

Addis Ababa University
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**Studies on the the Distribution and some Management Options of Bean bruchids,
Acanthoscelides obtectus Say (Coleoptera: Bruchidae) on Faba Bean
Grains (*Vicia faba* L.) in North Western Amhara, Ethiopia**

BY
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Studies on the the Distribution and some Management Options of Bean bruchids, *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae) on Faba Bean Grains (*Vicia faba* L.) in North Western Amhara, Ethiopia

Abstract

*Faba bean is one of the most important cultivated legume crops in the world that substitutes meat due to its high protein contents. Bruchids are damaging the grains starting from field to storage. A study was conducted in Amhara Region to assess bruchids distribution and species composition, to determine the time when bean bruchids start infesting faba beans in the field, to screen out effective botanicals against A. obtectus and to determine safe moisture (5-5.5%, 9-9.5, 11-11.5, 14-14.5, 16-16.5 and 20-20.5%) contents for faba bean grain storage. Day one old unsexed newly emerged bruchids were artificially infested on various stages of faba bean pods in the field and in laboratory experiments. Infested pods were followed to observe the sensitive stages of the pods due to A. obtectus infestation at opened matured pods, closed matured pods, bean grains reached for consumption, two weeks before harvest, first emerged pods and free matured pods with no grains. Seeds of botanical oils and various levels of moisture contents were evaluated to manage bruchids. The number of bruchid eggs, number of emerged progenies, number of perforated grains (pods), grain weight loss and developmental period of bruchids were recorded. Data were analyzed by SAS software version 9.2 and MS Excel 07. Hundred percent of the faba bean grain samples collected from various Districts were infested by bruchids. The bruchid species were Callosobruchus chinensis (86.25%), A. obtectus (76.25%) and Bruchus pisorum (33.75%). The Parent A. obtectus were laid significantly higher number of eggs on opened matured pods (20.8 ± 4.34) and closed matured pods (16.5 ± 1.3). All the the faba bean pods were free from bruchid eggs and no progenies emerged from first emerged pods and free matured pods with no grains. Four days after treatment application, 100% of the parent A. obtectus killed in ethiothion 5% dust and oil treated grains indicating the fast knock down effect of the treatments. Statistically lower number of eggs and bean bruchid progenies recorded from ethiothion 5% dust and oil treated grains than the acetone treated and the untreated grains. Treatments like Noug (*Guizotia abyssinica* L), Rape seed (*Brassica napus* L.) and Groundnut (*Arachis hypogaea* L.) were the top effective botanical oils to control A. obtectus parents and their progenies. There was no progenies emerged and egg laid at 5-5.5% grain moisture content, while 393 ± 5.86 eggs were recorded at 20-20.5% grain moisture content. The highest faba bean grain weight loss was recorded to $18.6\% \pm 1.87$ at 20-20.5% grain moisture content. About 98.3% of the grains germinated and developmental periods of the A. obtectus extended for additional 17.5 days at 9-9.5% moisture content. From the current study, it can be concluded that bruchids distributed in all study areas. Opened matured pods were the sensitive stages of A. obtectus infestation both in the field and laboratory studies. Oils inhibited emergence of A. obtectus from $71.7 \pm 2.56\%$ -100% and grain moisture content ranging from 9% to 11.5% were safe for faba bean grain storage. Botanical oils and faba bean grain moisture adjustments can control bruchids that used as a component of IPM techniques to manage bruchids.*

Key words:- Bruchids, *Acanthoscelides obtectus*, infestation, progenies, egg, grain, pod, oil, moisture

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List of abbreviations

AM	Actual Moisture
ARARI	Amhara Region Agricultural Research Institute
BPHC	Bahir Dar Plant Health Clinic
Cn	Number of Newly Emerged Insects in the Untreated Pot
CRD	Completely Randomized Design
CSA	Central Statistical Authority
D	Median Developmental Period
DA	Development Agents
DAT	Days After Treatment
FM	Final Moisture
IBRD	International Bank for Reconstruction and Development
IR	Inhibition Rate
M1	Moisture Content of Undried Grain
M2	Moisture Content of Dried Grain
Nd	Number of Damaged Grains
N _μ	Number of Undamaged Grains
PA	Peasant Association
SAS	Statistical Analysis System
Tn	Number of Newly Emerged Insects in the Treated Pot.
W1	Initial Grain Weight before Drying
W2	Final Grain Weight after Drying
Wd	Weight of Damaged Grains
W _μ	Weight of Undamaged Grains

Chapter One. General introduction

Pulse crops are playing an important and diverse role in the farming systems of poor peoples' diet in many corners of the world (Jones *et al.*, 2011). The crops are very essential to reduce poverty, improving human health and nutrition and enhancing ecosystem resilience (Akibode and Maredia, 2011). Pulse crops contain 20% to 25% protein by weight, which is double to the protein content of wheat and three times that of rice (Jones *et al.*, 2011). They provide protein, complex carbohydrates, several vitamins and minerals (Kosterin, 2014).

Faba bean (*Vicia faba* L.), referred to as the broad bean, horse bean or field bean and is known for cultivation of important leguminous plant from the very onset of agriculture till today (Kosterin, 2014). The crop has been domesticated with the beginning of agriculture around the Near East and its distribution has spread throughout the world. It is the earliest domesticated legumes after chickpea and pea (Amer *et al.*, 2012; Link *et al.*, 2008; Ahmed *et al.*, 2007). Faba bean is mostly included in the diets of inhabitants of the Middle East, the Mediterranean Region, China and Ethiopia (Chaieb *et al.*, 2011). The crop provides iron, magnesium, phosphorus, zinc and other minerals (Gnanasambandam *et al.*, 2012). It is a good source of protein, starch, cellulose and minerals in developing countries and animal feed in industrialized countries (Gnanasambandam *et al.*, 2012, Link *et al.*, 2008). As a result, its production is evenly distributed around the world than most of other leguminous grains (Ahmed *et al.*, 2007).

China is the first in beans producer and consumer country (65%) in the world (Kakahy *et al.*, 2012; Duc *et al.*, 2010), followed by Ethiopia (9%) (Alemayehu, 2009). Ethiopia and Afghanistan are considered to be secondary center of diversity of the crop (Iyad *et al.*, 2004). Ethiopia and Sudan are the leading producers of the crop in Tropical Africa mainly in East Africa (Duc *et al.*, 2010).

The main producer country (China) produced 1.9 million tons in 2003. During the same period faba bean production in Africa was estimated to be 510,000 tons almost entirely from Ethiopia (405, 000 tons) and Sudan (100,000 tons) (Jones *et al.* 2011; Duc *et al.*, 2010). The average yield of faba bean production in Africa is 1.3t/ha which is below world average (1.5t/ha). The average production of the crop in Asia and Europe is 1.7t/ha and 2.2t/ha, respectively (Jones *et al.*, 2011; Duc *et al.*, 2010; Link *et al.*, 2008).

Faba bean ranks first in its production volume and cultivated land among pulse crops in Ethiopia and it is valuable and the cheap source of protein in Ethiopian diet (Teklay *et al.*, 2014). In Ethiopia and Eritrea the main dishes to be prepared from faba bean includes shiro wot, kik wot, full, eshet, kollo, nifro, gunkul, ashuke and endushdush (Duc *et al.*, 2010). The straw is used as fuel for cooking in Ethiopia (Endale *et al.*, 2014). Larger proportion of the area and production was recorded from the faba bean crops up to 30.8% and 34.3%, respectively (CSA, 2015). Amhara Region is the main faba bean producer in the country (CSA, 2015).

Though, the crop is very important in Ethiopia including Amhara Region, insects mainly bruchids cause damage on matured crops in the field (Kananji, 2007; Schmale *et al.*, 2002) and in the storage (Mazzonetto and Vendramim, 2003). The Bean beetle (*A. obtectus*) causes significant damage to faba bean grains and other pulse crops (Paul, 2007). Larvae usually decrease the yield by eating the grain contents (Schmale *et al.*, 2002). Partially damaged grains lose their weight, germinating capacity and taste quality (Mulungu *et al.*, 2007).

Bruchids attack dry bean pods in the field or seeds both in the field before harvest and in storage warehouses (Schmale *et al.*, 2006). The female adult beetle deposits their eggs on the surface of bean pods or directly on the seeds (Maklakov *et al.*, 2007). The larvae hatched from the eggs burrow the

Pods and entered into the seeds to feed on the nutritious cotyledons (Paul, 2007). The whole durations from larva to pupa remain inside the seed (Ayamdoo *et al.*, 2013).

Deterioration of bean quality due to the insect attack is a common phenomenon (Kusolwa, 2007; Singh, 2001). More than 70 faba bean producer countries in the world are suffering from the infestation, damage and loss of faba bean grains due to *A. obtectus* (Amer *et al.*, 2012; Messina and Fry, 2003). The insect causes serious quality and quantity losses particularly in the tropics and subtropics where moisture and other environmental factors are appropriate (Mohamed and Abd-El Hameed, 2014). The extent of losses may vary depending on location, grain varieties, storage conditions and periods of stored faba bean grain durations (Thakur and Kalpna, 2015).

The average dry weight losses during storage have been estimated between 10% and 40%, but where management practice is poor; losses can be well above 50% (Ayamdoo *et al.*, 2013). Beans with multiple emergence holes due to bruchid are emitting a characteristic pungent odor which is useless for consumption and have no commercial value (Mazzonetto and Vendramin, 2003). The longer the bean grains are kept in storage, the greater the chance to increase the losses (Thakur and Kalpna, 2015).

Damaged faba bean seeds are covered with eggs and perforated chambers of the insect (Sacic *et al.*, 2003). The losses may be augmented by subsequent attacks from fungi and bacteria and other secondary storage insect pests. The moisture and temperature increase within the grain mass through respiration and metabolisms of the larvae; and thus inviting secondary rotting by microorganisms attack (Jones *et al.*, 2011). Holes in bean grains due to bruchid attack provided sights for entry and growth of fungi in the infested seeds which leads to poor plant development (Misangu, 1997). Heavily perforated bean seeds absorb water in the field that results failure to germination (Boeke, 2002).

The continuously growing world population needs substantial food resources (Sacilik *et al.*, 2003; Singh, 2001). Postharvest management practices are playing an important role to achieve this objective (Betancur *et al.*, 2009; Singh, 2001). It is crucial to know mechanisms of bruchids movement from field to storage which may help to develop environmentally friendly and economically feasible control methods to protect faba bean grains from bruchids (Agona and Muyinza, 2003).

Several methods may protect stored beans from bruchids without the need for insecticide applications (Mohapatra *et al.*, 2015). Combining methods may reduce the likelihood of the development of resistance (Mazzonetto and Vendramim, 2003). Botanicals have long been known by many tropical farmers and used traditionally for many years to control storage insect pests (Taponjou *et al.*, 2002). Oils affect egg laying as well as embryo and larvae development on the surface of the seed (Cardet *et al.*, 2005). It causes death to the eggs and larvae before they entered into the seed (Singh, 2001).

Farmers reported that the use of different plant extracts to protect stored beans against bruchids had proven to be very effective (Derbalah and Ahmed, 2011; Mazzonetto and Vendramim, 2003). Another important factor for bruchid control is moisture adjustment on stored faba bean grains (Mason and McDonough, 2012). The level of moisture contents in stored grain determines infestation and damage of the grains after storage (Nahar *et al.*, 2009). The risks of bruchids damage increases as grain moisture content increased (Garcia-Perea *et al.*, 2014). These strategies helped farmers to improve their food security and increase their income (Mazzonetto and Vendramim, 2003).

Bean grains are being damaged by *A.obtectus* in Africa including Ethiopia in general, Amhara regions of Eastern and Western Gojjam Zones in particular. The pest damage faba bean grains

starting from the field to storage (Kananji, 2007; Paul, 2007; Schmale *et al.*, 2006). As the result farmers are selling their bean grains immediately after storage at a low price and buying latter with higher price for consumption and seed purpose.

Bean grains are being damaged by *A.obtectus* in Africa including Ethiopia in general, Amhara regions of Eastern and Western Gojjam Zones in particular. The pest damage faba bean grains starting from the field to storage (Kananji, 2007; Paul, 2007; Schmale *et al.*, 2006). As the result farmers are selling their bean grains immediately after storage at a low price and buying latter with higher price for consumption and seed purpose.

The farmers don't differentiate bean beetles and weevils and call them storage insect pests as a whole (ARARI, 2002). In Amhara Region specifically in Eastern and Western Gojjam Zones subsistence farmers apply numerous strategies to control bruchids including botanicals in the form of dusts and oils, mixing faba bean grains to tef, ash, gravel (grins used for seed) (BPHC, 2009; Worku, 2002). Green plants act as a reservoir for inexhaustible source of innocuous pesticides, which are mammalian, nontoxic and easily biodegradable than synthetic chemicals (Tadele *et al.*, 2014; Yemane, 2013; Emanu, 1999).

Promising efforts have been made in the last 2-3 decades to identify botanicals with better insecticidal potential for bruchid management as an alternative insecticides (Dubale, 2014; Araya and Emanu, 2009). Nevertheless, there was limited information in the preparation of botanical oil extracts, their dose, toxicity and methods application (Araya and Emanu, 2009). In addition, moisture adjustments of faba bean grains has given low emphasis by the farmers, plant protection experts and researchers to manage bean bruchids.

The farmers are trying to use frequent sun drying of faba bean to create the conditions unfavorable for bean bruchid development (Astuti *et al.*, 2013; Nahar *et al.*, 2009). Cold storage rooms used to

retard the development and reproductive ability of bean bruchids (Paul, 2007). Other local control strategy is timely harvesting and use of air-tight containers to minimize bruchid infestation before and during storage (Joshua, 2007; Kingsolver, 2004). However, the period of infestation in the field and the sensitive stages of the plant is not well recognized in Ethiopia to manage bruchids. According to Schmale *et al.* (2002), a number of experiments has been done to manage bruchids, however, little attention was given to control the insect in the field.

A survey conducted in Ethiopia including Amhara Region has not given enough information about bruchids distributions, species composition and damage level on faba bean grains. In addition, there is a knowledge gap on the period of bean bruchid infestation and the sensitive stages of the plant in the field. As a result, the farmers are trying to manage bruchids mainly after storage. Applications of botanicals in different forms are a common practice by farmers and researchers to control bean bruchids. However, the efficacy of the current botanical oils are not clearly evaluated. In addition, faba bean grain moisture reduction to a well-defined level is not a common practice by the farmers during storage. This study was designed to know species composition and distribution of bruchids that affect bean grains and look for various management strategies both in the field and after storage. Hence, the current experiment was conducted to address the following objectives:

1.1. Objectives

1.1.1. General objective

To contribute the reduction of losses caused by bean bruchids, *A.obtectus* Say and studying the distribution and species composition of bruchids

1.1.2. Specific objectives

- To determine on distribution and species composition of bruchids in North Westrn Amhara, Ethiopia
- To determine the time when bean bruchids start infesting faba beans in the field
- To screen effective botanicals against *A.obtectus* and
- To determine safe storage bean moisture which can minimize *A.obtectus* infestation

Chapter Two. Literature review

2.1. Origin and facts of faba bean

Faba bean categorized under the leguminaceae family is an ancient crop domesticated early in archaeological deposits of the Stone, Bronze and Iron Ages in the Near East and Mediterranean basin: in Spain, Italy, France, Switzerland and Germany (Singh *et al.*, 2013; Cubero, 1973). The name faba originates from Greek which highlights its use for food and feed by the ancient Greeks and Romans (Cubero, 1973). Despite numerous studies, little is known about the origin and domestication of faba bean (Singh, 2001). Cubero (1973 and 1974) postulated that the Near East was its center of origin following the Neolithic Era around 10000-9000 BC. According to Saberi (2015) there were four different routes radiating from this center: (1) to Europe (2) along the North African Coast to Spain (3) along the Nile to Ethiopia; (4) from Mesopotamia to India.

Ethiopia is undoubtedly considered to be one of the important centers of secondary diversity of faba bean and field pea (Gemechu *et al.*, 2011; Singh, 2001). As many findings agreed that, South Western Asia is the principal center of *V. faba* origin (Saberi, 2015). Other scholars agreed that large seeded forms of the species are concentrates around the Mediterranean region (Singh, 2001). Now a days it is cultivated over a latitudinal range from the Equator to approximately 50°N and 40°S and altitude range from sea level to above 3000m (Duc *et al.*, 2010). The longer period of cultivation across very diverse environments has resulted in differentiation of germplasm in to distinct seed size and color of various varieties (Gnanasambandam *et al.*, 2012).

The various chemical compositions of faba bean are a suitable food for diabetics, heart disease and reduce levels of blood glucose (Baginsky *et al.*, 2013). Faba bean may be preferred by the food industry due to its high phenolic content to promote the benefits for human health from the

consumption of vegetable with a higher content of antioxidant compounds (Baginsky *et al.*, 2013). However, the crop is affected by different insect pests both in the field and in storage. *A. obtectus* is the prominent storage insect pest that affects both the quantity and quality of the crop (Alghamdi, 2009).

2.2. Constraints of faba bean in storage

Bean crops are attacked by numerous pests at all growing stages (Paul, 2007). The Bean beetle (*A. obtectus*) is one of the most economically important and devastating pests starting from matured faba bean pods or grains in the field to stored grains (Schmale *et al.*, 2002). It is a serious pest particularly in areas with a high density of bean production (Yemane, 2013). However, almost all farmers growing faba bean do not understand the beetle's life cycle and the origins of the damage done by the larvae (Schmale *et al.*, 2002).

There are about 1300 species of seed beetles in the family bruchidae (Khadim and Mbacke, 2011). About 20 are recognized (Khadim and Mbacke, 2011) as being pests, usually in stored legume seeds. Four species are cosmopolitan in distribution and economically more important (Kingsolver, 2004). These are *Callosobruchus chinensis*, *A. obtectus*, *C. maculatus* and *Zabrotes subfasciatus*. Other species of *Callosobruchus* species include *C. analis*, *C. rhodesianus* and *C. subinnotatus* constitute a secondary group of storage pests of legumes, and *Bruchus pisorum* L., *B. rufimanus* are important as pests in the field and early period of the crop in the storage (Kingsolver, 2004).

A considerable volume of stored faba beans grain losse is recorded every year due to bruchids (Rajashekar *et al.*, 2012). Bruchid damaged grains have low weight, reduced quality and viability (Nahar *et al.*, 2009; Misangu *et al.*, 2000). The degree of losses due to bruchid damage is quite variable and depends on the storage period and storage conditions of the surrounding environments (Nahar, *et al.*, 2009). Bruchids inflict damage on stored faba bean grains by direct feeding and causing

loss of weight and quality (Misangu *et al.*, 2000). They feed on the germ, resulting in poor seed germination and less viability (Astuti *et al.*, 2013).

According to Misangu *et al.* (2000) farmers limit the time that they keep their harvest to avoid bean losses due to bruchids. Many farmers sell the crop (usually at low price) shortly after harvest (IBRD, 2011). Another production strategy that farmers use is not to produce a large quantity during any one season for the fear of such post-harvest losses due to bruchids (IBRD, 2011). Where bean beetles are prevalent, significant market price fluctuations are observed throughout the year (Anton, 2000).

2.3. Pest status of bean bruchids, *A. obtectus*

The bean bruchid, *A. obtectus* is a major stored pest of faba bean (*V. faba*) in many corners of the world (Rugumaru, 2014). The insect is cosmopolitan pest of leguminous seeds both in the field and storage (Kananji, 2007; Schmale *et al.*, 2002). The adult bruchid is not harmful and economically important apart from egg laying by the female (Thakur, 2012). The larva consumes part of the seed, causing considerable damage (Moss and Credland, 1994). *A. obtectus* differ from all other bruchid species in that its egg is not firmly attached to the individual seeds. The eggs are scattered loosely amongst potential hosts (Thakur, 2012; Kananji, 2007). On hatching the larvae move freely to search suitable hosts (Moss and Credland, 1994).

A. obtectus may infest matured pods in the field by chewing with opening into the suture and laying an egg cluster into the pod cavity or singly scattered with the external surface of their host (Antonio *et al.*, 2014). The hatched *A. obtectus* larvae wander among the beans before entrance to leguminous grains (Sapunaru *et al.*, 2003). Once penetration takes place, both larvae and pupae pass their stage within the grain (Sapunaru *et al.*, 2003). In spite of, its particular infestation pattern in the bean field, its importance as a field pest is under estimated (Paul, 2007).

2.3.1. Morphology

The morphology of *A. obtectus* may be confused with other bruchid adults. However, adult can be distinguished by having single row of three to four closely located large spines on the outer end of each hind femur (Sapunaru *et al.*, 2003). Adult bean bruchid is 3.25-4.50 mm long, 1.50-2.50 mm wide and greyish brown in color (Thakur, 2012). The bruchid antenna is filiform with 1-4 segments, and more serrated form and more broadened with 5-10 segments and non serrated with 11 segment with apically acute (Thakur, 2012). Regarding color variations of antenna segments 1-5 are grey or of the same color as the body, 6-10 dark blackish and segment 11 red/orange (Kasambal and Hendry, 2004).

The beetle body is ovoid, slightly convex, light or dark brown, with yellow-green golden hairs and longitudinal spots from above, light gray hairs from below (Paul *et al.*, 2010). Dark brown short elytra do not cover abdominal end (Schmale, *et al.*, 2006). Pronotum is wider than its length; quadrangular scutellum is large. The insect is known to be yellow-red legs (Thakur, 2010). Eggs are white, about 0.6-0.7 mm in length (Thakur, 2010). Young cylindrical white larvae have pale cream and are scarabaei form with bristles and 3 pairs of reduced legs (Rugumaru, 2014). White pupa is about 4 mm in length (Rugumaru, 2014). Seeds with pupae inside have translucent windows through which emerging adult will escaped (Thakur, 2010).

2.3.2. Biology

Adult bruchids can infest faba bean pods or seeds in the field as well as seeds in storage (Archiv, 2010). The female bean bruchid lays their eggs in the field on the surface of mature pods, or laid loosely among seeds in storage (Paul, 2007; Schmale *et al.*, 2006). The hatched larvae moves among the grains to select suitable hosts and burrow in to the seed to complete the development (Paul, 2007). The larva and pupa remain within a single seed before emerging to adults (Khadim and Mbacke,

2011). The newly emerged adult *A. obtectus* mates within the first 24 hours and starts ovipositing during the next 24 hours (Thakur, 2012). Bean bruchids breed rapidly in storage and complete their life cycle within a short period of time (Paul, 2007). However, biological activities of the bruchids are very slow when grain moisture content is below 10% (Antonio *et al.*, 2014). The adult may feed on sugar/water, pollen and nectar in flowers, but does not normally feed (Sapunaru *et al.*, 2003).

Freshly emerged adults copulate at any time about one hour (Kusolwa, 2007). The male normally raises its fore and middle legs to hold the female during copulation and lasts for about 4-5 minutes (Sapunaru *et al.*, 2003). Gravid female lays up to 70 eggs on the host seeds (Sapunaru *et al.*, 2003). The female lays its eggs on ripening pods in groups of (5-20) eggs or depositing singly without stack to seeds that scatters them irregularly among host seeds (Anton, 2000). Eggs are ellipsoidal in shape and oviposition lasts for 6-10 days and the rate of egg lying is high around the first days of oviposition periods (Parsons and Credland, 2003). Freshly laid eggs are milky white, but become transparent before the larva hatches out (Betancur *et al.*, 2009).

The pest is sexually dimorphic; males are active, smaller in size with a vertical pygidium whereas females are more bulky, inactive with a sub-vertical pygidium (Alvarez, 2005). Like other bruchids, adult of *A. obtectus* are weak flyers and feign death during disturbance (Archiv, 2010; Thakur, 2010). The first instars larvae bore into the seed and then feed, grow and molt into successive four instars entirely within the seed. Since, there is no evidence of their appearance of holes except circular windows that are created when the last instar larvae gnaw close to the seed coat to prepared for adult emergence (Betancur *et al.*, 2009).

Larvae possess three pairs of legs, are white in colour and covered with white shining setae of variable size (Schmale *et al.*, 2002). First instar larva has a large golden head and white elongated body (Thakur, 2010). The First instar larvae bore into the host seed with the help of an 'H' shaped

prothoracic too like cuticular plate (Sapunaru *et al.*, 2003). Since the eggs are not glued on to seeds it is essential for freshly hatched first instar larva to find a suitable host seeds for food (Khadim and Mbacke, 2011).

Entrance holes into the host seed later become plugged by faecal matter (Mining *et al.*, 2014; Thakur, 2010; Sapunaru *et al.*, 2003). Adult bruchids emerged from their host through emergence holes made by the last instar larva (Paul, 2007; Schmale *et al.*, 2006). The pest is multi voltine and completes three to five overlapping generations per year (Thakur, 2012). Overwintering takes place at the stages of adult beetle or larva (other stages can also overwinter rarely); in store houses or plant residues (Kingsolver, 2004). Hibernating periods of larvae and pupae lasts for 4-5 months (Mining *et al.*, 2014).

2.3.3. Infestation

The beetles start to lay their eggs to infest bean pods or grains in the field and continue to develop during storage of grains (Misangu, 1997). Bruchids attract light when the surrounding temperature is above 20°C. They migrate out of the stored grains and travel up to 3 km to locate bean plants (Kingsolver, 2004). *A. obtectus* females are stimulated to oviposit by the presence of beans (Paul, 2007). It is probable that in the field the wilting pods attract the females (Paul, 2007). It was mostly observed that females attract more on dry matured pods than soft wilting and wet pods (Sapunaru *et al.*, 2006). Paul (2007) reported higher field infestation rates observed by *A. obtectus* in partially opened pods compared to closed pods due the presence of cuticular hydrocarbon compounds on the outer cuticle of parent bean bruchids (CHC₃). *A. obtectus* use intraspecific and intraspecific communications to identify their hosts due to the presence of such compounds (Paul, 2007; Sapunaru *et al.*, 2006; Kingsolver, 2004).

Pod openings attract female *A. obtectus* for oviposition, but some dehiscent pods also present orifices made by the insect (Paul, 2007). The insect is being attracted more to partially opened pods than closed pods (Schmale *et al.*, 2006). Leaving the crop in the field after maturity prolongs the time of exposure to the insect and increases rate of infestation (Schmale *et al.*, 2002; Olubayo and Port, 1997). Infested beans usually carried multiple larvae per bean and oviposition by *A. obtectus* in the field is confined to a very short period before harvest. This narrow time can be exploited for proper timing of control measures (Schmale *et al.*, 2002).

2.3.4. Distribution

Bruchids are a serious threat to broad bean throughout the world (Qazi, 2007). The pest is characterized by a worldwide distribution, in relation to ancient human cultivation and trade with legume seeds and large population are often found in seed storage (Obopile *et al.*, 2011). The bruchids have crossed the geographical boundaries and become cosmopolitan in distribution through human-mediated migrations and import/export of food grain (Napoles, 2010).

Bruchid infestation is hidden that can easily move across the geographical boundaries in import/export consignments and may pose a great phytosanitary threat in new ecological niches due to the absence of natural enemies (Thakur, 2010; Betancur *et al.*, 2009). This internal mode of life protects the insect from variations of temperature and humidity and enables them to be carried unnoticed during trade across the international boundaries (Parsons and Credland, 2003). Hence, *A. obtectus* is now found in many areas of the world, and has become a frequent pest in faba bean grains (Thakur, 2012).

2.4. Ecology

Bruchids are able to increase drastically in number under conducive storage environments within relatively short times (Basavaraja *et al.*, 2007). They reproduce in a broad range of ecological

conditions (Sapunaru *et al.*, 2006). Reproduction ability of the insect depends on the suitability of the surrounding environmental factors (Petzoldt and Seaman, 2006). The beetle can damage dry grains containing 12-13% moisture contents (Khaliq *et al.*, 2014). Below 10 percent grain moisture content ceases the activity of bruchids (Hagstrum and Milliken, 1988). In developing countries, farmers who produce beans experience significant losses because of the high reproductive rate and damage of *A. obtectus* in a wide ranges of ecological adaptations (Thakur, 2012).

