiopia's cereal diet. On average, 63.89 million tons are produced worldwide each year (USDA 2019). Sorghum is well adapted to arid and semi-arid climates where other cereal crops, like maize and wheat, fail to produce grain due to high temperatures and inadequate soil fertility (Blum, 2004). According to H. Gerbil Knife and Adane Tesfaye (2018), Ethiopia's average sorghum production is 2.1 tons per hectare.

In the East Gojjam administrative region's Dejen *Woredas* , sorghum is one of the most resilient field crops, and it has a potential production area with two agroecologies: lowland and Midland. This crop can only be cultivated once a year under rain-fed conditions, covering 6228 hectares. In terms of cereal crop yield, sorghum output in Dejen *Woreda* was second only to *teff* (Dejen Woreda Agricultural Development Office Annual Report, 2013 EC). It is also considered a crop with lower production costs, marginal areas, and a relative tolerance to moisture stress. However, both in the field and during storage, the crop faces a number of challenges.

A variety of pests can attack and harm sorghum grains, resulting in quality, quantity, nutrition, and viability losses (Abbas, 2014). One of the most serious issues with sorghum production is insect pest damage during storage. Many storage insect pests, including the rice weevil, *Sitophilus spp*., and *Sitotroga cerealella* (Olivier), are significant sorghum and other cereal crop pests in Ethiopia (Girma Demisse *et al*., 2008). The rice weevil is a grain-eating insect beetle that belongs to the *Coleoptera* order and the *Curculionidae* family. There are 60,000 identified species on the planet, 30 of which are pests of stored grain, thirty of which are *Sitophilus* species

and are extremely important (Siwale *et al*., 2007). *S. oryzae* is a small (4 mm) reddish brown beetle with round thorax and elytra punctures and four large, lighter spots on the elytra. Its wings have faint yellow or red markings (Emden, 2013).

Rice weevil is an important, polyphagous insect pest that seriously harms stored sorghum (Ladang *et al*., 2008). Weevils can be responsible for up to 75% of sorghum seed losses when stored in conventional storage structures, according to Dal Bello *et al*. (2001). The damage that weevils cause to the grains may cause them to breathe more heavily as a result of pests, which encourages the growth of heat and moisture and creates the ideal environment for the molds that make aflatoxin. After that, very high moisture levels are common for bacterial proliferation, which gradually causes a decrease and, in the end, total loss (Maribet *et al*., 2008).

Infestation of rice weevils can be reduced by management, whereas sorghum grain in storage requires careful handling. The most widely used strategy for eradicating the rice weevil has been synthetic insecticides (Mobolade and Francis, 2014). Chemical control techniques are the most common for eliminating these insect pests, according to Machingura (2014). Synthetic insecticides and fumigants have been employed extensively, but this has led to a number of major problems, including harm to the environment, the emergence of pesticide resistance, toxic residues in food, toxicity to consumers, and increased application costs (Bhargude *et al*., 2021).

As a result, it's vital to look for substitute organic sources that are simple to obtain, affordable, significantly less poisonous, and less damaging to the environment (Udo, 2005). Currently, attention and awareness are being given to the use of botanicals or plant materials with insecticidal properties as grain protectants (Longe, 2010). According to Aswalam *et al*. (2006), these plant components are simpler to obtain and less dangerous for the product's consumer. Botanical insecticides are compounds produced from plants that prevent the development of or eliminate the presence of pests (Hikal, 2017). The primary advantage of botanicals is their ease of production by farmers and small-scale businesses. They may also be less expensive (Nikkon, 2009). Furthermore, botanicals have no effect on non-target animals (Rajashekar, 2012). They do this by maintaining the biological diversity of natural enemies, which makes their use an eco-friendly alternative for pesticides in agriculture (Sola, 2014).

In Dejen *Woreda*, information on storage pest infestations, storage structures, and insect pest management techniques for sorghum grains is limited. Additionally, there is no research study about storage insect pests and botanical methods on grains of preserved sorghum. Assessment of storage structures, the status of pests, management practices, and the determination of the insecticidal effects of botanicals and locally available products on the ability of sorghum grain to resist the rice weevil, *Sitophilus oryzae*, were done in order to fill these gaps. Creating an effective, eco-friendly rice weevil management method can assist in protecting stored sorghum grains.

1.2. Statement of the Problem

For storage products, storage insect pests are a very important issue. According to Ladang (2008), the rice weevil is a significant and polyphagous pest that severely damages stored sorghum. It is the most important sorghum pest in Ethiopia, severely harming many subsistence farmers that grow sorghum. Sorghum weight is lost when stored as a result of both adult and larval *S. oryzae* feeding activities (Prasad *et al*., 2015). Sorghum losses by weevils were up to 75% (Dal Bello *et al*., 2001) when stored in traditional storage structures. Some empirical data on the prevalence of storage insect pests on sorghum is available in Dejen*Woreda*.

In the absence of control measures, the rice weevil, a prevalent storage insect pest that attacks stored sorghum grains in Dejen*Woreda*. However, the study area does not have quantified or record the amount of sorghum grain lost as a result of this weevil. Farmers employed botanical, cultural, physical, and chemical pesticide management techniques to lessen the harm this pest caused. From total 41%of farmers in this Dejen *Woreda* utilized chemical insecticides rather than other types of pest management. However, these insecticides are expensive for small-scale farmers and have toxic residues that harm the environment, human health, and other non-target species. They also lead to other associated issues. Therefore, it is essential to use locally accessible products and botanicals as an alternative means of rice weevil management because they are safe for the environment, beneficial for human health, and economically feasible. As a result, the following objectives for this study were established:

1.3. Objectives of the Study

1.3.1. General objective

- To assess the incidence and damage status of insect pests that affect stored sorghum and the efficiency of selected locally available Natural products on rice weevil under laboratory conditions in Dejen *Woreda*, Ethiopia.

1.3.2. Specific objectives

- To assess storage structures and management methods used by farmers in Dejen*Woreda*.
- To identify the major storage insect pests of sorghum and the damage and loss caused by the pests in the study area.
- To evaluate the efficacy of Selected locally available Natural products on sorghum grain against rice weevil under laboratory conditions.

2. LITERATURE REVIEW

2.1. Biology and origin of Sorghum

Sorghum is classified in the *Plantae* kingdom, division *Magnoliophyta*, class *Liliopsida*, order *Cyperales*, family *Poaceae*, tribe *Andropogoneae*, subtribe *Sorghinae*, and genus *Sorghum Moench* (Hariprasanna and Patil, 2015). Archaeological evidence suggests that it was domesticated in eastern Sudan around 3000 BC (Fuller and Stevens, 2018). Sorghum is native to Africa. However, the exact origin and location of domesticated sorghum are unknown (Venkateswaran *et al.*, 2019).

2.2. Sorghum Production in Ethiopia

In terms of overall production, sorghum is Ethiopia's second-largest crop after maize. With 1.8 million hectares of CSA in 2022, it stands third in terms of area covered by CSA after *teff* and maize, as well as production per hectare. The crop is typically cultivated under unfavorable circumstances, such as on marginal lands with little input (Akalu Teshome *et al*.,2007).

It is produced more than 2000 meters above sea level and is highly adapted to a wide variety of precipitation and temperature levels (Masresha Fetene, 2011). According to H. Gerbil Knife and Adane Tesfaye (2018), Ethiopia's average sorghum production is only 2.1 tons per hectare, which is much less than the global average of 3.2 tons per hectare. Due to problems with drought, Striga, insect pests, diseases, deteriorating soil fertility, poor adoption of currently available improved varieties, and a shortage of high-yielding and high-quality sorghum cultivars, (Wortman *et al*., 2006). Ethiopia's sorghum crop serves as the primary source of food for millions of disadvantaged and poor people who rely on it to survive (Reddy *et al*. 2004). It is planted all across the country at elevations between 400 and 2500 meters, with most of the cultivation taking place at lower altitudes along the western, south-western, northern, and eastern borders (Adugna Haile, 2007).

In the nation's east and northwest, 4.5 million smallholders cultivate sorghum. The majority of sorghum is produced in Oromia, Amhara, and Tigray, which contribute approximately 90.4% of the total output (FAO, 2021). The major sorghum-producing areas are East and West Hararghe in Oromia, North Gondar (Armacho) and North Shoa in Amhara, South Tigray (Alamata), and Derashe in SNNPR. 1302 kg/ha is Ethiopia's average national yield (CSA, 2021).

2.3. Importance of Sorghum in Ethiopia

Sorghum is a versatile grain that can be used to produce food, drinks, and biofuel. The stalks can also be used for building fences, animal feed, and fuel in some rural areas (Adugna Asfaw., 2007). It provides the majority of the world's food and is essential to food production (Mace *et al*., 2009). Sorghum grain is a staple crop in parts of Asia and Africa, where over 90% of it is eaten as food. Sorghum comprises one-third of the cereal diet in Ethiopia, according to (CSA 2015). About 10% of the nation's sorghum production is used to make domestic beverages, and 90% is used to directly make "*injera*," or bread and porridge. In the east and northwest of the nation, 4.5 million smallholders cultivate sorghum. It is a powerful source of energy with around 75% carbohydrates, zinc, iron, and vitamin B complex (Dayakar *et al*., 2014).

Africa is one of the many continents where sorghum is a common ingredient in traditional food. Sorghum grains are used to make a variety of foods, including *injera, dabo, ambasha, kocho, bula, ergo, siljo, tella, teji, areki, borde, cheka, shamita, korefe, keribo, bukire, kineto,* and *Merissa,* according to the (EIAR,2014). *Kitta, Kollo, Nifro,* and *Genfo,* (roasted) are also sorghum-produced foods consumed by all age groups Demissew Sertse and Tesfaye Disasa *et al*., 2014. Sorghum is well adapted to arid and semi-arid climates where other cereal crops, like maize and wheat, fail to produce grain due to high temperatures and inadequate soil fertility (Blum, 2004). However, biotic and abiotic limitations make it more difficult to produce. The parasitic weed known as Striga is one of the biotic variables that have a significant impact on sorghum (Rich and Ejeta, 2008). However, insect pests have had a negative impact on sorghum yields at the storage level.

Due to its exposed seed, sorghum is more susceptible to pest infestation in storage than other grain crops. Post-harvest insect pests, or storage insect pests, are insects that harm grains that have been stored. Weevils, moths, and beetles are the three most prevalent insect pests that harm sorghum while it is stored (Waktole Sori 2014). They often belong to two main groups of insects, such as the Coleoptera (beetles) and Lepidoptera (moths), which are two insect orders. The greatest order of insect pests, the Coleoptera, has the most significant stored product. Only the larvae of the Lepidoptera group, as well as both adults and larvae in Coleoptera are responsible for the harm (Khare, 1994).

2.4. Storage Insect Pests of sorghum

Due to its exposed seed, sorghum is more susceptible to pest infestation in storage than other grain crops. Post-harvest insect pests, or storage insect pests, are insects that harm grains that have been stored. Weevils, moths, and beetles are the three most prevalent insect pests that harm sorghum while it is stored (Waktole Sori 2012). They often belong to two main groups of insects, such as the Coleoptera (beetles) and Lepidoptera (moths), which are two insect orders. The greatest order of insect pests, the Coleoptera, has the most significant stored product (Ahmad *et al*., 2021). Only the larvae of the Lepidoptera group, as well as both adults and larvae in Coleoptera are responsible for the harm to stored grains (Prakash *et al*., 2014)

There are several stored product pests that harm stored sorghum, including *Sitophilus spp*., *Corcyra cephalonica*, *Sitotroga cerealella*, *Plodia interpunctella*, *Rhyzopertha Dominica*, and *Ephis* (Firmansyah and Tenrirawe *et al*., 2013). These insect pests, which are also a major concern in the post-harvest storage products of numerous grains, including sorghum, throughout the world, can have a severe impact on the weight, quality, commercial value, and seed viability of the grains (Anonymous, 2004).