The most favorable environmental conditions for *A. obtectus* development in terms of temperature is ranging from 27-29°C for adults, 24-27°C for larva and 22-26°C for pupa (Reuss *et al.*, 1995). Higher and lower temperature causes fecundity reduction (Thakur, 2012). It emerges at the temperature of 12.5°C, but in active below 16°C. When the environmental conditions are ideal (around 20°C), the insect migrates to the nearby fields (Reuss *et al.*, 1995). The adult prefers high humidity (Mboya, 2013).

2.5. Management of bean bruchids, *A. obtectus*

The bean bruchid, *A. obtectus* is known to cause heavy losses on faba bean grains that necessitating immediate and long term control measures. It is crucial to manage bruchids through integrated approaches. Management of the insect focuses at different levels of the plant stages in the field when faba bean crops are physiologically matured and also in the storage (Joshua, 2007; Berier *et al.*, 2005).

2.5.1. Cultural

Several methods may protect stored beans from bruchid without the need for chemical insecticides (Joshua, 2007). The effectiveness of adequate control might depend on a combination of compatible control strategies (Yemane, 2013). Experiences show that a combination of measures, e.g. time of harvesting, proper drying, store in a suitable storage structures and adequate protection of stored beans can offer effective protection to the grains from bean bruchids (Utono, 2013). Some storage

pests including bean beetles infest legume pods or grains in the field only when the crop is almost dry that pushes to control the insect in all stages of the crop starting from field to storage (Schmale *et al.*, 2006).

In many parts of the world farmers are not aware of the fact that *A. obtectus* attack beans when the plants are still in the field (Schmale *et al.*, 2002). Time of harvesting determines the level of field infestation (Paul, 2007). Timely harvesting also can therefore ensure bruchids are not carried over to the storage along with bean grains (Joshua, 2007). Thus, timely harvesting significantly reduces infestation by the pest (Olubayo and Port, 1997). Each week of delayed harvesting increases infestation by *A. obtectus* (Kingsolver, 2004). As a rule, do not leave crops in the field when they are ready for harvest so as to decrease the chances of bruchids infestation in the field (Schmale *et al.*, 2002). It is required to burn or to avoid left over crops immediately after harvest (Khadim and Mbacke, 2011).

Drying is an important method of bruchid protection (Astuti *et al.*, 2013). It also prevents seeds from germination and protects attack by fungi and other storage insect pests (Nahar *et al.*, 2009). Some fungi can cause cracking of grain thereby making the grain more susceptible to bruchid attack (Weinberg *et al.*, 2008). All seed must be dried in order to be stored safely (Paul, 2007). Put one seed or kernel in the mouth and chew to make sure the seed is properly dried. If it cannot easily be cracked it is dry enough unless the reverse is true (Tabu *et al.*, 2012).

Heat used for drying the produce kills larvae, pupae and chase away adult bruchids (Weinberg *et al.*, 2008). Care should be taken to avoid overheating since excessive heat can damage the seed or grains. Heating should be done between 35°C and 50°C (Antonio *et al.*, 2014). A thermometer can be used as heating to any higher temperature will destroy the germination capability of the seeds (Nukenine, 2010). Seed can be spread out in the sun on a hard clean surface to dry until a seed cannot be bitten

into when putting it in the mouth (Tabu *et al.*, 2012). The thickness of the layers of pods or grains must not exceed 5 cm during drying (Antonio *et al.*, 2014). The seed must be turned regularly in order to ensure good and even aeration (Mohapatra *et al.*, 2015).

Store and treat infested and normal grains separately to prevent clean produce from infestation (Renuka *et al.*, 2014). Removal of infested grains can be done by hand (Mohapatra *et al.*, 2015). Sieving (a mesh of 1 to 3 mm), winnowing or moving the grain (shaking) (Dua *et al.*, 2010) that separate the pests from the stored product to kill them and to avoid re-infestation (Morya *et al.*, 2010). In case of heavy infestation discard the produce to save other sound grains (Paul, 2007).

As many experts agreed, keeping the storage structure and its surroundings clean well before and after newly harvested grains are stored ahead of time is advisable (Kasambal and Hendry, 2004). Cleaning the storage room and removal of old grains minimizes bruchid infestation and buildup of its population (Morya *et al.*, 2010). Fumigate or disinfected the whole building to decrease cross infestation (Koono and Njoya, 2004). These measures prevent the breeding of carry-over insects from former crops. The walls, roof and floor should be watertight white washed and kept and free from small holes and cracks, which are potential breeding places for bruchids (Nukenine, 2010).

Turning the grain is thought to kill bruchids by crushing them; however, there are other reasons why moving grains causing mortality (Nukenine, 2010). *A. Obtectus*, larva needs over 24 hours to enter bean grains (Nukenine, 2010). According to Messina and Fry (2003), rolling beans every 8 hours reduce the bruchid population by 97% due to neonate larvae are never able to finish an entry hole. A combination of measures, e.g. time of harvesting, proper drying before storage, usage of suitable storage structures and adequate protection of stored beans can offer effective protection from bean bruchids without the need of insecticide applications (Koono and Njoya, 2004).

2.5.2. Grain moisture adjustments

Grain moisture content is one of the important factors that determine the duration and quality of faba bean grains after storage (Garcia-Perea *et al.*, 2014). The grain moisture content during storage is directly associated with environmental factors like moisture, temperature, relative humidity and other factors that affect seed physiology during storage (Rembold *et al.*, 2015). Well dried faba bean grains at a moisture content of 11% or below can be stored for extended periods of time (Weinberg *et al.*, 2008). However, dried grain can absorb moisture from the surrounding environments occupied by high relative humidities and causes qualitative and quantitative losses (Rembold *et al.*, 2015). Viability of highly moistened faba bean grains decrease rapidly due to infestation by insects and fungi soon after storage and growing quickly with a high rates of multiplication (Punzo, 1975).

Safe storage moisture is very important factor to keep quality grains after storage (Ofuya *et al.*, 2010). Matured grains dried in the field before storage when the moisture content of the surrounding environment is lower (Astuti *et al.*, 2013). The humidity of the air determines the rates of moisture migration to or out of stored grains (Weinberg *et al.*, 2008). Entrance of moisture from the surrounding air to stored grains can be protected (Fowler, 1995). Relative humidity, moisture migration and air flow rate determines the availability of moisture with in stored grains and the emergence of bruchids during storage (Tavakoli *et al.*, 2009). Initial infestations of bruchids are mainly affected by the availability of moisture on stored grains (Garcia-Perea *et al.*, 2014). Grains having high moisture contents at storage commonly stored for short periods of time due to bruchid infestation (Regmil and Dhoji, 2011; Fowler, 1995).

Moisture contents available in stored grains are increasing or decreasing the activities of grain enzymes (Fowler 1995). In damp grains, enzyme activities increase and insect infestation and their damage enhanced to cause grains spoilage rapidly (Weinberg *et al.*, 2008). The increment of moisture

makes the grain more favorable for infestation and bruchid multiplication (Fowler, 1995). Most storage insects are biologically dormant or die during storage in 9% or lower moisture content of stored grains (Punzo, 1975). In general, insects are not reproducing in large number in grains stored with moisture content of 11% or less (Weinberg *et al.*, 2008). Storage insects prefer grains of high moisture contents to cause damage and to multiply rapidly (Astuti *et al.*, 2013).

2.5.3. Botanical

Botanicals such as plant essential oils and their chemical constituents are reported for their developmental inhibitory activities against bruchids (Warra, 2011). On the basis of insect physiological activities, experts conventionally classified the plant components into 6 groups namely, repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemo-sterilants, and attractants (Sman, 2006). Focus on the toxicants and grain protectants, essential oil extracts, and its constituents has increased since the 1980s (Mohamed, 2012; Upadhyay and Ahmad, 2011).

Of the several control measures adapted against the menace of bruchids, pesticides have provided rapid curative action in minimizing crop damage, flexibility in usage and a more practical measure (Karunamoorth *et al.*, 2009). But, due to environmental contamination and residue in food, potential chronic toxicities, disruption of non-target organism; resistance development, resurgence of pests; and steady increase in cost of pesticides, alternative measures are sought for farmers (Uddinll and Sanusi, 2013). Admixed plant oils with stored product are a common practice by peasant farmers in rural Africa to drive away insects or deter them from feeding (Yahaya *et al.*, 2013).

Most of the grains produced in Sub-Saharan Africa come from small-scale farmers, many of whom use different kinds of plant products for bruchid control (Swella and Mushobozy, 2007). Applications of botanicals in various forms to protect the grains are a traditional method in many rural areas. Botanicals such as essential oils, extracts of leaves, bark, seed kernel, powdered plant parts, have

been subjected to laboratory condition and field trials to control bruchids (Jemaa, 2014). Using bio-products is safe alternative for synthetic pesticides (Swella and Mushobozy, 2007).

The use of plant extracts to protect stored beans against bruchids had proved to be very effective (Swella and Mushobozy, 2007). Many research findings and the farmers report indicated that botanical preparation and measures can be carried out locally and are easy to apply (Ibrahim and Aliyu, 2014). They no longer use expensive and hazardous chemical pesticides (Yahaya *et al.*, 2013). These strategies have helped farmers to improve their food security and increase their income, which is used for paying school fees, buying food products or hiring land (Swella and Mushobozy, 2007).

The mode of action of oils is partially attributed to interference in normal respiration, resulting in suffocation (Lal and Raj, 2012; Derbalah and Ahmed, 2011). It is thought that oils exert some lethal action on developing embryos or first instar larvae, for example, by the reduction in rate of gaseous exchange due to a “barrier” effect and/or direct toxicity by penetrated oil fractions (Derbalah and Ahmed, 2011). However, the effect of oil treatment decreases with time, so seeds stored this way should be treated again when sign of infestation observed (Olotuah, 2013). If neem seed oil or any other non-food oil is used the bitter taste can be removed by immersing the seed in hot water for a few minutes before food preparation (Ibrahim and Aliyu, 2014).

Plant essential oils (EOs) exhibit biological activity against a wide spectrum of plant pests and may act as fumigants, contact insecticides, repellents, and antifeedants, or they can affect the growth rate, reproduction, and behavior of insect pests (Uddinll and Sanusi, 2013; Mbailao *et al.*, 2006). In addition, the low mammalian toxicity of EOs and their rapid degradation in the environment make them attractive alternatives compared to conventional pesticides (Bhardwaj and Verma, 2012).

Many plant oils are effective to control adult bruchids and interfere with other developmental stages (Uddinll and Sanusi, 2013). Oils extracted from plants reduced the emergence of F₁ or F₂ progenies

to minimize damage of pulse grains due to bruchids (Swella and Mushobozy, 2007). Oils cause high mortality of bruchid eggs and larva on the surfaces of the grains (Swella and Mushobozy, 2007). The use of plant oils reduce negative effects on stored crops and the associated environments (Ibrahim and Aliyu, 2014). Such oils are relatively safe, biodegradable, economically feasible and easily available in nature around every localities where farmers are living (Ibrahim and Aliyu, 2014).

Botanical oils are not very selective due to their target to a broad range of insect pests (Sman, 2006). Most plant oils have naturally had more than one ingredient that synergistically works to protect resistance development (Hossain and Haque, 2010). Farmers in Africa are admixed plant oils to their stored grains to drive away and deter bruchids from feeding (Yahaya *et al.*, 2013). Plants are traditionally used as crop protectants, when used alone or in mixtures (Kareru *et al.*, 2013). Indigenous knowledge and traditional practice are contributing a great role to produce organic products (Sman, 2006).

2.5.4. Chemical

Bruchids can be managed by applications of insecticides or other practices depending on the level of infestation and damage on grains (Murugesan *et al.*, 2012). Count 100 beans and looks round holes on the surface of bean grains made by the bruchid larvae (Mendki *et al.*, 2001). This process should be repeated several times (Mendki *et al.*, 2001). If 4 out of 100 beans count have these little holes in the testa of infested grains, it is required to apply insecticides (Murugesan *et al.*, 2012). Less damage than this will not cause a significant reduction in germination, food quality, or market price that needs to control the insect with other management strategies (Kropff, 2008).

Applications of insecticides can be both effective and safe, if carried out intelligently and consciously (Remia and Logaswamy, 2010). Insecticide application is one means of preventing grain losses during storage (Olotuah, 2013). Insect pest control at farm level is increasingly relying on the use of

synthetic insecticides by farmers who lack technical knowledge in the safe handling and use of application (Thein *et al.*, 2013). The misuse of synthetic insecticides has led to accidental poisoning, the development of insect resistance and other environmental and health hazards (Murugesan *et al.*, 2012).

Wise utilization of synthetic insecticides including fumigants, dusts and sprays control effectively the bruchids and other storage insect pests (Martha, 2010). Spraying of insecticides is possible in the field before larvae are entered to the pod (Olotuah, 2013). Fumigate the grains immediately after harvest and stored insect proof structures that cause bean beetles in trouble (Pathak *et al.*, 2014). Fumigation of infested cull grains before releasing for animal feed (pandey *et al.*, 2011). It is important to the farmers and other users to have good knowledge of the classification, mode of action and residue of the insecticides to enable them more efficient and reduce risk (Obeng-Ofori, 2010). Continuous applications and heavy usage of synthetic insecticides may result to direct toxicity of non-targeted organisms (Talukder, 2009). In addition, certain chemicals may get concentrated and may cause lethal effects on human beings (Talukder, 2009). There is a need for frequent training on selective, right and safe use of insecticides to ensure human safety and environmental protection (Obeng-Ofori, 2010).

In general, insecticides such as effective against most storage insect pests, low toxicity to warm blooded animals and low tendency to create resistance development are preferable to manage bruchids (Talukder, 2009). In addition, good insecticide satisfies no harmful residue left in stored grains, no effect on smell or taste on the treated faba bean grains, simple to use and low price that can afforded by small scale farmers (Sarwar, 2013).

2.5.5. Integrated pest management

Management of bruchids should not rely upon any single method of control, but should be based on various most effective, economical and compatible control techniques together (Talukder, 2009). Integrated pest management (IPM) uses a combination of cultural practices in order to host resistance, biological control and chemical control methods simultaneously (Obeng-Ofori, 2010). IPM prefers more on non-chemical practices for protection of stored products free from residue problems in stored grains (Berier *et al.*, 2005). In addition, health hazards are avoided when chemicals are not used for grains for consumption (Joshua, 2007). The approach of integrated pest management has safety to human and animals, no pollution to faba bean grains and long lasting control effectiveness (Obeng-Ofori, 2010). The grains should be examined frequently and bruchids can be managed most effectively with an integrated approach of different friendly control strategies together (Sarwar, 2013).

In order to control bruchids in the field and after storage, frequent monitoring and identification of the insect is an important prerequisite for IPM (Sarwar, 2013). It is needed to develop numerous strategies to control or eliminate field infestations on faba bean plants before or after the grains are stored (Jemaa, 2014). Since bruchids, are increasing tenfold with each generations, controlling the insect at early stage is advisable either in the field or during storage (Berka-Zoygali *et al.*, 2012). For holding the best faba bean quality during storage, it necessitates to integrate a number of control methods together with insecticides to prohibit infestation, bruchid development and grain quality impairment (Singh, 2001). Therefore, conclusions could be drawn that selected control strategies must be integrated for effective management of the bruchids (Sarwar, 2013).

It is essential to understand the factors, which promote the growth of bruchids either in the field or after storage (Weinberg *et al.*, 2008; Schmale *et al.*, 2006). Proper drying of the grains is not only

killing the insect, but also reduces grain moisture contents to the limit of safe storage (Nahar *et al.*, 2009). Lack of sanitation and improper storage environments may increase faba bean moisture contents after storage that creates conducive conditions for re-infestation (Mohapatra *et al.*, 2015). This, eventually results in to quality deterioration of the grains during storage (Kasambal and Hendry, 2004). The grains should be examined frequently and bruchids can be managed most effectively with an integrated approach of different eco-friendly control strategies together (Sarwar, 2013).

Chapter Three. Survey on faba bean grains (*Vicia faba* L.) handling and bruchid distribution in North Western Amhara region, Ethiopia

3.1. Introduction

Faba bean (*V. faba* L) grains are commonly stored by farmers due to their valuable nutrient content and ease of storage (Abebe and Bekele, 2006). It is the major legume crop grown in Ethiopia both as a sources of protein and export crop for earning foreign exchange (Araya and Eman, 2009). However, faba bean storage is a crucial operation due to bruchid infestation all the year round under favorable conditions that completes several generations a year (Alemayehu, 2009). The crop suffer heavy losses within a short period of time after storage (Dasbak *et al.*, 2009). Large quantities of the grain are destroyed or contaminated due to the attack of bruchids (Endale *et al.*, 2014). The insect damage the grains by feeding and thereby reduce dry weight, germination, nutritive value and increase susceptibility to secondary pests and other microorganisms (Tadele *et al.*, 2014).

Faba bean grain losses in Ethiopia are a serious problem due to bruchids (Endale *et al.*, 2014). Bruchids are characterized by high rates of production and shorter developmental periods enabling them to multiply rapidly and inflict damage (Kananji, 2007; Reuben *et al.*, 2006). The degree of grain losses are a function of environmental factors (moisture, temperature and relative humidity within the storage structures), the sites where storage structures are located, cleanness of bean grains and period of storage (Sapunaru *et al.*, 2006).

Inappropriate management practices during storage, poor quality faba bean grains used for seed and bruchid infestation leads to faba bean grain losses before and after harvest (Yahaya *et al.*, 2013). Starting from harvest, bean grains undergo a serious of operations during which quantitative and qualitative losses may occur (Basavaraja *et al.*, 2007). There are multiple causes of postharvest faba bean losses; however, the most significant losses are caused by bruchids. Lack of appropriate storage

facilities, inappropriate package, inadequate transportation and lack of expertise advisory service are some of the factors that exaggerate faba bean grain losses (USAID, 2013). The extents of losses fluctuate considerably depending upon whether conditions, varieties, location and the process and storage conditions (Sales *et al.*, 2000).

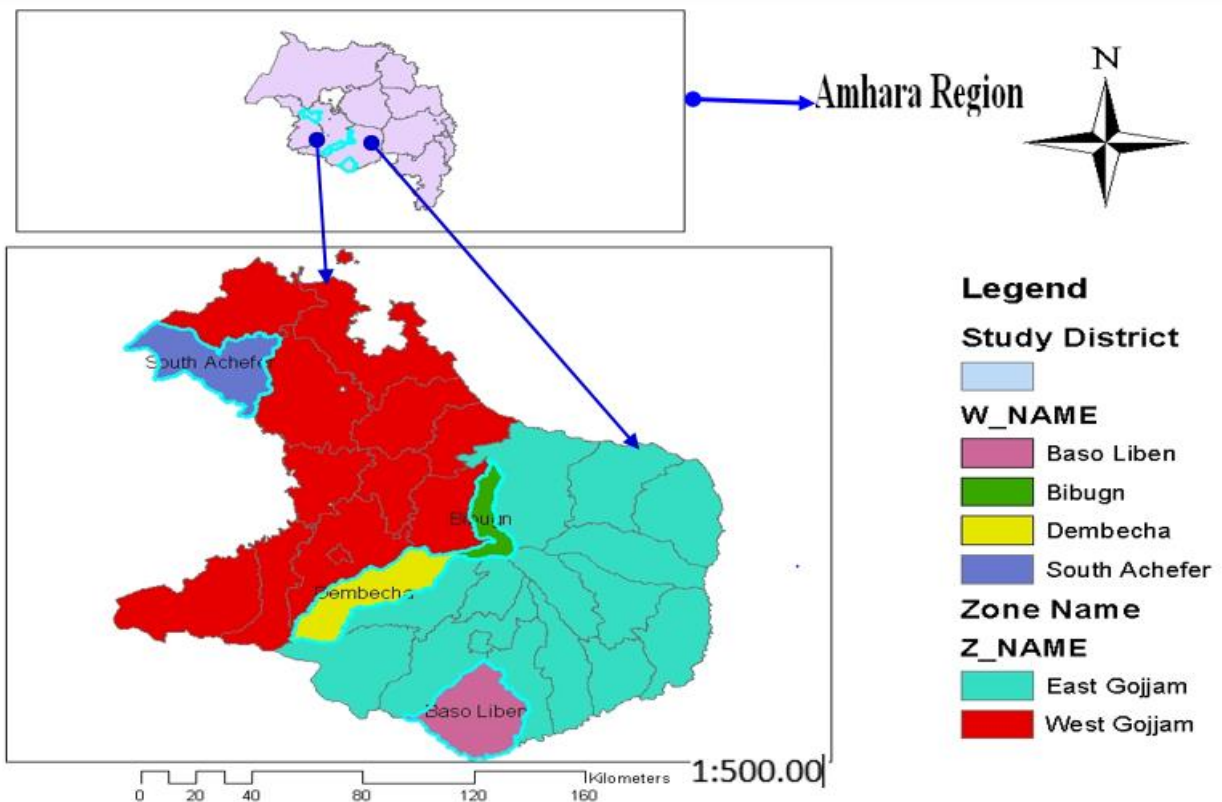
Faba bean is the predominant leguminous plant produced in Ethiopia in general and Amhara Region in particular. The farmers are using the grain for home consumption, seed purpose and supply to the local market for material exchange and other purposes. However, there is no postharvest handling facilities and advisory service given to farmers. Hence, studies are required on the extent of faba bean grain losses, species composition of the bruchid species involved in the infestation and geographical distribution of the bruchids. The information in turn would help to develop proper measures to reduce these losses caused by bruchids. Therefore, the objective of the current study was to undertake survey at the farm level to know distribution, species composition and to estimate faba bean grain losses due to bruchids.

3.2. Materials and methods

3.2.1. Study sites description

The study was conducted in Ethiopia, (2013 and 2014) in North Western Amhara Region of Eastern and Western Gojjam Zones. Two Districts were purposively selected from each Zone. The Districts were Bibugn and Basoliben in Eastern Gojjam Zone which are located at 80 km and 27 km from Debere Markose City, respectively. Dembecha and Southern Achefer were selected from Western Gojjam Zone at 235 km and 60 km from Bahir Dar town, respectively (Figure 3.1).

Figure



3.1. Map of the study sites

Two representative Peasant Associations were selected from each District based on their faba bean production potential. The selected Peasant Associations were Genamemcha and Woynewoha in Bibugn District, while Yelamej and Cork from Basoliben District in Eastern Gojjam Zone.

Wadeyesus and Yezeleka in Dembecha District as well as Yismala and Yismalajankit from South Achefer District were selected in Western Gojjam Zone. Farmers for sample collection and questionnaire purposes were chosen randomly from the lists registered by Development Agents (DAs).

All the selected Districts were productive for cereals, pulses and other crops. The Districts were known by diverse climatic conditions which are suitable to grow various types of crops. The Faba bean is one of the major pulse crops grown by the farmers in the study areas. The rainy period is commonly short lasting from June to August and the dry season extends from September to May. The major occupation of the people is mixed farming. The common staple food crops grown in the areas are tef (*Eragrostis tef* Zucc.), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and millet (*Pennisetum glaucum* L.) from cereals and faba bean (*Vicia faba* L.), field pea (*Pisium sativum* L.), chickpea (*Cicer arietinum* L.), rough pea (*Lathyrus hirsutus* L.) from pulse crops. Variety of Fruits, Vegetables and Oil crops were also grown in the study areas.

3.2.2. Data collection

3.2.2.1. Sample collection

Data on faba bean grains damage and weight loss were collected on faba bean grains from five randomly selected farmers in each Peasant Association. The data were collected in June after the grains were stored for eight months. The samples were randomly taken from the storage structures using two meters sample probe. The probe was intentionally cleaned before proceeding to take sample from another store.

A composite sample of 200 g faba bean grains was randomly taken from each storage structure. About 50gm faba bean grains were taken from each part (top, middle, sides and bottom) of the storage

structures. Sub-sampled grains were added together and 500 grains of working samples were taken after thoroughly mixing the samples. The samples collected from each household were placed in a separate polyethylene bag and labeled using required information (Nchimbi-Msolla and Misangu, 2002). Number and weight of damaged and undamaged grains were recorded and separately measured. Grains with windows observed before adult emergence was considered as damaged grains. The data obtained were used to calculate the percentage weight loss. Percentage weight losses were determined by the count and weigh method applied by Gwinner *et al.* (1996): The survey was arranged in a mixed model nested design (Mesele *et al.*, 2013).

$$\text{Percent weight loss} = \frac{(W_{\mu} \times Nd) - (Wd \times N_{\mu})}{W_{\mu} \times (Nd + N_{\mu})} \times 100$$

Where: W_{μ} = weight of undamaged grains N_{μ} = number of undamaged grains
 Wd = weight of damaged grains Nd = number of damaged grains

3.2.2.2. Distribution and species composition of bruchids

Survey on the distribution and species composition of bruchids were collected from the already selected Peasant Associations. The samples were taken to the laboratory together with bruchids. Wire mesh with three mm sieve size was used to separate bean grains from bruchids for identification (Ileke and Oni, 2011). Trays were placed in ice cubes to immobilize and collect bruchids to facilitate counting and identification (Nchimbi-Msolla and Misangu, 2002). The bruchids were introduced to vials to count and identify bruchids based on Haines (1991) identification key.

3.2.2.3. Questionnaire based data collection

Five additional farmers were randomly selected from each Peasant Association based on the lists registered by Development Agents (DAs) to take questionnaire (Plate 3.1). Semi-structured questioner were prepared in English and translated to local language (Amharic) to administer personal

interview with selected farmers. In each Peasant Association ten farmers were participated on the questionnaire. The questioners were planned and prepared to collect data about awareness of farmers on the problems of bruchid related to stored faba bean grains. The type of storage structures utilized by farmers, maximum period of bean grains storage and other related issues were raised during the interview.



Plate 3.1. Participation of farmers to fill the questionnaire in the field

Data on types of bruchids damaging faba bean grains, period of infestation (in the field or in a storage) and its damage level on bean grains were assessed. Market demand, consumer interest and seed purpose of damaged faba bean grains were asked to the farmers. Bruchid management practices, willingness of experts to give advisory service and other required information were collected and analyzed. Qualitative interpretation and descriptive statistics such as mean, standard error, percentage and other required information were analyzed and used.

The questionnaire were clarified and delivered to the respondents carefully to collect required information with no confusion. Chances were given to the respondents to raise any question or other related issues after the questionnaire. Participants were asked permission to take their pictures, storage structures and other properties of interested assets used to give additional information to the results (Plate 3.2 and 3.3).



Plate 3.2. Indoor storage structure ('Gota') of faba bean grains



Plate 3.3. Bruchid infested faba bean grains stored for five months

3.2.3. Statistical analysis

Data were analyzed using ANOVA procedures according to Gomez and Gomez (1984) and Rogaswamy (2007) method. Significant means were separated by Tukeys test at 5% significance level. All statistical procedures were performed using SAS (version 9.2) and MS Excel 07.

3.3. Results

Postharvest bean grain losses due to bruchids

All of the faba bean grain samples were infested by bruchids and the damage recorded ranged from 36.43±2.54% to 42.59±3.52%. Significantly, higher percentages of faba bean grains were damaged in Southern Achefer than Bibugn and Bsoliben Districts. Higher faba bean grain weight losses were recorded in all study areas. However, maximum grain losses was recorded in Southern Achefer (19.49±1.68%) District. Grain losses recorded in Eastern Gojjam Zone such as Bibugn and Basoliben were statistically lower than Southern Achefer and Dembecha Districts (Table 3.1).