Among a number of storage insect pests in Ethiopia, the rice weevil, *Sitophilus* species, and *Sitotroga cerealella* (Olivier) are significant pests of sorghum and other cereal crops Girma Demisse (2008) Despite the fact that the sorghum infestation by the rice weevil starts in the field, the damage the weevil causes to the grains occurs during storage (Girma Demissie *et al*., 2008; Tadele Tefera, 2012). The rice weevil (*Sitophilus oryzae* L.), maize weevil (*Sitophilus zeamais*), and granary weevil (*Sitophilus granarius* L.), three significant pest species from the genus *Sitophilus spp*., are the most devastating major pests of stored grain in the world, including Ethiopia (Abraham Tadesse, 2003).

2.5. Morphology and Biology of Rice Weevil

The rice weevil has four spots that can be either pale yellow or reddish on the corners of the elytra or on stiffened forewings, but these spots are not always present or noticeable (Mackled, 2017). The rice weevil also has a small (4 mm) snout. A third of the overall length, or 1 mm, is

made up by the snout. With a snout, the prothorax, also known as the elytra, is the same length as the head (Nargis, 2015). The prothorax is highly pitted, and the elytra have rows of pits arranged in longitudinal grooves. The larva has no legs and lives inside the hollow of the grain kernel. Its body is plump with a cream hue and has a black head capsule that resembles an elongated snout (Koehler, 2008). Depending on the size of the grain they eat, adult rice weevils develop from 2 to 3 mm long (Campbell, 2002). Larger weevils are a result of eating larger grains. The shape of the rostrum, which is shorter and wider in men than in females, allows males to be recognized from females in *S. oryzae*, despite the fact that the two sexes initially appear to be comparable (Chitra and Subramanian, 2016). Rice weevils and maize weevils have a similar appearance, but maize weevils are larger and darker.

A rice weevil has four stages in its life cycle: eggs, larvae, pupae, and adults. The full life cycle takes 28 days at 30 °C and 14% moisture content, although it takes much longer in colder climes. It has been discovered that an insect's life cycle is influenced by the temperature, humidity, and amount of moisture in the grain in its habitat (Singh, 2017). Adult females lay one egg three days after emerging from their pupa cocoons. They can lay up to 8–10 eggs each day and 300–400 eggs throughout their lifetime. The eggs hatch in around three days. The larvae molt after 3–4 days at a temperature of 25 °C and a relative humidity of 70%. For a median age of 18 days. When 1.5-mm-diameter holes on the grains are left irregularly by the growing larva, which dwells and eats inside the grain kernel (Rajat *et al*., 2020).



Figure 2.1: Life cycle of rice weevils, *Sitophilus oryzae* Linnaeus (Longstaff, 1991).

2.6. Ecology and Distribution of the Rice Weevil

The rice weevil is one of the world's most dangerous stored grain pests. This stored grain pest started in India and spread to Europe and other regions of the world via the grain trade, resulting in global dissemination (Arthur, 2002).The rice weevil is most common in warm, humid weather Correa (2016). This pest is almost universal and can be found in practically every section of the earth. It was discovered in Europe, Australia, Asia, Fiji, and New Zealand (Zunjare, 2014). The high moisture content of grains, high relative humidity, and high environmental temperature during storage provide an ideal environment for the reproduction of insect pests (Dars *et al*., 2001). Corn, wheat, barley, oats, sorghum, buckwheat, dry beans, cashew nuts, wild bird seed, and cereal products, particularly macaroni, are among the targeted products (Nargis, 2015). Rice weevils also attack sorghum significantly as a secondary host (Adedire, 2001).

2.7. Economic Importance of Rice Weevil

Storage insect pests cause significant economic losses in storage circumstances (Jean *et al*., 2015). They can badly damage grain and other stored items, as well as cause direct and indirect grain losses in storage. Storage insects were estimated to be responsible for up to 63.85% of weight losses in sorghum grains after three to six months of storage ,however reduction, varies from location to location, ranging from 35.33 to 91.67% (Waktole Sori, 2014). Postharvest losses from storage insect pests in sorghum have been found to range from 8.30% to 29.33%, with weight losses of up to 25% and 40% for *S. zeamais* and *S. oryzae*, respectively Muluken Goftishu, Ketema Belete (2014).

The rice weevil is a major pest of stored sorghum throughout the tropics and subtropics, including Ethiopia (Gwinner, 1998). It is a costly storage pest that causes extensive product damage (Ngamo, 2001; Ladang, 2004). Sorghum grain losses are entirely caused by infection, with annual grain losses from rice weevils ranging from 25 to 40% after six months of storage (Posamentier *et al.,* 1998). Even though *S. oryzae* infestations frequently start in the field, storage systems sustain significant damage. (Girma Demissie, 2008). The adults and larvae of the rice weevil are both internal feeders that significantly reduce grain yields and cause crop

destruction (Parket, 2003). Stored-product Insect pests can cause direct damage to grains by feeding on them, or they can cause indirect damage by causing the grain to decay and become contagious through excretions, exuviae, or secondary infection. Grain weight, nutritional value, germination, and market value are all reduced as a result of insect pests' direct feeding. In contrast, the presence of insects promotes deterioration and contamination, lowering grain production and market value due to insect parts, molds, odors, and heat damage (Tyagi *et al*., 2019). Damaged grain is less nutritious, less likely to germinate, lighter, and less expensive to sell (Tadele Tefera, 2012).

2.8. Management practices of rice weevil

To prevent sorghum grain from being destroyed or infested by insect pests, a variety of management measures are used **(**Mekasha, 2004). There are several selection and application options for the control of stored pests depending on the type of facility, the pest species, the type of grain maintaining the infestation, and the legal and practical control techniques available at the time (Savidan, 2002).

2.8.1. Cultural practice

The most cost-effective and extensively used pest management strategy is typically this one (Girma Demissie, 2006). The basic principle of cultural control of insect pests is the intentional alteration of the environment to make it less favorable, which exerts economic control over the pests or, at the very least, lowers their rates of spread and damage (Araya G. Silassie, 2007).

Sanitation, or store hygiene, another cultural practice, is the most essential preventive measure for managing insect pests in stored grain (Harberd, 2004).. It is a low-cost and effective method of reducing the effects of storage insects. Cleanliness around local stores, silos, cribs, and other sites must be maintained to the greatest extent possible (Abraham Tadesse, 2003). Adopting proper sanitation is a simple, inexpensive, and effective strategy to control the rice weevil (Emana Getu, 2002). By ensuring that storage containers are clean before adding additional commodities, the demand for synthetic pesticides is greatly reduced. Proper sanitation includes removing grains from the previous year's harvest, removing any contaminated objects from the

storeroom, and cleaning and sterilizing the storage unit's floors, fissures, and fractures (Jacobs and Calvin, *et al*., 2001).

2.8.2. Physical practice

Physical control approaches can be rapid, simple, and secure methods of managing insect pests in grain storage facilities. Physical control strategies have been promoted as effective pesticide replacements for grain handling and storage pest prevention and management (Jayaprakash *et al*., 2010). Physical techniques are important instruments for preventing, detecting, and managing pests in stored objects within the scope of integrated pest management (IPM) and integrated stored product protection. Chemically inert substances such as ashes, powders, sand, and other abrasive materials are used in physical control to remove or make conditions unfavorable for the pest to survive. These inert compounds are typically provided in large quantities to occupy available space in grain bulks and limit insect mobility (Haile Tesfaye, 2020). Because of its low mammalian toxicity, the use of inert dust is effective (Vincent *et al*., 2003). In large quantities, inert dust such as ashes, sand, and other mineral powders and small-sized grains act as a barrier to insect movement by filling up free space in grain bulks (Girma Demissie, 2006).

Certain inert materials are harmful to storage insect pests, resulting in their deaths. By virtue of its toxic physical qualities, wood ash as inert dust causes insect mortality; it reduces the insect cuticle and causes oxygen deprivation in insects (Jean *et al*., 2015). According to research at Bako Agricultural Research Centre (BARC), mild roasting or warming of maize on a heated clay pan and exposure to sunlight produced results comparable to the conventional insecticide pirimiphos-methyl at 10 ppm in protecting maize grain from maize weevil (Demissew Kitaw *et al*., 2002).

2.8.3. Use of Resistance Varieties

Host plant resistance is a plant defense mechanism that prevents stored insect pests from consuming it Tadele Tefera *et al*. (2016) Define host plant resistance as the ability of plant species to avoid, tolerate, or recover from injury by insect populations, lowering their successful use for insect feeding or reproduction. It is usually a link between plant resistance and

morphological traits such as long, tight husks that limit weevil attack (Smith, 2018).The use of varietal resistance is one of the most well-known parts of integrated pest control, particularly for farmers who do not have the financial means to purchase standard insecticides (Emana Getu, 2018). Another strategy for preventing crop losses caused by storage pests is to adopt resistant cultivars. According to Prasad *et al*. (2015) and Kudachi and Balikai (2014), sorghum shows resistance to *S. oryzae*. Insect feeding inhibitors, pericarp surface texture, enzyme inhibitors, grain hardness, grain temperature, and moisture content are all factors that make stored sorghum insect-resistant (Fikremariam Abebe *et al*., 2009; Muluken Goftishu, and Ketema Belete, 2014). According to Bamaiyi *et al*. (2007), grain hardness is the key resistance factor for S. oryzae in stored sorghum. Sorghum cultivars, particularly regional landraces, exhibit resistance to Sitophilus species (Chuck-Hernández *et al*., 2013). Seed damage was significantly decreased in 2219A/B, 116B, IS9487, CSV8R (M), and a local yellow sorghum variety (Anonymous, 2014).

2.8.4. Biological practice

A biological control method is one that uses biological agents to lessen or eliminate pest harm, such as predators, parasites, and insect diseases, pheromones for pest monitoring, and mating disruption Abraham Tadesse (2003). Biological management strategies may be an effective tactic. For beneficial insects that exist naturally or can be distributed by farmers when necessary (Poulsen, 2000), in the biological management strategy, the parasitoid, predator, or disease affects the pest's reproductive process, behavior, feeding, and other biotic aspects (Audu, 2005). Furthermore, because this method is non-toxic and does not impact human health or the environment, it is a safe alternative to fumigation and traditional chemical pesticides (Flinn *et al*., 2006).

2.8.5. Botanical application

Because synthetic insecticides are toxic, researchers are looking for less dangerous and more environmentally friendly alternatives, such as using botanicals to manage insect pests. (Chowański *et al*., 2014). The practice of storing various household items in natural sources against pests dates back to the oldest eras of known history (Suleiman and Rugumamu *et al*., 2017). To prevent the storage of insect pests, botanical products can be taken from specific plant

parts such as seeds, leaves, and bark. People have utilized botanicals to protect various home items from pests since the dawn of recorded history (Karthikeyan, 2009).

The use of botanical pesticides to protect stored products is because they have the ability to adjust environmental conditions, which is less cost-effective for large amounts of grain storage. The majority of them are nontoxic to consumers and easily accessible (Asawalan and Hassanali *et al*., 2006). Because of their efficacy against rice weevils, plant materials that are safe for human food and can retain their insecticidal potency over time should be recommended (Suleiman *et al*., 2018). Several compounds with insecticidal characteristics have been extracted and found in plant parts such as leaves and seeds, making them potential insecticides. These active chemicals in the plant extract operate as storage insect pest repellents, antifeedant, and feeding deterrents (Eziah *et al*., 2013). Many studies have been conducted to investigate the insecticidal effect of plant products against the rice weevil (Jayakumar *et al*., 2017; Idouaarame *et al*., 2018). Some botanical pesticides have been examined against rice weevil and show promise for development as natural insecticides for attacking this weevil (Kardinan' *et al*., 2021).