Table 3.1. *Mean (±) faba bean grain damaged and weight loss at District level due to bruchids

Zone	District	Percent of damaged grains	Percent weight loss
Eastern Gojjam	Bibugn	36.43±2.54 ^b	11.28±1.67 ^c
	Basoliben	37.30±3.39 ^b	11.82±2.67 ^c
Western Gojjam	Dembecha	38.31±6.14 ^{ab}	13.46±5.48 ^b
	Southern Achefer	42.59±3.52 ^a	19.49±1.68 ^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

*Data from both years pooled together

Faba bean grain samples were infested by bruchids in all the study Peasant Associations and the percent damaged grains were ranged from 35.68±3.81% to 43.77±5.12%. Significantly ($p < 0.05$) higher number of damaged grains were recorded in Yismalajankit (43.77±5.12%) and Yismala (41.41±3.89%). Weight loss of faba bean grains due to bruchids ranged from 11.14±3.32% to 19.51±2.79%. Significantly higher percentages of faba bean grain weight losses were recorded in Yismala (19.51±2.79%) and Yismalajankit (19.37±3.11%) followed by Wadeyesus (14.98±8.51%) (Table 3.2).

Table 3.2. *Mean (\pm) faba bean grain damaged and weight loss caused by bruchids at Peasant Association level

Zone	District	Peasant Association	Percent damaged grains	Percent weight loss
Eastern	Bibugn	Woynwoha	37.22 \pm 2.8 ^{bc}	11.58 \pm 2.59 ^c
Gojjam	Basoliben	Genamemcha	35.68 \pm 3.81 ^{bc}	11.14 \pm 3.32 ^c
		Yelamgej	37.7 \pm 5.92 ^{bc}	11.85 \pm 3.28 ^c
		Cork	36.9 \pm 6.37 ^{bc}	11.79 \pm 4.43 ^c
Western	Dembecha	Wadeyesus	38.48 \pm 8.8 ^{abc}	14.98 \pm 8.51 ^b
Gojjam	Southern Achefer	Yezeleka	37.41 \pm 4.38 ^{bc}	11.94 \pm 3.5 ^c
		Yismala	41.41 \pm 3.89 ^a	19.51 \pm 2.79 ^a
		Yismalajankit	43.77 \pm 5.12 ^a	19.37 \pm 3.11 ^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

*Data from both years pooled together

Distribution and species compositions of bruchids

The bruchid species found in Eastern and Western Gojjam Zones were *Acanthoscelides obtectus*, *Callosobruchus chinensis* (L.) and *Bruchus pisorum* (L.). *C. chinensis* and *A. obtectus* were the two familiar bruchid species found everywhere of the assessed areas. The faba bean grain samples were damaged by *C. chinensis* and *A. obtectes*. *C. chinensis* infested and damaged grains were about 86.25% of the samples, while *A. obtectes* recorded from 76.25% of the samples (Table 3.3). The two dominant species were the most destructive storage insect pests of pulse grains in all assessed Peasant Associations (Plate 3.4). Faba bean grain damage and weight losses recorded in the current study were caused by the two main bruchid species.



Plate 3.4. Damaged faba bean grains and associated bruchids in Southern Achefer

Table 3.3. Bruchid composition and distribution in faba bean grains of Eastern and Western Gojjam Zones

Zone	District	Peasant associations	No. of samples with bruchid species:		
			<i>C. chinensis</i>	<i>A. obtectus</i>	<i>B. pisorum</i>
Eastern Gojjam	Bibugn	Woynwoha	16±1.13	17±1.2	0±0
		Genamemcha	13±0.92	9±0.66	0±0
	Basoliben	Yelamgej	20±1.41	14±0.99	5±0.35
		Cork	15±1.1	13±0.92	5±0.35
Western Gojjam	Dembecha	Wadeyesus	18±1.27	17±1.2	7±0.49
		Yezeleka	17±1.2	18±1.27	9±0.64
	Southern Achefer	Yismala	20±1.41	16±1.13	11±0.78
		Yismalajankit	19±1.35	18±1.27	17±1.2
No. of samples (%)			86.25	76.25	33.75

B. pisorum was found only in bean and pea grains stored together. The insect was not totally found in faba bean grains stored alone. It was predominantly found in Southern Achefer District than all the other assessed Districts. The insect was recorded in 28, 16 and 10 farmer storage structures in Southern Achefer, Dembecha and Basoliben Districts, respectively. On the other hand, the species was not totally recorded in Bibugn District (Table 3.3).

Farmers' perceptions about time of bruchid emergence on faba bean grains

All the farmers were not aware about bruchids infestation on faba bean seeds/pods in the field. The respondents said that bruchids do not infest faba bean pods or grains before storage. However, only three farmers in Southern Achefer and two farmers in Dembecha District observed infested pea pods due to *B. pisorum* one week before harvest.

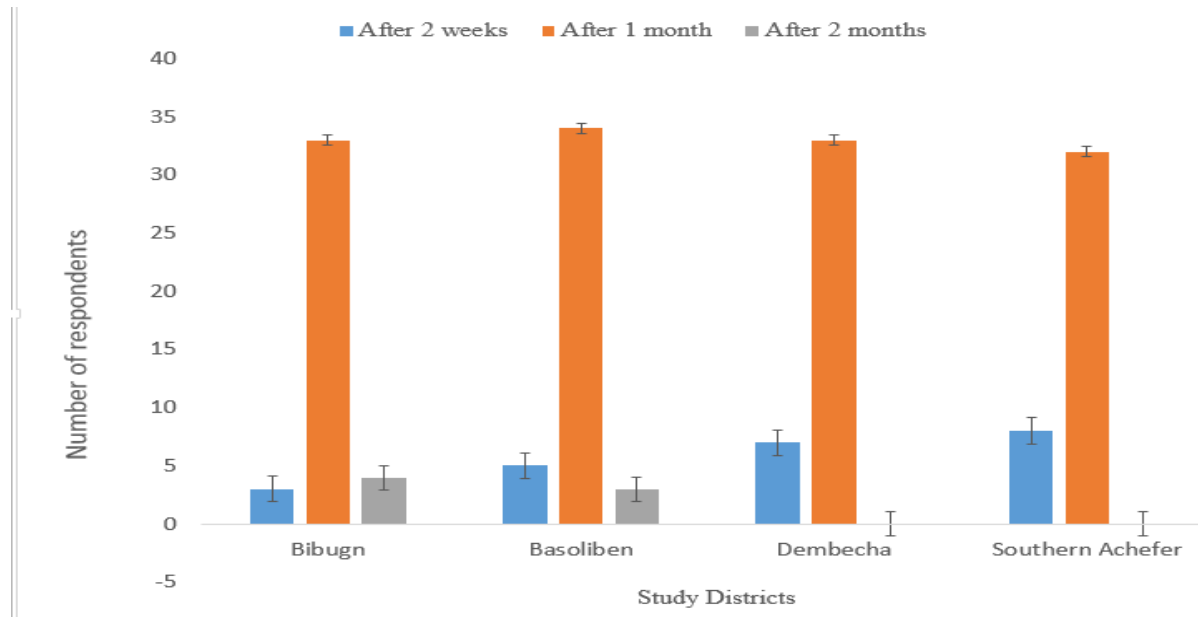


Figure 3.2. Time of bruchids infestation on faba bean grains after storage according to farmers' response

About 22.5% of the respondents observed perforated faba bean grains, bruchid eggs and movable adults on faba bean grains two weeks after storage as it can be seen in Figure 3.2. However, the biology of the bruchids required more than 22 days to complete their life cycle. This shows that adult bruchids were unable to emerge and complete their development within the stated periods. The farmers' observation indicated that infestations of bruchids on stored faba bean grains were started in the field before storage. Majority (73.75%) of the respondents were observed emergence of bruchids in their bean grains one month after storage. In Southern Achefer and Dembecha Districts, bean grains were infested by bruchids below two months of storage periods (Figure 3.2).

Farmers used various types of storage structures to store faba bean grains. The selection of storage structures by farmers were based on the purpose of bean grains stored. The current result indicated (Figure 3.3) the dominant storage structure used by farmers was “Gota”. The bean grains stored in Gota were mainly used for home consumption and other miscellaneous activities. About 18.75% of the farmers stored their faba bean grains in the sacks primarily for market. “Clay pots” were other materials to store faba bean grains to be used for seed purpose.

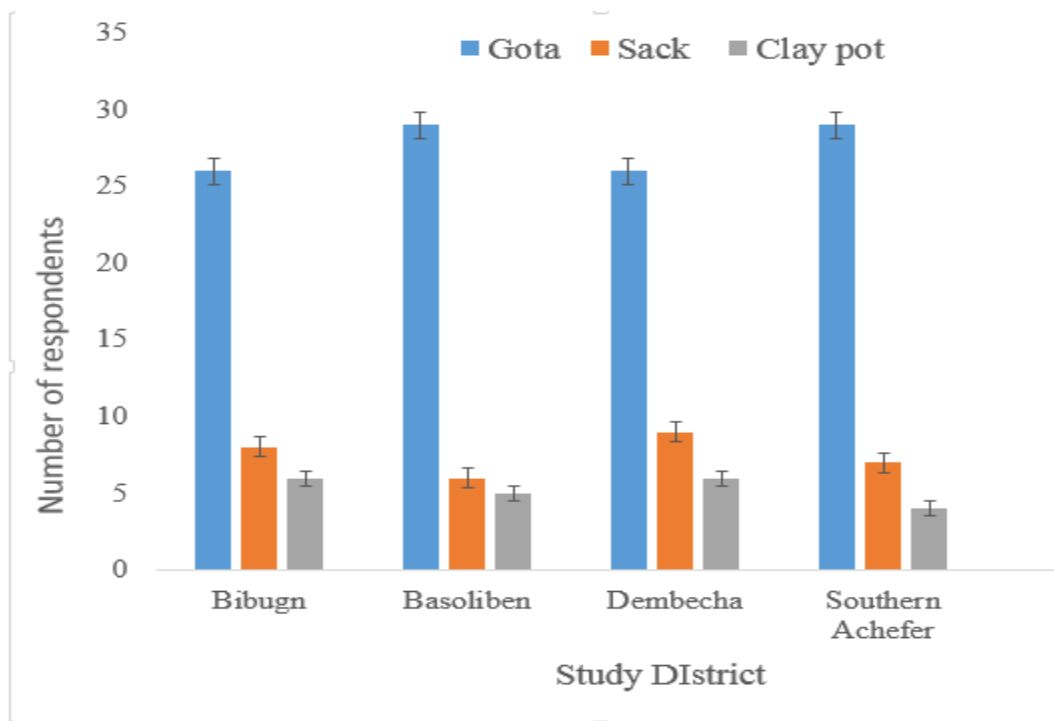


Figure 3.3. Storage structures in Eastern and Western Gojjam Zones for faba bean grains

Majority of the farmers (46.87%) stored their faba bean grains from four to eight months, while 6.88% and 3.75% of the respondents stored the grains for less than four months and more than one year, respectively (Table 3.4). About 100% of the farmers living in Southern Achefer and Demebecha Districts finished their grains less than a year due to serious infestation and damage of the bruchids. The current results indicated that faba bean grain infestation, damage and weight losses due to bruchids were more severe in Western Zone than Eastern parts of the study areas.

Table 3.4. *Mean (\pm) faba bean grain storage durations in Eastern and Western Gojjam Zones

District	Percentage of farmers storing faba bean grains for:			
	< 4 months	4-8 months	9-12 months	>12 months
Bibugn	5 \pm 0 ^a	40 \pm 2.56 ^b	50 \pm 7.14 ^a	5 \pm 2.16 ^{ab}
Basoliben	5 \pm 2.88 ^a	47.5 \pm 2.16 ^a	37.5 \pm 8.71 ^b	10 \pm 5.94 ^a
Dembecha	10 \pm 5.77 ^a	47.5 \pm 2.34 ^a	42.5 \pm 7.93 ^{ab}	0 \pm 0 ^b
Southern Achefer	7.5 \pm 2.16 ^a	52.5 \pm 7.01 ^a	40 \pm 7.51 ^b	0 \pm 0 ^b
Average	6.88	46.87	42.5	3.75

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

*Data from both years pooled together

Level of bruchid damage to faba bean grains and purpose of storing faba bean

The losses of faba bean grains due to bruchids were related to the durations of storage and management practices applied by farmers. Results of the current study indicated that losses of faba bean grains due to bruchids ranged from 33.3% to 100% within six months of storage if control measures are not applied (Table 3.5).

Farmers used faba bean grains for consumption, seed, financial resources, material exchanges, cattle feed (left over plants and straw) and other purposes depending on the quality of grains. However, 73.12% of the respondents said that 50% holed grains due to bruchids not be used either for food or feed. The farmers indicated that highly perforated faba bean grains spread on the ground for soil fertility improvement purpose (better to avoid). About 10% to 16.88% of the respondents indicated that 50% perforated faba bean grains can be used for seed purpose in the year of drought and some can be sold in a local market at reduced price.

Table 3.5. *Mean (\pm) faba bean grain losses due to bruchids with no protection for six months

District	Percent farmers loss of faba bean grain due to bruchids:			
	One third	Half	Three fourth	100% loss
Bibugn	7.5 \pm 5.93 ^{ab}	47.5 \pm 7.93 ^a	37.5 \pm 5.77 ^b	7.5 \pm 2.88 ^b
Basoliben	10 \pm 7.32 ^a	37.5 \pm 9.64 ^{ab}	40 \pm 7.32 ^b	12.5 \pm 7.63 ^{ab}
Dembecha	5 \pm 0 ^b	27.5 \pm 7.93 ^{bc}	50 \pm 3.09 ^{ab}	17.5 \pm 5.98 ^a
Southern Achefer	5 \pm 0 ^b	20 \pm 5.54 ^c	55 \pm 9.6 ^a	20 \pm 5.76 ^a
Average	6.85	33.13	45.63	14.38

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

*Data from both years pooled together

Farmers' management practices to control bruchids on faba bean grains

Farmers use different management practices to control bruchids on faba bean grains after storage. Applications of botanicals in different forms were the most commonly adapted practices to reduce bruchid damage on faba bean grains (Table 3.6). The botanicals were mainly applied after storage in the form of dusts being mixed with the grains. Farmers were fumigating their storage structures (Gota) with pepper and other plant products smoke.

Farmers mixed faba bean grain with ash to reduce temperature rise and to minimize the movement of bruchids within the grain mass. About 50%, 47.5%, 42.5% and 35% of the respondents mixed ash with faba bean grains to be used for seed purpose in Bibugn, Basoliben, Dembecha and Southern Achefer Districts, respectively. Farmers roasted faba bean grains to store for extended periods of time without damaged by bruchids which will be used only for consumption in Bibugn (12.5%), Basoliben (17.5%), Dembecha (47.5%) and Southern Achefer (55%) Districts. Another management practice used by farmers was mixing tef with bean grains. A farmer could apply two or more control practices (Table 3.6).

The common and adapted practices by the farmers were applications of insecticides to control bruchids. Farmers used any types of insecticides available in the localities to manage bruchids. They were not aware about the effects of insecticides on the health of the consumers and the environment (Table 3.6). However, the common insecticide applied by farmers was ethiothion 5% dust due to its low cost and its availability around their localities. None of the respondents aware about the optimum dose, time and method of insecticides applications including ethiothion 5% dust.

Table 3.6. Bruchids' management practices by farmers on faba bean grains in Eastern and Western Gojjam Zones

Management practices	Districts							
	Bibugn		Basoliben		Dembecha		Southern Achefer	
	Freque ncy	Perc ent	Freque ncy	perc ent	Freque ncy	perc ent	Freque ncy	percent
Botanicals	32	80	35	87.5	37	92.5	39	97.5
Mix ash to faba bean grains	20	50	19	47.5	17	42.5	14	35
Mix tef to faba bean grains	4	10	5	12.5	5	12.5	4	10
Fumigate storage structure by pepper	13	32.5	10	25	17	42.5	22	55
Roast faba bean grains	5	12.5	7	17.5	19	47.5	22	55
Insecticide	29	72.5	38	95	40	100	40	100

One farmer can apply more than one management strategies and summation of percentiles in the different management practices are greater than 100%

3.4. Discussion

Bruchids infested and damaged faba bean grains in all assessed Districts and Peasant Associations. However, the damage and weight losses of grains vary from District to District. This result is consistent with the findings of Robin (1998) who reported that insects cause up to 17.7% grain weight losses in various Districts of Amhara region. The current result is in line with the finding of Ibrahim and Aliyu (2014) who reported that bruchids caused up to 43.8% grain weight loss in Ethiopia. Kananji (2007) also confirmed that bean grain losses due to bruchids in Malawi ranged from 16.9% to 38.2%. Similar result was reported by Waktole and Amsalu (2012) in that 64.5% damage and 41% to 80% maize grain weight losses recorded in Jimma Zone due to cereal storage insect pests. Tadele *et al.* (2011) also noted that maize grain infestation levels were 57.8 ± 6.2 - 94.3 ± 2.5 after three months of storage.

The results recorded in the current study indicated that none of the faba bean grain samples were free from infestation. Tremendous amounts of the faba bean grains were holed by bruchids for adult emergence. The grains were covered by a number of bruchid eggs and adult bruchids collected together with the grains. This result is in line with the findings of Dubale (2014) who reported that postharvest losses due to insects' ranged from 5% to 26% in Ethiopian grain handling system. Abass *et al.* (2014) reported that 15 to 25% grain weight losses recorded in Tanzania. According to Dasbak *et al.* (2009) report, bruchids caused 9.76% to 12.87% pigeon pea grain weight losses.

Different bruchid species were found in faba bean samples collected from farmers' stores. *C. chinensis* and *A. obtectus* were the dominant bruchid species. The damage and weight losses of the grains were recorded due to the two bruchid species. The present results is in agreement with that of Umbuyeyi and Rukazambuga (2014) who indicated that bean grain weight losses reached to 38% due to *A. obtectus*, *C. chinensis* and *Z. subfasciatus*. Similar result was reported by Misangu *et al.* (2000)

that *A. obtectus*, *C. chinensis* and *Z. sabfasciatus* were the dominant species damaging pulse grains in Tanzania. Kananji (2007) also noted that *A. obtectus* was recorded in 93% of the samples and causes more than 50% weight losses of bean grains.

Pea beetle, *B. pisorum* was the other bruchid species found during the survey in faba bean and field pea grains stored together. The insect was recorded in both study Zones with low proportion and area coverage. Similarly ARARI (2002) reported that pea beetle was recorded in various Districts of Amhara Region from field pea and faba bean grains stored together or from field pea grains stored alone. Worku (2002) and ARARI (2002) indicated that *B. pisorum* was most likely first recorded in Ethiopia in 1970s and in Amhara Region in 1986 and distributed to various Districts of the Region. BPHC (2009) reported that the Pea beetle was distributed in non-infested areas of Gondor, Gojjam and Awi Zones of Amhara Region (Unpublished data).

All the respondents' believed that infestation of bruchids starting after storage. According farmers' observation, bruchid infestation started from two weeks to two months after storage. But, the biology of *A. obtectus* and *C. chinensis* cannot complete their life cycle within two weeks period that assures bruchid infestation on faba bean grains starting in the field before storage. Thakur (2012) and Minney (1990) indicated that the biology of the bruchids required more than 22 days to complete their life cycle. This shows that adult bruchids were unable to emerge from stored bean grains within the stated periods. Similar result was reported by Paul (2007) and Schmale *et al.* (2002) that farmers can't recognize infestation and emergence of bruchids in the field before storage.

Majority of the farmers were stored their faba bean grains from four to eight and nine to twelve months. All of the farmers in Southern Achefer and Dembecha Districts could not store their faba bean grains more than a year, due to the serious problem of bruchids. However, some farmers in Bibugn and Basoliben Destricts stored their faba bean grains for more than one year. For example,

Hodges (2011) indicated that 4.17%, 50% and 19.3% of the respondents stored their grains for less than four months, seven to ten months and more than one year, respectively. This result is consistent with the findings of Waktole and Amsalu (2012) indicated that storage durations of maize grains in Jimma was three to six months and the damage recorded was 64.5%.

The respondents used various types of traditional storage structures to store faba bean grains which include *Gota*, Sack and *clay pots*. The majority of the farmers used '*Gota*' to store faba bean grains mainly for home consumption. Similar study conducted by Abebe and Bekele (2006) in Ethiopia indicated that only 14.3%, 9% and 5% of the respondents in Hotesa, Ada and Bako, respectively stored their grains in *clay pots*, while the rest of the farmers used *Gota* for storage. Subsistence farmers in developing countries rely on traditional storage structures, which are vulnerable to bruchid attack (Dubale, 2014; Yemane, 2013).

In the current study farmers indicated that bruchids caused faba bean grain losses ranging from 33% to 100% if stored for six months without protection. Comparable result was reported by Kananji (2007) who indicated that 93% of the collected samples lost up to 50% due to bruchids. Furthermore, a recent study conducted by Addis Ababa University in two communities of Eastern Gojjam Districts indicated that grain losses ranged from 30 to 50% (USAID, 2013).

The present result indicated that farmers discarded 50% and above holed faba bean grains by bruchids. Such a type of grains can't be used for consumption, animal feed and seed purpose. Umbuyeyi and Rukazambuga (2014) noted that 46.2% of the respondents rejected bruchid damaged grains for seed, consumption and animal feed. Comparable result was reported by Utono (2013) in that 30% or less holed maize grains were used only for home consumption depending on the income of the households. Heavily infested bean grains (*P. vulgaris*) and cowpea (*Vigna unguiculata*) grains were not used for food, feed or planting (Sales *et al.*, 2000).

Various strategies were used by farmers to control bruchids. A single farmer applied more than one control techniques to reduce damage caused by bruchids. Application of botanicals was a common practice by the farmers. Similar result was reported by Yemane (2013) who reported that various botanical insecticides were effective against oviposition and emergence of adult bruchids. Similar result was reported by Olayemi *et al.* (2012) who demonstrated that manipulation of moisture and temperature and application of botanicals were promising and effective to manage bruchids.

All the farmers were not instructed by Development Agents (DAs) and other experts about the management of bruchids and ways of pesticide applications. The present result indicated that 42% of the farmers were attained knowledge from their parents and neighbors to manage bruchids, while 31% of the respondents gained information from insecticide suppliers. Umbuyeyi and Rukazambuga (2014) reported that only 1% of the farmers were instructed to apply insecticides and other control strategies. The previous study done by Kananji (2007) directed that farmers learn bruchid control options from pre-informed farmers, their parents, relatives and insecticide suppliers.

3.5. Conclusion

Faba bean is very important and widely grown crop Eastern and Western Gojjam Zones of Amhara Region. The crop is damaged by bean bruchids starting from field to storage. Huge amounts of faba bean grains were lost in the two Zones. The losses were mainly caused by *C. chinensis* and *A. obtectes*. The farmers used traditional storage structures to store faba bean grains that create suitable conditions for bruchids. The main storage structure used in the study area was “*Gota*”.

Since the farmers were not instructed from Development agents and other experts to manage bruchids. In addition, the farmers are not aware about infestation the grains due to the insect both in the field and after storage. The farmers observed infested and damaged faba bean grains only after storage. Hence, bruchids cause significant damage on faba grain loss within a short period of time after storage. As a result, majority of the farmers stored their grains for less than one year. Consequently farmers applied various control strategies including insecticides (any) available in the localities to minimize the loss of faba bean grains due to bruchids.

Further assessments are needed throughout the Region on the damages of faba bean grains due to bruchids. It is required to build the capacity of farmers, experts, decision makers and other stakeholders to manage bruchids. Attention is needed from development agents and other experts to control bruchids from field to storage. It is important to integrate economically feasible and environmentally eco-friendly management strategies together to reduce the losses of faba bean grains due to bruchids and to increase the incomes of subsistence farmers.

Chapter Four. Phenology of faba bean (*Vicia faba* L.) versus bean bruchid (*Acanthoscelides obtectus* Say) (Coleoptera: Bruchidae) field infestation

4.1. Introduction

Faba bean is a very long cultivated cool season food legume crop in the old world agriculture, being among the most ancient domesticated plant (Gemechu *et al.*, 2007; Senayt and Asrat, 1994). Numerous traditional dishes are being prepared from the crop that attached to every aspect of Ethiopian life as food, straw for animal feed and soil fertility improvement (Abebe and Bekele, 2006; Senayt and Asrat, 1994).

Bean beetle, *A. obtectus* is a major threat of faba bean from field to storage (Thakur, 2012; Qazi, 2007). The flying adults move and inhabit faba bean pods or grains in the field up to a distance of three kilometers from pre-infested fields and residence houses (Paul, 2007). Adult female lays their eggs loosely in the pod cavity of ripening pods or directly to the seed surface (Schmale *et al.*, 2006). Bruchids lay eggs singly or in small groups on faba bean pods concentrated on the lower parts of the plant and entered to the grains to feed and grow (Paul, 2007).

Framers living in many areas are not aware about the infestation of faba bean pods due to bruchids in the field (Paul, 2007; Schmale *et al.*, 2002). The extent of infestation is not easily visible until the first progeny adults emerge after storage (Sapunaru *et al.*, 2003). All stages of the insect may be taken in to storage along with field infested grains (Sallam, 2014). The insect can re-infest stored grains taken from the field (Sarwar, 2015). The longer matured faba bean plant stayed in the field leads to heavy infestation and high population buildup of bruchids in the storage (Baidoo *et al.*, 2010; Schmale *et al.*, 2002).

Farmers in Amhara Region do not consider bruchids as pests of faba bean under field condition because of lack of awareness about the behavior that it is field to storage pest. There is no information on the exact time of field infestation starting by bruchids (Schmale *et al.*, 2002). Thus, there is no copying mechanism of the pest under field condition. Farmers start controlling *A. obtectus* after the emergence of one or two generations in the storage. It is crucial to know when the infestation begins and reach pick under field condition for effectively managing either in the field or may be early after storage. Hence, the current study was initiated to understand the field infestation scenarios of bruchids which can pave ways for designing an overall bruchid management practices.

4.2. Materials and methods

4.2.1. Description of the study area

The study was conducted in Eastern Gojjam Zone, Debre Markose University which is located at 300 km and 265 km away from Addis Ababa and Bahir Dar, respectively. The average elevation of the study area was 2,400 meters above sea level (masl). The rainfall pattern was uni-modal with a mean annual rainfall of 1500 millimeter (mm). The daily average temperature was 24⁰C. Major crops grown were tef (*Eragrostis tef* Zucc. (Trotter)), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), faba bean (*Vicia faba* L.), chickpea (*Cicer arietinum* L.) and rough pea (*Lathyrus hirsutus* L.).

4.2.2. Rearing of bean bruchid *A. obtectus*

Cultures of *A. obtectus* were established at Debre Markose University to obtain the same age group and required number of adult bruchids for the experiment. None infested faba bean grains were collected from local market and added to ten liters capacity of three plastic pots. The pots were half filled with 5 kg faba bean grains having 14% moisture contents as a substrate (Kananji, 2007). The grains were washed with potable water to avoid any obscure sources of infestation and frozen at a temperature of -4±1⁰C for three weeks to avoid fungal development and to distribute the moisture uniformly to the grains (Ileke and Olotuah 2012).

The bruchids used for rearing were collected from infested grains of the local stores. Three millimeter wire mesh was used to separate the infested grains and bruchids available within the grains. The grains were shaken for one minute to enhance emergence and to get similar age group bruchids for further rearing (Dua *et al.*, 2010). About 150 unsexed adults of *A. obtectus* were added to each pot assuming that 50% of the adults were females and the rest are males as the sex ratio of *A. obtectus* is 1:1 (Thakur, 2010). The pots were covered with muslin cloths held in place by rubber bands at

28±1.5°C and 65±5% RH (Ibrahim, 2012; Ileke and Olotuah, 2012; Pandey *et al.*, 2011; Ayvaz *et al.*, 2010; Bittnera *et al.*, 2008; Kananji, 2007). The temperature used for rearing was adjusted by electric power, while relative humidity and temperature were observed using Thermo-Hygro meter (≠ TH-439) and thermometer (≠DET6Q.MFR≠12410) (Nahar *et al.*, 2009). Frequent inspections of the culture for progeny emergence was carried out daily starting from twenty two days after introduction (Bhardwaj and Verma, 2012; Thakur, 2012; Minney, 1990). The newly emerged day one old adult F₁ progenies were used for the experiment (Thakur and Kalpna, 2015).