Adane Tesfaye (2021) tested six botanical plant powders and their extraction for sorghum defense against *S. oryzae*, the results showed that the treated seed performed significantly better than the untreated seed, after 28 days of exposure, the biological activity of neem seed powder and garlic bulb powder against *S. oryzae* was considerably higher, in comparison to the control, neem leaf powder, Mexican tea, orange peel, and ginger all performed better. Asmare Dejene (2002) investigated the effectiveness of 20 botanical species in controlling maize weevil on sorghum in a laboratory test within 28 days of infestation, Sirinka, Chenopodium, *Jatroha curcas*, and *Phytoloca dodecandra* all resulted in 100% insect mortality. A mixture of Malathion dust and Mexican tea powder, similar to current insecticides, efficiently controlled weevils for up to five months (Ahmed Ibrahim, 2015). Many of these plants may have insecticidal properties if appropriately tested against storage insect pests. In general, because botanical insecticides are less expensive than synthetic insecticides, farmers and small-scale businesses can easily produce and apply them (Fikremariam Abebe, 2005).

A. Neem (*Azadirachta indica* A. *Juss*)

The neem tree (*Azadirachta indica* L.) belongs to the Meliaceae (*mahogany*) family and is a tropical evergreen plant with high adaptability and pest resistance (Oparaeke, 2006). Neem, the world's most investigated tree, is well known for its insecticidal properties and is highly effective against a wide range of insect pests (Radha, 2014). Neem's well-known insecticidal properties make it an effective deterrent to a wide range of insect pests. Most of the effective insecticidal chemicals are found in the seeds, leaves, and other parts of the neem tree (Sonalkar, 2014). It is effective against a wide range of pests, and the compound is also effective against insects such as mealy bugs, caterpillars, aphids, and pests of stored products (Morgan, 2009). It has been employed as a home remedy, cosmetic, and health aid for thousands of years (Sharma, 2007). Neem seed powder completely protected the maize weevil from causing seed weight losses, progeny emergence, percentage seed damage, or progeny survival (Danga *et al*., 2015). It has a wide range of activities, including acting as a growth regulator in insects, a repellent, a feeding deterrent, an inhibitor of oviposition, and a sterilizer (Isman, 2006).

B.Garlic (*Allium sativum*)

Garlic (*Allium sativum* L.) belongs to the *Alliaceae* family (Allen, 2009). It is the world's most important vegetable crop, ranking second only to onions (Voigt, 2004). That can effectively control pests and makes an excellent, economical, non-toxic biological pesticide for use in agriculture (Patterson, 2014). Its strong aroma can mask normal host-finding or feeding cues in insects and provides an olfactory camouflage against insects like aphids, ants, termites, white flies, beetles, borers, caterpillars, slugs, and army worms (Kaluwa and Kruger, 2012). According to Kilgori *et al*. (2007) and Samavatean *et al*. (2011), reported garlic has therapeutic potential that has been well established in the prevention and treatment of hypertension, worms, bacterial and fungal diseases, diabetes, cancer, ulcers, rheumatism, and other ailments. Garlic is widely regarded and valued for its many therapeutic properties (Rabinowitch and Currah *et al*., 2002). Additionally, garlic extract has insecticidal effects and exhibits significant toxicity to a variety of pest species at all life stages (Mousa *et al*., 2013).

C. Ginger *(Zingiber officinale Roscoe*)

Ginger (*Zingiber officinale*), a member of the *Zingiberaceae* family, is a well-known spice used either fresh or dried in the daily diet in many countries (Denim and Yingying 2010). Ginger is native to Southeast Asia but is now cultivated in all the tropical and subtropical regions of the world (Priebe, 2011).Mostly, ginger is grown on a large scale in India, China, Southeast Asia, the West Indies, Africa, and Australia. Ginger has a long history of use in ethno medicine and, as such, has been featured as a constant spice in cuisines. Ginger contains extensive photochemistry and has potential health benefits (Butt and Sultan, 2011). Different scientists have reported the antifungal, antimicrobial, and insecticidal properties of ginger (Ukeh, 2008). It is effective against a number of stored insect pests. Ginger is helpful for reducing inflammation that causes migraines and other neurological diseases, as well as the nausea and pain that come with rheumatoid arthritis, gout, and muscular spasms (Nicoll and Henein, 2009). When used to treat mosquito larvae and *Diphtheria spp*., *Zingiber officinale* showed high insecticidal efficiency (Okonkwo and Ohaeri 2013).

D. Endod *(Phytolacca dodecandra*)

Phytolacca dodecandra L (*Phytolaccaceae*), called '*endod*' in Ethiopia, is a robust perennial climber or scrambling shrub has upright, racemic, dioecious flower stalks, pinkish or red berries, and stems that are 5 to 10 meters long (Polhill,2000). Endod is a plant that yields tiny berries that, when dried, powdered, and mixed with water to make a foamy detergent solution, are traditionally used in Ethiopia to wash clothing, it is also used as soap, shampoo, and as a toxin to stun fish (Araya G. Silassie, 2007). The use of endophytic leaves and seeds has been used to control insect pest storage. Asmare Dejene (2002) claims that adding powdered Endod berries to maize and sorghum grain caused significant adult mortality, decreased offspring emergence, and decreased grain damage against the maize weevil.

E. Bisana (*Croton macrostachyus Hochst*)

Croton macrostachyus is a deciduous tree that belongs to the family of *Euphorbiaceae* and has broad-leaved, round crown with a slender trunk and immense spreading branches Getachew Alemayehu, 2018

In Ethiopia, this plant has different medicinal uses, including kidney problems, wound managem ent, malaria, intestinal parasites, and heart failure (Orwa *et al*., 2009). The bark, fruits, and an in vitro study of the fruit extract indicated that the plant had good antiplasmodial activity (Sorsa, 20 07). Moreover, the methanol leaf extract of *Croton macrostachyus* exhibited larvicidal activity a gainst late third instar larvae of *Anopheles arabiensis* Patton, a potent malaria vector in Ethiopia (Karunamoorthi *et al*., 2010).

2.8.6. Insecticide application

Synthetic insecticides are used to help protect grains from damage caused by insects (Rajashekar, 2012). A wide range of synthetic insecticides is available for use in the world. The Two major chemical methods used for managing or suppress insect pests of stored grains are Fumigation and grain protection by contact insecticides Kostyukovsky (2016). Fumigants such as phosphine, cyanogens, ethyl formate, and sulfuryl fluoride, which quickly destroy all life stages of stored product insects in storage facilities, are one of the most efficient strategies to stop stored product losses from insect pests (Donahaye, 2000). Contact insecticide is sprayed directly on the grains and kills the insects when they contact the treated surface (Nyzam *et al*., 2017).

Ethiopian farmers use chemical insecticides to protect their produce (Mendesil *et al*., 2007). According to a survey conducted in south-west Ethiopia, farmers used Actelion 2%, DDT 5%, and Malathion 5% to manage storage insect pests. Furthermore, farmers who live near towns are more inclined to use chemical insecticides. However, the vast majority of farmers never applied. Pesticides and their residues have caused an increase in the number of problems. Synthetic insecticides are hazardous to both the environment and people. They not only cause health problems for non-target organisms, but they also cause soil erosion, water pollution, insect resistance and resurgence, the extinction of native plants and animals, harm to agricultural goods, and other problems, despite these disadvantages, they will continue to be critical for agricultural advancement, particularly in poor countries (Fikremariam Abebe, 2005).

2.8.7. Integrated pest management (IPM)

The IPM concept emphasizes the integration of disciplines and control methods like pesticides, insecticidal plants, natural enemies, cultural methods, and varietal resistance into a total management system to prevent pests from reaching harmful levels and to keep the pest population below levels that would result in economic harm (Capinera *et al*., 2008). Integrated pest management is currently a successful and acknowledged strategy (Rajashekar *et al.*, 2010). The IPM approach stresses the prudent use of non-chemical techniques, including botanicals, host plant resistance, and selective synthetic treatments, making it a particularly effective means to prevent the development of resistance (Obeng-Ofori, 2010). Synthetic pesticides should not be used regularly or in conjunction with botanicals when utilizing IPM to control insect pests. Broad-spectrum insecticidal plant extracts can be easily produced on farms using locally available resources (Azad *et al*., 2013). Amruta *et al*. (2015) discovered increased seed quality and effective storage pest control when botanicals and emamectin benzoate were used. Other research has found that the neem ingredient Azadirachtin, a component of integrated management, kills rice weevils completely (Athanassiou *et al*., 2005). IPM promotes a holistic pest management approach that strives to maximize the use of a variety of pest management approaches in a specific cropping system. Girma Demissie, Tadele Tefera, and Tadesse Almu, *et al*. (2008) reported on the integrated usage of Chenopodium plant powder, botanical triplex, SilicoSec, and filter cake against maize weevil in Ethiopia .The goal of integrated pest control was to reduce the use of insecticides by using economic thresholds as well as alternate control mechanisms such as biological ones (Dent, 2000).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The research was carried out in the Amhara National Regional State's in Dejen*Woreda*, Ethiopia. Dejen*Woreda* is the administrative center, located 335 kilometers from Bahir Dar, the administra tive capital of the Amhara National Regional State. Also, it is 230 kilometers north of Addis Ababa**.** It is located at latitudes 10°7 to 10°11' north and longitudes 38°6' to 38°10' east, with an altitude range of 1071 to 300 m a.s.l. It receives bimodal rainfall with short and lengthy periods of rain, with an average annual rainfall of 1200 mm.

The long rains (Meher) come between June and September, whereas the short rains (Belg) fall between April and May. For cities in the study district, agriculture is the main activity. Mixed farming, which combines the production of both agriculture and livestock, is practiced in the region. Kassa Chanie *et al.* (2023), the majority of agriculture are now focused on annual crops like *tef*, wheat, sorghum, beans, and peas. Chickpeas and vetch, as well as short-rain crops like chickpeas and vetch. Three climatic regions comprise the district: 41% highland, 31% midland, and 28% lowland. Sorghum is the main crop produced in the district's lowland and midland zones (DDARDO, 2013).

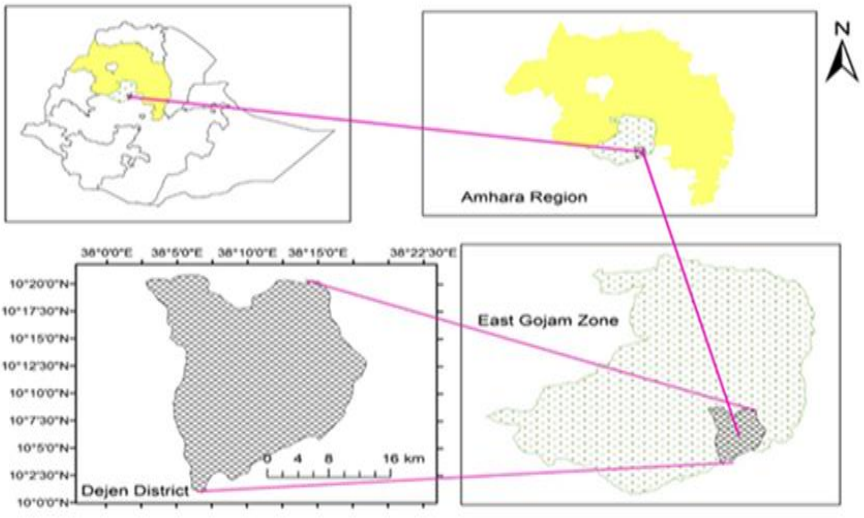

Figure 3.1. Map Description of the Study Area

3.2. Sorghum Storage Insect Pest Assessment in Dejen Woreda

3.2.1. Sampling size and sampling techniques

The survey was conducted in major sorghum-growing *kebele* administrations of the Dejen *Woreda*. Which have, 26 rural *kebele* administrations, 13 of them grow sorghum (DDARDO, 2013). *Geligele, Kurar, Miniji*, and *Zemetin* are the four *kebele* in total to select for assessment. A total of 100 store farms from the selected *Keble* administrations were assessed (Table 3.1). The evaluation sites were selected in particular for their high potential for sorghum production. Each *Keble's* growers were picked using Simple random sampling methods. Key informants were personally questioned while visiting each home to collect the necessary data using the established checklists. The types of storage structures, storage infestations, and storage insect pest management practices were all investigated using open-ended questionnaires. A composite sample 300-gram of sorghum grain (from the top, middle, and bottom) from each store was combined. Each sample was put in a plastic container and labeled with the relevant data (site name, sample number, and date of sampling), after which it was examined in a lab to find out whether storage insect pests were present and other important details regarding weight loss, grain damage, and germination. By comparing the features of the collected insect pests, a compound microscope was utilized to determine the species.