Effect of different pod stages on bean bruchid, *A. obtectus* infestation under laboratory conditions

Sites for pod infestation were selected at three km distance from the residence houses (Paul, 2007). All agronomic practices were done per the local practices of farmers except for the applications of fertilizer and spacing. Faba bean was planted with the recommended spacing of eight cm between plants and forty centimeter between rows. Two faba bean seeds were sown per hole and weakly performed seedling was discarded after two weeks of emergence. The experiment was done in 2014 and 2015 cropping seasons in 50 m by 50 m plot size.

Different stages of faba bean pods were separately collected from various growth stages of the plant grown for this purpose to evaluate and determine the suitable stages of the pods for bruchid infestation. The treatments were first emerged pod, faba bean pod containing grains reached for consumption, pods from plants to be harvested after two weeks, matured closed pods, matured opened pods with grains and free matured pods with no grains.

The pods of each treatment were added in three litter capacity plastic pots containing adult *A. obtectus*. About 50 faba bean pods were added to each pot. Twenty unsexed day one adult *A. obtectus* were added to the pots containing the pods. The pots were covered with muslin cloth held in place by

rubber bands. The experiment was conducted in a completely randomized design (CRD) with three replications. The number of eggs laid by gravid female bruchids on faba bean pods were recorded at 2, 4 and 10 days after treatment application. Adult emergence was expected and frequent follow up was continued starting from 22 days after treatment application (Thakur, 2012; Minney, 1990).

Data on the total number of eggs laid and holes 10^{-1} pods were recorded once per month for three months. The number of holes 20^{-1} grains and maximum number of holes per grain and per pod were recorded. The total number of emerged progenies and developmental periods of *A. obtectus* were noted. The median developmental period (D) in days of bean bruchids was determined by the biology of the insect from the middle of oviposition to 50% of F₁ progeny adult emergence (Astuti *et al.* 2013).

Effect of different podding stages of bean bruchids, *A. obtectus* infestation under field conditions

Sites for artificial pod infestation in the field was done following the procedures of laboratory pod infestation by bean bruchids. Faba bean pods were infested by *A. obtectus* at various growth stages of the plant.

Three different field plots were planted with faba bean seeds. Each plot was prepared by a length of 20 m and 12 rows of 40 cm between plants. Two boarder rows and two meters in both sides of the plot were left to avoid boarder effect. Ten unsexed newly emerged day one old adult, *A. obtectus* were released to the plants every four meters with in rows. A total of 320 adult bruchids were released to each plot at the different stages of the plant. More sensitive stages of the pods were evaluated after the grains were separated from the pods and reserved in laboratory for three months.

The treatments were first pod formation, bean grains reached for consumption and two weeks before harvest. All procedures of harvesting, collecting and threshing were followed as per the practices of

the local farmers. Three kg composite samples were collected from each growth stages of the pods. The grains were taken to the laboratory and divide to three equal weighted samples (1 kg each). The emergence of *A. obtectus* was observed in laboratory experiments.

Each Kg of the samples was added to two litter capacity plastic pots. The experiment was conducted in completely randomized design (CRD) in three replications. Frequent inspection of adult emergence, time taken from field infestation to F₁ progeny emergence were followed. The number of infested grains, eggs and holes 20⁻¹ grains and maximum eggs per grain were recorded for three months under laboratory experiments.

4.2.3. Statistical analysis

Analysis of variance (ANOVA) was done based on Gomez and Gomez (1984) Rogaswamy (2007) procedures. All obtained data were transformed using square root and logarithmic transformations before the analysis. SAS (SAS version 9.2) and MS Excel 07 soft wares were used for the analyses. Tukey's studentized range test (HSD) ($p < 0.05$) was used to separate significantly different means. Results were reported using back transformed values.

4.3. Results

Laboratory infested faba bean pods due to *A. obtectus*

The number of eggs in opened matured pods (7.67 ± 1.14) and closed matured pods (5.5 ± 1.39) were significantly higher than the other treatments two days after treatment application. Significantly lower number of eggs was recorded in first emerged pods and free matured pods with no grains. (Table 4.1).

Four days after treatment application 13.7 ± 1.35 and 11 ± 1.51 *A. obtectus* eggs were recorded in the opened matured pods and closed matured pods, respectively. Statistically comparable results were recorded in bean grains reached for consumption (5.17 ± 1.77), in the first emerged pods (3.83 ± 1.18) and matured pods with no grains (4.30 ± 1.35) four days after treatment application (Table 4.1).

Ten days after treatment higher number of bruchid eggs were recorded in faba bean pods at two weeks before harvest (13.3 ± 1.69) following from opened matured pods with grains (20.8 ± 4.34) and closed matured pods (16.5 ± 1.3). Statistically lower number of eggs was recorded in the early stages of the pods (first emerged pods and the bean grains reached for consumption) and matured pods with no grains (Table 4.1).

Table 4.1. Parent bruchid eggs infested faba bean pods

Treatment	No of bruchid eggs 10 ⁻¹ pods after (*)		
	2DAT	4DAT	10DAT
Opened matured pods	7.67±1.14 ^a	13.7±1.35 ^a	20.8±4.34 ^a
Closed matured pods	5.5±1.39 ^{ab}	11±1.51 ^{ab}	16.5±1.3 ^{ab}
Bean grains reached for consumption	3.87±0.6 ^{bc}	5.17±1.77 ^c	7.8±1.12 ^c
Two weeks before harvest	5.2±0.98 ^{ab}	9±1.81 ^b	13.3±1.69 ^b
First emerged pod	2.5±1.62 ^c	3.83±1.18 ^c	5.33±0.87 ^c
Free matured pods with no grains	3.67±0.98 ^{bc}	4.30±1.35 ^c	7.0±1.32 ^c

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

DAT = days after treatment application

Data from both years pooled together

Bruchid damaged faba bean pods and grains

The number of infested pods 10⁻¹ pods in opened matured pods and closed matured pods by bruchid were 9.83±0.24 and 8.5±0.8, respectively. Statistically lower number of faba bean pods was infested in bean grains reached for consumption compared to open matured pods with grains. Bruchid progenies were not totally emerged and all the pods were free from infestation in the first emerged pods and free matured pods with no grains. In general, matured pods were more infested and perforated by bruchids than immature stages of the plant (Table 4.2).

Significantly higher number of bruchid eggs were recorded in opened matured pods (97.33±10.65) than other treatments. The number of eggs recorded in closed matured pods, bean grains reached for consumption and two weeks before harvest were 64.17±8.1, 22.17±6.35 and 45.00±1.8, respectively.

Significantly higher number of holed faba bean pods 10^{-1} pods were recorded in opened matured pods (7.83 ± 1.03) followed by closed matured pods (4.33 ± 1.53). Lower number of faba bean pods were perforated in the bean grains reached for consumption (1.17 ± 0.94) and two weeks before harvest (2.33 ± 1.01) than matured pods. First emerged pods and free matured pods with no grains to lay eggs and no progeny were emerged (Table 4.2).

Table 4.2. Number of infested faba bean pods, number of eggs and number of holes due to bruchids

Treatment	No of infested 10^{-1} pods (*)	No of eggs 10^{-1} pods (*)	No of perforation 10^{-1} pods (*)
Opened matured pods	9.83 ± 0.24^a	97.33 ± 10.65^a	7.83 ± 1.03^a
Closed matured pods	8.5 ± 0.8^{ab}	64.17 ± 8.1^b	4.33 ± 1.53^b
Bean grains reached for consumption	6.67 ± 1.99^b	22.17 ± 6.35^d	1.17 ± 0.94^c
Two weeks before harvest	7.83 ± 0.43^{ab}	45.00 ± 1.8^c	2.33 ± 1.01^c
First emerged pod	0.0 ± 0^c	0.0 ± 0^e	0.0 ± 0^d
Free matured pods with no grains	0.0 ± 0^c	0.0 ± 0^e	0.0 ± 0^d

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

Pooled data from 2014 and 2015

Bruchids laid higher number of eggs per pod on opened matured pods with grains than all other treatments except closed mature pods at ($p \leq 0.05$). Significantly higher number of eggs per pod were laid in opened matured pods (18.00 ± 3.8) and closed matured pods (13.5 ± 1.95) compared to the immature stages of the pods (0 ± 0 to 9.5 ± 0.52) and the standard check (0 ± 0) (Table 4.3). The result presented in Table 4.3 indicated that significantly higher number of eggs were recorded on bean

grains reached for consumption and two weeks before harvest compared to the first emerged pods, free matured pods with no grains and the standard check at ($p \leq 0.05$).

Bruchid progenies were not emerged up to the end of the experiment in the first emerged pod and in the free matured pods with no grains. Maximum holes per pod were recorded three months after the start of the experiment in opened mature pods (13.00 ± 1.89) and closed matured pods (7.33 ± 0.79). The number of holes 20^{-1} grains in opened matured pods (19.50 ± 6.31) were significantly higher than the other treatments. Comparable number of holed grains were recorded at closed matured pods (11.33 ± 4.55) and two weeks before harvest (8.50 ± 0.73). No holed grains were recorded in first emerged pods up to 90 days from the start of the experiment (Table 4.3).

Table 4.3. Mean (\pm) number of perforated faba bean pods and grains due to bruchid progenies

Treatment	Maximum No of eggs per pod (*)	Maximum No of holes per pod (*)	No of holes 20 ⁻¹ grains (*)
Opened matured pods	18.00 \pm 3.8 ^a	13.00 \pm 1.89 ^a	19.50 \pm 6.31 ^a
Closed matured pods	13.5 \pm 1.95 ^{ab}	7.33 \pm 0.79 ^b	11.33 \pm 4.55 ^b
Bean grains reached for consumption	8.0 \pm 2.33 ^b	2.33 \pm 0.3 ^c	3.2 \pm 1.13 ^c
Two weeks before harvest	9.5 \pm 0.52 ^b	3.67 \pm 1.01 ^c	8.50 \pm 0.73 ^{bc}
First emerged pod	0.0 \pm 0 ^c	0.0 \pm 0 ^d	0.0 \pm 0 ^d
Free matured pods with no grains	0.0 \pm 0 ^c	0.0 \pm 0 ^d	NR

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

NR = Non relevant

Data from both years pooled together

Progeny emergence and developmental time of *A. obtectus* on laboratory infested pods

Results presented in Table 4.4 indicated that higher number of bruchids emerged and higher number of holes per grain were recorded from opened matured pods than other treatments. The number of bruchid progenies recorded from different pod classes were ranged from 0 \pm 0 to 311.5 \pm 10.23. *A. obtectus* progenies shown comparable developmental period ranged from 41.33 \pm 2.71 to 51.67 \pm 3.42 days. On the other hand, eggs laid by parent bruchids on the first emerged pods and in the free matured pods with no grains were not emerged up to three months.

Table 4.4. *Mean (\pm) number of holes, number of adults emerged and developmental period of bean bruchid *A. obtectus* on faba bean pods

Treatment	Maximum No of holes per grain (*)	No of adults emerged (**)	Developmental period (Days) (*)
Opened matured pods	11.33 \pm 2.89 ^a	311.5 \pm 10.23 ^a	41.33 \pm 2.71 ^{ab}
Closed matured pods	5.00 \pm 2.69 ^b	137.5 \pm 7.42 ^b	45.70 \pm 2.56 ^{ab}
Bean grains reached for consumption	1.67 \pm 0.3 ^c	33.38 \pm 7.86 ^d	51.67 \pm 3.42 ^a
Two weeks before harvest	3.67 \pm 1.19 ^{bc}	87.67 \pm 7.6 ^c	48.33 \pm 2.3 ^a
First emerged pod	0.0 \pm 0 ^d	0.0 \pm 0 ^e	0.0 \pm 0 ^c
Free matured pods with no grains	NR	0.0 \pm 0 ^e	0.0 \pm 0 ^c

*Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) and logarithm (**) back transformed values

NR = Non relevant

Data from both years pooled together

Bruchids were infested more on opened matured pods than other pod classes. Higher number of bruchid eggs gave higher number of bruchid progenies and more number of perforated faba bean pods (Plate 4.1). Treatments like first emerged pod and free matured pods with no grains were not infested and the pods were not perforated by bruchids.



Plate 4.1. Bruchid infestation and perforation on opened matured faba bean pods

According to the results of the current experiment, the relation between eggs laid by the parent bruchids within the first ten days and the progenies emerged in various pod classes were positively correlated ($r^2 = 65\%$). The two parameters were weakly correlated due to the eggs laid by the bruchids in the first emerged pod and free matured pods with no grains were not emerged up to the end of the experiment (Figure 4.1).

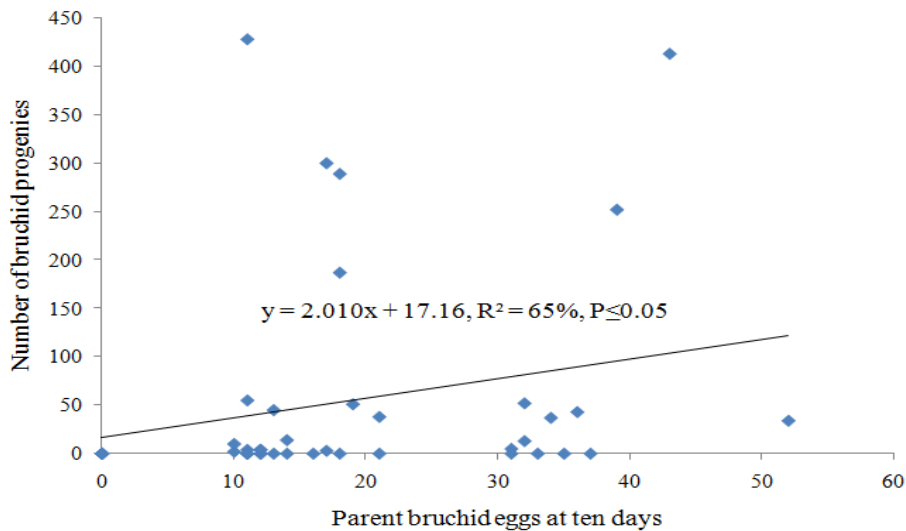


Figure 4.1. Relationship of bruchid progenies and parent eggs on laboratory infested pods

Bruchids emerged in laboratory on the field infested faba bean grains

The number of infested grains (replace this one) progenies of *A. obtectus* emerged (remove it) in the laboratory from field infested pods ranged from 5.3 ± 2.3 to 12.7 ± 3.4 in 2014 and 6.67 ± 0.9 to 15.3 ± 3.2 in 2015 cropping seasons. These values were recorded only from faba bean grains reached for consumption and two weeks before harvest treatments. Bruchids did not infest faba bean grains and progenies were not emerged from the first emerged pods (0.0 ± 0). Significantly higher number of bruchid eggs were recorded in 2014 (14.3 ± 3.7) and 2015 (15.3 ± 1.7) cropping season in the two weeks before harvest treatment than the other treatments. Significantly higher number of eggs per grain was also recorded in the two weeks before harvest treatment in both cropping seasons (Table 4.5).

Table 4.5. *Mean (\pm se) number infested and damaged faba bean grains due to bruchid under field and laboratory conditions

year	Treatment	Data recorded 20^{-1} grains (*)		Maximum No of eggs per grain (*)
		Infested grains	Total No of eggs	
2014	First emerged pods	0.0 ± 0^c	0.0 ± 0^c	0.0 ± 0^b
	Bean grains reached for consumption	5.3 ± 2.3^b	5.3 ± 1.56^b	1.0 ± 1.5^{ab}
	Two weeks before harvest	12.7 ± 3.4^a	14.3 ± 3.7^a	2.33 ± 0.58^a
2015	First emerged pods	0.0 ± 0^c	0.0 ± 0^c	0.0 ± 0^b
	Bean grains reached for consumption	6.67 ± 0.9^b	7.67 ± 4.3^b	1.3 ± 0.89^{ab}
	Two weeks before harvest	15.3 ± 3.2^a	15.3 ± 1.7^a	2.67 ± 1.8^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

The number of holed grains in the two weeks before harvest treatment were significantly higher than the first emerged pods both in 2014 and 2015 main cropping seasons. The number of emerged

progenies in the two weeks before harvest and in the bean grains reached for consumption treatment were 63.7 ± 9.5 and 18.7 ± 5.6 , respectively in 2014 and 84.7 ± 8.4 and 27.3 ± 6 , respectively in 2015 cropping seasons (Table 4.6).

The developmental period of *A. obtectus* was comparable in the two weeks before harvest treatment and in the bean grains reached for consumption treatment. The developmental period of *A. obtectus* was ranged from 65.67 ± 4.26 to 69.33 ± 3.57 days in 2014 and 62.67 ± 2.6 to 66.7 ± 3.94 days in 2015 main cropping seasons. In the first emerged pods treatment no bruchid progenies were emerged in both years until the end of the experiment. As a result developmental period of the insect was not recorded (Table 4.6).

Table 4.6. Mean (\pm se) number of bruchids and developmental time on the field and laboratory infested faba bean grains

Year	Treatments	N ₀ of holed grains (*)	N ₀ of bruchid progenies (*)	Developmental period (days) (*)
2014	First emerged pods	$0.0 \pm^b$	$0.0 \pm^c$	$0.0 \pm^b$
	Bean grains reached for consumption	0.3 ± 0.3^{ab}	18.7 ± 5.6^b	69.33 ± 3.57^a
	Two weeks before harvest	0.7 ± 0.4^a	63.7 ± 9.5^a	65.67 ± 4.26^a
2015	First emerged pods	$0.0 \pm^b$	$0.0 \pm^c$	$0.0 \pm^b$
	Bean grains reached for consumption	0.3 ± 0.2^{ab}	27.3 ± 6.1^b	66.7 ± 3.94^a
	Two weeks before harvest	0.97 ± 0.3^a	84.7 ± 8.4^a	62.67 ± 2.6^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

4.4. Discussion

Laboratory infested and perforated pods due to bruchids

The parent *A. obtectus* laid their eggs differently on various faba bean pod classes. Matured pods were preferable hosts for female parent bruchids to lay eggs than immature faba bean pods. Medium maturity stage faba bean pods were more preferable by bruchids than first emerged pods. The present result is in line with Paul (2007) who reported that parent *A. obtectus* infested ripe faba bean pods in the field as well as in the laboratory. Previous study by Schmale *et al.* (2006) showed that *A. obtectus* prefer to infest matured dried faba bean pods in the field and the damage continued and enhanced in the storage. Schmale *et al.* (2002) noted that the bruchids were deposited their eggs into matured lately harvested pods. Paul (2007) indicated that faba bean fields in the farm were infested by bruchids during maturity stages (one week before harvest).

The current result indicated that parent female adult bruchids laid lower number of eggs in the early stages of faba bean pods. The number of eggs laid by parent *A. obtectus* were increased as the maturity stages of the pods increased. Many scholars reported that bruchid infestation starts in the field on matured and nearly matured pods. Similarly Paul (2007) indicated that bruchids preferred partially opened dried matured pods than green pods for oviposition. Baidoo *et al.* (2010) also reported that *C. maculatus* start to infest matured cow pea pods in the field and its damage continued in the storage. Kananji (2007) conducted similar experiment that female *A. obtectus* oviposited their eggs in to matured pods. Primary storage insect pests preferred to infest dried pods in the field and re-infested grains in storage (Sarwar, 2015). The beetles oviposited their eggs in to matured pods or directly to exposed grains (Jones *et al.*, 2011).

Based on the results obtained in the current experiment, bruchid progenies infestation and perforation were more on matured pods than early stages of faba bean pods. Parent bruchid eggs laid at very early

stages of the pods were not developed into adult stage. Similar result was reported by Schmale *et al.* (2002) in that bruchids infestation was more on matured and partially opened pods starting from two weeks before harvest. Schmale *et al.* (2006) and Paul (2007) reports also confirmed that matured pods containing seeds were more stimulant for bruchids to lay eggs than matured pod with no grains. Seidenglaz and Hunady (2016) indicated that each week delay faba bean harvest after physiological maturity increased the bruchid infestation by 7%.

The current study indicated that higher number of bruchid progenies and high number of perforated pods were recorded from opened matured pods and closed dried pods. Bruchid progenies were not totally emerged from early pod stages and matured pods without grains. The present result was in agreement with Olubayo and Port (1997) who reported that more number of bruchid progenies and higher levels of infestations were recorded from matured pods. Baidoo *et al.* (2010) added that the damage levels of faba bean grains due to bruchid progenies were serious in dried pods of late harvested grains after storage. Similarly, Owunsu-Akyaw *et al.* (2014) and Baidoo *et al.* (2010) noted that bruchids emerged in 28 days and 7 days after storage in early and late harvested grains, respectively.

The results recorded in the present study indicated that gravid adult female bruchids laid eggs in all pod classes. However, early stages of the pods were free from bruchid progenies and their re-infestations. This result is in line with the findings of Paul (2007) who indicated that bruchid eggs laid differently in all stages of pod classes, but progenies were not emerged from free matured pods with no grains and early pod stages till the end of 16th weeks. He added that, the percentage of infestation in early green pods, matured closed pods and matured opened pods were $0\pm 0\%$, $55.2\pm 5.8\%$ and $73.2\pm 5.6\%$, respectively. Matured pods and grains within the pods simultaneously contributed to attract female adult bruchids (Seidenglaz and Hunady, 2016).

In the current result, high number of bruchids emerged from matured pods. Bruchids were not totally emerged from very early stage and matured pods with no grains. This result is in line with the finding of Baidoo *et al.* (2010) who reported that the number of bruchid emerged from late, mid and early harvested cowpea seeds after eight weeks of storage were 136.7, 81.3 and 1.7, respectively. Owunsu-Akyaw *et al.* (2014) and Obembe and Kayode (2013) remarked that higher number of bruchid progenies emerged from matured cowpea grains. Lately harvested plants created suitable conditions for bruchid infestation in the field that multiplies rapidly, causes up to 100% damage and 60% weight loss after storage (Owunsu-Akyaw *et al.*, 2014).

The current result showed that bruchid progenies were not emerged from early stages of faba bean pods. Bruchids emerged and developmental periods were recorded only from medium level and matured pod classes. This result is consistent with the findings of Nahdy and Agona (1996) who reported that developmental periods of bruchids from medium level to maturity stages of the pods were 41.2 to 48.2 days. Paul (2007) indicated that bruchids emerged from various bean pod classes were shown similar developmental period, however, eggs laid by the parents on first emerged pods were not totally emerged.

Bruchids emerged in laboratory from field infested grains

Results of the present experiment confirmed that, *A. obtectus* laid significantly higher number of eggs in the two weeks before harvest and in the bean grains reached for consumption in both 2014 and 2015 main cropping seasons. First emerged pods were free from bruchid eggs. Similar result was reported by Paul (2007) that bruchids can emerge in laboratory from hidden infested grains in the field. The current result is in agreement with that of Olubayo and Port (1997) who reported that the damage levels of hidden infested grains were increased after storage. Thakur (2010) report was in line with the current findings in that greater damage during storage was recorded from highly infested

plants in the field. The time of faba bean harvest determines the level of stored grain damage and buildup of insect population after storage (Alemayehu, 2009).

Late harvested grains are found more infested, damaged and perforated than early harvested grains after storage (Paul, 2007). Owunsu-Akyaw *et al.* (2014) reported that populations of *C. maculatus* increased after storage when collected from late harvested cowpea plants. Similarly, Nahdy and Agona (1996) reported that number of *A. obtectus* progenies in early harvested (6 March) and late harvested (27 March) were 1 and 23 adults, respectively. Lately harvested beans were four times infested and perforated by bruchids than early harvested grains after storage (Sallam, 2014; Baidoo *et al.*, 2010).

From the present study concluded that the first emerged pods were not infested and bruchids were not emerged. Higher number of bruchid progenies were recorded only from the two weeks before harvest and the bean grains reached for consumption in both years. According to Paul (2007) report, immature pods in the field were not infested by bruchids and no progenies recorded after storage. Seidenglaz and Hunady (2016) reported comparable result in that mean number of holed grains from field infested pods due to bruchids in the year 2006 and 2007 ranged from 0.35-1.91 and 0.25 to 1.83, respectively. *C. maculatus* infested matured pods in the field and caused up to 50% damage after three to four months of storage (Owunsu-Akyaw *et al.*, 2014; Baidoo *et al.*, 2010). Obembe and Kayode (2013) finding indicated that higher number of bruchid progenies and higher weight losses recorded from late harvested matured cowpea grains.

4.5. Conclusions

Faba bean pods were infested by bruchids differently in accordance with the maturity of the plant. All stages of the pod classes except standard check were infested with eggs by the parent bruchid eggs. However, first emerged pod, free matured pods with no grains and standard check were free from bruchid progeny emergence. Higher number of infested and perforated pods and higher number of bruchid progenies were recorded from opened matured pods and closed matured pods. Very early stages of faba bean pods were not suitable hosts for bruchids. The faba bean pod stages started from two weeks before harvest were favored by bruchids to feed, to lay eggs, and in produce higher number of progenies.

The bean bruchid, *A. obtectus* is a destructive storage insect pest of faba bean grains starting from the field (matured stage) and continue to the storage. It is necessary to control the parent bruchids in the field before or during egg laying and before the entry of first instar larva to the pods. Frequent follow up of faba bean pods in the field and the grains after storage improves management strategy of the insect. Design compatible control strategies both in the field as well as after storage saves the irreversible loss of faba bean grains due to bruchids.

Chapter Five. Management of bean bruchids (*Acanthoscelides obtectus* Say) (Coleoptera: Bruchidae) using botanical oils

5.1. Introduction

Faba bean (*Vicia faba* L.) is one of the most domesticated and vastly distributed legume crop throughout the world (Amer *et al.*, 2012). It is an important crop used as a source of organic protein (El-Tokhy and Kasem, 2012). However, bean storage at small scale subsistence farming levels is limited due to bruchid infestations that result in heavy losses (Mushobozy *et al.*, 2009). The bean beetle, *A. obtectus* is the common insect pest where bean plants are growing and stored (Taponjou *et al.*, 2002).

Farmers are using synthetic insecticide to keep their grains free of infestation and to reduce damage after storage (Bittnera *et al.*, 2008). However, most of the synthetic insecticides result lead to development of resistance, persistent residues, atmospheric pollution and toxification of the fauna and flora (Prakash *et al.*, 2008; Koon and Njoya, 2004). Currently insect pest management (IPM) faced problem of economic and ecological consequences on the use of pest control measures (Khater, 2012). As a result, another alternative approach is designed to manage bruchids (Olotuah, 2013).

Oils of plants as pesticidal effect are known to have one or more useful properties such as fumigants, repellents, insecticidal, high oviposition deterrent, antifeedant, fast knockdown effects, reduce insect resistance, biodegradability, broad-spectrum and growth inhibitory activities (Rotimi and Ekperusi, 2012; Mollaei *et al.*, 2011; Verma *et al.*, 2000). Some of the plant oils are effective, easily produced by farmers and promising alternatives to control bruchid near or above the synthetic insecticides (Owolabi *et al.*, 2014; Ndomo *et al.*, 2010; Cardet *et al.*, 2005). Oil products have recently emerged as the most important insecticides to manage bruchids and other insect pests (Ayvaz *et al.*, 2010).

Currently, research is focusing on botanical insecticides that are safe, leave little or no residues and naturally derived with minimal impacts (Souguir *et al.*, 2013).

In Amhara region, farmers are always in a problem of stored bean grain damage and loss due to *A. obtectus*. Hence, they are using various insecticides to control bruchids. However, majority of the farmers are illiterate, they don't know the optimum dose of insecticides, time of application and its effect on human beings including their families, non-target animals and the environment. Instead botanical oils are easily available, biodegradable, simple to prepare and majority of them are safe to apply (Mushobozy *et al.*, 2009). Hence, the objective of this study was to screen some effective botanical oils against *A. obetctus* on faba bean grains.

5.2. Materials and methods

5.2.1. Description of the Study area

The study was conducted in Eastern Gojjam Zone, Debre Markose, the same site in section 4.2.1.