The sample size for a quantitative study can be determined using a number of different techniques. These comprise employing algorithms to determine the sample size, obtaining publicly available tables, and other methods. The sample size needed for this investigation was calculated using Yamane's (1967) sampling formula with a 10% degree of precision. The range of accuracy in determining the true value of the parameter is represented by the degree of precision, which can alternatively be expressed as a percentage (AlSubaihi, 2003).

Table 3.1: Sample respondents selected from each "*kebele*" administration in Dejen District

"Kebele"	Number of households	Sample households

Geligele	7898	30
Kurar	6717	25
Miniji	7185	27
Zemetin	4840	18
Total sample households	26640	100

A total of 26640 households were found in the four *kebeles*. To estimate the sample size Yemane formula was adopted (Yamane, 1967).

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

Where, n = is the total number of sample sizes needed,

N = is the total number of households (26640) in the study area and

e is the level of precision considered (10%) for the study.

n = 26640/ (1+26640(10%) ^{2}) = 100

Thus, out of 26640 households in the study area, 100 respondents were selected**.**

3.2.2. Data collection

Data on the types of sorghum varieties produced, storage structures, storage insect pest management practices, and storage pests infested in various types of storage structures were collected. Parameters such as weight loss percentage, grain damage percentage, germination percentage, percentage of store infestation, and relative abundance of insect pests were collected.

Relative abundance of insect pests: This parameter was performed after insect pests were recognized and counted from grain samples collected from grain stores. Relative abundance is computed using the following formula (Rahaman *et al*., 2014).

$$\text{Relative abundance (\%)} = \frac{\boldsymbol{Number\ of\ individual\ insect\ speces\ in\ the\ sample}}{\boldsymbol{total\ insect\ species\ in\ the\ sample}} X\ 100$$

Percentage of weight loss: A sampled grain collected from different storage structures was separated into damaged and undamaged grains to determine the percentage of weight loss and the number of damaged and undamaged grains was counted and weighted. The percentage of weight loss was determined using the count and weight method of Gwinner *et al*. (1996) as indicated:-

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

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

Percentage of grain damage: From the collated samples, a representative sample of sorghum grains was randomly selected, and the number of damaged grains was manually counted. Then, the proportion of damaged grain was determined (Wambugu *et al*., 2009).

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

Percentage of germination: One hundred randomly selected seeds from the collocated samples were used in a germination test. To remove fungal contamination, the seeds were treated with a 1% sodium hypochlorite solution for one minute and washed with distilled water for another one minute (Adane Tesfaye *et al*., 2021), then placed on moist filter paper in a germination box and kept at room temperature. Raun *et al*., (2002) formula was used to calculate the germination percentage.

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

Percentage of store infestation; the percentage of store infestation was assessed using the formula developed by Utono (2013) as

$$\text{Infestation percent} = \frac{Number\ of\ stores\ infested\ by\ specific\ insects}{Total\ number\ of\ visited\ stores} X\ 100$$

3.3. Evaluation of Treatments against Rice Weevil under Storage Conditions

3.3.1. Establishment of rice weevil culture

The experiment was conducted at the Dejen agricultural quarantine center under laboratory conditions. In order to provide rice weevils for the experiment that were the same age, a culture of rice weevils was established. Adult rice weevils were gathered from naturally contaminated sorghum grains at the farmer's home. The Disinfected sorghum grains were used to raise the rice weevils. About one kilogram of sorghum grains was placed in four plastic jars along with 200 adult rice weevils that were not sexed. The tops of the plastic jars were covered with nylon cloth to enable ventilation and tightly fastened with a rubber band to stop weevils from escaping and other insects from causing trouble within the jars. The adult rice weevil was removed and left in the sorghum after fifteen days of oviposition periods until a new adult emerged. The experiment was conducted using newly emerged adult rice weevils that were 42 days old under laboratory conditions; this culture was kept alive according to Hendrival and Meutia (2016).

3.3.2. Experimental design

The treatments include eight botanicals: *Azadirachta indica* seed, *Azadirachta indica* leaf, *Allium sativum bulb, Croton macrostachyus Hochst* leaf, *Croton macrostachyus Hochst* seed, *Phytolacca dodecandra* seed, *Phytolacca dodecandra* leaf, *Zingiber officinale Roscoe* powder, and two locally available products: wood ashe and *Teff* with Malathion Dust 5% standard check and untreated control. The design of the experiment was completely random (CRD) and replicated three times.

3.3.3. Preparation of botanicals

Botanicals like neem were obtained from Jawi District and the rest of the others gathered around the experimental site, while garlic and ginger were purchased in Dejen local market. The leaves and seeds of botanical plants were collected and dried in the air under shade. The leaves and seeds of neem, *endod, bisana*, garlic bulb, and ginger rhizome were milled finely by using a mortar and pestle and then sieved through a mesh to obtain fine and uniform dust. The powders

were preserved in sealed polythene bags and stored at room temperature until their use for insect bioassays to prevent quality loss (Chayengia *et al*., 2010; Devi *et al*., 2014). Ashe and *Teff* products with Malathion 5% dust and untreated (control) products were also included for comparison in the experiment Table 3.2.

Table 3.2: Lists of treatments used for the management of rice weevil

No	Scientific Name	Local Common Name	Common Name	Parts Used	Rate % (w/w	Reference
1	*Azadirachta indica*	Mimi zaf	Neem	seed powder	5%	Yeshiwork Alemnew, 2017
2	*Azadirachta indica*	Mimi zaf	Neem	leaf powder	5%	Yeshiwork Alemnew ,2017
3	*Allium sativum*	Niche Shenkurt	Garlic	Bulb powder	5%	Liiban Abdi, 2011
4	*Zingiber officinale Roscoe*	Zengebele	Ginger	Rizme powder	5%	Liiban Abdi, 2011
5	*Phytolacca dodecandra*	Endod	Endod	seed powder	5%	Kalkidan Degefa,2019
6	*Phytolacca dodecandra*	Endod	Endod	Leaf powder	5%	Kalkidan Degefa,2019
7	*Crotonmacrostachyus Hochst*	Bisana	Bisana	seed powder	5%	Daniel Getahun & Mulatwa Wondimu, 2020
8	*Crotonmacrostachyus Hochst*	Bisana	Bisana	Leaf powder	5%	Daniel Getahun & Mulatwa Wondimu, 2020
9	*Eragrostis teff*	Teff	Teff	Seed	20%	Ahmed Ibrahim ,2015
10	Ash	Amed	Ash	Dust	10%	Wolfson JL,1991
11	Malathion 5% Dust	Yetebay merz	Insecticide	Dust	5%	Ahmed Ibrahim,2015

12	Untreated check	-	-	-	0

3.3.4. Application of treatments for the control of rice weevil

In the experiment, "*Mako*," a local variety of sorghum, was used. The disinfected, newly growing sorghum grains, local varieties "*Mako*," were brought from farmers in Dejen local market Farmers in Dejen *Woreda* are currently cultivating and widely utilizing these local sorghum varieties. Healthy grains were used to avoid any pre-storage infestations. Sorghum grains were kept in the refrigerator to disinfect the grain if there was any apparent or hidden infestation. The grain moisture content of each variety was measured, and the grains were conditioned to comparable moisture content before they were exposed to the test insects. Botanical plant powders were added to the sorghum grains at a rate of 5% w/w, along with locally available products such as *teff* seed (20% w/w), wood ash dust (10% w/w), and malathion (5%) w/w. In the experiment, 200g of sorghum grains were utilized and maintained in a medium-sized (1 liter capacity) plastic jar. For each jar or experimental unit, 10g of botanical powders, 20 g of ash dust, and 40 g of *teff* seed were added to the experiment and mixed thoroughly to ensure equal distribution. After that, twenty randomly selected unsexed F1 progeny of rice weevil were used and introduced into each jar. All the experiments were carried out under laboratory conditions.

3.3.5. Data collection

Adult mortality: The treated grains in the jar were preserved for about seventy days, and mortality rate evaluations were made on regularly three, seven, fourteen, twenty-one, and twenty-eight days after treatment application. The assessment dates were selected from the earlier reports by Girma Demisie *et al.* (2008). Dead adult weevils were counted and discarded on each assessment day, while live weevils were restored to their respective treatments. The remaining weevils, both dead and alive, were counted and discarded on the seventieth day. To prevent future infestations, all dead and alive weevils were removed from the area by excavating a hole. The percent data for adult weevils were corrected as follows using the Abbott (1925) formula:

Percentage of corrected mortality = 1- $(\frac{n\ inT\ after\ tertment}{n\ in\ control\ \ after\ tertment})X\ 100$

Where n= number of adults, T= treated, and Co= control.

Adult emergence: After the removal of both dead and alive weevils, the grains were kept under the same experimental settings for an additional 42 days to allow for the F1 progeny emergency. At 42 days, the number of living and dead insects emerging from each replication of the treatment was counted and recorded, and the quantity of F1 progeny was used. The assessment dates were chosen in accordance with Swamynarayana *et al*. (2014), who found that the whole length of the rice weevil's life cycle, from egg to adult, ranges between 34 and 49 days, with a mean of 42 days.

Efficacy of treatments: The efficacy of different treatments in protecting the seed against the progeny of F1 was calculated. El-Ghar and El-Sheikh's (1987) formula was used to compute the percentage reduction in adult emergence or inhibition rate (% IR) as follows:

$$\% \text{ protection} = \frac{TF1PC - TF1PT}{TF1PC} x\ 100$$

Where, TF1PC = Total F1 progeny in control and

TF1PT = Total F1 progeny in treatment.

Weight loss (%): Weight loss tests were performed on both treated and untreated grains. To calculate the percentage weight loss, grain samples were obtained at random from each jar. The number of damaged (grains with characteristic holes) and undamaged grains was counted and weighted, and the percentage weight loss was calculated using the method provided by Gwinner *et al*. (1996):

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

Where, Wu = Weight of the undamaged grain,

Nu = Number of undamaged grain,

Wd = Weight of the damaged grain and

Nd = Number of damaged grains.

Grain Damage (%): Each trial evaluated sorghum grain damage. Calculating the percentage of damaged (holed and infested) grain yielded the percentage of grain damaged by rice weevils. Taking a random sample of 100 grains from each jar, counting the number of grains with rice weevil boreholes, and translating it to a percentage as follows (Fekadu Lemessa *et al*., 2000; Wambugu *et al*., 2009):

Grain damage (%) = $\frac{Number\ of\ insect\ damaged\ grain}{Total\ number\ of\ grains} x\ 100$

Germination percentage: At the end of the experiment, a germination test was performed to determine the viability of each botanical grain treated and to compare the treatments. To conduct the germination test in each jar, 100 randomly selected seeds were placed in the germination box on moist filter paper and kept at room temperature. The germination % was estimated as follows using the Raun *et al*. (2002) formula, as stated in Rahman *et al*. (2019):

Percentage of germination = $\frac{Number\ of\ seed\ \ germenated}{total\ number\ of seeds} x\ 100$

3.4. Data Analysis

The assessment data was summarized using MS Excel, and descriptive statistical analysis using percentages was performed. SAS software was used to perform an analysis of variance (ANOVA) on the experiment data. To standardize the variances, the data were changed using the square root transformation method for percentage data. An ANOVA was used to examine the effects of the treatments on the obtained data, and the mean values were separated using Tukey's Studentized Range (HSD) test at a 5% level of significance.

4. RESULTS AND DISCUSSION

4.1. Assessment of Storage Structures, Storage Insect Pests, and their Management Methods on Sorghum

4.1.1. Sorghum varieties produced in the study area

Dejen is one of the *woredas* in East Gojjam with enormous sorghum production potential; unfortunately, farmers in the Dejene *woredas* did not have access to improved sorghum varieties. There are also several local sorghum varieties grown in Dejen *Woreda* (Table 4.1). According to the assessment, due to its high yield and ability to adapt to unfavorable climatic conditions, the "*Mako*" sorghum variety was widely dispersed in almost all of the assessed areas, accounting for 65%, the *Jemele* sorghum variety for 16%, the *Achiro* sorghum variety for 11%, and the *Temego* sorghum variety for 8% .Due to a lack of research extension-farmer linkage, enhanced sorghum varieties have not been well adapted in Ethiopia, and farmers in many areas are unaware of the improved varieties(Adugna Asfaw, 2007).

Table 4.1: Sorghum varieties cultivated at Dejen Woreda during 2013

Sorghum varieties	*Kebeles*				Total %
	Geligele	Kurar	Miniji	Zemetin	
Achiro	12	13	14	6	11%
Jemele	17.5	16.8	18.7	11	16%
Mako	71	75.9	78	35.1	65%
Temego	6	6.7	8	11.3	8%

4.1.2. Storage structures used by farmers in Dejen Woreda

Farmers stored their sorghum grains in a variety of structures, according to the areas examined. Among the different storage structures underground pits account for 48% of all storage structures. A pit is a hole dug in the ground floor, heavy clay soil, or rocks that constricts outside the house, and "*Gota*" (25%) is the most prevalent grain storage material, followed by fertilizer

bags (20%), also common grain storage materials, and PICS bags (7%), which have improved storage materials (Figure 4.1).However, only a few of farmers in Dejen *Woreda* used PICS bags to store their sorghum grains, showing that most farmers in the assessed areas did not use improved storage materials. In the study area, underground pits were largely used for sorghum storage.

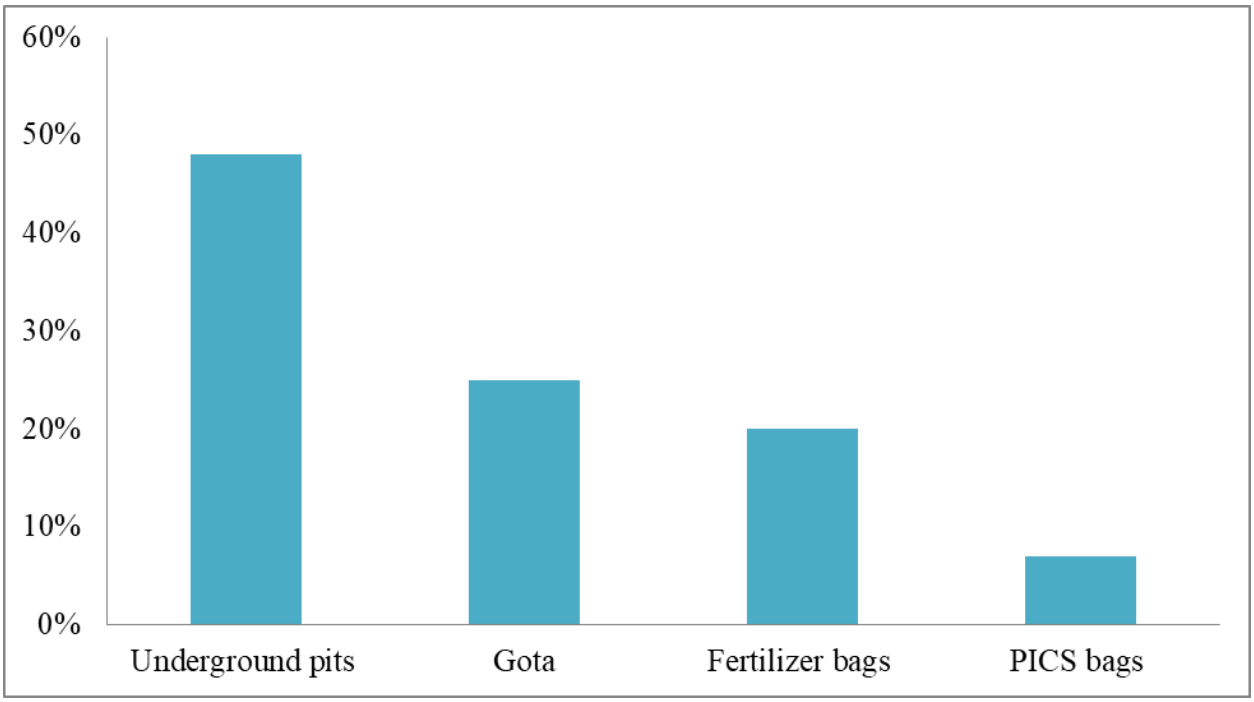

Figure 4.1: Storage structures used by farmers in the study area

The vast majority of farmers in the area choose it since it can be built close to their farms, saving on transportation expenses, where sandy or stony soils are more common, there is a gentle topography, and water drainage is less of a problem. They also chose it because of its large grain storage capacity, efficacy in mite and fire prevention, and low construction and maintenance costs. In addition to its role, pit storage has a number of drawbacks, such as decreased grain quality, reduced viability, and a loss of some nutritional value due to the grain's rising moisture content with time spent in storage, which causes mold infestation and storage insect pest development. When storing sorghum, mold infection develops more frequently and at higher levels than is required to maintain grain quality. Farmers stored sorghum grains in gota,

particularly grains that were used for domestic consumption and market purposes, until the pit opened. Farmers also use fertilizer bags, which are popular with farmers since they are simple to handle and transport. Traditional grain storage facilities were more susceptible to pest infestation because insects could easily enter and damage the grain, reducing both the quality and amount of grain.

The findings of this study were consistent with previous investigations conducted in Hararghe, Ethiopia. 70% of sorghum grains were stored in an underground pit by farmers (Mashilla Dejene 2004). According to Sunano (2016), the majority of farmers in underdeveloped nations, particularly in Africa, including Ethiopia, employ local storage systems that lack air conditioning. Negasa Fufa *et al*. (2021) also reported that most Ethiopian farmers store their grain using traditional techniques that are poorly constructed using locally available materials and are incapable of protecting stored grains from storage pests such as insect pests and rodents, which cause severe damage to the grains in storage. Another study revealed that 93.3 percent of Ethiopian farmers store their grains in traditional structures, exposing them to pests, mold, and other loss-causing variables (Dubale Befikadu *et al*., 2012). Gladys and Norton (1999) reported that high expenses and limited access are some of the barriers that prevent farmers from accepting new technologies.

4.1.3. Storage insect pests of sorghum in Dejen *Woreda*

Insect pests accounted for 76% of the pests discovered in the research area, with mold accounting for 12%, rats accounting for 8%, and termites accounting for 4%. Figure.4.2. As a result, sorghum losses ranged from moderate to severe. The rice weevil and maize weevil were the main storage insect pests of sorghum in the research area, accounting for 38% and 25%, respectively, while the Angoumois grain moth accounted for 13% of the assessed area minor pests (Figure 4.2). In the district next to storage, insect pests and mold infestations of sorghum grains also pose a series of problems. The vast majority of farmers in the study area store their sorghum grains in conventional underground pits (bare pits), which cause moisture to migrate into the grain from the nearby soil walls. This circumstance increases the temperature, relative humidity, and moisture content of the grain, promoting the development of storage insect pests and fungi that cause mold infestation and grain destruction. Severely deformed grain loses its physical characteristics, including grain weight, percentage of germination, and other essential

characteristics. Rodent and termite issues with above-ground sorghum storage buildings also happened in the district. Rodents posed a lesser threat to the storage of sorghum grain, and in the locations that were investigated; they were less destructive and degrading than insect pests. To keep rodents away, most farmers store their sorghum grains in underground pits. In comparison to other storage pests, termite infestations were also low.

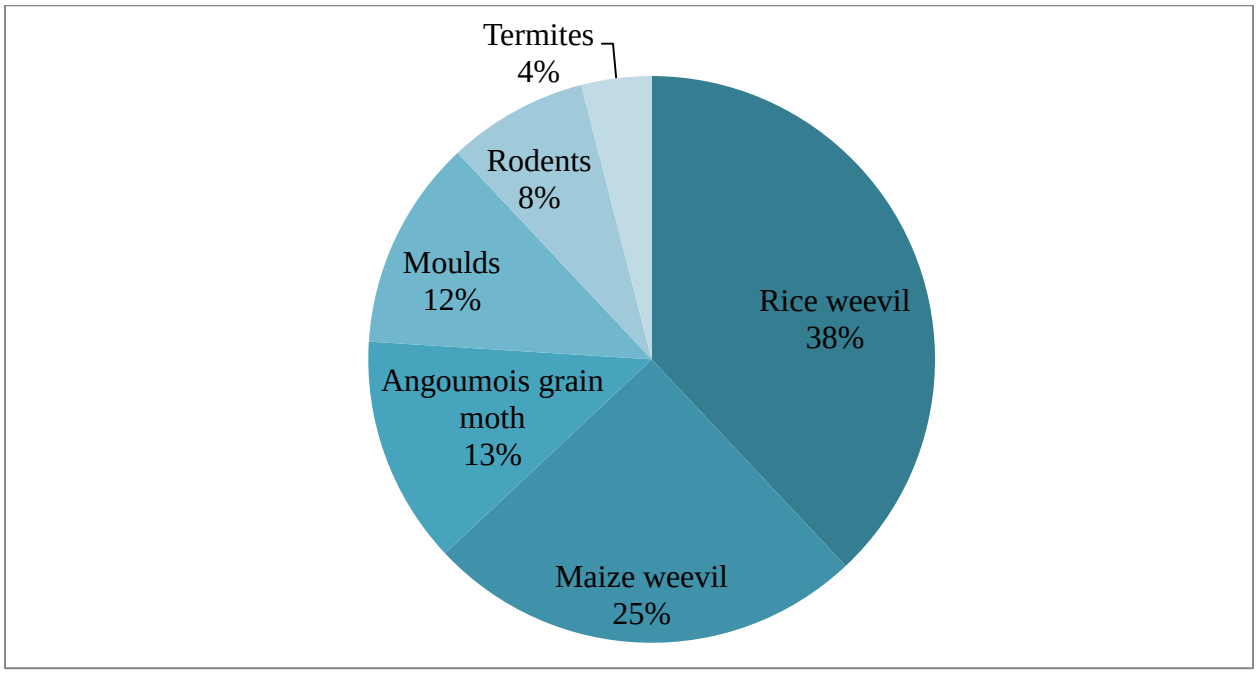

Figure 4.2: Major Storage insect pests of sorghum in Dejen *Woreda*.

The results of other researchers confirm this study. Mold infections seriously affected sorghum grains stored in underground pits, in addition to storage insects (Abraham Mulu and Zelalem Belayneh, 2016). Other researchers' findings (Girma Demissie and Rahaman, 2014) demonstrate that insect pests have a significant impact on the quantity and quality of sorghum during storage if they are not handled in a timely manner. *S. zeamais*, *S. cerealella*, *T. confusum*, and *O. surinamensis* are pests that infest storage sorghum grains in Africa, especially Ethiopia. Many storage insect pests damage grain harvests in Ethiopia when they are being stored. The maize weevil, Angoumois grain moth, rice weevil, and flour beetle were identified as the major storage pests among a variety of insect pests (Waktole Sori and Amsalu Ayana, 2012). According to

Tadele Tefera (2016), the Angoumois grain moth and the rice weevil are prominent cereal crop pests in Ethiopia.