5.2.2. Rearing of bean bruchid *A. obtectus*

Cultures of *A. obtectus* were established at Debre Markose University to obtain the same age group and required number of adult bruchids. About three plastic pots having 5 L capacity was used. Each pot was half filled with 3 kg faba bean grains to serve as food for bruchids. About 100 unsexed adult *A. obtectus* were released to each jar following the procedures of section 4.2.2.



Plate 5.1. Thermo-Hygro and thermometer follows Relative Humidity and Temperature

5.2.3. Treatment preparation

The botanical seeds were collected from the localities nearby Debre Markose University. Oils were extracted from various collected plant species using acetone (a solvent to extract the oils). The plant species used for the experiment were seed of noug (*Guizotia abyssinica* L.f), rape seed (*Brassica napus* L.), lantana (*Lantana camara* L. (Sensu lato)), pepper (*Capsicum annum* L.), tephrosia

(*Tephrosia vogelii* Hook.), groundnut (*Arachis hypogaea* L.) and castor oil (*Ricinus communis* L.) (Table 5.1). Untreated check, ethiothion 5% dust and Acetone were used in the experiment for comparison.

The seeds were dried under shade until the moisture content was completely removed and grinded with pestle and mortar to obtain fine dusts. The dusts were further grinded until it passed through 0.5 mm perforated sieves (Ileke and Oni, 2011). The dusts were separately dissolved in acetone in a two liter plastic pot to separate oils from fine dusts. Each mixture was stayed for one month and shaken daily for 15 minutes (Bhardwaj and Verma, 2012). The liquid that contains oil and acetone was floated on the upper surface of the containers. Each container was pierced with scissor at the site of layer formed between dust residues and the floated liquids. The liquids that float on the surface of the containers were come out through the hole prepared between the layers. Each liquid was collected and filtered again using muslin cloths. The oils and solvents were exposed to air for two days. Subsequently, acetone was evaporated through the air and the oils collected from each botanical were stored separately in clean vials at a temperature of 4°C in a refrigerator until use (Douiri *et al.*, 2013; Ileke and Olotuah, 2012; Ileke and Oni, 2011).

A concentration of 3 to 4 ml oils /kg were added in one liter plastic pots containing 500 g of faba bean grains. The pots containing faba bean grains, the botanical oils, ethiothion 5% dust and acetone were vigorously shaken and rolled for one minute to coat the treated grains uniformly (Ibrahim, 2012; Abhay *et al.*, 2011). The treated bean grains in each pot were infested with 24 hour old 20 unsexed adult bruchids (Chelav and Khashaveh, 2013). The pots were covered with muslin cloth. The experimental design was a Completely Randomized Design (CRD) with three replications.

Table 5.1. Botanical oils evaluated for their efficacy against bean bruchid *A. obtectus* on faba bean grains

Common Name	Scientific name	Plant parts used	Rate of application
Noug oil	<i>Guizotia abyssinica</i> L.	Seed	4ml/kg
Castor oil	<i>Ricinus communis</i> L.	“	4ml/kg
Groundnut	<i>Arachis hypogaea</i> L.	“	3ml/kg
Pepper	<i>Capsicum annum</i> L.	“	3ml/kg
Tephrosia	<i>Tephrosia vogelii</i> Hook	“	3ml/kg
Lantana	<i>Lantana camara</i> L.	“	4ml/kg
Rape seed	<i>Brassica napus</i> L.	“	4ml/kg
Ethiothion 5% dust	-	-	50g/qt
Acetone	Dimethyl ketone	-	4ml/kg
Untreated check	-	-	-

5.2.4. Data collection

Effects of botanical oils on parent bruchid fertility and mortality

Parent adult *A. obtectus* mortality and the number of eggs laid per 20 grains were recorded from each pot at 1, 2, 4, 8 and 10 days after treatment application. In each subsequent count, dead bruchids were counted and removed. Ten days after treatment application all dead and alive bruchids were counted and removed from the pots.

Emergence of adult bean bruchids, *A. obtectus*

Bruchid progenies inspection and continuous follow up were started from 22 days after treatment application (Thakur, 2012; Minney, 1990). Subsequent counts of dead and alive adult bruchids were released. The bruchids were separated from bean grains with the help of three mm sieve made from wire mesh (Ileke and Oni, 2011). Data on grains with and without eggs and holes per 20 randomly selected grains were noted for three months.

Percentage protection

Protective efficacy of the botanical oils was calculated based on the emerged progenies using Taponjou *et al.* (2002) and El-Ghar *et al.* (1987) procedures. Percentage reduction to adult emergence or inhibition rate (% IR) was calculated as:

$$\text{Percent IR} = \frac{(C_n - T_n)}{C_n} \times 100$$

Where: C_n = the number of newly emerged insects in the untreated pot

T_n = the number of newly emerged insects in the treated pot

Seed weight loss determination

On the 90th day of treatment application, 1000 grains were randomly taken from each treatment following the procedures in section 3.2.2.1.

Germination test of treated grain

The Effects of botanical oils on bean grain germination was conducted three months after treatment application (Ibrahim, 2012). Fifty grains were randomly selected from each treatment and separately treated with Sodium Hypochlorite (Clorox 10%) for one minute. Grains from each treatment treated with sodium hypochlorite were washed by water for one minute to avoid physical damage. The seeds were placed on moist filter paper in petridishes for seven days. The number of sprouted seeds was counted and noted seven days after incubation. Subsequently, germination percentage was determined using the following formula (Sawant *et al.*, 2012; Gwinner *et al.*, 1996):

$$\text{Germination (\%)} = \frac{\text{Total number of bean grains germinated}}{\text{Total number of bean grains added to petridish}} \times 100$$

5.2.5. Data analyses

Analysis of variance (ANOVA) was done according to Gomez and Gomez (1984) and Rogaswamy (2007) following the procedures indicated in section 4.2.3.

5.3. Results

Parent Bean bruchid eggs on oil treated faba bean grains

The number of eggs laid by parent bruchids on treated (the oils, ethiothion 5% dust and the acetone) and untreated grains are shown in Table 5.2. Bruchid eggs were recorded on day one after treatment application. Significantly ($p < 0.05$) higher number of bruchid eggs were laid on untreated check (7.33 ± 0.53) and acetone (7.5 ± 0.68) treated faba bean grains compared to the botanical oils (0.33 ± 0.33 to 3.17 ± 0.48) and ethiothion 5% dust treated grains which did not yield any bruchid egg one day after treatment application.

Two days after treatment application the number of eggs laid by bruchids on noug oil and rape seed oil treated faba bean grains were 0.67 ± 0.3 and 1.33 ± 0.33 , respectively. Significantly ($p < 0.05$) higher number of bruchid eggs were laid on pepper (5.13 ± 0.26), lantana (5.17 ± 0.63) and tephrosia (6.17 ± 0.75) than the rest of the oil treatments. The highest number of bruchid eggs were recorded on untreated grains (11.83 ± 0.79) and acetone (11.67 ± 0.67) treated grains.

There were no extra bruchid eggs recorded four days after treatment application than the two days after treatment on ethiothion 5% dust, noug oil, rape seed oil and groundnut oil treated grains. Significantly higher number of eggs were recorded on oils of castor (4.83 ± 0.95), lantana (6.67 ± 2.6), tephrosia (7.17 ± 0.75) and pepper (10.67 ± 0.91) treated faba bean grains four days after treatment. The number of bruchid eggs were significantly higher than the rest of the treatments in the untreated (16.67 ± 1.13) and acetone (16.33 ± 0.89) treated grains four days after treatment application (Table 5.2).

Eight days after treatment, no extra bruchid eggs were recorded in ethiothion 5% dust and oil treated faba bean grains. However, the number of bruchid eggs laid in the acetone treated and the untreated grains were recorded to 19.33 ± 0.67 and 18.33 ± 1.2 eggs, respectively. The number of *A. obtectus* eggs

laid in acetone (20.67 ± 1.05) treated and the untreated (20.83 ± 1.27) faba bean grains were slightly increased ten days after treatment (Table 5.2).

Table 5.2. *Mean (\pm se) number of eggs laid by adult female parent bruchid during the first ten days of treatment application (2013-2014)

Treatment	Rate	**Parent bruchid eggs after treatment application				
		1 st day	2 nd day	4 th day	8 th day	10 th day
Noug	4ml/kg	0.33 ± 0.33^c	0.67 ± 0.3^{de}	0 ± 0^d	0 ± 0^b	0 ± 0^b
Rape seed	4ml/kg	0.50 ± 0.35^c	1.33 ± 0.33^{de}	0 ± 0^d	0 ± 0^b	0 ± 0^b
Groundnut	3ml/kg	0.50 ± 0.35^c	2.00 ± 0.58^d	0 ± 0^d	0 ± 0^b	0 ± 0^b
Castor	4ml/kg	2.17 ± 0.75^b	4.33 ± 0.78^c	4.83 ± 0.95^c	0 ± 0^b	0 ± 0^b
Lantana	4ml/kg	2.83 ± 0.63^b	5.17 ± 0.63^{bc}	6.67 ± 2.67^{bc}	0 ± 0^b	0 ± 0^b
Tephrosia	3ml/kg	2.67 ± 0.33^b	6.17 ± 0.75^b	7.17 ± 0.75^{bc}	0 ± 0^b	0 ± 0^b
Pepper	3ml/kg	3.17 ± 0.48^b	5.13 ± 0.26^{bc}	10.67 ± 0.91^b	0 ± 0^b	0 ± 0^b
Ethiothio 5% dust	50g/Qt	0 ± 0^c	0 ± 0^e	0 ± 0^d	0 ± 0^b	0 ± 0^b
Acetone	4ml/kg	7.50 ± 0.68^a	11.67 ± 0.67^a	16.33 ± 0.89^a	19.33 ± 0.67^a	20.67 ± 1.05^a
Untreated check	-	7.33 ± 0.53^a	11.83 ± 0.79^a	16.67 ± 1.13^a	18.33 ± 1.2^a	20.83 ± 1.27^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

*Data from two years were pooled

**Means presented in the table are square root back transformed values

Effects of botanical oils on the survival of parent bruchids

The oils killed parent bruchids starting from day one after treatment application. Parent bruchids died in ethiothion 5% dust, noug oil and rape seed oil were 100%, $90.85 \pm 0.63\%$ and $78.4 \pm 0.78\%$, respectively day one after treatment application. About $28 \pm 0.52\%$ to $70.85 \pm 0.85\%$ of the parent bruchids were died in groundnut, lantana, tephrosia and pepper oil treated grains. In contrary, 100% of the parent bruchids were survived in acetone and untreated check treated grains day one after treatment application (Table 5.3).

Treatments like ethiothion 5% dust, noug, rape seed and groundnut oils were statistically shown similar results that $98.35 \pm 1.27\%$ to 100% of the parent bruchids were died after two days of treatment application. The rest of the botanical oils were shown superior efficacy ($70 \pm 0.67\%$ to $90 \pm 0.98\%$) to kill parent bruchids than acetone treated and the untreated check faba bean grains that 96.65% of the parents were continued to exist. Four days after treatment 100% of the parent bruchids were died in ethiothion 5% dust and oil treated faba bean grains. In acetone and the untreated check 88.65% and 88.35% of the parent bruchids, respectively were alive and continued to lay their eggs (Table 5.3).

The dead bruchids in acetone and the untreated check after eight days of experiment were $50 \pm 0.53\%$ and 55 ± 1.49 , respectively. The number of dead parent bruchids was increased in acetone and the untreated check with time due to natural death was expected. As a result, the dead parent bruchids were $85.85 \pm 0.35\%$ in untreated check and $86.65 \pm 0.41\%$ in acetone treated faba bean grains ten days after treatment application. About $14.15 \pm 0.26\%$ and $13.35 \pm 0.63\%$ of the parent bruchids in the untreated check and acetone treated grains, respectively were continued and alive after ten days of the experiment (Table 5.3)

Table 5.3. *Dead adult parent bruchids in the first ten days of treatment application

Treatment	Rate	**Mortality of bruchids (%) after treatment application
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		1 st day	2 nd day	4 th day	8 th day	10 th day	Live bruchids after 10 days
Noug	4ml/kg	90.85±0.63 ^{ab}	100±0.0 ^a	0±0 ^c	0±0 ^b	0±0 ^b	0±0 ^b
Rape seed	4ml/kg	78.35±0.78 ^{bc}	100±0.0 ^a	0±0 ^c	0±0 ^b	0±0 ^b	0±0 ^b
Groundnut	3ml/kg	70.85±0.85 ^c	98.35±1.27 ^a	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
Castor	4ml/kg	52.5±1.0 ^d	90±0.98 ^b	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
Lantana	4ml/kg	37.5±0.97 ^e	75±1.06 ^c	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
Tephrosia	3ml/kg	28.35±0.52 ^e	70±0.67 ^c	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
Pepper	3ml/kg	30±0.81 ^e	73.35±0.88 ^c	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
Ethiothion 5% dust	50g/Qt	100±0.0 ^a	0±.00	0±0 ^c	0±0 ^b	0±0 ^b	0±0 ^b
Acetone	4ml/kg	0±0.0 ^f	3.35±0.53 ^d	10.85±0.6 ^b	50±0.4 ^a	86.7±0.41 ^a	13.35±0.63 ^a
Untreated check		0±0.0 ^f	3.35±0.56 ^d	11.65±0.5 ^b	55±1.4 ^a	85.9±0.35 ^a	14.15±0.26 ^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

* Data from two years were pooled

**Means presented in the table are square root back transformed values

Effects of botanical oils on adult progeny emergence and the capacity of adult progeny in egg laying

Eggs laid by bruchids on bean grains were vary due to various efficacy of treatments. Number of eggs laid in noug, rape seed and groundnut oils were statistically lower (0±0) at par with ethiothion 5% dust treated grains. Significantly lower number of bruchid eggs was laid on castor, lantana, tephrosia and pepper oil (37.67±3.16 to 98±8.19 eggs) treated grains compared to 498.3±41.5 eggs in untreated check and 493.3±41.1 eggs in acetone treated grains. The number of eggs laid in acetone and untreated check were fivefold that that of pepper oil shows better number of eggs laid than other oil treatments (Table 5.4).

Table 5.4. Eggs laid and bruchids emerged due to the effects of botanical oils on bean grains

Year	Treatment	Rate	Number of bruchids and their eggs**	
			Bruchid eggs	Emerged progenies
2013	Noug	4ml/kg	0±0 ^f	0±0 ^f
	Rape seed	4ml/kg	0±0 ^f	0±0 ^f
	Groundnut	3ml/kg	0±0 ^f	0.0±0 ^f
	Castor	4ml/kg	37.67±3.16 ^e	22.7±2.69 ^e
	Lantana	4ml/kg	61.67±5.15 ^d	41.7±4.91 ^d
	Tephrosia	3ml/kg	72.67±6.05 ^c	58±6.86 ^c
	pepper	3ml/kg	98.00±8.19 ^b	77.7±9.19 ^b
	Ethiothion 5% dust	50g/Qt	0±0 ^f	0±0 ^f
	Acetone	4ml/kg	493.3±41.1 ^a	465.3±54.83 ^a
	Untreated check	-	498.3±41.5 ^a	462.3±54.48 ^a
2014	Noug	4ml/kg	0±0 ^f	0±0 ^f
	Rape seed	3ml/kg	0±0 ^f	0±0 ^f
	Groundnut	3ml/kg	0±0 ^f	0±0 ^f
	Castor	4ml/kg	39.3±4.62 ^e	28.7±3.38 ^d
	Lantana	4ml/kg	63.7±7.49 ^d	52.3±6.24 ^c
	Tephrosia	3ml/kg	73.7±8.67 ^c	62±7.29 ^{bc}
	pepper	3ml/kg	95.3±11.22 ^b	71.7±8.43 ^b
	Ethiothion 5% dust	50g/Qt	0±0 ^f	0±0 ^f
	Acetone	4ml/kg	486.3±57.3 ^a	449.7±54.2 ^a
	Untreated check	-	496±57.3 ^a	448±52.4 ^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are logarithmic (**) back transformed values

There was no bruchid progeny emerged in oil treatments like noug, Rape seed, Groundnut and ethiothion 5% dust treated grains (Table 5.4). The maximum number of bruchid progenies emerged from castor, lantana, tephrosia and pepper oils were 28.8 ± 2.69 , 52.3 ± 4.91 , 62 ± 6.86 , and 77.7 ± 9.19 , respectively. Statistically higher number of bruchid progenies were recorded in acetone (465.3 ± 54.83) and the untreated check (462.3 ± 54.48) (Table 5.4).

Effect of botanical oils, ethiothion 5% dust and acetone on germination and bean grain weight loss due to bruchids

The oil treatments and ethiothion 5% dust were statistically shown lower percentage weight loss than untreated check and acetone treated bean grains. There was no weight loss recorded in ethiothion 5% dust, noug, rape seed and groundnut oil treated grains. Higher weigh losses were recorded from tephrosia oil ($3.2 \pm 0.51\%$) and pepper oil ($5.2 \pm 0.27\%$) treated faba bean grains than the rest of the oil treatments, however, the loss recorded from the untreated check was 3.5 to 18.4 folds exceeded than the oil treatments and the standard check (Table 5.5).

Higher bean grain germination was recorded from ethiothion 5% dust ($98.7 \pm 1.05\%$), noug ($98.7 \pm 1.33\%$), rape seed ($97 \pm 1.73\%$) and groundnut oil ($96 \pm 2.13\%$) treated grains. All the treatments were statistically shown better bean grains germination than acetone and untreated check after three months of the experiment. Ethiothion 5% dust and oils were inhibited emergence of bruchids from $71.7 \pm 2.56\%$ to 100% compared to $0 \pm 0\%$ in acetone and untreated check. In general oils and ethiothion 5% dust were shown lower faba bean grain weight loss, better germination percentage and better seedling performance even after germination than acetone treated and untreated faba bean grains (Table 5.5).

Table 5.5. Weight loss and germination percentage of bean grains and inhibition rates of botanical oils on bruchids, 2013-2014

Treatment	Rate	Weight loss (*)	Germination (%) (*)	IR (*)
Noug	4ml/kg	0±0 ^c	98.6±1.33 ^a	100±0 ^a
Rape seed	4ml/kg	0±0 ^c	97±1.73 ^{ab}	99.3±0.51 ^a
Groundnut	3ml/kg	0±0.1 ^c	96.2±2.13 ^{ab}	97.3±1.35 ^a
Castor	4ml/kg	0.4±0.39 ^c	93.8±1.65 ^{bc}	92.2±1.55 ^{ab}
Lantana	4ml/kg	2.9±0.43 ^c	84.3±1.81 ^d	78.9±3.64 ^{bc}
Tephrosia	3ml/kg	3.2±0.51 ^{bc}	87.2±1.84 ^{dc}	81.4±2.47 ^{bc}
pepper	3ml/kg	5.2±0.27 ^b	79.3±1.75 ^d	71.7±2.56 ^c
Ethiothion 5% dust	50g/Qt	0±0 ^c	98.7±1.05 ^a	100±0.0 ^a
Acetone	4ml/kg	18.3±0.4 ^a	67.3±4.23 ^e	0±0 ^d
Untreated check	-	18.4±0.44 ^a	66.7±3.02 ^e	0±0 ^d

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Data from two years were pooled

IR = Inhibition Rate

Means presented in the table are square root back transformed values

5.4. Discussion

Faba bean grains were differently infested by parent female bruchid eggs within the first ten days of treatment application. The grains treated with oil and ethiothion 5% dust were effectively protected from bruchids for egg laying. All of the oil treatments and the standard check were promising remedies to keep faba bean grains from bruchid infestation. The current result was similar to that of Ibrahim (2012) who reported that sesame, olive and sunflower oils were effectively decreased the egg laying capacity of *C. maculatus* on chickpea grain up to the end of the experiment. Similar results were reported by Abdulahi (2011) who tested four levels of *Balantia aegyptiaca* leaf extract and found that the botanical treatments were an efficient ovipositional deterrent compared to the untreated check. Tabu *et al.* (2012) conducted similar experiment and reported that bruchids inhibited oviposition on botanical treated chickpea grains.

Faba bean grains treated with oils and ethiothion 5% dust were not infested by additional eggs four days after treatment application. Acetone treated and the untreated faba bean grains were infested by additional female parent bruchid eggs up to ten days after treatment application. Yahaya *et al.* (2013) indicated that, significantly lower number of parent *C. maculatus* eggs were recorded on cowpea grains treated with botanical oils. Similar results were reported by Uddinll and Sanusi (2013) such that no bruchid eggs recorded on cowpea grains treated with groundnut and palm kernel oils. Ibrahim (2012) remarked that sesame (98.49%), olive (96.54%) and sunflower (95.37%) oils at the rate of 7.5ml/kg (v/w) were effectively deterring bruchids oviposition. Comparable result was reported by Shukla *et al.* (2007) in that *Murraya koenigii* L. and *Eupatorium cannabinum* L. dusts deter bruchid oviposition by 90.62% and 86.46%, respectively. Sangeeta and Apte (2015) reported that green gram grains treated with botanical oils were 100% free from parent *C. maculatus* infestation.

Parent bruchids were killed by the oils and the standard check starting from first days of treatment application. Some oils were more effective to kill parent bruchids. The death rates were increased up to four days of treatment application. Bruchids added in acetone treated and untreated grains were alive and lay eggs up to ten days of treatment application. Olotuah (2013) conducted similar experiment to control *C. maculatus* that the oils killed 100% of the parent bruchids within six minutes, while 100% of the parents survived in the untreated check. Chickpea grains treated with dusts of *A. indica* at 2% (w/w) were killed parent bruchids 80%, 91.67% and 93.67% after one, two and four days, respectively (Tabu *et al.*, 2012). Tadele *et al.* (2014) also confirmed that botanical dusts completely eradicated soldiers and worker termites a day after treatment application. Okonkwo and Okoye (2008) evaluated the efficacy of *Dennettia tripetela* dusts at 1.5g to 2.5g/kg to manage *S. zeamais* on maize grains that 100% of the parent weevils died within 24 hours of treatment application.

The current experiment demonstrated that all of the parent bruchids died in ethiothion 5% dust and oil treated faba bean grains after four days of treatment application, while the majority of the parents survived in the acetone treated and the untreated check. Some bruchids were alive even after ten days of treatment application in acetone treated and the untreated grains. Similar result was reported by Bhardwaj and Verma (2012) management of beetles by botanical dusts, edible oils and inert materials were appeared to be more effective four days after treatment application.

Similar result was reported by Tabu *et al.* (2012) in that *Chenopodium ambrosioides* leaf dusts at 4% (w/w) were killed 88.34% to 91.67% of the parent bruchids within four days of treatment application. Waktole and Amsalu (2012) reported similar findings that a dust of *Chenopodium* spp was achieved 66.67% mortality of *S. zeamais* parents at par with Acetellic 2% dust (70.39%). Sangeeta and Apte (2015) indicated that parent *C. maculatus* not survived in green gram grains treated with botanical

oils. Shukla *et al.* (2007) confirmed that parent bruchids effectively controlled by *M. koenigii* and *E. canabinum* leaf dusts.

The eggs of bruchid progenies were effectively controlled by ethiothion 5% dust and the oil treatments than acetone and untreated check. The progenies were continued to lay their eggs that increases bruchid population in the untreated check and acetone treated faba bean grains. In line with this study Yahaya *et al.* (2013) stated that palm, groundnut and coconut oils treated chickpea grains were completely protected from *C. chinensis* egg laying for three months. Sangeeta and Apte (2015) indicated that green gram grains treated with botanical oils were free from bruchid eggs for one year. Consistent with this study Abdulahi (2011) indicated that the eggs laid by bruchids on actellic 2% and botanical dusts treated cowpea grains were lower (88.6 ± 4.6 to 203.6 ± 5.9) than acetone (798.6 ± 27.4) and the untreated check (794.3 ± 15). Shukla *et al.* (2007) report was similar to the current findings in that bruchids laid lower number of eggs on 2% (w/w) leaf dusts of *M. koenigii* (17.67 ± 5.5) and *E. canabinum* (22.34 ± 4.5) treated chickpea grains compared to the control (127.67 ± 8.05).

The current study indicated that faba bean grains treated with oils and ethiothion 5% dust were significantly reduced adult progeny emergence. In some oil and ethiothion 5% treated grains were completely free from bruchid progeny emergence. On the contrary, higher numbers of bruchid progenies were emerged from acetone treated and untreated faba bean grains. Okonkwo and Okoye (2008) reported the same result that oils completely suppressed the emergence of F₁ progenies and given protection up to four months of storage. Abdulahi (2011) reported the related result on number of bruchids emerged from actellic 2% dust and botanical dust treated cowpea grains ranged from 9.3 ± 1.2 to 40.3 ± 7.9 compared to the acetone (698 ± 24.46) and the control (672.3 ± 19.6).

Similar result was reported by Regmil and Dhoji (2011) that number of bruchids emerged in oil and dust treated chickpea grain were significantly lower (0 to 2292 ± 204.6) compared to control (4713 ± 204.6). Tabu *et al.* (2012) reported similar results on the number of progenies emerged from *A. indica* at 2% (w/w) and *C. ambrosiodes* at 4% (w/w) were 42 and 24.33, respectively compared to 320 bruchids recorded from untreated check. Ibrahim (2012) reported that sesame seed oil treated chickpea grains decreased adult emergence by 96.03% and 96.22% respectively. A similar result was reported by Yahaya *et al.* (2013), e.g., applications of groundnut or palm oil significantly suppress *C. maculatus* progeny emergence.

The results of the current study indicated that higher faba bean grain weight losses were recorded from the untreated check and acetone than oils and ethiothion 5% dust treated grains. Highly infested and holed in acetone treated and untreated grains were recorded to high faba bean grain weight losses. The results are in line with the findings of Regmil and Dhoji (2011) reported that chickpea grains treated with oils and botanical dusts were no loss compared to $38.44\% \pm 9.43$ weight loss was recorded in the control treatment. Previous study by Loth *et al.* (2007) showed that lower seed weight loss (0%-8.54%) in botanical dust treated grains than 14.64% in the untreated check after three months of experiment.

The present experiment indicated that faba bean grains treated by the oils and ethiothion 5% dust were better germinated. The faba bean grains damaged by the bruchids were weakly germinated at the end of the experiment. Ibrahim (2012) added that 80% to 93% of chickpea grains treated with botanical oils were effectively germinated after 90 days of experiment. Tabu *et al.* (2012) remarked that *A. indica* 2% (w/w) *C. ambrosiodes* at 4% (w/w) seed dust treated chickpea grains were effectively germinated from 98.3% to 100%. Mushobozy *et al.* (2009) conducted similar research to manage *Z. subfasciatus* that the oil were shown better germination ability of grains.

The present result indicated that bruchids were inhibited to emerge in oils and ethiothion 5% dust treated faba bean grains. Bruchids were not inhibited to emerge in acetone and untreated check. Okonkwo and Okoye (2008) reported that *C. maculatus* and *S. zeamais* were effectively controlled by the botanical oils in the first 24 hours that inhibited to lay eggs and emerge to adults. Similar result reported by Tabu *et al.* (2012) that bruchids inhibited (86.85% and 92.36%) to emerge in seed dust *A. indica* 2% (w/w) and *C. ambrosiodes* 4% (w/w) treated chickpea grains.

5.5. Conclusions

Ethiothion 5% dust and oils killed parent *A. obtectus* from day one to day four after treatment application. The parent bruchids continued to live and lay eggs up to ten days in the untreated check and acetone treated faba bean grains. The majority of the parent bruchids died in acetone treated and the untreated grains onwards from day eight after treatment application due to natural death. The number of eggs laid by parent bruchids during the first ten days of experiment were significantly lower in ethiothion 5% dust and oil treated bean grains. The female parent bruchids were laid higher number of eggs in acetone treated and the untreated check grains within the first ten days of treatment application.