4.1.4. Percentage of store infestation, weight loss, grain damage, and germination percentage in store

A. Percentage of store infestation

Storage insect pests found in both samples (Table 4.2) were rice weevil, maize weevil, and Angoumois grain moth, which affected all of the stores sampled in the study area. During the study period, rice weevil infested 100% of the stores in *Miniji*, whereas it infested 80%, 76%, and 61% of the stores in *Geligele, Kurar*, and *Zemetin*, respectively. Similarly, maize weevil contaminated 72.22% of storage facilities in *Zemetin*, whereas the Angoumois grain moth infested 55.56%. This finding was supported by Mihale *et al*. (2009), who stated that insects are responsible for 15–100% of pre- and post-harvest loss in developing countries, which supports this finding. Jamaal Barre (2022) also revealed that all storage structures were infested with two storage insect pests: maize weevil and Angoumois grain moth (10% to 100%) at Gabilay district Somaliland. According to comparable findings from this study by Adane Tesfaye *et al.* (2021), all stores sampled throughout the study period were affected by one or more storage pests, and the infestation level in the store was 100%.

Table 4.2: Percentage of storage infestation by insects at Dejen*Woreda* during 2013

Kebeles	Storage insect pests	No of infected stores	Infestation%
Geligele	Rice weevil	24	80.00
	Maize weevil	14	46.67
	Angoumois grain moth	6	20.00
Kurar	Rice weevil	19	76.00
	Maize weevil	16	64.00
	Angoumois grain moth	7	28.00
Miniji	Rice weevil	27	100.00
	Maize weevil	11	40.74

	Angoumois grain moth	4	14.81
Zemetin	Rice weevil	11	61.11
	Maize weevil	13	72.22
	Angoumois grain moth	10	55.56

B. Grain damage

In the research district, the average grain damage for sorghum grains was 14.4%. *Kurar* (16.6%), *Minji* (15.2%), and *Geligele* (14.5%) caused the highest grain damage, whereas *Zemetin* caused the least grain damage (11.4%) (Table 4.3). It could be due to warm environmental factors, insufficient storage practices, and a longer storage time of sorghum grains in *Kurare*, *Minji*, and *Geligele* than in *Zemetin*, resulting in high grain damage.

A number of factors, including storage method, storage period length, and management procedures, may have contributed to high levels of insect pest damage (Tadele Tefera, 2012). Storage insect pests are the most important biotic factors because they feed on grain during storage, causing weight, viability, and nutritional value loss as well as contaminating the grains. As a result, insufficient storage methods expose grains to insect and rodent pest attacks, leading to significant grain losses during storage. All of these variables reduce grain quality and render it useless (Herbert, 2012). Similar findings from this study by Adane Tesfaye *et al*. (2021) indicated that the average physical grain damage of sorghum was 7.22%. Despite this result, Tadeos Shiferaw (2018) discovered considerable physical grain damage, up to 29.27%. Grain damage can occur as a result of a number of variables, including storage period, storage type, and management practices.

C. Grain weight loss

Weight loss as a percentage ranged from 8.5 to 11%, with a mean value of 9.9% for sorghum during storage in Dejen *Woreda*. *Kurar* (11%), *Miniji* (10.5%), and *Geligele* (9.9%) recorded the greatest weight loss (Table 4.3). It was stated that the grains had high storage insect pest infestations and had been kept for an extended period of time. The limited weight loss recorded with *Zemetin* 8.5% could be attributed to environmental factors and storage techniques. Insect

pests in Ethiopia were accountable for up to 13.12% of weight loss in threshed sorghum and 8.34% of weight loss in unthreshed sorghum, according to research by Suleiman and Rugumamu (2017). The average mean weight loss of sorghum, according to Adane Tesfaye *et al.* (2021), was 13.63%. Spillage, insect consumption, physical changes in temperature and moisture content and chemical changes can all reduce sorghum weight loss. Adugna Haile *et al*. (2003) observed similar results: the weight loss of stored grain sorghum ranged from 9 to 29%.

Table 4.3: Grain damage and Weight loss, of sorghum grains recorded in Dejen *Woreda*.

"Kebele"	Grain damage (%)	Weight loss (%)
Geligele	14.5	9.9
Kurar	16.6	11
Miniji	15.2	10.5
Zemetin	11.4	8.5
Mean	14.4	9.9

D. Germination test

Each storage method used by farmers in the research area evaluated germination tests. The overall mean germination percentage in the selected *kebeles* was 89% for PICS bags, 84% for fertilizer bags, 80.5% for *Gota*, and 54.75% for underground pits (table 4.3). Grain stored in PICS bags had the highest germination percentage, whereas grain stored in pits had the lowest germination rate in the assessed *kebeles.* Grains stored in fertilizer bags and *Gota* also recorded the highest germination of sorghum seeds. *The* vast majority of farmers in the district used bare pits. These determine the germination capacity of sorghum due to many interactive factors, such as insect infestation and fungal growth.

Table 4.4: Germination percentage of each storage material and assessed kebeles

No	Kebeles	Type of storage material	Germination percentage
1		Fertilizer bag	85%
	Geligele	*Gota*	80 %

		PICS Bag	89%
		Underground pit	54%
2	Kurar	Fertilizer bag	84%
		Gota	81%
		PICS Bag	88%
		Underground pit	55%
3	Miniji	Fertilizer bag	83%
		Gota	82%
		PICS Bag	89%
		Underground pit	56%
4	Zemetin	Fertilizer bag	84%
		Gota	79%
		PICS Bag	90%
		Underground pit	54%

Masilla Dejene (2004) reported that germination of sorghum stored in pits for 7 to 8 months decreased from 83 to 27% on average due to storage fungi. In the other study, by Weinberg *et al.* (2008) stated that the germination percentage of grains stored in sealed containers decreased over the storage period and decreased as the moisture content increased. These findings indicated that storage pests had a relatively negative impact on sorghum grain germination percent in an above-ground storage structure but a significantly more negative impact on sorghum grain germination percent in an underground pit, which may explain why the seeds failed to germinate. This finding confirms a study by Fekadu Lemessa *et al.*, (2000), which indicated that the germination of sorghum seeds stored in underground pits decreased with time.

4.1.5. Management practice used by farmers in Dejen *Woreda*

Farmers in Dejen *Woreda* used chemical, physical, botanical, and cultural pest management techniques to preserve their grains from storage pests. Figure 4.3 show that 41% of the farmers in the study area used insecticides to protect their grains from pests. Most farmers used these pesticides mostly before insect pests appeared in order to lower their population and infestation levels. Although they prevented their grains from becoming infested, they also applied pesticide,

mostly after a storage insect pest infestation; during packaging, they simply applied pesticide on the bottom and top of packaging materials without knowing the exact formulation. In the research locations, about 25% of farmers utilized cultural methods to protect their sorghum grains against storage pests. About 16% of the farmers in the study area used physical management methods. A few farmers (2%) in Dejen *Woreda* use botanicals for simply scrubbing the inside wall of the pit and gota by the leaf of *Senegalla catechu* (*Digeta*) in Amharic, and also simply putting the leaf on top of the pit before closing the pit gate. Farmers in Dejen *Woreda* accounts (16%) did not use any management techniques; the majority of them grow a small amount of sorghum, are unable to purchase pesticides, and do not keep their sorghum grain in storage for long periods of time.

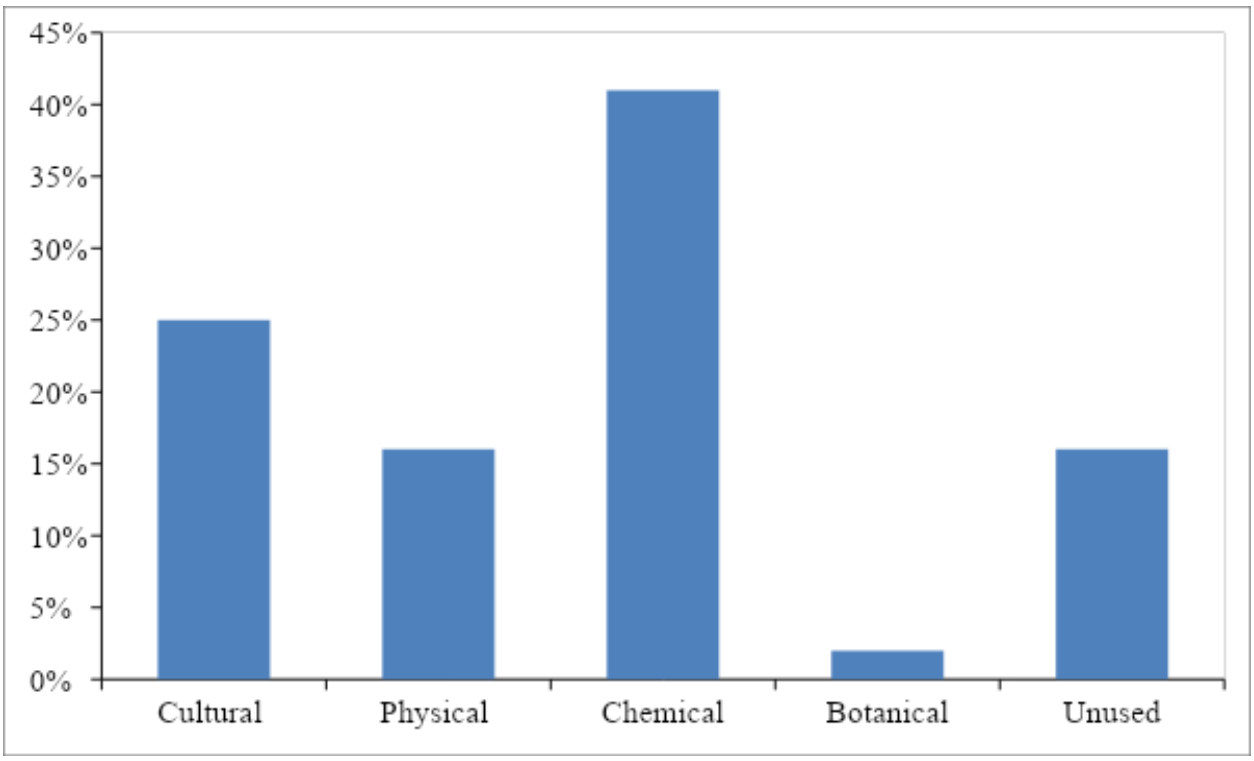

Figure 4.3: Management practice used by farmers in Dejen*Woreda*.

The findings of these studies were supported by Nezif Abamecha *et al.*'s (2020) survey results, which showed that chemical insecticides were the most widely used practice in the surveyed

areas. The survey was conducted in the Jimma, West Shoa, and East Wollega zones of southwest Ethiopia. According to Khan and Damalas (2015) and Rehman *et al.*, (2015), farmers continue to use chemical pesticides despite the fact that the chemicals are detrimental to the environment. However, respondents stated that, despite widespread usage of synthetic insecticides, they continue to encounter pest problems.

4.2. Management of rice weevil on sorghum using Botanicals

4.2.1. Effect of botanicals on parent adult weevil mortality

The effects of treatments on weevil mortality at various days after treatment application are recorded in Table 4.5. There were significant differences *(P<0.05)* between treatments in causing adult mortality (Appendix Table 1). Three days after treatment application, Malathion 5% dust resulted 100% mortality of adult rice weevils, and it was the most effective of all the treatments tested. *P. dodecandra* seed powder (36.67%), *A. indica* seed powder (26.67%), and *P. dodecandra* leaf powder (21.67%) caused the highest adult weevil mortality from botanically treated grains, while *C. macrostachyus* leaf and seed powder (1.67%) and (3.33%), respectively, caused the lowest adult mortality. No mortality was recorded in sorghum treated with *E. teff* (0.00%) on these three days after treatment application (Table 4.5). Seven days after application of the botanical treatments, the greatest mortality was noted at *P. dodecandra* seed powder (80.00%), *P. dodecandra* leaf powder (75.00%), and *A. indica* seed powder (71.67%), *A. sativum* (61.67%), and *A. indica* leaf powder (56.67%). Wood ash dust (45%) had the highest death rate of weevils among locally available products. The lowest weevil mortality was recorded in *E. teff* (3.33%), followed by the untreated control (0.00%) Table 4.5.

Fourteen days after application of the treatment, the rate ranges from 1.13 percent (untreated check) to 100 percent (Malathion 5% dust). Adult mortality from the botanical treatments was highest with *P. dodecandra* seed powder (94.92%), followed by *A. indica* seed powder (88.14%), and *P. dodecandra* leaf powder (84.75%). The lowest adult mortality in the botanical treatments was found in the seed and leaf powders of *C. macrostachyus*, with adult mortality rates of 35.60% and 28.83%, respectively (Table 4.4). On these days, the adult rice weevil mortality rate on the untreated check began, recording 1.13%. Twenty-one days after treatment application from the botanical treatments, *P. dodecandra* seed powder (100.00%) significantly

((*P<0.05*) gave the highest percent adult mortality of rice weevils (Appendix Table 1), which was comparable to Malathion 5% dust. The *A. indica* seed powder, *P. dodecandra* leaf powder, and *A. sativum* powder produced the highest percentages of adult rice weevil mortality during this time, at 94.74, 91.23, and 82.46, respectively, when compared to the control. Grains treated with *E, Teff* (21.05%), and an untreated control (1.75%) had the lowest adult weevil mortality

Table 4.5: Mean value (±SE) of corrected cumulative mortality of rice adult weevils in sorghum grains treated with different botanical insecticides.

Treatment	Mortality After Treatment Application (%)				
	3- DAT	7- DAT	14- DAT	21- DAT	28- DAT
A. indica seed	26.67±1.67^{c}	71.67±4.41^{bc}	88.14±4.48^{b}	94.74±3.04^{a}	100.00±0.0^{a}
A. indica leaf	11.67±1.67^{de}	56.67±7.26^{d}	67.80±6.11^{de}	77.19±4.64^{c}	90.38±1.92^{b}
A. sativum	15.00±2.89^{d}	61.67±4.41^{cd}	74.58±5.87^{cd}	82.46±4.64^{bc}	94.23±3.33^{ab}
Z. officinale	5.00±2.89^{fg}	28.33±6.01^{f}	49.16±5.87^{f}	59.65±4.64^{de}	73.07±5.09^{c}
P. dodecandra seed	36.67±4.41^{b}	80.00±2.89^{b}	94.92±2.94^{ab}	100.00±0.0^{a}	100.00±0.0^{a}
P. dodecandra leaf	21.67±1.67^{c}	75.00±2.89^{b}	84.75±2.94^{bc}	91.23±3.51^{ab}	100.00±0.0^{a}
C. chyus seed	3.33±1.67^{fg}	20.00±2.89^{fg}	35.60±4.48^{g}	47.37±6.08^{f}	59.61±3.33^{d}
C. chyus leaf	1.67±1.67^{g}	16.67±4.41^{g}	28.83±2.94^{g}	50.88±3.51^{ef}	61.53±5.09^{d}
E. teff seed 20%	0.00±0.00^{g}	3.33±1.67^{h}	10.19±1.69^{h}	21.05±3.04^{g}	36.53±3.33^{e}
Wood ash dust 10%	8.33±1.67^{ef}	45.00±2.89^{e}	57.63±1.69^{ef}	64.91±4.64^{d}	78.84±5.09^{c}
Malathion 5% dust	100.00±0.0^{a}	100.00±0.0^{a}	100.00±0.0^{a}	100.00±0.0^{a}	100.00±0.0^{a}
Control (untreated)	0.00±0.00^{g}	0.00±0.00^{h}	1.13±1.13^{h}	1.75±1.75^{h}	2.56±2.56^{f}
Mean	19.17	46.53	57.73	65.94	74.73
CV (%)	18.95	14.55	11.60	9.87	7.37
LSD	6.12	11.41	11.28	10.96	9.28

Means within a column followed by a different letter(s) are significantly at P<0.05, Fisher Least Significant Difference (LSD) method; CV= coefficient of variance DAT= days after treatment.

The botanical treatments *A. indica* seed powder (100%), *P. dodecandra* seed powder (100%), and *P. dodecandra* leaf powder (100%), significantly (P<0.05), gave the highest percent adult

mortality of *S. oryzae* 28 days after treatment application. All treatments had a mean percentage of adult *S. oryzae* mortality on the 28 days after application. Botanicals, including *A. sativum* leaf powder (94.23%) and *A. indica* leaf powder (90.38%), were successful in lowering adult *S. oryzae* mortality rates. When compared to the untreated control and Malathion 5% dust standard checks. Treatments such as wood ash dust (78.84%) and *Z. officinale* (73.07%) showed high mortality rates of adult *S. oryzae*. *C. macrostachyus* seed and leaf powder were the least effective botanical treatments for adult mortality, but they were better than the control (untreated) and *E. teff*, which was less effective in adult *S. oryzae* mortality after twenty-eight days of treatment application.

The results of these experiments revealed that botanicals, such as *P. dodecandra* and *A. indica* leaf and seed powder, produced results similar to Malathion 5% dust, which may reduce the life span of *S. oryzae* and is more effective than other treatments at killing the parent adult rice weevil on the third, seventh, fourteenth, twenty-one, and twenty-eighth days after treatment applications. In general, on the third, seventh, fourteenth, twenty-one, and twenty-eighth days after treatment applications, the seed part of botanicals like *A. indica*, *P. dodecandra*, and *C. chyus* showed the largest mortality compared to the leaf part. On the 28 days after treatment application, however, there was no significant difference in adult mortality between seed and leaf parts in *P. dodecandra* (Table 4.5). Furthermore, all the botanical treatments, including wood ash dust, significantly increase the adult mortality of rice weevil compared to the untreated control and reduce the longevity of rice weevil.

This result lines up with other research findings on the effectiveness of botanical powders that kill large numbers of storage insect pests like rice weevils. According to Asmare Dejene (2002), of the 20 species of botanicals tested for their ability to control maize weevil on sorghum in the laboratory at Sirinka, *Phytoloca dodecondra* produced 100% mortality of the pest within 28 days of infestation. Other scholars, Adane Tesfaye *et al*., (2021), reported that botanical treatment of sorghum grain with garlic and neem seed powder was more effective at eradicating *S. oryzae* on the 28th day of treatment application. The highest percentage of adult *Sitophilus zeamais* mortality, 100%, was caused by neem seed and garlic leaves 28 th days after treatment application Jamal Barre *et al*., 2022

4.2.2. Effect of botanicals on the progeny of adult emergence

The effects of the treatments on the emergence of adult progeny were significantly different *(P< 0.05)* from one another. When compared to the control, *P. dodecandra* seed powder showed a small amount of F1 progeny emergence (0.67%), while malathion 5% dust completely prevented the grains from F1 progeny 0.00 (Table 4.6). Additionally, *A. indica* leaf powder 3.33, *P. dodecandra* leaf powder 1.67, *A. sativum* 2.67, and *A. indica* seed powder 1.33 all revealed strong insecticidal effects by lowering the emergence of adult progeny. The highest number of adult progeny emergencies was observed on grains treated with *E. teff* (20.00) and from the botanical treatments *C. macrostachys* seed (8.67) and leaf powder (10.33). In comparison to the untreated control, other treatments such as wood ash dust (5.67) and *Z. officinale* (6.33) were also helpful in lowering the emergence of adult progeny. In the untreated check, there was considerably *(P< 0.05)* more adult progeny than in any other treatment. *P. dodecandra* seed powders were successful in reducing the amount of progeny produced by *S. oryzae* by preventing the development and reproduction of progeny. Additionally, *A. indica* seed powders, *P. dodecandra* leaf powder, and *A. sativum* were effective botanical treatments for reducing *S. oryzae*.

This was most likely caused by the high mortality of adults who had few or no opportunities to mate and reproduce. Additionally, in this experiment, botanical powder treatments significantly reduced the emergence of adult *S. oryzae* compared to the controls (untreated checks). This study supported the findings of Kifle *et al.* (2016), who found that sorghum treated with 5 and 10% neem seed powder produced no progeny emergencies. Other researchers, Ferdu Azerefegne *et al.* (2001), found that *P. dodecondra* seed and leaf powder reduced progeny emergence in maize weevils. Botanicals have the potential to inhibit F1 progeny production from many storage insect pests, according to Shaheen (2006) and Asmare Dejene (2002).

4.2.3. Effect of botanicals on percent protection of grains

In comparison to the untreated control, all treatments significantly decreased the number of F1 progeny and increased seed protection (Table 4.6). Additionally, botanicals showed that there

was a significant difference *(P<0.05)* in the percentage of grains that were protected (Appendix Table 2). *P. dodecondra* seed powders (98.25%) had a comparable effect on sorghum grains Malathion dust (5%), which completely protected the grains against F1 progeny, *A. indica* seed powder (96.49%), *P. dodecandra* leaf powder (95.61%), *A. sativum* (92.98), and *A. indica* leaf powder (91.23%) provided the highest effective percentage of seed protection, compared to Malathion dust's 5% (Table 4.6).

Botanicals, *C. macrostachyus* seed (77.19%) and *C. macrostachyus* leaf (72.81%) powder, performed least effectively but better than *E. teff* and control in preventing F1 progeny from damaging sorghum grains. When compared to the untreated control, *Z. officinale* (83.33%) and wood ash dust (85.09%) protected a larger percentage of seeds (Table 4.6). As a result of the present study, all of the tested treatments were statistically superior and provided greater protection against rice weevil than the untreated control. The best botanicals for preventing *S. oryzae* from infecting stored sorghum grains were *P. dodecandra* seed powder, *A. indica* seed powder, *P. dodecandra* leaf powder, *A. sativum,* and *A. indica* leaf powder. Yeshiwork Alemnew (2017) reported similar outcomes. While *C. macrostachys* was the least efficient in protecting maize grains from F1 progeny but was still significantly better than the control, maize grains treated with *A. indica* seed powder were almost completely protected from F1 progeny. Other scholars, Jamaal Barre *et al.,* (2022), who carried out an experiment involving treatments with garlic, neem, lantana, ginger rhizome, and pepper tree leaves, reported similar outcomes. Treatments with neem seeds, similar to Malathion dust, efficiently preserved the maize grains.

4.2.4. Effect of botanicals on percent weight loss

The percent of weight loss differed significantly *(P<0.05)* among treatments (Table 4.6). The lowest percentages of seed weight losses were observed in the treatments used in this experiment, with grains treated with various botanical powders. Malathion 5% dust (0.0%), P. dodecandra seed powder (0.63%), and the remaining botanicals, *A. indica* seed powder (0.77%), and *P. dodecandra* leaf powder (0.93%), all significantly reduced the weight loss of the grains. (Table 4.6) In comparison to other botanical treatments, less weight loss was recorded when those botanical treatments were used to control weight loss. Because of the weevil's consumption of the grains, the largest weight loss was found in untreated sorghum grains, which was recorded

at 7.53%. The botanical grains treated with *C. macrostachyus* leaf powder (3.57%), *C. macrostachyus* seed powder (3.13%), and *Z. officinale* (2.03%) as compared to the control, followed by *E. teff* mixing (4.60%), showed the highest percentages of grain weight losses. Other treatments, *A. sativum*, *A. indica* leaf, and wood ash dust, reduced weight loss by 1.03%, 1.08%, and 1.60%, respectively. Compared to the untreated control, weight loss was significantly reduced when botanical powders were combined with the sorghum grains.