Faba bean grains treated with ethiothion 5% dust and oils were shown lower number bruchid progenies and lower number of eggs laid by progenies compared to acetone and untreated check. Ethiothion 5% dust and oil treatments were shown promising efficacy such as lower percentage of grain weight loss, better germination percentage of the grains. Bruchid emergence were highly inhibited in ethiothion 5% dust and oil treated faba bean grains. In contrary, acetone treated and untreated grains were highly infested and damaged by bruchids. As a result, higher number of progenies was emerged and higher number of holed grains and higher grain weight losses recorded.

It is needed to screen out the botanical oils efficacy, biodegradability and their effect on bruchids in different agro-ecological zones both in the field and after storage. The farmers can manage bruchids using the evaluated botanical oils due to their availability, ease of extraction and application. As a result the botanical oils can be used as one component of Integrated Pest Management (IPM).

Chapter Six. Safe storage of moisture on faba bean (*Vicia faba* L.) against bean bruchid, *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae)

6.1. Introduction

Faba bean, *V. faba* L. is one of the earliest domesticated legume crops probably in the late Neolithic period (Teklay *et al.*, 2014). It is an important food, cash and break crop in high lands of Ethiopia that the farmers are cognizant of the roll of the crop to improve soil fertility by fixing atmospheric nitrogen and widely use them in rotation with cereals (CSA, 2015; Saberi, 2015). The crop grows on a wide range of soil types with moderate fertility levels, well drained with an altitude range of 1800-3000 masl. It requires annual rainfall of 700-1000 mm and frost free growing periods (Tolera and Daba, 2009; Gemechu *et al.*, 2007). Today, faba bean are a major crop in many countries like China, Ethiopia and Egypt, and are widely grown for human food throughout the Mediterranean Region and in parts of Latin America.

Bean bruchids are important factor that limit the storage periods of the grain in Ethiopia, including Amhara Region in relation to the moisture contents of the grains (Obopile *et al.*, 2011). Grain moisture content is a very critical factor for bruchid infestation in the storage (Tavakoli *et al.*, 2009). The risk of bruchid damage is high on faba bean grain stored at grain moisture content above 11% (Brook, 2014; Nahar *et al.*, 2009). Hence, looking for optimum grain moisture content at which reproduction and development of bruchids are curtailed is crucial (Nahar *et al.*, 2009). Therefore, the objective of the current experiment is to look for optimum grain moisture content at the time of grain storage which is avoid or minimize bruchid infestation.

6.2. Materials and methods

6.2.1. Description of the study site

The study was conducted in Eastern Gojjam Zone, Debre Markose University at the same site stated in section 4.2.1.

6.2.2. Rearing of bean bruchid *A. obtectus*

Cultures of *A. obtectus* were established at Debre Markose University to obtain the same age group and required number of adult bruchids. About three plastic pots having 5 L capacity was used. Each pot was half filled with 3 kg faba bean grains to serve as food for bruchids (Abhay *et al.* 2011; Udo, 2011). About 50 unsexed adult *A. obtectus* were released to each jar following the procedures of section 4.2.2.

6.2.3. Treatment preparation

Faba bean grain moisture contents were prepared to approve optimum moisture levels for bruchids infestation, damage and multiplication. Bean grains free from bruchid eggs and exit holes were collected from local market and used for the experiment. Hand lens was used to examine the grains to be free from bruchid eggs. The selected grains were washed using potable water before using them for experiment to prevent any adverse effects or any other microbial contamination on the external surface of the grains (Wijenayake and Karunaratn, 1999).

The treatments used for the experiment were 5-5.5%, 9-9.5%, 11-11.5%, 14-14.5%, 16-16.5% and 20-20.5% grain moisture contents. Higher moisture levels such as 16-16.5% and 20-20.5% were prepared by faba bean grains immersed in water with sufficient head space for thorough mixed. After the addition of water grains were shaken six times a day for five minutes and left for three weeks in a refrigerator at $-4\pm 1^{\circ}\text{C}$ to protect mold growth (Nahar *et al.*, 2009) and to enable the moisture to be

distributed uniformly throughout the grains (Ileke and Olotuah, 2012; Tavakoli *et al.*, 2009). The required amounts of water to be added were determined using by Nahar *et al.* (2009), Kenneth and Hellenvange (1995) method as follows:

$$\text{Water to be added (g)} = \frac{\text{FM (\%)} - \text{AM (\%)}}{100 - \text{FM (\%)}} \times \text{Measured weight (g)}$$

Where: FM = Final moisture, AM = Actual moisture

Farmers around the experimental site store their bean grains at 14-14.5% moisture content. Hence, 14-14.5% grain moisture content was set as a control. The rest of the treatments like 5-5.5%, 9-9.5% and 11-11.5% moisture contents of faba bean grains were adjusted by oven dry chamber (Tavakoli *et al.*, 2009). Each treatment was dried to the pre-determined moisture content by placing grains on drying trays. Trays with grains were placed in an oven set at 103°C for 14, 32 and 52 hours for 11-11.5%, 9-9.5% and 5-5.5% moisture levels, respectively. The amount of water removed from each treatment was calculated based on Kenneth and Hellenvange (1995) formula.

$$W_2(g) = W_1 - \frac{W_1(M_1 - M_2)}{100 - M_2}$$

Where: W₁ = Initial grain weight before drying M₁ = Moisture content of undried grain (%)

W₂ = Final grain weight after drying M₂ = Moisture content of dried grain (%)

The initial and final bean grain moisture content was measured by moisture testing device (LDS-1H 20122032 7-5). Electronic sensitive balance (WT-G, SST-160mm) with ±0.01 gram accuracy was used to measure weight of the grains before and after moisture adjustments. The treatments were placed in laboratory for one week to ensure moisture homogeneity and to adapt the experimental room (Weinberg *et al.*, 2008).

The experiment was conducted in two liters plastic pots contained one kg bean grains. The pots were covered with muslin cloth held in place by rubber bands. The research was carried out for two years

in 2013 and 2014. The experiment was arranged in a Completely Randomized Design (CRD) with three replications. Twenty unsexed day one F₁ adult *A. obtectus* were added to each pot having grains of different moisture contents.

6.2.4. Data collection methods

Data on the number of eggs laid were collected at two, four, seven and ten days after parent bruchids introduction. All dead and alive bruchids were removed ten days after treatment application. First progeny adult emergence was expected and frequent follow up was continued starting from 22 days after treatment application (Thakur, 2012; Moss and Credland, 1994; Minney, 1990). The number of eggs and holes, grains with and without eggs per twenty grains and total number of emerged adult progenies were recorded for three months. The suitability of the treatments for bruchids containing different moisture levels were evaluated based on 'Growth Index' used by Astuti *et al.* (2013) as follows:

$$\text{Growth Index} = \frac{\text{LogF}}{D} \times 100$$

Where, F is emerged adults in percent, while D is the median developmental period in days mentioned above in section 4.2.2. If no bruchids were emerged over the test period, the growth index value was given as zero (Astuti *et al.* 2013). The faba bean grains with high growth indexes were considered suitable (kananji, 2007). This was based on the assumption that a few insect progenies would emerge out and developmental period would take longer time to reach an adult stage in non-suitable treatments (Astuti *et al.*, 2013).

Seed weight loss determination

On the 90th day of treatment application, faba bean grain weight loss was determined following the procedures in section 3.2.2.1.

Germination test of treated grain

The effects of the moisture levels on grain germination were evaluated three months after treatment following the the procedure in section 5.2.4.

6.2.5. Statistical analysis

Analysis of variance (ANOVA) was done according to Gomez and Gomez (1984) and Rogaswamy (2007) following the procedures indicated in section 4.2.3.

6.3. Results

Effect of faba bean grain moisture levels on egg laying by parent female adult *A. obtectus*

Parent *A. obtectus* laid significantly lower number of eggs (0.67 ± 0.33) at 5-5.5% grain moisture content and significantly higher number of eggs (4 ± 1.47) was recorded at 20-20.5% moisture contents two days after treatment application. Four days after treatment significantly higher number of bruchid eggs (10.83 ± 3.4) was recorded at 20-20.5% grain moisture content (Table 6.1). Bruchids laid significantly lower number of eggs (3.83 ± 1.11) at 5-5.5% grain moisture content as compared to the highest number of eggs (19.3 ± 4.39) laid on grains with 20-20.5% moisture content seven days after treatment application. Parent adult female laid the highest number of eggs on grains having 20-20.5% moisture content 10 days after treatment application.

Table 6.1. Eggs of bean bruchid *A. obtectus* infested on moisture treated faba bean grains

Treatments	No of eggs laid by parent bruchids 20^{-1} grains *			
	2 nd day	4 th day	7 th day	10 th day
5-5.5%	0.67 ± 0.33^c	1.67 ± 0.63^c	3.83 ± 1.11^d	5.17 ± 1.88^e
9-9.5%	1.16 ± 0.48^{bc}	4.5 ± 0.67^b	6.0 ± 1.78^{cd}	6.3 ± 1.33^{de}
11-11.5%	2.17 ± 0.48^{ab}	5.8 ± 0.95^b	6.67 ± 0.98^{cd}	9.3 ± 1.45^{cd}
14-14.5%	2.33 ± 0.52^{ab}	6.0 ± 0.58^b	7.50 ± 1.34^c	10.8 ± 0.49^c
16-16.5%	3.0 ± 0.91^a	10.67 ± 0.78^a	14.5 ± 0.97^b	17.8 ± 1.11^b
20-20.5%	4.0 ± 1.47^a	10.83 ± 3.4^a	19.3 ± 4.39^a	22.6 ± 5.28^a

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

Data from both years pooled together

Effect of grain moisture content on progeny emergence and oviposition of *A. obtectus*

Bruchid progenies were not totally emerged from 5-5.5% grain moisture content. In contrary, higher number of progenies (366.7 ± 9.38) was recorded from 20-20.5% grain moisture content. Faba bean grains were highly infested and damaged by bruchids at grain moisture contents of 20-20.5%, 16-16.5% and 14-14.5% than grains with low moisture contents such as 5-5.5% (Table 6.2). Bruchids were not emerged from grains having 5-5.5% moisture content. Hence, there is no egg laid at this grain moisture content. Significantly higher number of eggs (393 ± 5.86) were recorded at 20-20.5% grain moisture content (Table 6.2). Table 6.2 demonstrated that faba bean grains having 5-5.5% moisture contents were free from holes done by bruchids. Higher number of holed grains (53.7 ± 4.29) was recorded on grains having 20-20.5% moisture content.

Table 6.2. Emergence of bean bruchid *A. obtectus* progenies and eggs laid on moisture treated faba bean grains

Treatments	Total number of eggs (**)	Total number of bruchids (**)	Total No of holes/20 grains (*)	Grains free from bruchid eggs /20 grains (*)	Free from holes/20 grains (*)
5-5.5%	0 ± 0^e	0 ± 0^d	0 ± 0^d	17.8 ± 2.41^a	20 ± 0^a
9-9.5%	37.7 ± 0.84^{cd}	13 ± 0.55^{cd}	2.3 ± 1.72^d	13.3 ± 1.75^b	17.2 ± 0.48^a
11-11.5%	76.2 ± 6.33^d	51.7 ± 1.28^c	8.5 ± 2.07^c	3 ± 1.27^c	12.2 ± 1.3^b
14-14.5%	273.5 ± 14.44^c	246.7 ± 17.51^b	20.3 ± 4.22^b	1 ± 2.82^d	7.5 ± 1.17^c
16-16.5%	342.5 ± 29.92^b	321.8 ± 17.26^{ab}	45 ± 5.7^a	0 ± 0^d	4.8 ± 1.3^d
20-20.5%	393 ± 5.86^a	366.7 ± 9.38^a	53.7 ± 4.29^a	0 ± 0^d	3.7 ± 1.35^d

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are back square root (*) and log (**) transformed values

Data from both years pooled together

Higher number of parent bruchid eggs in line with higher number of perforated grains due to bruchid progenies were recorded at 14-14.5%, 16-16.5% and 20-20.5% moisture treated grains. Lower moisture content such as 5-5.5% treated grains were not suitable for parent female bruchids to lay eggs and the grains were free from holes (figure 6.1).

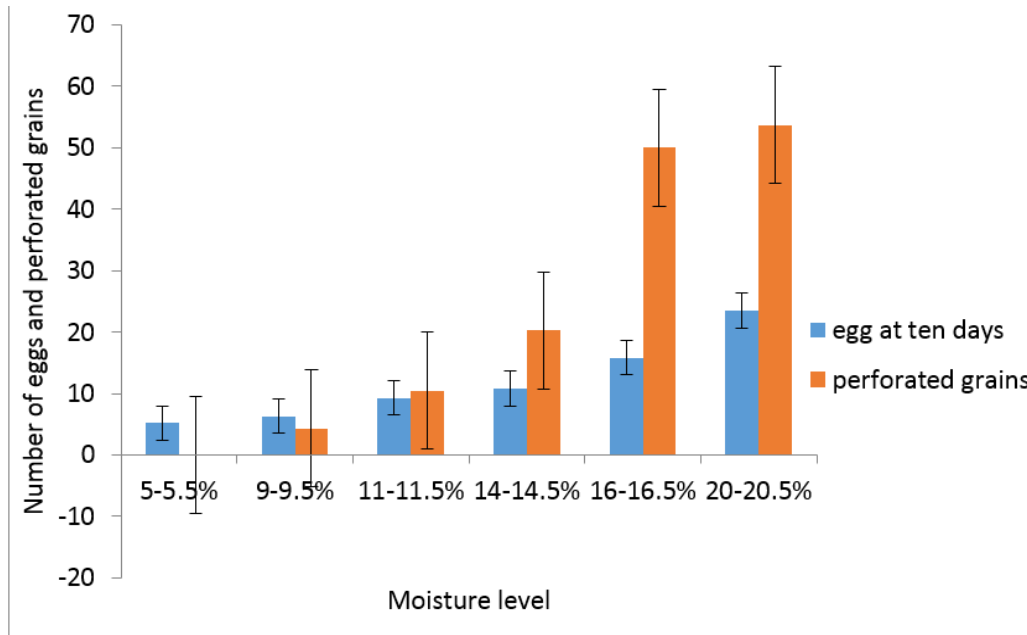


Figure 6.1. The relationship between parent female bruchid eggs at ten days and number of holed grains

Effects of grain moisture content on bean grain weight loss due to bean bruchids, *A. obtectus*

Bean grain weight loss was not recorded at grain moisture content of 5-5.5%. Significantly higher weight losses ($18.6\% \pm 1.87$) were recorded on grains having 20-20.5% grain moisture content (Table 6.3). Medium moisture contents of the grains such as 9-9.5% and 11-11.5% were not suitable moisture levels for bruchids that causes lower faba bean grain weight losses ranged from $1 \pm 0.59\%$ to $2.2 \pm 1.98\%$.

Effects of grain moisture content on germination capacity of bean grains

Germination percentage of faba bean grains stored at various moisture contents are shown in Table 6.3. Grains with moisture contents of 9-9.5%, 11-1.5% and 14-14.5% showed high germination percentage capacity than the other treatments. Germination percentages of faba bean grains with 5-5.5% and 20-20.5% moisture contents were $70.8\% \pm 8.71$ and $80.7\% \pm 5.22$, respectively.

Effects of grain moisture content on developmental period of *A. obtectus*

The effect of faba bean grain moisture content on developmental period of *A. obtectus* is shown in Table 6.3. According to the Table, faba bean grains having 9-9.5% and 11-11.5% moisture contents took longer periods of 48.7 ± 1.15 and 41 ± 1.35 days, respectively for development. As there was no egg laid on grains having 5-5.5% moisture content no investigation was conducted on developmental period.

Table 6.3. Weight loss of faba bean grains, developmental period and Growth index of bean bruchid *A. obtectus*

Treatments	% weight loss (*)	Developmental period (days) (*)	Growth index (*)	% Germination (*)
5-5.5%	0 ± 0^d	0 ± 0^d	0 ± 0^c	70.8 ± 8.71^d
9-9.5%	1 ± 0.59^c	48.7 ± 1.15^a	0.3 ± 0.13^c	98.3 ± 0.76^a
11-11.5%	2.2 ± 1.98^c	41.7 ± 1.35^b	1.5 ± 0.29^b	93.2 ± 4.68^{ab}
14-14.5%	12.9 ± 1.06^b	32 ± 0.71^c	2.4 ± 0.50^a	87.8 ± 2.86^{bc}
16-16.5%	16.5 ± 2.88^a	31.2 ± 0.46^c	2.8 ± 0.19^a	84.3 ± 6.43^{bc}
20-20.5%	18.6 ± 1.87^a	31.3 ± 0.57^c	2.8 ± 0.11^a	80.7 ± 5.22^c

Columns within the same letter are not significantly different at $\alpha \leq 5\%$ Tukey's studentized range test (HSD)

Means presented in the table are square root (*) back transformed values

Data from both years pooled together

Relationship between faba bean grain weight loss and bruchid developmental period

Faba bean grain moisture contents that reduced grain weight losses were extended the developmental periods of bruchids and the two parameters were negatively correlated (Figure 6.2). Shorter developmental periods and higher faba bean grain weight losses were recorded at 20-20.5%, 16-16.5% and 14-14.5% grain moisture content. There was no weight loss and development at lower grain moisture content of 5-5.5%.

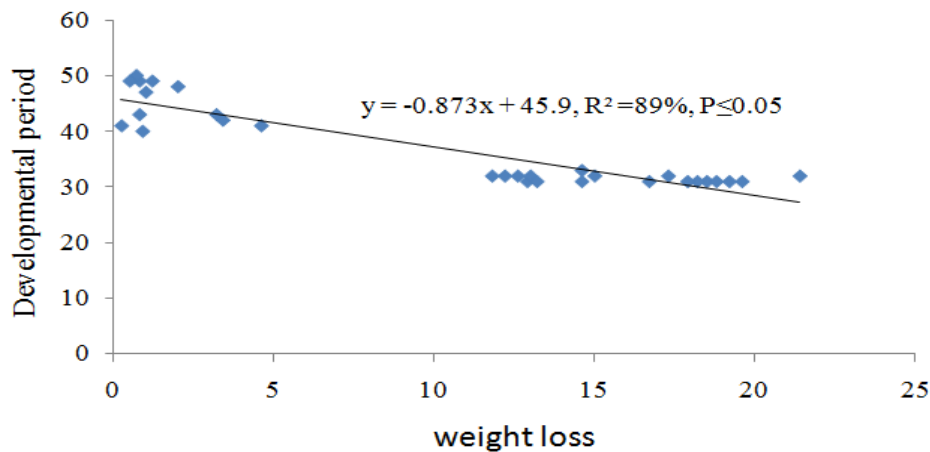


Figure 6.2. Relationship between bean bruchids *A. obtectus* developmental period and faba bean grain weight loss in grains of having different moisture contents

Relationship between developmental period and Growth index of bean bruchids, *A. obtectus*

In the present experiment 9-9.5% and 11-11.5% faba bean grain moisture contents were extended the developmental periods of the bruchids from 10.5 to 17.5 days. Grains with higher moisture contents led to higher growth index and short developmental periods of *A. obtectus*. Longer developmental periods of bruchids led to lower growth index and the relationship was strongly negative with $r^2 = 94\%$ (Figure 6.3).

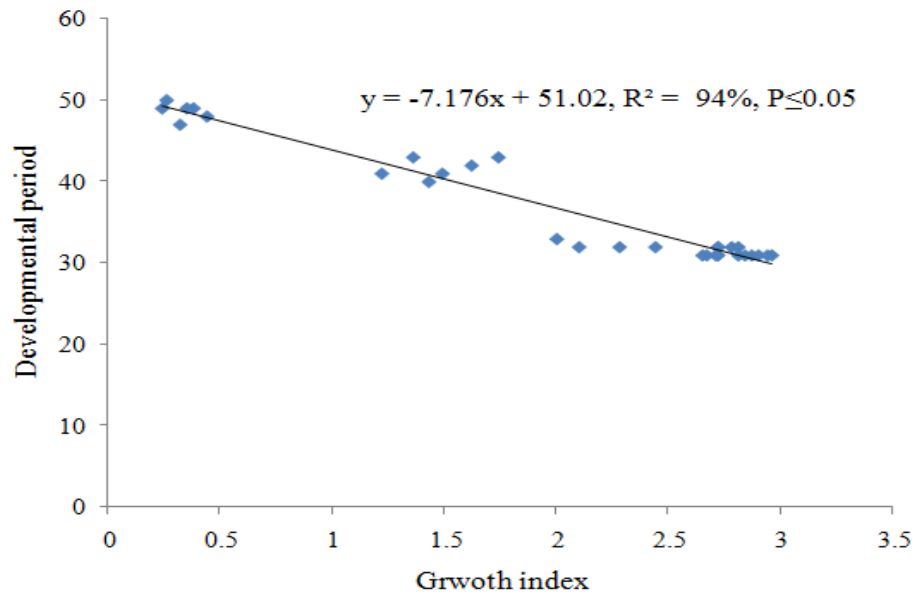


Figure 6.3. Relation between developmental period and growth index of *A. obtectus* in grains of having different moisture contents

6.4. Discussion

The current result indicated that faba bean grains with low moisture contents of less than 11.5% were not suitable for Adult female *A. obtectus* to lay eggs. Faba bean grain moisture content ranging from 14% to 20.5% found to be suitable for *A. obtectus* egg laying. This result is in line with the findings of Hyma (2003) who reported that 8-11% grain moisture content inhibited egg laying by storage insect pests such as *A. obtectus*. Similarly, Mason and McDonough (2012) reported that grains with low moisture contents significantly reduced egg laying by parent bruchids and minimize adult emergence after storage.

Previous study by Astuti *et al.* (2013) indicated that parent *Rhizopertha dominica* (F.) laid lower number of eggs on milled rice at lower moisture contents. Ekechukwu (1999) reported that stored grains below 10% moisture content were not suitable for egg laying by adult females. Weinberg *et al.* (2008) reported that cereal stored grain insect pests were unable to develop and reproduce under cool and well dried grains. Ogendo *et al.* (2004) noted that moisture contents of maize grains decreased from 14.38% to 12.89% were decreased infestations and emergence of the progenies as well as increased storage durations from 30 to 120 days.

The current results demonstrated that there was no progeny emergence at lower grain moisture content (5-5.5%). In contrary, large number of progenies were emerged from grains having high moisture contents which is proportional to the number of eggs laid. Moreover, number of holes and total number of damaged grains by bruchids was higher on faba bean grains having high moisture contents. The current findings are in line with investigations of a number of scientists. For instance, Hyma (2003) noted that lower number of progenies emerged from grains stored at lower moisture contents. Hagstrum and Milliken (1988) also reported that higher moisture contents of stored grains were conducive to higher insect population buildup during storage. Ekechukwu (1999) also reported

that storage insects faced a problem to sustain and reproduce in pulse grains below 10% moisture contents.

Faba bean grains having low and medium moisture contents suppressed egg laying by bruchids. Higher number of eggs were recorded from higher moisture contents of the bean grains. This result is consistent with Mason and McDonough (2012) who reported that bruchids were unable to lay eggs on well dried pulse grains. The current result is in agreement with that of Johnson and Townsend (2013) finding, storage insects were required better moistened grain for maximum feeding and reproduction. Study of Khaliq *et al.* (2014) showed that grains stored at lower moisture contents were infested with lower number of eggs and lower number of emerged adults. The same result was reported by Mboya (2013) that the presence, build up and multiplication of insects were affected by the availability of grain moisture contents during storage.

The result obtained on bean grain weight loss clearly demonstrated that bean grain that are stored at low moisture content suffer less from *A. obtectus* grain losses, while grains stored at high moisture content are susceptible to *A. obtectus* damage which eventually lead to high losses. The current findings are in line with Mason and McDonough (2012) and Ekechukwu (1999) who reported that dry grains stored in a dry storage environment suffer less from losses due to stored grain insect pests. Weinberg *et al.* (2008) indicated that insects develop easily and cause remarkable weight losses in grains with high moisture contents. Allotey *et al.* (2012) indicated that dried and moistened Lentils (*Lense esculenta* variety Giza 9) weight losses infested by *C. maculatus* were 35% and 20%, respectively.

The current findings indicated that intermediate grain moisture content enhanced the germination capacity of faba bean grains. The result is in line with Weinberg *et al.* (2008) who reported that germination percentage of maize grains dropped from 84.3% to 28.6% after 75 days of storage at

lower (14%) and higher (22%) grain moisture contents. Obopile *et al.* (2011) demonstrated that pulse grains stored at higher moisture contents have low viability and germination. Comparable result was reported by Reuss *et al.* (1995) that viability of infested grains stored for three months at 13.1% and 9% moisture contents were increased from 28% to 89%, respectively.

The present result indicated that medium moisture contents were extended the developmental periods of *A. obtectus* than high moisture contents. In low moisture contents (5-5.5%) emergence of bruchids were not observed and no developmental period of the bruchids was recorded. The result was in agreement with Astuti *et al.* (2013) who reported that grains stored at high moisture contents shorten developmental periods of the insects. The same result was reported by Thakur (2012) that the developmental periods of *A. obtectus* ranged from 31.42 ± 0.364 to 46.71 ± 2.02 days in grains stored at higher and lower moisture contents, respectively. This result is consistent with the findings of Ekechukwu (1999) reported that grains stored below 10% moisture levels extended the developmental periods of insects. In line with the present result, Obopile *et al.* (2011) indicated that the developmental periods of *C. maculatus* were ranged from 28.25 ± 7.84 to 43.3 ± 1.67 days in higher and lower moisture contents, respectively. Previous study by Weinberg *et al.* (2008) indicated that insects develop quickly and cause significant grain damage in highly moistened grains.

The current study indicated that high moisture content of the grains were conducive for *A. obtectus* to cause high faba bean grain weight losses and to reduced bruchid developmental periods. Weinberg *et al.* (2008) report in line with the current finding that, insects infested in a higher grain moisture contents were caused substantial weight losses and complete their development shortly. Mason and McDonough (2012) added that grains stored at lower moisture contents efficiently reduced grain weight losses and increased the developmental period of the insect. Stored grains at safe moisture contents extended the developmental periods of the insect and reduce grain weight losses and the two parameters were negatively correlated (Astuti *et al.*, 2013).

The present result indicated that higher moisture contents of faba bean grains were increase growth index and decrease developmental periods of *A. obtectus*. Similarly, Astuti *et al.* (2013) reported that grains stored at low moisture contents increased the development periods and reduced growth index of the insects. Thakur (2012) report was also confirmed that bruchids were needed high moisture contents for short developmental period and high growth index that the two parameters were negatively correlated. Suitable grain moisture contents were increased the value of growth index and reduced developmental periods of insects (Obopile *et al.*, 2011).

6.5. Conclusions

Faba bean grain moisture content highly influenced the infestation of *A. obtectus*. The lower grain moisture content below 11% led to low number of eggs laid by adult female, low number of progeny emergence, low grain weight loss, high germination percentage and long developmental period. Hence, from the current experiment it can be concluded that if faba bean grains before storage in dried to less than 10% or 11% grain moisture content it can be stored for more than three months without significant problem posed by *A. obtectus*.

Chapter Seven. General conclusions and recommendations

7.1. Conclusions

The present study provides some basic information about the damage of faba bean grains due to bruchids in Westwrn Amhra Region, Ethiopia. The study confirmed that different bruchid species were recorded in the study areas. The bruchid species were *Callosobruchus chinensis* (L.), *Acanthoscelides obtectus* (Say) and *Bruchus pisorum* (L.). Faba bean grain samples were damaged by the bruchids in all assessed Districts and Peasant Associations. The first two species were founded in all assessed Peasant Associations and damaged faba bean grains both in the field and after storage. *B. pisorum* was confirmed in faba bean grain and field pea grains stored together while the insect was not totally recorded in Eastern Gojjam, Bibugn District.

The present study indicated that faba bean grains were seriously infested by bruchids starting from field (matured pods) to storage. Emergence and infestation of bruchids on faba bean grains started from two weeks up to two months after storage in 'Gota' kept in doors. Damage and loss were severe in Western part than Eastern part of Gojjam. The majority (73.12%) of the respondents rejected to use 50% and above holed faba bean grains due to bruchids. The farmers use bruchid damaged grains mainly for soil fertility enhancement. They stored their faba bean grains less than a year due to the fear of bruchids. Farmers applied various control strategies including insecticides (any) to control bruchids after emergence.