Table 4.6: Mean value (±SE) of the effect of botanicals on F1- progeny, protection percent, grain damage, weight loss, and germination percentage

Treatment	F1- progeny	Protection %	Grain damage (%)	Weight loss (%)	Germination (%)
A. indica seed	1.33±0.88^{g}	96.49±2.32^{a}	1.93±0.47^{gf}	0.77±0.23^{f}	92.67±2.03^{abc}
A. indica leaf	3.33±1.45^{efg}	91.23±3.82^{abc}	3.57±0.72^{e}	1.08±0.17^{ef}	87.00±2.31^{de}
A. sativum	2.67±0.88^{fg}	92.98±2.32^{ab}	3.23±0.50^{ef}	1.03±0.24^{ef}	88.67±2.40^{cd}
Z. officinale	6.33±1.45^{de}	83.33±3.82^{cd}	5.23±0.98^{d}	2.03±0.38^{d}	80.33±2.60^{fg}
P. dodecandra seed	0.67±0.67^{g}	98.25±1.75^{a}	1.67±0.23^{g}	0.63±0.20^{f}	95.33±1.45^{a}
P. dodecandra leaf	1.67±0.88^{g}	95.61±2.32^{a}	2.87±0.15^{efg}	0.93±0.15^{f}	90.00±1.73^{bcd}
C. chyus seed	8.67±1.45^{cd}	77.19±3.82^{de}	8.20±0.72^{c}	3.13±0.27^{c}	76.00±1.73^{gh}
C. chyus leaf	10.33±0.88^{c}	72.81±2.32^{e}	7.73±0.35^{c}	3.57±0.15^{c}	75.00±1.15^{hi}
E. teff seed 20%	22.00±1.53^{b}	42.11±4.02^{f}	12.87±0.35^{b}	4.60±0.17^{b}	70.67±1.20^{ij}
Wood ash dust 10%	5.67±0.88^{def}	85.09±2.32^{bcd}	4.33±0.22^{de}	1.60±0.17^{de}	83.00±1.73^{ef}
Malathion 5% dust	0.00±0.00^{g}	100.00±0.0^{a}	0.00±0.00^{h}	0.00±0.00^{g}	94.00±1.15^{ab}
Control (untreated)	38.00±1.73^{a}	0.00±0.00^{g}	16.67±0.58^{a}	7.53±0.15^{a}	66.67±1.45^{j}
Mean	8.39	77.92	5.69	2.24	83.28
CV (%)	23.84	6.75	15.67	16.22	3.77
LSD	3.37	8..87	1.50	0.61	5.28

Means within a column followed by different letters are significantly at P<0.05, Fisher Least Significant Difference (LSD) method; where CV= coefficient of variance.

The results were also supported by the findings of Govindan *et al.* (2020), who indicated that less seed weight loss occurred in seeds treated with botanicals as compared to those untreated during storage in sorghum seeds treated with insecticidal plant powders against rice weevil. According to Kalkidan Degefa (2019), maize grains treated with *P. dodecondra* seed powder had a considerable weight loss reduction and were nearly completely protected from *S. zeamais* seed damage. According to Adugna Haile *et al*. (2003), stored grain sorghum could lose up to 9–29% of its weight.

4.2.5. Effect of botanicals on percent grains damage

On stored sorghum, there were significant differences (*P<0.05)* between the treatments in terms of grain damage caused by rice weevil. On treatments with botanicals, grain damage ranged from 1.67% to 8.20% (Table 4.6). The untreated grains (16.67%) had the highest proportion of grain damage. In grains treated with Malathion dust 5%, which was measured at 0.0%, no grain damage was recorded. Comparing the treatments to the control, all of them reduced grain damage. As compared to untreated, the three botanical powder treatments that caused the most grain damage were *C. macrostachyus* seed powder (8.20%), *C. macrostachyus* leaf powder (7.73%), and *Z. officinale* (5.23%). In comparison to untreated, *P. dodecandra* seed powder (1.67%) and *A. indica* seed powder (1.93%) were the treatments that induced the least grain damage. As compared to untreated, treatments with *A. sativum* (3.23%), *A. indica leaf* (3.57%), and wood ash dust (4.33%) resulted in moderate grain damage. In the treatments, mixing *tef* (12.87%) had higher grain damage. The results of this study showed that *P. dodecandra* seed powder and *A. indica* seed powder are effective botanical substances that provide results similar to those of Malathion 5% dust, which is also utilized as an alternate technique to control rice weevil and lessens the adverse effects of synthetic pesticides. This research supports Bhargude *et al. (*2021); He evaluated the effectiveness of various botanical products against *S. oryzae* in stored sorghum seeds. He found that *A. indica* seed kernel powder at a rate of 5% recorded low seed damage infestation by *S. oryzae*. This finding agrees with Adane Tesfaye *et al.'s 2021* investigation on the control of rice weevil using six botanicals on preserved sorghum. In comparison to the control, neem seed powder and garlic treated with sorghum showed low grain damage.

4.2.6. Effect of botanicals on germination of seeds

The germination percentage was evaluated at the end of the experiment to assess the effect of the treatments on seed germination. The germination test results showed that none of the botanical powders used to treat sorghum grain against *S. oryzae* had an adverse effect on grain germination percentages.The untreated seeds had the minimum germination percentage (66.67%). This sugge sts that weevil damage to sorghum grains reduced the percentage of germination. Low germination percentages were recorded on *C. macrostachyus* seed powder (76.00%), *C. macrostachyus* leaf powder (75.00%), and *E. teff* seed (70.67%) when compared to control (Table 4.6). Treatments with *A. sativum, A. indica* leaf, wood ash dust, and *Z. officinale* had high rates of germination (88%, 87%, 83%, and 80%, respectively) as compared to the control (Table 4.6).

The maximum rate of germination was seen on sorghum grain treated with *P. dodecandra* seed powder (95.33%), Malathion 5% dust (94.00%), *A. indica* seed powder (92.67%), and *P. dodecandra* leaf powder (90.00%) (Table 4.6). These findings are consistent with those of other scholars. According to Asmare Dejene (2002), sorghum seeds treated with the powder of *P. dodecandra, A. indica, D. stramonium*, and *J. curcas* against *S. zeamais* had no adverse effect on germination capacity, and another study by Kalkidan Degefa (2019) investigated botanicals in the control of maize weevil on maize seeds and found no adverse effect of botanicals on the germination of treated seeds. Daniel Getahun (2020) also supported this study, finding no significant difference in mean seed germination among all treatments. The germination rate of *Croton macrostachyus* was found to be comparatively lower (75.55% at a 5% rate).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The main reasons for sorghum post-harvest losses in the examined locations are storage pests and traditional storage structures. Most often, they kept sorghum grains in the underground pit and g*ota.* It was inadequate for secure grain storage since it increased grain moisture content and granary temperature, which favored storage insect pest infestation and the growth of microorganisms (mold). Storage pests like the rice weevil and maize weevil, as well as the Angoumois grain moth, were the main issues with sorghum products. The majority of farmers in the district chose chemical management techniques rather than other control techniques. The use of chemical insecticides to control storage pests is a problem; thus, alternatives such as botanicals and locally available products are needed to effectively manage the pests and avoid the issues with synthetic insecticides, with significantly less adverse consequences for both the environment and people.

All of the tested plant materials and locally available products showed insecticidal properties as grain protectants against *S. oryzae*. They were also significantly different from the untreated control in lowering the percentage of weight loss, the amount of damaged grain, the emergence of progeny, and the adult weevil mortality. Within 28 days of the experiment's beginning, *A. indica* seed powder, *P. dodecandra* leaf powder, and *P. dodecandra* seed powder caused a 100% mortality rate of *S. oryzae* and showed the equivalent effect to that of the chemical pesticide Malathion 5% dust. Overall, the results demonstrated that all botanicals examined had a significant progeny reduction emergency and were capable of killing adult rice weevils. Endod seed powder, endod leaf powder, and neem seed powders, followed by garlic, were found to be relatively the most effective botanicals in causing a significantly higher rate of mortality of adult rice weevils compared to control. In addition to the effectiveness of these botanicals, high germination percentages, low grain damage, and weight loss of sorghum due to weevil were recorded, which suggests a potential alternate control strategy for these pests. From locally available products, wood ash dust provides efficient protection for sorghum against rice weevil.

5.2. Recommendations

- Farmers who want to protect their stored grains from storage pest infestations should use improved storage structures, which have been shown to protect stored grains from storage pests.
- Farmers should encourage utilizing the botanicals *A. indica*, *A. sativum*, and *P.dodecandra* because they showed a promising outcomes in protecting storage insect pests.
- Storage pests are one of the limiting issues for sorghum production in the Dejen Woreda However, more research that covers all growing areas should be required to assess the economic importance of pest infestations and control methods for pests related to stored sorghum.
- Future research becomes needed to investigate the efficacy of locally accessible products that should be tested for use by farmer's alternative materials that may be effective at a lower cost should be considered.

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7. APPENDIX

Appendix Table 1: Mean squares of analysis of variance of adult rice weevil mortality from sorghum grains treated with botanical treatments.

SOV	DF	3- DAT	7- DAT	14- DAT	21- DAT	28- DAT
Botanical	11	2341.67***	3194.63***	3292.23***	2982.39***	2801.02***
Error	24	13.19	45.83	44.83	42.32	30.31
CV (%)	-	18.95	14.55	11.60	9.87	7.37

*SOV= Source of variation, DF= Degree of freedom, DAT= Days after treatment, CV= Coefficient of variance, and ***= very highly significant at P<0.05.*

Appendix Table 2: Mean squares of analysis of variance of F1- progeny, protection percent, grain damage, weight loss, and germination of sorghum grains treated with botanicals.

SOV	DF	F1- progeny	Protection percent	Grain damage (%)	Weight loss (%)	Germination (%)
Botanical	11	371.14***	2570.23***	72.47***	13.87***	273.20***
Error	24	4.00	27.70	0.80	0.13	9.83
CV (%)	-	23.84	6.75	15.67	16.22	3.77

*SOV= Source of variation, DF= Degree of freedom, CV= Coefficient of variance, and ***= very highly significant at P<0.05.*

Appendix Table 3: Assessment questionnaires checklist

Name of Respondent ----------

Gender---------- Age----------

Education Level: A) Illiterate, B) Primary, C) Secondary, D) Middle Level, E) University

Zone---------- Worda/District---------- Kebele---------- Locality----------

Telephone No---------		
Name of Enumerator:		Date:
No	**Questions**	**Responses**
1	For what purpose do you grow sorghum? A) Food, B) Income, C) Both	
2	What category of product do you produce? A) Grain, B) Seed	
3	During the last two years, which variety did you grow?	
4	Where do you get planting seeds and technical advice on varieties to grow?	
5	What major pest problems have you encountered within the product in the last 2 years?	
6	Do you assess your storage structure for pests? Yes or no. If yes, how often?	
7	What type of storage structure is used for grain seeds?	
8	How long is the grain in storage (date of storage to end for use)?	
9	How did you clean your storage structure?	
10	Which storage structure is more effective in your locality? Why?	
11	How do you store your cereal crops, such as sorghum?	
12	Which storage pests cause so much loss? Affect your crop seriously?	
13	Which methods do you use to control storage losses of Sorghum?	

Appendix Table 4: Sample pictures taken during the experiment and assessment.



Botanical powders, *Mako* local sorgum Varity used in the experiment and laboratory materials



Setup of experiment in CRD Germination test



Sorghum storage structures








Sample taking

BIOGRAPHICAL SKETCH

The author was born in August 1989 in East Gojjam Zone. She attended her elementary education at 02 Primary School in Dejen and her secondary education at Dejen Senior Secondary and Preparatory School in Dejen. In 2008, she joined Dilla University College of Agriculture and Natural Resource Management and graduated with a BSc. Degree in Plant Science in 2010. Then, after working as a Sinner technical assistant for two years at Mettu University, she joined Bahir Dar University for her MSc. Program in plant protection in 2013.