Results from the present study indicated that *A. obtectus* started infestation on matured and nearly matured faba bean pods in the field and the damage continued after storage. The parent female bruchids laid their eggs in all faba bean pod classes of laboratory experiments. However, the progenies emerged and damaged at opened matured pods and closed matured pods. Immature stages of the pods were not suitable hosts for bean bruchids both in the field and in laboratory experiments

and the progenies were not emerged up to the end of the experiment. The progenies emerged, infested and make emergence holes on the pods and the grains on opened matured and closed matured pods. Small number of bruchid progenies was emerged and lower number of holed pods was recorded from medium matured pods.

Bruchids were effectively controlled by the botanical oils and ethiothion 5% dust after storage. The parent bruchids were completely eradicated in oils and ethiothion 5% dust treated faba bean grains starting from day one to day four after treatment. The bruchids found in the acetone treated grains and the untreated check were survived and continued to lay eggs up to ten days.

Higher number of eggs and higher number of bruchid progenies recorded in the untreated check and the acetone treated faba bean grains. As a result, higher weight losses and lower sprouted grains achieved from the untreated check and the acetone treated faba bean grains. In contrary, the oils and ethiothion 5% dust were significantly inhibited bruchid progeny emergence. Hence, the oils and ethiothion 5% dust treated grains faced negligible grain weight losses and gave better germination of the treated grains. Based on the current result, the oils were promising alternatives to manage bean bruchids which are easily prepared, biodegradable and available everywhere around the farmers.

The present study indicated that, faba bean grain moisture adjustment was another effective controlling mechanism of bruchids during storage. The parent bruchid laid lower number of eggs and the grains were free from holes in lower moisture contents (5-5.5%). The bruchids attracted to lay eggs and to damage the grains in to higher faba bean grain moisture contents. The faba bean grains stored at 16-20.5 moisture contents were conducive for bean bruchids infestation, damage, emergence and multiplication. Hence, bean bruchids were cause minimum or negligible weight losses in lower moisture contents and required longer developmental periods to complet their life cycle.

7.2. Recommendations

1. Further assessments of faba bean grain damage due to bruchids are required to generate more information for decision making.
2. It is required to assess species composition of bruchids in different Agro Ecological Zones all the year round both in the field and after storage.
3. Awareness creation and capacity building to the farmers on time of faba bean harvesting and moisture minimizations of the grains after storage to manage bean bruchids.
4. Decision makers, plant protection experts and development agents should give equal attention for integrated bean bruchid management and faba bean production activities both in the field as well as after storage.
5. Bruchids should be managed both in the physiologically matured plants as well as after storage. It is needed to control parent bruchids and their eggs including first instar larva before entrance to faba bean pods.
6. Bruchids are effectively controlled by moisture adjustments and botanical oils mainly after storage which are cheaply available everywhere, easily prepared, environmentally eco-friendly and easily biodegradable (botanical oils). Therefore, control bruchids both in the field and after storage, stored faba bean grains in optimum moisture contents and the uses of botanical oils are the best complimentary strategy to control and manage faba bean grain damage due to bruchids and enhance the income of small holder farmers.

References

- Abass, A.B.; Ndunguru, G.; Mamiro, P.; Alenkhe, B.; Mlingi, N. and Bekunda, M. (2014). Post-harvest food losses in a maize-based farming system of semi-arid Savannah area of Tanzania. *Journal of Stored Product Research* 5: 49-57.
- Abdulahi, N. (2011). Studies on the efficacy of leaf extract of *Balanites aegyptiaca* on the oviposition and survival of immature stages (larvae and pupae) of *Callosobruchus maculatus* (F.) on treated cowpea seeds. *Bavero Journal of Pure and Applied Science* 4(1): 40-43.
- Abebe H/Gebrel and Bekele Hundie (2006). Farmers' post-harvest grain management choices under liquidity constraints and impending risks: Implications for achieving food security objectives in Ethiopia. *Poster Paper Prepared for Presentation at the International Association of Agricultural Economics conference, Gold Cost Australia, August 12-18, 2006.*
- Abhay, P.K.; Pooja, S.; Uma, P. and Tripathi, N. (2011). Use of essential oils of aromatic plants for the management of pigeon pea infestation by pulse bruchids during storage. *Journal of Agricultural Technology* 7(6): 1615-1624.
- Agona, J.A. and Muyinza, H. (2003). Synergetic potential of different botanical combinations against bean bruchids in storage. *African Crop Science Conference Proceeding* 6: 216-219.
- Ahmed, E.A.; Mohamed, A. and Siddig, K. (2007). Economics of faba bean production and marketing in Northern Sudan. University of Gottingen. *Conference on International Agricultural Research for Development, 2007 October 9-11.*
- Akibode, S. and Maredia, M. (2011). Global and Regional Trends in Production, Trade and Consumption of food Legume Crops. *Annual Report, 2-6.*
- Alemayehu Workalemahu (2009). The effects of indigenous root-nodulating bacteria on nodulation and growth of faba bean (*Vicia faba* L.) in the low-input agricultural systems of Tigray Highlands, Northern Ethiopia. *Medical Element Journal of Science* 1(2): 30-43.
- Alghamdi, S.S. (2009). Chemical composition of faba bean (*Vicia faba* L.) genotypes under various water regimes. *Pakistan Journal of Nutrition* 8(4): 477-482.
- Allotey, J.I.; Sefa-Debah, S.; Osei, A.K. and Collison, E.K. (2012). Comparative study of the effects of steam and solar heat treated cowpea seed on the development and control of *Callosobruchus*

- maculatus* (F.) (Coleoptera: Bruchidae). *African Journal of Food, Agriculture, Nutrition and Development* 12(3): 6065-6078.
- Alvarez, N. (2005). Ancient and recent evolutionary history of the bruchid beetle, *Acanthoscelides obtectus* Say a cosmopolitan pest of beans. *Blackwell publishing Ltd*, 14: 1015-1024.
- Amer, N.; Kakahy, N.; Ahmad, D. and Abdulahi, A.S. (2012). The effects of planting distance on yields of bean (*Vicia faba* L.) under drip irrigation system. *African Journal of Agricultural Research* 7(46): 6110-6114.
- ARARI (Amhara Region Agricultural Research Institute). (2002). Economic importance of pulses in the Amhara region of Ethiopia. *Proceedings of a National Workshop of the Management of Pea Weevil (Bruchus pisorum)* November 25 – 27, 2002 Bahir Dar Ethiopia, 2-8.
- Araya G/Selassie and Emanu Getu (2009). Evaluation of botanical plant powders against *Zabrotes subfasciatus* (Boheman) Coleoptera: Bruchidae) in stored haricot bean under laboratory condition. *African Journal of Agricultural Research* 4: 1073-1079.
- Anton, K.W. (2000). Five new species of the *Callosobruchus chinensis* group from Oriental Region and Australia (Coleoptera: Bruchidae: Bruchinae). *Genus* 11: 13-28.
- Antonio, M.G.; Jemenze, S.A.; Castilo, F.; Mendez, A.A. and Moreno, E.M. (2014). Elimination of common bean weevil *Acanthoscelides obtectus* (Say) by hermetic storage of dry common bean at different moisture contents. *Journal of Entomological Research Society* 16(2): 13-22.
- Archiv, J.K. (2010). Invasion and threats of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) to kidney beans in India - a first record. *Journal of Stored Products Research* 17: 23-28.
- Astuti, L.P.; Mudjiono, G. and Rhardjo, B.T. (2013). Influence of temperature and humidity on the population growth of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on milled rice. *Journal of Entomology* 10: 89-94.
- Ayamdoo, A.J.; Demuyakor, B.; Badii, K.B. and Sowley, E.N. (2013). Storage systems for Bambara groundnut (*Vigna subterranean*) and their implications for Bruchid pest management In Talesi-Nabdum District, Upper East Region, Ghana. *International Journal of Scientific and Technology Rresearch* 2(2): 2277-8616.

- Ayvaz, A.; Sagdic, O.; Karaborkulu, S. and Ozturk, I. (2010). Insecticidal activity of the essential oils from different plants against three stored product insects. *Journal of Insect Science* 8: 1-6.
- Baginsky, C.; Ivaropen, N.; Caceres, A.; Hurenandez, T.; Esterella, I.; Morales, H. and Pertuze, R. (2013). Phenolic compound composition in immature seeds of faba bean (*Vicia faba* L.) varieties cultivated in Chile. *Journals of Food Composition and Analysis* 31: 1- 6.
- BPHC (Bahir Dar Plant health Clinic). (2009). Assessment of pea beetle (*Bruchus pisorum* L.) distribution in different Districts of Amhara Region. *Annual Survey Report*. 1-8.
- Baidoo, P.K.; Mochiah, M.B. and Owusu-Akyaww, M. (2010). The effect of harvest time on damage caused by the cowpea weevil *Callosobruchus maculatus* (Fab.) (Coleoptera: Bruchidae). *Journal of Stored Product and Postharvest Research* 1(3): 24-28.
- Basavaraja, H.; Mahajanashetti, S.B. and Udagatt, N. C. (2007). Economic analysis of post-harvest losses in food grains in India: A Case Study of Karnataka. *Agricultural Economics Research Review* 20: 117-126.
- Berier, H.; Collins, P.; Burril, P.; Lucy, M.; Bulleen, K. and Kingaroy, F. (2005). Grain storage bruchids in mung bean and other pulse crops. A major treat to the pulse grain industry. *Journal of Australian Mung Bean* 7: 1-5.
- Berka-Zoygali, B.; Ferhat, M.; Hassani, A.; Chemat, F. and Allaf, K. (2012). Comparative study of essential oils extracted from Algeria *Myrtus communis* L. leaves using microwaves and hydro distillation. *International Journal of Molecular Science* 13(4): 4673-4695.
- Betancur, J.R.; Silva, G.A.; Rodríguez, C.M.; Fischer, S.G. and Zapata, N.S.M. (2009). Insecticidal activity of (*Peumus boldus* Molina) essential oil against *Sitophilus zeamais* Motschulsky. *Journal of Economic Entomology* 45: 1610-1615.
- Bhardwaj, A. and Verma, S.C. (2012). Evaluation of vegetable oils against pulse beetle, *Callosobruchus chinensis* (Coleoptera; Bruchidae) infesting pea seeds (*Pisium sativum* L.). *Journals of Pest Management in Horticultural Ecosystem* 18(1): 46-53.
- Bittnera, M.; Casanuevam, E.; Arbert, C.C.; Aguilera, M.A.; Hernandez, V.J. and Becerra, J.V. (2008). Effects of essential oils from five plant species against the granary weevils *Sitophilus*

- zeamais* and *Acanthoscelides obtectus* (Coleoptera). *Journal of Chilean Chemistry Society* 53(1): 71-79.
- Boeke, S.J. (2002). Traditional African plant products to protect stored cowpeas against insect damage; the battle against the beetle. *Ph.D. Thesis, submitted to Wageningen University* P 151.
- Cardet, C.; Kandji, T.; Delobel, A. and Danthu, P. (2005). Efficacy of neem and groundnut oils in protecting leguminous tree seeds against seed beetles in the Sahel. *Journal of Agro-forestry Systems* 40(1): 29-40.
- CSA (Central Statistical Authority). (2015). Woreda level crop production in Ethiopia: a pooled data approach. *Annual Report* 9-25.
- Chaieb, N.; Bouslama, M. and Mars, M. (2011). Growth and yield parameters variability among Faba bean (*Vicia faba* L.) Genotypes. *Journal of Natural Product and Plant Resources* 1(2): 81-90.
- Chelav, S. and Khashaveh, A. (2013). Insecticidal activity of poppy (*Papaver somniferum* L.) seed oil against cowpea weevil (*Callosobruchus maculatus* F.) in stored cowpea. *Phytopathology and Plant Protection* 46(19): 2314-2322.
- Cubero, J.I. (1974). The Evolutionary trends of *Vicia faba* L. *Theory and Applied Genetics* 45: 47-51.
- Cubero, J.I. (1973). The Evolutionary trends in *Vicia faba* L. *Theory and Applied Genetics* 43: 59-65.
- Dasbak, M.A.; Echenzona, B.C. and Asiegbu, J.E. (2009). Postharvest bruchid richness and residual activity of primiphos-methyl on *Callosobruchus maculatus* F. infested pigeon pea (*Cajanus cajan* L. Millsp.) in storage. *African Journal of Biotechnology* 8(2): 311-315.
- Derbalah, A.S. and Ahmed, S.I. (2011). Oil and powders of spearmint as an alternative to *Sitophilus oryzae* chemical control of wheat grains. *Journals of Plant Protection Research* 51(2): 145-150.
- Douiri, L. F.; Boughadad, A.; Assobhei, O. and Moumni, M. (2013). Chemical composition and biological activity of *Allium sativum* essential oils against *Callosobruchus maculatus*. *International Organization of Scientific Research (IOSR) Journal of Environmental Science, Toxicology and Food Technology* 3(1): 30-31.

- Dua, V.K.; Pandey, A.C. and Dash, A.P. (2010). Adulticidal activity of essential oils of *Lantana camara* leaves against mosquitoes. *Indian Journal of Medical Research* 131: 434-439.
- Dubale Befekadu (2014). Factors affecting quality of grain stored in Ethiopia traditional storage structures and opportunities for improvement. *International Journal of Science: Basic and Applied Research (IJSBAR)*. 18(2). 235-257.
- Duc, G.; Bao, S.; Baum, M.; Redden, B.; Sadiki, M.; Suso, M.J.; Vishniakova, M. and Zong X. (2010). Diversity maintenance and use of *Vicia faba* L. Genetic resources. *Journal of Field Crop Research* 115: 270-278.
- Ekechukwu, O.V. (1999). Review of solar-energy drying systems. An overview of drying principle and theory. *Journal of Energy Conversion and Management* 43: 593-613.
- El-Ghar, G.; El-Shelken, A.E. and Gesa, E. E.L. (1987). Effectiveness of some plant extracts as surface protectant of cowpea seed against the pulse beetle, *Calosobruchus chinensis* (L.). *Phytoparasitica* 17: 109-113.
- El-Tokhy, F. and Kasem, A. (2012). Studies on fertilizer requirements on faba bean. A Thesis submitted to Cairo University Department of Agronomy, Faculty of Agriculture, in partial fulfillment of the Requirement for the Degree of Master of Science Pp 1-13.
- Emana Getu (1999). Use of botanical plants in the control of stored maize grain insect pests in Ethiopia. In: Maize Production Technology for Future. Pp 105-108. *Proceedings of the sixth Eastern and Southern Africa Regional Maize Conference*, 21-25 September 1998, Addis Ababa, Ethiopia: CIMMYT and EARO.
- Endale Hailu, Gezahegn Getaneh, Tadesse Sefera, Nigusie Tadesse, Beyene Bitew, Anteneh Boidom, Daniel Kassa and Tamene Temesgen (2014). Faba bean Gall; A new treat for faba bean (*Vicia faba* L.) production in Ethiopia. *Advanced Crop Science Technology* 2(4): 1-4.
- Fowler, D.B. (1995). Winter cereal production harvesting drying and storage. *Winter Wheat Production Manual*. Crop Development Center, University of Saskatchewan Pp 2-12.
- Garcia-Perea, M.A.; Jimenez-Ambri, S.; Castillo-Gonzalez, F.; Mendez-Albores, A. and Moreno-Martinez, E. (2014). Elimination of the common bean weevil *Acanthoscelides obtectus* (Say) by

- hermetic storage of dry common bean at different moisture contents. *Journal of Entomology Research Society* 16(2): 13-22.
- Gemechu Keneni, Endashaw Bekele, Emana Getu, Muhammad Intiaz, Tebkew Damte, Bayeh Mulatu and Kifle Dagne (2011). Breeding food legumes for resistance to storage insect pests: Potential and limitations. *Reviewed Paper* 3: 1399-1415.
- Gemechu Keneni, Mussa Jarso and Tezera Wolabu (2007). Eco-geographic distribution and microcenters of genetic diversity in faba bean (*Vicia faba* L.) and field pea (*Pisium sativum* L.) Germplasm collection from Ethiopia. *East Africa Journal of Science* 1: 10-24.
- Gnanasambandam, A.; Paull, J.; Torres, A.; Kaur, S.; Leonforte, T.; Li, H.; Zong, X.; Yang, T. and Materne, M. (2012). Impact of Molecular Technologies on faba bean (*Vicia faba* L.) breeding strategies. *Reviewed Paper in Agronomy* 2: 132-166.
- Gomez, K.A. and Gomez, A.A. (1984). Statistical procedures in agricultural research. John Wiley and sons, New York Pp 8-30.
- Gwinner, J. R.; Harnisch, J. and Muck, O. (1996). Manual of the prevention of post-harvest grain losses. *Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH* P. 38.
- Hagstrum, D.W. and Milliken, G.A. (1988). Quantitative analysis of temperature, moisture and diet factors affecting insect development. *Forum: Annual Entomological Society of America* 81(4): 539-546.
- Haines, C.P. (1991). Insects and Arachnids of tropical stored product: their biology and identification. (*A Training Manual*). 2nd Edn. Chatham maritime, UK, Natural Resource Institute Pp 1-246.
- Hodges, R.J. (2011). Postharvest weight losses of cereal grains in Sub-Saharan Africa. APLIS (African Postharvest Loss Information system). *A transitional Network of Cereal grain Experts* Pp 4-10.
- Hossain, M.A., and Haque, M.A. (2010). Efficacy of some indigenous plant extracts as grain protectant against pulse beetle, *Callosobruchus chinensis* (L.). *Journal of Agroforestry and Environment* 4(1): 197-202.

- Hyma, J. (2003). The storage of tropical agricultural products. 2nd Ed. Otterloo-butler S.V. printed by: STOAS Digigraphy, Wageningen, the Netherlands, ISBN: 90-77073-60-4. Pp 6-42.
- Ibrahim, M.Y. (2012). Efficacy of some pant oils against stored-product pest cowpea weevil; *Callosobruchus maculatus* (Coleoptera: Bruchidae) on chickpea seeds. *Journal of Persian Gulf Crop Protection* 1(1): 4–11.
- Ibrahim, N.D. and Aliyu, S.M. (2014). Evaluation of plant seed oils and bitter leaf powder for their repellency and control of cow pea beetle (*Callosobruchus maculatus* Fab.) (Coleoptera Bruchidae) in stored cowpea. *Research Journal of Agriculture and Environmental Management* 3(8): 370-375.
- IBRD (The International Bank for Reconstruction and Development). (2011). Missing food. The case of postharvest grain losses in Sub-Saharan Africa. *Annual Report*. Number 60371-AFR.
- Ileke, K.D. and Olotuah, O.F. (2012). Bio-activity of *Anacardium occedentale* (L.) and *Alium sativum* (L.) powder and oil extracts against cowpea bruchid *Callosobruchus maculatus* (Fab.) (Coleoptera; Chrysomelidae). *International Journal of Biology* 4(1): 96-103.
- Ileke, K.D. and Oni, M. O. (2011). Toxicity of some plant powders to maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae) on stored wheat grains. *African Journal of Agricultural Research* 6(13): 3043-3048.
- Iyad, W.; Musallam, M.; Haddad, N.J.; Rahman, A.; Tawaha, M. and Migdadi, O.S. (2004). The importance of bee-pollination four genotypes of Faba bean (*Vicia faba*). *International Journal of Agriculture and Biology* 6(1): 9-12.
- Jemaa, J.M. (2014). Essential oil as a source of bioactive constituents for the control of insect pests of economic importance in Tunisia. *Journal of Medicinal Aromatic Plants* 3(2): 158-165.
- Johnson, D.W. and Townsend, L.H. (2013). Controlling insects in stored grain. *University of Kentucky College of Agriculture*, KY 4546-0091.
- Jones, M.; Alexander, C. and Lowenberg-Deboer, J. (2011). Profitability of hermetic produce improved crop storage (PICS) bags for African common bean producers. *Journal of Economic*

- Literature*. Department of Agricultural Economics, Purdue University West Lafayette, Indiana 47907-2056, November 2011.
- Joshua, D.K. (2007). Harvest time modification, neem seed product and primiphos-methyl as methods of reducing field infestation of cow pea storage bruchids in the Nigerian Guinea Savannah. *International Journal of Agricultural Research* 2: 870-876.
- Kakahy, A. N. N.; Ahmad, D. and Abdullahi, A. S. (2012). The effect of planting distance on yield of beans (*Vicia faba* L.) under drip irrigation system. *African Journal of Agricultural Research* 7(46): 6110-6114.
- Kananji, G.A.D. (2007). Small holder farmers' perceptions of dry bean damage by bean weevil and varietal preference in Malawi and their implications for breeding. *A Thesis submitted in Partial fulfillment of the requirements of the Degree of Doctor of Philosophy (PhD) in plant breeding*. Submitted to Kwanzulu University, Natal Republic of South Africa. Pp 4-162.
- Kareru, P.; Rotich, Z.K. and Maina, E.W. (2013). Use of botanicals and safer insecticides designed in controlling insects: The African Case. *Insecticides Development of Safer and More Effective Technologies* 3: 297-308.
- Karunamoorth, K.; Bishaw, D. and Mula, T. (2009). Toxic effects of traditional Ethiopian fish poisoning plant (*Milletia ferruginea* (Hoschst) seed extract on aquatic macro invertebrates. *Journal of Medical and Pharmacological Sciences* 13: 179-185.
- Kasambal, S. and Hendry, A. (2004). Avoidance bruchid infestation in stored beans. *Journal of Stored Product Research* 84: 124-128.
- Kenneth, J. and Hellenvange, P.E. (1995). Grain moisture effects and management. *Extension Agricultural Engineer. Revised AE-905, North Daccota State University Fargo, ND 58105*, Pp 1-8.
- Khadim, K. and Mbacke, S. (2011). Cowpea (*Vigna unguiculata* L. Walp) Field infestation by the bruchids (Coleoptera: Bruchidae) in the Northern Senegal: Preliminary biological and ecological data. *Journal of Applied Bioscience* 41: 2788-2796.

- Khaliq, A.; Javed, M.; Sohail, M. and Sagheer, M. (2014). Environmental effects on insects and their population dynamics. *Journals of Entomology and Zoology Studies* 2(2): 1-7.
- Khater, H.F. (2012). Prospects of botanical bio-pesticides in insect pest management. *Pharmacologia* 3: 641–656.
- Kingsolver, J.M. (2004). Handbook of Bruchidae of the United State and Canada (Insecta, Coleoptera) United States Department of Agriculture. *Agricultural Research Service Technical Bulletin*, Number 1912.
- Koona, P. and Njoya, J. (2004). Effectiveness of soya bean oil and powders from leaves of *Lantana camara* Linn. (Verbenaceae) as protectants of stored maize against infestation by *Sitophilus zeamais* Motsc (Coleoptera: Cuculionidae). *Pakistan Journal of Biological Society*. 7: 125–139.
- Kosterin, O.E. (2014). The lost ancestors of the broad bean (*Vicia faba* L.) and the origin of plant cultivation in the Near East. *Institute of Cytology and Genetics SB RAS, Novosibirsk, Russia*, DOI10.18699/VJ15.118.
- Kropff, W. (2008). Effectiveness and safety of botanical pesticides applied in black pepper (*Piper nigrum*) plantations. *PhD Thesis Submitted Wageningen University, Wageningen, the Netherlands* Pp. 35-42.
- Kusolwa, P.M. (2007). Breeding for bruchid resistance in common bean (*Phaseolus vulgaris* L.): Interspecific introgression of lectine-like seed proteins from Tepary bean (*Phaseolus acutifolius* A. Gray), Genetic control and bruchid resistance characterization. *A PhD Thesis Dissertation, Submitted to Oregon State University* Pp 2-6.
- Lal, D. and Raj, D.V. (2012). Efficacy of application of four vegetable oils as grain protectant against the growth and development of *Callosobruchus maculatus* and on its Damage. *Journal of Advances in Bioresearch* 3 (2); 55-59.
- Link, W.; Hanafy, M.; Malenica, N.; Jacobson, H. and Jelenic, S. (2008). Faba bean. Transgenic legume grain and forages. *Black well publishing LTD*, ISBN 978-1-405-16924-0.
- Loth, S.; Mulungu, O.; Elice, N.; Luwondo, N.; Shazia, O.W.M. and Robert, N. (2007). Effectiveness of local botanicals a protectants of stored beans (*Phaseolus vulgaris* L.) against bean bruchid

- (*Zabrotes sabfasciatus* Boh) (Genera: *Zabrotes*. Family: *Bruchidae*.) *Journals of Entomology* 4: 210–217.
- Maklakov, A.A.; Kremer, N. and Arnqvist, G. (2007). The effects of age at mating on female life-history traits in seed beetle. *Oxford Journal* 18(3): 551-555.
- Martha Megerssa (2010). Studies on Susceptibility of Different Pulse grains to *Callosobruchus chinensis* (L.) (Coleoptera: *Bruchidae*) under Laboratory Condition. A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Biology (*Insect Science*) Pp 18-19.
- Mason, L. and McDonough, M. (2012). Biology, behavior and ecology of stored grains and legume insects. *Kansas State University Agricultural Experiment Station and Cooperative Extension Service* Pp 1-12.
- Mazzonetto, F. and Vendramim, J.D. (2003) Effect of powders from vegetable species on *Acanthoscelides obtectus* (Say) (Coleoptera: *Bruchidae*) in stored beans. *Neotropical Entomology* 32: 145-149.
- Mbailao, M.; Maoura, N.; Bianbambe, A.; Bono, G. and Alladoubaye, E. (2006). Effects of six common plant seed oils on survival, egg laying and development of the cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: *Bruchidae*). *Journal of Biological Sciences* 6: 420-425.
- Mboya, R.M. (2013). Overcoming high grain moisture content prior to storage in poor communities: The Case of Rungwe District, Tanzania. *Global Journal of Science Frontier Research Agriculture and Veterinary* 13 (4): 75-96.
- Mendki, P.S.; Maheshwari, V.L.; Kothari, R.M. and Gowda, B.S (2001). Botanical pesticides: Emerging trends, advantage and limitations. *Journal of Physiology and Molecular Biology of Plants* 7(2): 107- 115.
- Mesele Gemu, Emanu Getu and Abdurazak Yosuf (2013). Pre-harvest assessment of *Sithophilus zeamais* (Motshulsky) and *Sitotroga cerealella* (Oliver) in maize producing areas: Evidence from South Ethiopia. *Discourse Journal of Agriculture and Food Sciences* 1(6): 103-110.

- Messina, F.J. and Fry, J.D. (2003). Environment-dependent reversal of a life history trade off in the seed beetle *Callosobruchus maculatus*. *Journal of Environmental Biology* 16: 501-509.
- Mining, J.; Lagat, Z.O.; Akenga, T.; Tarus, P.; Imbuga, M. and Tsanuo, M.K. (2014). Bioactive metabolites of *Senna didymobotrya* used as bio-pesticide against *Acanthoscelides obtectus* in Bungoma, Kenya. *Journal of Applied Pharmaceutical Science* 4 (09): 56-60.
- Minney, B.H. (1990). Breeding *Phaseolus vulgaris* (Common bean) for resistance to the major pest bruchids *Zabrotes subfasciatus* and *Acanthoscelides obtectus*. Biochemical basis for seed resistance in wild lines. A Thesis submitted in partial fulfillment of the requirements of the Degree of Doctor of Philosophy (PhD) in breeding. Submitted to Durham University, Pp 21-29.
- Misangu, R.N.; Nchimbi-Msolla, S. and Reuben, S.O. (2000). Research notes on the distribution and relative importance of bruchid species *Acanthoscelides obtectus* (Say) *Zabrotes subfasciatus* (Boh.) in Tanzania. *Tanzanian Journal of Agricultural Science* 3(2): 181-184.
- Misangu, R.N. (1997). Distribution of bean Bruchid species in the major bean growing regions in Tanzania. Ph.D. Thesis. Submitted to Sokoine University of Agriculture. P. 2.
- Mohamed, H.I. and Abd-El Hameed, A.G. (2014). Molecular and biochemical markers of some (*Vicia faba* L.) genotypes in response to storage insect pest infestation. *Journal of Plant Interaction* 9(1): 618-626.
- Mohamed, Y.I. (2012). Efficacy of some plant oils against stored-product pest cow pea weevil, *Callosobruchus maculatus* (Coleoptera: Bruchidae) on chickpea seeds. *Journals of Persian Gulf Crop Protection* 11: 4-11.
- Mohapatra, D.; Kar, A. and Giri, S.K. (2015). Insect pest management in stored pests: An Overview. *Journal of Food Bioprocess Technology* 8: 239-265.
- Mollaei, M.; Izadi, H.; Hossein, D.; majid, A. and Reza R.K. (2011). Bioactivity of essential oil from *Satureja hortensis* (L.) against three stored product insect pests. *African Journal of Biotechnology* 10(34): 6620-6627.

- Morya, K.; Pillai, S. and Patel, P. (2010). Effect of powdered leaves of *Lantana camara*, *Clerodendrum inerme* and *Citrus limonon* on the rice moth, *Corcyra cephalonica*. *Bulletin of Insectology* 63 (2): 183-189.
- Moss, C.J. and Credland, P.E. (1994). The measurement of resistance to *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) in seeds of *Phaseolus vulgaris* L. *Proceedings of the Six International Conference on Stored Product Protection*. Pp 3-5.
- Mulungu, L.S.; Luwondo, E.N.; Shazia, O.W.M.; Robert, R. and Misangu, N. (2007). Effectiveness of local botanicals as protectants of stored beans (*Phaseolus vulgaris* L.) against bean bruchid (*Zabrotes subfasciatus* Boh) (Genera: *Zabrotes*. Family: Brucidae). *Journal of Entomology* 4: 210-217.
- Murugesan, S.; Rajeskannan, C.; Suresh, D.; Sumathi, R. and Manivachakam, P. (2012). Identification of insecticidal properties in common weed – *Lantana camara* Linn by Gas Chromatography and mass spectrum (GC-MS-MS). *Advances in Applied Science Research* 3(5): 2754-2759.
- Mushobozy, D.M.K.; Nganilevanu, G.; Ruheza, S. and Swella, G.B. (2009). Plant oils as common bean (*Phaseolus vulgaris* L.) seed protectants against infestations by Mexican bean weevil *Zabrotes subfasciatus* (Boh.). *Journal of Plant Protection Research* 49(1): 35–40.
- Nahar, K.; Ali, M.H.; Ruhul, A.K.M. and Hasanuzzaman, M. (2009). Moisture content and germination of bean (*Phaseolus vulgaris* L.) under different storage conditions. *Academic Journal of Plant Sciences* 2(4): 237–241.
- Nahdy, S. and Agona, A. (1996). Studies on the control of the bean bruchids *Acanthoscelides obtectus* (Say) and *Zabrotes subfasciatus* (Bohman) (Coleoptera: Bruchidae) in the East African Region. *Second Meeting of the Pan African Working Group of Been Entomology Harare, Zimbabwe 19-22 September 1993*. CIAT African Workshop Series, No. 25.
- Napoles, J.R. (2010). A new species of *Acanthoscelides schilsky*, (Coleoptera: Bruchidae) from Nuevo, Leon, Mexico with a Key to the *obtectus* species group. *Coleoptera Bulletin* 64: 125-128.

- Nchimbi-Msolla, S. and Misangu, R.N. (2002). Seasonal distribution of common bean (*Phaseolus vulgaris* L.) bruchid species in selected areas in Tanzania. *Bean/Cowpea Collaborative Research Support Program-East Africa proceedings. Bean Seed Workshop Arusha, Tanzania, January 12-14.* 1-5.
- Ndomo, A.F.; Tapondjou, L.A.; Ngamo, L. and Hance, T. (2010). Insecticidal activity of essential oil of *Callistermon viminalis* applied as fumigant and powder against two Bruchids. *Journal of Applied Entomology* 134(4): 333–341.
- Nukenine, E.N. (2010). Store product protection in Africa. Past, present and future. *10th International Workshop Conference on Stored Product Protection* 425: 26-41.
- Obembe, O.M. and Kayode, J. (2013). Insecticidal activity of the Aqueous extracts of four under-utilized Tropical plants as protectants of cowpea seeds from *Callosobruchus maculatus* infestation. *Pakistan Journal of Biological Sciences* 16: 175-179.
- Obeng-Ofori, D. (2010). Residual insecticides, inert dusts and botanicals for the protection of durable stored products against pest infestation in developing countries. *10th Internationaal Working Conference on Stored product protection* Pp. 774-778.
- Obopile, M.; Masiapeto, K. and Gwafila, C. (2011). Variation in reproduction and developmental parameters of *Callosobruchus maculatus* (F.) reared on Botswana cowpea landraces. *African Journal of Biotechnology* 10(63): 13924-13928.
- Ofuya, T.I.; Olotuah, O.F. and Akinyoade, D.O. (2010). The effect of storage on the efficacy of *Eugenia aromatic* (Baill.) in the control of *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) pest. *Journal of Applied Science and Environmental Management* 14(1) 97-100.
- Ogendo, J.O.; Deng, A.L.; Belmain, S.R.; Walker, D.J. and Musandu, A.A. (2004). Effects of insecticidal plant materials *Lantana camara* L. and *Tephrosia vogelii* Hook on the quality parameters of stored maize grains. *The Journal of Food Technology in Africa* 9(1): 29-36.
- Okonkwo, E.U. and Okoye, W.I. (2008). The efficacy of four seed powders and the essential oils as protectants of cowpea and maize grains against infestation by *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) and *Sitophilus zeamais* (Motschulsky) (Coleoptera curculionidae) in Nigeria. *International Journal of Pest Management* 42(3): 143-146.

- Olayemi, F.F.; Adegbola, J.A.; Bamishaiye, E.I. and Awagu, E.F. (2012). Assessment of postharvest losses of some selected crops in eight local Government areas of river state, Nigeria. *Asian Journals of Development* 2: 13-23.
- Obtuh, O.F. (2013). Comparative use of botanical oil extracts in pest management. *Agriculture and Biology Journal of North America*. 4(4). 419-421.
- Olubayo, F.M. and Port, G.R. (1997). The efficacy of harvest time modification and intercropping as methods of reducing the field infestation of cowpea by storage bruchids in Kenya. *Journal of Stored Product Research* 33(4): 271-276.
- Owolabi, M.S.; Padilla-Camperos, E.; Ogundajo, A.L.; Ogunwande, I.A.; Flamini, G.; Yusuf, O.K.; Allen, K.; Flores-Fernandez, K.I. and Flores-Fernandez, J.M. (2014). Insecticidal activity and chemical composition of the *Morinda incida* essential oil against pulse beetle *Callosobruchus maculatus*. *Scientific World Journal* 14: 31-41.
- Owunsu-Akyaw, M.; Baidoo, P.K. and Mochiah, M.B. (2014). The effect of time of harvest on the damage caused by the storage beetle, *Callosobruchus maculatus* (Fab.) (Coleoptera: Bruchidae). *Global Advanced Research Journal of Agricultural Sciences* 3(11): 351-355.
- Pandey, A.K.; Pooja, S.; Uma, P.T. and Trimpthi, N.N. (2011). Use of Essential oils of aromatic plants for the management of pigeon pea infestation by pulse bruchids during storage. *Journal of Agricultural Technology* 7(6): 1615-1624.
- Parsons, D.J. and Credland, P.F. (2003). Determinants of oviposition in *Acanthoscelides obtectus*: a nonconformist bruchid. *Physiological Entomology* 28:221-231.
- Pathak, H.; Maru, S. and Silawat, S. C. (2014). Field study for the effectiveness of some plants leaf extracts against insect *Eutectona macheralisor* Teak skeletonizer in forest nursery of Indore, Madhya Pradesh. *American Journal of Agriculture and Forestry* 2(4): 110-113.
- Paul, U.V.; Hailbeck, A. and Edwards, P.J. (2010). Pre-harvest infestation of beans (*Phaseolus vulgaris* L.) by *Acanthoscelides obtectus* Say (Coleopteran: Bruchidae) in relation to bean pod maturity. *International Journal of Pest Management* 56(1): 41-50.

- Paul, U.V. (2007). Bean pest management in East Africa, a scientific evaluation of organic insect control practices used by Tanzanian farmers. *A PhD Thesis submitted to the Swiss Federal Institute of Technology* 30-47.
- Petzoldt, A.K.C. and Seaman, A. (2006). Climate change and agriculture: Promoting practical and profitable response. *Climate change effects on insects and pathogens. Geneva, NY* 14456.
- Prakash, A.; Rao, J. and Nandagopal, V. (2008). Futures of Botanical pesticides in rice, wheat, pulses and vegetable pest management. *Journals of Bio-Pesticides* 1(2): 154–169.
- Punzo, F. (1975). Effects of temperature, moisture and thermal acclimation on the biology of *Tenebrio molitor* (Coleoptera: Tenebrionidae). *Retrospective Thesis and Dissertations Paper*, 5438 Pp 9-160.
- Qazi, M.A. (2007). Fecundity and host preference of *Callosobruchus chinensis* (L.) (Bruchidae: Coleoptera). *Pakistan Journal Agricultura Research* 20: 3-4.
- Rajashekar, Y.; Bakthavatsalam, N. and Shivanandappa, S. (2012). Botanicals as grain protectants. *Psyche. Journal of Entomology* 6: 1-13.
- Ram, B.; Panerul, P. and Gopal, P.S. (2000). Use of botanicals for the management of pulse beetle (*Callosobruchus maculatus* F.) in lentil. *Nepal Agricultural Research Journal* 4: 67-78.
- Rashid Shahidur, Chilot Yirga, Befekadu Behute and Selomone Lemma (2010). Pulse value chain in Ethiopia. Constraints and opportunities for enhancing exports. *International Food Policy Institute* Pp 3-36.
- Regmil, H. and Dhoji, Y. (2011). Eco-friendly management of pulse beetle. *The Journal of Agriculture and Environment* 12: 81-90.
- Rembold, F.; Hodges, R.J.; Bernard, M.; Knipschild, H. and Leo, O. (2015). Improving methods for estimating post-harvest losses. *A Review of Methods for Estimating Grain Post-Harvest Losses*. 1-52.
- Remia, K.M. and Logaswamy, S. (2010). Larvicidal efficacy of leaf extract of two botanicals against the mosquito vector *Aedes aegypti* (Diptera: Culicidae). *Indian Journals of Natural Products and Resources* 1(2): 208-212.

- Renuka, D.; Thakur, R. and Sharma, R.K. (2014). Bio-efficacy of *Biden pilosa* L. against *Acanthoscelides obtectus* (Say) and *Zabrotes subfasciatus* (Boheman), stored pests of kidney beans, worldwide. *International Journal of Agricultural Crop Science* 7(15): 1470-1477.
- Reuben, S.O.; Masunga, M.; Makundi, R.; Misangu, R.N. and Kilonzo, B. (2006). Control of cowpea weevil (*Callosobruchus chinensis* L.) in stored cowpea (*Vigna unguiculatus* L) grains using botanicals. *Asian Journal of Plant Science* 5: 91-97.
- Reuss, R.; Damcevski, K. and Annis, P.C. (1995). The impacts of temperature, moisture contents, grain quality and their interactions on changes in storage vessel atmosphere. *Proceedings of the Six International Workshop Conferences on Stored Product Protection* 1:178-182.
- Robin, B. (1998). Grain post-harvest loss assessment in Ethiopia: *Final report (Working paper)*. Greenwich Academic Literature Archive. Available at: <http://gala.gre.ac.uk/10758>.
- Rogaswamy, R. (2007). A text book of agricultural statistics. 2nd Ed. New Age International (p) Ltd publisher. Newdelhi, India.
- Rotimi, J. and Ekperusi, O. A. (2012). Effectiveness of citrus oil as cow pea seed protectant against damage by the cow pea bruchid *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Advances in Applied Science Research Journal* 3(6): 3540-3544.
- Rugumaru, C.P. (2014). Potency of Traditional insecticide materials against stored bean weevil, *Acanthoscelides obtectus* (Coleoptera: Bruchidae) in Tanzania. *Journal of the Open University of Tanzania* 16: 11-18.
- Saberi, A. (2015). Response of faba bean (*Vicia faba* L.) to different planting pattern; an Overview. *Journal of Natural Science* 3(1): 1-6.
- Sacilic, K.; Ozturk, R. and Keskin, R. (2003). Some physical properties of legume seed. *Bio-Systems Engreering* 86(2): 191-198.
- Sales, M.; Gerhardt, I.R.; Grosidesa, M.F. and Xavier-Filho, J. (2000). Do legume storage proteins play a role in defending seed against bruchids? *Journal of Plant Physiology* 124(2): 515-522.
- Sallam, M. (2014). Insect damage postharvest operations. *Postharvest Compendium (INPHO)*. International Center of Insect Physiology and Ecology (ICIPE). 10-19.

- Sangeeta, G. and Apte, S.D. (2015). Effects of botanicals (Oils) on green gram (*Vigna radiata* L. Wilczek) against *Callosobruchus maculatus* (Fab.). *European Journal of Experimental Biology* 5(8): 31-33.
- Sapunaru, T.; Filipescu, C.; Georgescu, T. and Yvonne-Cecilie, B. (2006). Bioecology and control of bean weevil (*Acanthoscelides obtectus* Say). *Cercatari Agronomicu in Moldova* 39(2):5-12.
- Sapunaru, T.; Filipescu, C.; Georgescu, T. and Yvonne-Cecilie, B. (2003). Biology and control of bean weevil *Acanthoscelides obtectus*). *PhD Thesis. University of Agricultural Sciences and Veterinary Medicine of IASI* Pp 5-11.
- Sarwar, M. (2015). Extermination of insect pests (Coleoptera: Bruchidae) and damage of stored pulses by different methods in market. *American Journal of Marketing Research* 1(3): 99-105.
- Sarwar, M. (2013). Development and boosting of integrated insect pest management in stored grains. *Journal of Agriculture and Allied Sciences*, ISSN: E 234-226x, P 2319-9857. Pp 3-9.
- Sawant, A.A.; Patil, S.C.; Kase, S.B. and Thakor, N.J. (2012). Effects of temperature, relative humidity and moisture content on germination percentage of wheat stored at different storage structure. *Journal of Agricultural Engnering International* 14: 25-34.
- Schmale, I.; Wakers, F.L.; Cardonac, C. and Dorn, S. (2006). Biological control of the bean weevil, *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) by the native parasitoid *Dianrmus basalis* (Rondani) (Hymenoptera: Pteromalidae) on small scale farms in Colombia. *Journal of Stored Product Research* 42: 31-41.
- Schmale, I.; Wackers, F.L.; Cardona, C. and Dorn S. (2002). Field infestation of *Phaseolus vulgaris* by *Acanthoscelides obtectus* (Coleoptera: Bruchidae), parasitoid abundance, and consequence for storage pest control. *Journal of Environmental Entomology*. 31(5): 859-863.
- Seidenglaz, M. and Hunady, I. (2016). Effects of faba bean (*Vicia faba*) varieties on the development of *Bruchus rufimanus*. *Czech Journal of Plant Breeding* 52(1): 22-29.
- Senayt Yetneberk, and Asrat Wodimu (1994). Utilization of cool season food legumes in Ethiopia. *In: Asfaw Telaye Saxena, M.; Solh, M. and Geletu Bejiga (eds.). Cool season food legume in Ethiopia. Proceedings of the First National Food Legume Review Conference, 16-20 December*

- 1993, Addis Ababa, Ethiopia. ICARDA (International Center for Agricultural Research in Dry Areas). Addis Ababa, Ethiopia, 60-75.
- Shukla, R.; Srivastava, B.; Kumar, R. and Bubej, N.K. (2007). Potentials of some botanical powders in reducing infestation of chickpea by *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Journal of Agricultural Technology* 3(1): 11-19.
- Singh, A.K.; Bharati, R.C.; Manibhushan, N.C. and Pedapati, A. (2013). An assessment of faba bean (*Vicia faba* L.) current status and future prospect. *African Journal of Agricultural Research* 8(50): 6634-6641.
- Singh, S.P. (2001). Broadening the genetic base of common bean cultivars. *A review of Crop Science* 41: 1659-1675.
- Sman, M.B. (2006). Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. *Annual Review Entomology* 51: 45-66.
- Souguir, S.; Chaieb, I.; Cheikh, Z.B. and Larif, A. (2013). Insecticidal activity of essential oils from some cultivated aromatic plants against *Spodoptera littoralis* (Boisd). *Journal of Plant Protection Research* 5(4): 88-91.
- Swella, G.B. and Mushobozy, D.M.K. (2007). Evaluation of the efficacy of protectants against cowpea bruchid *Callosobruchus maculatus* (F.) on Cowpea seeds (*Vigna unguiculata* (L.) Walp.). *Journal of Plant Protection Science* 43: 68-72.
- Tabu, D.; Selvaraj, T.; Singh, S.K. and Mulugeta Negari (2012). Management of Adzuki bean beetle (*Callosobruchus chinensis* L.) using some botanicals, inert materials and edible oils in stored chickpea. *Journal of Agricultural Technology* 8(3): 881-902.
- Tadele Shībru, Habtamu Ashagrie and Mulugeta Negari (2014). Effects of some botanicals against termite, macrotermes Spp (Isoptera: Termitidae) under laboratory conditions. *International Journal of Sustainable Agricultural Research* 1(2). 52-57.
- Tadele Tefera, Mugo, S. and Likhayo, P. (2011). Effects of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil *Sitophilus zeamais* and

- larger grain borer *prostephanus truncates*. *African Journal of Agricultural Research* 6(10): 2249-2254.
- Talukder, F. (2009). Pesticide resistance in stored-product insects and alternative bio rational management. *A Brief Review. Agricultural and marine sciences*. 14: 9-15.
- Taponjou, L. A.; Adler, C.; Bouda, H. and Fontan, D.A. (2002). Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six- stored product beetles. *Journals of Stored Product Research* 38(4): 395–402.
- Tavakoli, H.; Rajabipour, A. and Mohatasebi, S.S. (2009). Moisture-dependent some engineering properties of soybean grains. *Agricultural engineering International: The International Commission of Agricultural and Biosystem Journal* 11: 1-12.
- Teklay Abebe, Tsehaye Birhane, Yemane Nega and Workneh Assefa (2014). The prevalence and importance of faba bean diseases with special consideration to the newly emerging “Faba bean Gall” in Tigray, Ethiopia. *Discourse Journal of Agriculture and Food Science* 2(2): 33-38.
- Thakur, D.R. and Kalpna. (2015). Some description and life history traits of Indian Biotype of *Acanthoscelides macrphthalmus* (Schaeffer) (Coleoptera: Bruchidae). *International Journal of Zoological Research* 11: 19-28.
- Thakur, D.R. (2012). Taxonomy, Distribution and pest status of Indian biotypes of *Acanthoscelides obtectus* (Coleoptera: Chrysomelidae: Bruchinae)-A new record. *Pakistan Journal of Zoology* 44(1): 189-195.
- Thakur, D.R. (2010). Invasion and treats of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) to kidney bean in India-a first record. *10th International Working Conference on Stored Product Protection* 193-196.
- Thein, W.M.; Javier, P.A. and Ceballo, F.A. (2013). Insecticidal activity of crude plant extracts against *Sitophilus* Spp (Coleoptera: Curculionidae) and *Callosobruchus chinensis* (Coleoptera: Bruchidae). *Journal of Philippine Agricultural Scientists* 96(2): 1-2.
- Tolera Abera and Daba Feyisa (2008). Faba bean and field pea seed production for intercropping system In Horro Highlands of Western Ethiopia. *African Crop Science Journal* 16(4): 243-249.

- Uddinll, R.O. and Sanusi, S.A. (2103). Efficacy of olive oil, Soybean oil and palm kernel oil in the control of *Callosobruchus maculatus* (F.) in stored cowpea (*Vigna unguiculata* L. Walp). *Journal of Agro-Research* 13(2): 67-72.
- Udo, I.O. (2011). Protectant effect of plant oils against cowpea weevil (*Callosobruchus maculatus*) on stored cowpea (*Vigna unguiculata*). *Journal of Agriculture and Biological Science* 6(12): 58–61.
- Umbuyeyi, S. and Rukazambuga, N.D.T. (2014). Farmer’s knowledge on grain losses from bean bruchid, pesticides use by small-scale farmers and implication on food security and sefty in Huye District, Ruwanda. *Annual Report* 1-13.
- Upadhyay, R. K. and Ahmad, S. (2011). Management strategies for the control of stored grain insect pests in farmer stores and public ware houses. *World Journal of Agricultural Sciences* 7(5): 527-529.
- USAID (United States Agency for International Development). (2013). Postharvest loss challenges discussion paper. Bureau of Economics and Business Affairs, November 13, 2013.
- Utono, I.M. (2013). Assessment of grain loss due to insect pest during storage for small-scale farmers of kebbi. *Journal of Agriculture and Veterinary Science* 3(5): 38-50.
- Verma, N.; Thripathi, A.K.; Prajaapati, V.; bahl, J. R.; Khanuja, S.P.S. (2000). Toxicity of essential oil from *Lippia alpa* towards stored grain insects. *Journal of Medical and Aromatic Plant Science* 22(1): 50–54.
- Waktole sori and Amsalu Ayana. (2012). Storage pests of maize and their status in Jimma Zone, Ethiopia. *African Journal of Agricultural Research* 7(28): 4056-4060.
- Warra, A.A. (2011). Sesame (*Sesamum indicum*) seed oil methods of extraction and its prospects in cosmetic industry: A Review. *Bayero Journal of Pure and Applied Science* 4(2): 164-168.
- Weinberg, Z.G.; Yan, Y.; Chena, Y.; Finkelmana, S.; Ahebella, G. and Navarroa, S. (2008). The effects of moisture level on high-moisture maize (*Zea mays* L.) under hermetic storage conditions-in vitro studies. *Journal of Stored Product Research* 44: 136-144.

- Wijenayake, D.U. and Karunaratn, M.S. (1999) Ovipositional preference and development of the cowpea beetle *Callosobruchus chinensis* on different stored pulses. *Vidyodaya Journal of Science* 1(19): 8135-8147.
- Worku Teka (2002). The importance and distribution of pea weevil (*Bruchus pisorum*) in the Amhara Region. *Proceedings of The National Workshop on the management of Pea Weevil, Bruchus pisorum*; November 2002; Bahir Dar, Ethiopia, Pp 30-36.
- Yahaya, M.M.; Bandiya, H.M. and Yahaya, M.A. (2013). Efficacy of selected seed oils against Fecundity of *Callosobruchus maculatus* (F.) Coleoptera: Bruchidae). *International Journal of Science and Technology* 8(1): 513–321.
- Yemane Takashi (2013). Bio-rational control methods for protection of stored grain legumes against bruchid beetles. *Journal of Agricultural Science* 4(12): 762-766.

Appendices



Appendix 1. Bruchid infested faba bean grains treated by oils



Appendix 2. Partially opened matured pods infested by bruchids



Appendix 3. Bruchid infested and damaged faba bean grains treated with acetone



Appendix 4. Grain moisture tester and weight measure

Appendix 5. Published paper

Management of bean bruchids (*Acanthoscelides obtectus* Say.) (Coleoptera: Bruchidae) using botanical oils in Western Amhara, Ethiopia. The manuscript is published by *Journal of Stored product and Postharvest Research* (JSPPR) 8(3): 31-39. Article Number: 4490CC263190, ISSN 2141-6566.

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*Botanical oils were screen out for the management of bean bruchids on faba bean grains. The tested oils were from seeds of Noug (*Guizotia abyssinica* L. f.), Rape seed (*Brassica napus* L.), Lantana (*Lantana camara* L.), Pepper (*Capsicum annum* L.), Tephrosia (*Tephrosia vogelii* Hook), Groundnut (*Arachis hypogaea* L.) and Castor (*Ricinus communis* L.). The untreated check, Acetone (solvent used to extract oils) and Ethiothion 5% dust were used for comparison. Four days after treatment application, 100% of the parent bruchids were killed in ethiothion 5% dust and oil treated grains indicating the fast knock down effect of the treatments. Statistically lower number of eggs and progeny (adults) were recorded from ethiothion 5% dust and oil treated grains than the acetone treated and the untreated grains. Bean grain losses due to bruchids were $18.3 \pm 0.4\%$ in acetone treated grains and $18.4 \pm 0.44\%$ in the control, while 0% to $5.2 \pm 0.27\%$ losses were recorded in other treatments. Ethiothion 5% dust and the oils inhibited emergence of bruchids from $71.7 \pm 2.56\%$ to $100 \pm 0.53\%$. Ethiothion 5% dust and all the tested oils can effectively control bean bruchid and recommended for the management of Bean bruchid.*

Key words: Bean bruchid, botanical oil, faba bean grain (*Vicia faba* L.), mortality, survival, progeny

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Appendix 6. Questionnaires used for data collection

Debre Markose University

Collage of Agriculture and Natural Science

Department of Plant Sciences

Questionnaire

Dear Respondents,

The purpose of this Questionnaire is to collect data based on the “Survey on faba bean grains (*Vicia faba* L.) handling and bruchid distribution in North Western Amhara region, Ethiopia”. The questionnaire will be filled out by randomly selected farmers from different Peasant Associations. The respondents are politely asked to feel and reply the questionnaire truly for quality and success of the data and the results too. The Author would like to assure you that the collected data will be used only for research purpose and it will be kept confidentially.

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Sample Code-----

Date of sample collection-----

I. Study areas and personal data of the respondents

Zone ----- District-----Altitude----- PA-----

Coordinates-----Sex-----Age-----.

II. Effects of bruchids on faba bean grains

1. Is there bruchid problem in the locality on bean grains?

Yes No

2. If your answer is yes at what time bruchid infestation is started before /after storage?

If your answer is before storage at which stage of the bean plants in the field? Thick the relevant alternative/s

A. Bean plants reached for harvest

B. After harvest before threshing

C. other specify

3. If your answer is after storage after what time the grains are stored? Thick the relevant alternative/s

A. After two weeks

B. After one month

C. After two months

D. other specify

4. Name(s) of faba bean grain storage insect pests?

5. How do you know whether your bean grains are infested by bruchids or not?

A. Before storage in field condition

1. Looking flying adults

2. Looking holed pods

3. Observe insect eggs on bean grains

4. Observe perforated grains by bruchids

5. Other specify

B. After storage

1. Looking moving adults
2. Observed insect eggs on bean grains
3. Observed perforated faba bean grains due to bruchids
4. Heard sounds within the storage structure
5. Increase temperature within stored bean grains
6. Other specify

6. The name(s) of storage structures used by farmers in the area

- A. Gota
- B. Gottera
- C. Sack
- D. Clay pot
- E. Other specify

7. Maximum durations of bean grains stored in the storage structure

- A. Less than 4 months
- B. 4 to 8 months
- C. 9 to 12 months
- D. More than one year

8. Maximum damage level of grains due to bruchids stored >6 months with no protection

- A. one-tenth
- B. one-fourth
- C. one-third
- D. Half
- E. three-fourth
- F. 100% loss

9. Purpose of faba bean for farmers damaged by bruchids that causes below or above 50% holed on the grains

- A. Consumption
- B. Seed purpose
- C. For market
- D. Feed for cattle
- E. Other specify
- F. Not used for any purpose

10. Mention possible control methods of bruchids

- A.
- B.
- C.
- D.
- E.
- F.

11. What are common insecticides used by farmers to manage bruchid

- A.
- B.
- C.
- D.

12. Sources of insecticides mentioned above (Question 11)

- A.
- B.
- C.
- D.

13. Are DAs and other experts give advice about bruchids management Yes No

14. If your answer is no who advised you to control bruchids & to apply insecticides

- A. Locally communications
- B. Insecticide supplier merchants
- C. Pre informed farmers and parents